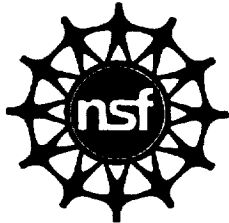


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World Technology Evaluation Center



**WTEC**

WTEC Panel Report on

# Research Submersibles and Undersea Technologies

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 ON RESEARCH SUBMERSIBLES AND  
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## **WTFC PANEL ON RESEARCH SUBMERSIBLES AND UNDERSEA TECHNOLOGIES**

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### **INTERNATIONAL TECHNOLOGY RESEARCH INSTITUTE JTFC/WTFC PROGRAM**

The Japanese Technology Evaluation Center (JTFC) and its companion World Technology Evaluation Center (WTFC) at Loyola College provide assessments of foreign research and development in selected technologies under a cooperative agreement with the National Science Foundation (NSF). Loyola's International Technology Research Institute (ITRI), R.D. Shelton Director, is the umbrella organization for JTFC and WTFC. Paul Hoser, Senior Advisor for Planning and Technology Evaluation at NSF's Engineering Directorate, is NSF Program Director for JTFC and WTFC. Other U.S. government agencies that provide support for the program include the National Aeronautics and Space Administration, the Department of Energy, the Department of Commerce, and the Department of Defense.

JTFC/WTFC's mission is to inform U.S. policy makers, strategic planners, and managers of the state of selected technologies in foreign countries in comparison to the United States. JTFC/WTFC assessments cover basic research, advanced development, and applications/commercialization. Small panels of about six technical experts conduct JTFC/WTFC assessments. Panelists are leading authorities in their field, technically active, and knowledgeable about U.S. and foreign research programs. As part of the assessment process, panels visit and carry out extensive discussions with foreign scientists and engineers in universities and in industry/government labs.

The ITRI staff at Loyola College help select topics, recruit expert panelists, arrange study visits to foreign laboratories, organize workshop presentations, and finally, edit and disseminate the final reports.

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**WTEC Panel on**

**RESEARCH SUBMERSIBLES  
AND UNDERSEA TECHNOLOGIES**

**FINAL REPORT**

**June 1984**

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D. Richard Blidberg  
Claude P. Brancart  
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Algis N. Kalvaitis  
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## ABSTRACT

This report covers research submersibles and related subsea technologies in Finland, France, Russia, Ukraine and the United Kingdom. Manned, teleoperated, and autonomous submersibles were of interest. The panel found that, in contrast to the United States, Europe is making substantial progress in cooperative and coordinated research in subsea technology, including the development of standards. France is a leader in autonomous vehicle technology. Because much less was known a priori about the technologies in Russia and the Ukraine, there were more new findings in those countries than in those Western European nations visited. However, Russia and Ukraine have a sizeable (and currently underutilized) infrastructure in this field, including a highly educated and experienced manpower pool, impressive (in some cases unique) facilities for physical testing, extensive fleets of seagoing research vessels capable of long voyages, and state-of-the-art facilities for conducting oceanographic investigations. The panel visited newly-formed commercial companies associated with long-standing submersible R&D and production centers in Russia and Ukraine. So far, these new efforts are undercapitalized, and as such represent opportunities at very low cost for Western nations, as detailed in the site reports.

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## FOREWORD

The National Science Foundation has been involved in funding technology assessments comparing the United States and foreign countries since 1983. A sizable proportion of this activity has been in the Japanese Technology Evaluation Center (JTEC) and World Technology Evaluation Center (WTEC) programs. We have supported more than 30 JTEC and WTEC studies over a wide range of technical topics.

As U.S. technological leadership is challenged in areas of previous dominance, such as aeronautics, space, and nuclear power, many governmental and private organizations seek to set policies that will help maintain U.S. strengths. To do this effectively requires an understanding of the relative position of the United States and its competitors. The purpose of the JTEC/WTEC program is to assess research and development efforts ongoing in other countries in specific areas of technology, to compare these efforts and their results to U.S. research in the same areas, and to identify opportunities for international collaboration in pre-competitive research.

Many U.S. organizations support substantial data gathering and analysis efforts directed at nations such as Japan. But often the results of these studies are not widely available. At the same time, government and privately sponsored studies that are in the public domain tend to be "input" studies. That is, they provide enumeration of inputs to the research and development process, such as monetary expenditures, personnel data, and facilities, but do not provide an assessment of the quality or quantity of the outputs obtained.

Studies of the outputs of the research and development process are more difficult to perform because they require a subjective analysis performed by individuals who are experts in the relevant technical fields. The National Science Foundation staff includes professionals with expertise in a wide range of disciplines. These individuals provide the technical expertise needed to assemble panels of experts that can perform competent, unbiased, technical reviews of research and development activities.

Specific technologies, such as telecommunications, biotechnology, and nuclear power, are selected for study by government agencies that have an interest in obtaining the results of an assessment and are able to contribute to its funding. A typical assessment is sponsored by two to four agencies. In the first few years of the program, most of the studies focused on Japan, reflecting concern over Japan's growing economic prowess. Studies were largely defined by a few federal mission agencies that contributed most of the funding, such as the Department of Commerce, the Department of Defense, and the Department of Energy.

The early JTEC methodology involved assembling a team of U.S. experts (usually six people, from universities, industry, and government), reviewing the extant literature, and writing a final report. Within a few years, the program began to evolve. First, we added site visits. Panels traveled to Japan for a week visiting 20-30 industrial and research sites. Then, as interest in Japan increased, a larger number of agencies became involved as co-sponsors of studies. Over the 10 year history of the program, 15 separate branches in six agencies of the Federal Government (including NSF) have supported JTEC and WTEC studies.

Beginning in 1990, we began to broaden the geographic focus of the studies. As interest in the European Community (now the European Union) grew, we added Europe as an area of study. With the breakup of the former Soviet Union, we began organizing visits to previously restricted research sites opening up there. These most recent WTEC studies have focused on identifying opportunities for cooperation with researchers and institutes in Russia, Ukraine, and Belarus, rather than on assessing them from a competitive viewpoint.

In the past four years, we have also begun to considerably expand dissemination efforts. Attendance at JTEC/WTEC workshops (in which panels present preliminary findings) increased, especially industry participation. Representatives of U.S. industry now routinely number 50% or more of total attendance, with a broad cross section of government and academic representatives making up the remainder. JTEC and WTEC studies have also started to generate increased interest beyond the science and technology community, with more workshop participation by policymakers and better exposure in the general press (e.g., *Wall Street Journal*, *New York Times*). Publications by JTEC and WTEC panel members based on our studies have increased, as has the number of presentations by panelists at professional society meetings.

The JTEC/WTEC program will continue to evolve in response to changing conditions in the years to come. We are now considering new initiatives aimed at the following objectives:

- o Expanded opportunities for the larger science and technology community to help define and organize studies. This may be accomplished through a proposal competition in which NSF would invite universities and industry (preferably working together) to submit proposals for JTEC and WTEC studies. These would then be peer reviewed much as NSF reviews research proposals.
- o Increased industry sponsorship of JTEC and WTEC studies. For example, NSF recently funded a team organized by the Polymer Science & Engineering Department at the University of Massachusetts (Amherst) to visit Japan for two weeks studying biodegradable plastics and polymers R&D there. Twelve industrial firms put up over half of the funds.

- o Including a broader policy and economic context to our studies. This is directed at the need to answer the question, "So what?" that is often raised in connection with the purely technical conclusions of many JTEC and WTEC panels. What are the implications of the technical results for U.S. industry and the economy in general? We will be adding an economist to an upcoming JTEC study on optoelectronics in Japan as a new effort to address these broader questions.

In the end, all government funded programs must answer the following question: *How has the program benefitted the nation?* I would like to point out a few of the benefits of the JTEC/WTEC program:

- o JTEC studies have contributed significantly to U.S. benchmarking of the growing prowess of Japan's technological enterprise. Some have estimated that JTEC has been responsible for over half of the major Japanese technology benchmarking studies conducted in the United States in the past decade. Our reports have also been widely cited in various competitiveness studies.
- o These studies have provided important input to policymakers in federal mission agencies. JTEC and WTEC panel chairs have given special briefings to senior officials of the Department of Energy, the NASA Administrator, and even the President's Science Advisor.
- o JTEC/WTEC studies have been of keen interest to U.S. industry, providing managers with a sense of the competitive environment internationally. Members of the recently completed study on satellite communications have been involved in preliminary discussions concerning the establishment of two separate industry/university consortia aimed at correcting the technological imbalances identified by the panel in its report.
- o JTEC and WTEC studies also have been valuable sources of information for both U.S. and foreign researchers, suggesting potential new research topics and approaches, as well as opportunities for international cooperation. One JTEC panelist was recently told by his Japanese hosts that, as a result of his observations and suggestions, they have made significant new advances in their research.
- o Not the least important is the educational benefit of the studies. Since 1983 over 170 scientists and engineers from all walks of life have participated as panelists in the studies. As result of their experiences, many have changed their viewpoints on the significance and originality of foreign research. Some have also developed lasting relationships and ongoing exchanges of information with their foreign hosts as a result of their participation in these studies.

**As we seek to refine the JTEC/WTEC program in the coming years, improving the methodology and enhancing the impact, we will still be operating from the same basic premise that has been behind the program from its inception: the United States can benefit from a better understanding of cutting-edge research that is being conducted outside its borders. Improved awareness of international developments can significantly enhance the scope and effectiveness of international collaboration and thus benefit all of our international partners in collaborative research and development efforts.**

**Paul J. Herer  
National Science Foundation  
Arlington, VA**



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The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

Furthermore, it is noted that the records should be kept in a secure and accessible format. Regular backups are recommended to prevent data loss in the event of a system failure or disaster.

In addition, the document highlights the need for consistent data entry. Standardized formats and codes should be used throughout the system to avoid confusion and errors. This consistency is crucial for generating accurate reports and analyses.

Finally, it is stressed that all users should be trained on the correct procedures for data entry and record management. This training should cover not only the technical aspects but also the importance of data integrity and security.

The second part of the document provides a detailed overview of the system's architecture. It describes the various components that make up the system, including the database, the application layer, and the user interface.

The architecture is designed to be modular and scalable, allowing for the addition of new features and the handling of increasing amounts of data. This flexibility is essential for the long-term success of the system.

The document also includes a section on system security. It outlines the various measures in place to protect the data from unauthorized access, including firewalls, encryption, and strict access controls.

Regular security audits are conducted to identify and address any vulnerabilities. This proactive approach helps to ensure that the system remains secure and reliable at all times.

The third part of the document focuses on the system's performance and optimization. It discusses the various factors that can affect performance, such as hardware configuration, network bandwidth, and database indexing.

Recommendations are provided for monitoring system performance and identifying areas for improvement. This includes the use of performance metrics and the implementation of optimization techniques to ensure the system runs smoothly and efficiently.

The document concludes with a summary of the key points discussed. It reiterates the importance of data accuracy, system security, and performance optimization.

It is hoped that this document will provide a comprehensive guide for the system's users and administrators, ensuring that the system continues to meet the organization's needs for many years to come.



## **EXECUTIVE SUMMARY**

### **BACKGROUND**

The World Technology Evaluation Center (WTEC) panel on Research Submersibles and Undersea Technologies was formed to review the state of the art in this broad field within the countries of the former Soviet Union (FSU), particularly Russia and Ukraine, and in selected Western European countries. The panel visited leading companies, academic research programs, and government laboratories in Finland, France, Russia, Ukraine and the United Kingdom. Because of the large geographic area and the breadth and technical complexity of the subject, the study could not be comprehensive. However, by carefully selecting the sites to be visited -- based upon the substantial prior knowledge of many committee members -- it was possible to acquire a meaningful evaluation. The end of the Cold War and the resulting efforts to commercialize some military technology, plus the increased utilization of sophisticated equipment in the exploration for and production of oil and gas in the North Sea, had led the sponsors of this study to the belief that a review of subsea technology in this geographical area would be productive. This was verified by the panel's findings.

Because much less was known a priori about the technologies in Russia and the Ukraine, there were more new findings in those countries than in the Western European nations visited. Some general conclusions will be drawn based upon the panel's overall experiences, and these will be followed by more specific conclusions in each of the study's subject areas.

There is a pronounced emphasis in the United Kingdom on the development of advanced sensors and affordable autonomous and remotely operated vehicles. These vehicles are being developed for use in both the research community and the offshore industry.

Research and development is being conducted in the United Kingdom and in France on developing very great endurance (hundreds of kilometers to full ocean width) for autonomous vehicles.

Europe is making substantial progress in cooperative and coordinated research in subsea technology, including the development of standards. No such cooperative research and development is underway in the United States, which may have a significant impact on future competitiveness.

The economic stimulus for subsea technology development in Western Europe appears to be largely to support fisheries management and offshore oil and gas production.

All of the countries visited and all of the agencies interviewed see shrinking horizons for research and development and for economic opportunities in this field.

Russia and Ukraine have developed a highly educated and experienced manpower pool, skilled in almost all phases of subsea technology, that is substantially underutilized at this time. Russia and Ukraine possess impressive, and in some cases unique, facilities for physical testing. These assets are also underutilized and offer opportunities at very low cost for Western nations.

Researchers in Russia and Ukraine have extremely limited computing facilities compared to Western engineers in this field. As a result, researchers there take a strong theoretical or analytical approach to most problems, which appears to be very valuable. It has also resulted in an ability to write extremely efficient computer code to facilitate numerical analyses and signal processing on limited computer platforms. Given the ready availability of large platforms in the West and the greater difficulties in maintaining tightly coded programs, it is not clear that this capability represents a technological asset to the rest of the world.

Russia and Ukraine possess extensive fleets of seagoing research vessels capable of long voyages and possessing state-of-the-art facilities for conducting oceanographic investigations. With the exception of those vessels under contract to Western nations, these vessels are largely inactive at this time.

Russia and Ukraine have a philosophy of including human presence in nearly all subsea geophysical and oceanographic investigations. They have produced an impressive variety of manned research submersibles, again largely unused at this time. The beginning of research on autonomous vehicles in Russia means that country has, in effect, largely skipped the development of conventional cable-controlled remotely operated vehicles.

The panel principally visited government entities in Russia. In a few cases, it was possible to visit newly formed commercial companies associated with such centers. It became apparent that large numbers of companies with shared personnel and objectives have been established surrounding many of the important "mother" research and development facilities, and that these companies form sources of technology and commercial capability that were not adequately assessed by the panel.

Many of the panel's observations can be assumed to represent only the general state of the art in the research and development laboratories in that country. That is, there are almost certainly more advanced technical investigations and facilities that the panel was not able to visit.

## **SPECIFIC CONCLUSIONS**

### **Sensors and Instrumentation**

Deep ocean submersibles, such as the *Mir* (Russia) and *Nautille* (France), continue to be effective platforms for undersea work and research because of their extensive sensor, instrumentation, and manipulative capability. Some scientists consider the *Mir* submersibles, built by Rauma in Finland, to be the best equipped and most capable research tools for deep sea (6,000 m) research.

Although Russia and Ukraine have developed limited remote sensing capability for ocean studies using Lidar and acoustic Doppler current profilers, these designs are not unique and are within the current international state of practice.

The countries of the FSU are marketing oceanographic instruments (such as conductivity, temperature, and depth, or CTDs, and current meters). Their data quality is unknown, and intercalibrations should be conducted to determine measurement capabilities. Other factors, such as reliability, maintainability, and service must also be addressed. Prices are currently quite low, but this may be a short-term situation that will eventually change to correlate more closely to Western prices.

Several European countries outside of the FSU are actively developing research-type remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). The European Economic Community is supporting as major programs unmanned platforms for undersea and oceanographic research using enhanced sensors and samplers. This is in marked contrast to the United States, where there is no major focused thrust for developing scientific AUVs.

### **Energy, Hydrodynamics, and Propulsion**

**Energy.** The WTEC teams did not see any particularly new concepts in energy systems at any of the sites visited. However, at the same time, panelists were impressed with the variety of sources being used, or designed for use, in underwater vehicles. The spectrum of systems in use in the FSU range from small, simplified nuclear reactors to conventional lead-acid batteries (used in the numerous manned submersibles in the FSU). In Europe, the panel found fuel cells, semi-fuel cells, Rankine Cycle engines, Sterling Cycle engines, and hydrazine gas generators all presently at sea onboard various vehicle platforms.

In Russia, the most impressive directions were nuclear power systems (first developed for military submarines) and fuel cells (first developed for the space program). While the fuel cells were of conventional design, several had been built and many hours had been logged in spaceflight conditions.

In Europe there was a clear developmental trend towards high energy density energy sources such as the Rankine, Sterling, and Hydrazine-powered engines. The semi-fuel cells, such as Alupower's aluminum oxygen battery, offer long-duration power supplies that can make AUVs true underwater satellites. As in Russia, there was very little research and development work evident in storage battery technologies. Most designers were using advanced concept batteries from the automotive and aerospace sectors.

**Hydrodynamics.** Design of both relatively slow-speed manned submersibles and remotely operated vehicles is less dependant on hydrodynamic considerations than are high speed vehicles. For military submarines and torpedoes, speed is a virtue. For long-duration autonomous unmanned vehicles, onboard energy conservation is critical to permit prolonged mission times.

As might be expected, the former Soviet Union has an extensive family of organizations and institutions concerned with hydrodynamics. Having the largest and most diverse submarine force in the world required a major technical support base. While this was evident to the WTEC teams, unfortunately, not much of this work has direct relevance to deep submergence technologies, the primary subject under investigation.

**Propulsion.** Efficient conversion of energy to propulsive force/thrust is critically important in manned submersibles, remotely operated vehicles, and autonomous unmanned vehicles. Here energy conservation and the resulting tradeoffs are key concerns of the designer. However, with the exception of the work being done with the Autosub project in England, the panelists did not see much research and development work in this area. At several of the sites in Russia, there was some mention made of work they were doing in propulsion for high speed submarines, but no documentation was provided.

On a much larger application scale, the Russians are doing work in magneto-hydrodynamic propulsion (MHD), and in the Ukraine there is ongoing work on mechanical emulation of fish swimming motions. But in both cases it is difficult to see how these mega-technologies can be applied to deep submersible vehicles.

### **Manned Submersibles**

There is great interest among ocean engineers and ocean researchers in the former Soviet Union in manned submersibles and tourist submarines. Previous interest in manned submersibles in the United Kingdom has been replaced by remotely operated vehicles and a growing effort in autonomous underwater vehicles. IFREMER, in France, continues to support the notion of placing man in situ using *Nautille*.

The WTEC group was surprised by the variety and number of manned submersibles built in the FSU, in operation now, and planned for the future. Several visited activities, mostly those that have been either involved in manned submersibles or military submarines in the past, now have tourist submarine plans on their drawing boards. (Computer-aided design is essentially unavailable.)

The existing manned submersibles are fundamental, low cost, uncomplicated, reliable, tested, and available. Ocean researchers are enthusiastic users who are quite satisfied with the capabilities of these tools. The ability to use and fabricate titanium in undersea vehicles in Russia and Ukraine is advanced. The acceptability of Russian Registry Certification by Western insurance companies needs to be examined carefully before contracting for use of manned submersibles built in the FSU.

Academically, industrially and operationally, the existing manned submersible base in Russia and Ukraine is truly impressive and has great potential.

### **Unmanned Submersibles**

*Great Britain and France.* Slingsby Engineering Ltd. (SEL), located north of London, is the major large ROV supplier in Great Britain. The company's only competition is Perry Tritech, a Florida-based company owned by a French company (Coflexip) and International Submarine Engineering (ISE) of Port Coquitlan, B.C., Canada. SEL identifies the customer needs and designs the hardware accordingly, as is the case with its MRVROV. Where needed, SEL continues to improve the components. SEL will remain a small organization because the customer market is small and because more user/service companies are fabricating their own special purpose ROVs.

The *Mobil-FSSL* project is a typical example of a major oil company starting with a large working ROV (the SEL MRV) and adding specialty tools to undertake major underwater tasks. This trend will continue.

Great Britain has a respectable position in scientific unmanned systems. The Deacon Laboratory Autosub project is very ambitious but must wait at least five more years to see final results. The Marconi ODAS vehicle, based on torpedo technology, could have a major impact on the scientific community because of its low cost.

The observed trend is for universities to take a narrower view of technology development because of funding constraints. Also there is a cooperative culture for technology development, not just within Great Britain, but within the European Community. A prime example of this is the European Community Marine Science and Technology (MAST) research programs. A new MAST program aimed at furthering autonomous underwater vehicles is the Advanced Research for Unmanned Autonomous Underwater Vehicles. The contributors to this program are Deacon Laboratory and DRA from Great Britain, IFREMER, ECA, and INRIA from France, the

National Technical University of Athens, Greece, and Instituto Hidrográfico in Portugal. There may be something to learn from this type of cooperative technology development, especially in a tight money environment.

*Former Soviet Union.* Russia's present position relative to the Western world is difficult to establish. The country's low-cost ROVs are dated technology. However, the operating techniques of Russia's 6,500 m ROV systems have much to offer. There is nothing technologically exciting about their unmanned systems, primarily because the nation's efforts have been concentrated on manned systems.

The observed trend is for members of universities and governmental agencies to form private ventures in an effort to generate needed funds. There are many ventures formed to develop tourist submarines. This is disappointing because the world market for tourist submarines is already nearly saturated. Another trend is for foreign firms to form teaming agreements with individuals and facilities to conduct business on a world-wide basis. The Interhalf company of Russia demonstrates this trend. Russia must overcome the credibility and logistic support gap before it can compete in the world markets for underwater unmanned systems.

### **Acoustic Applications**

In Western Europe the technology developments are very similar to those efforts in the United States. Some of Western Europe's sonar imaging systems are more interesting than similar units manufactured in the United States due to price and performance issues. In the FSU the situation is different. The following observations relate mostly to what was seen in Russia and Ukraine.

*Understanding of Basic Theory.* The researchers participating in the discussions were very clearly aware of the basic principles of the technology with which they were involved. Possibly the limitation of computer capability and the need for efficient problem solving has forced this need for in-depth basic understanding. This is clearly different in the United States, where computer capability and the cost of people can force development to proceed along lines where an engineering solution is more important than reaching a total understanding of all aspects of a problem.

*Application Ideas.* There were several interesting discussions about new applications under consideration by researchers in Russia and Ukraine. Some of these ideas appeared to be novel, and had not been considered in the United States, at least in circles represented by members of the WTEC team. It may well be that the new freedom to determine research directions has allowed researchers to consider novel applications of technology. It may also be that having to compete in a world marketplace demands new and novel products and ideas.

*Implementation Software and Hardware.* As alluded to above, there is general agreement among the panel that research in Russia and Ukraine has been

undertaken in an environment with limited computer hardware capability. This limitation has most probably been the reason for the direction of software development there. The emphasis has been on efficient algorithms and highly capable microprogramming.

*Maturity of Applications.* There have been many applications of technology that are both interesting and novel. It must be understood, however, that the actual maturity of those applications is not clear. Many of the technological concepts discussed were in their conceptual stages only. With limited financial resources, it is unclear just how many of those applications will come to fruition.

*Infrastructure.* The changes in the FSU have had a strong impact on the technology infrastructure. Communications among various groups is unclear. Also, the method for moving from concept to final prototype was controlled very completely in the past, and the resources needed to accomplish a development effort were planned and in place. It seems that this is no longer the case and it will be a while before such an infrastructure evolves in this new environment.

Several factors affecting technology development in Russia and Ukraine were apparent during the visits and discussions. Although not necessarily related to technology development, the following factors are among those that are important to the process used to develop technology:

- o Publishing in professional journals
- o Acquiring better computer hardware
- o Establishing better communication channels
- o Better understanding of how to do business with the West
- o Better understanding of technology outside of the FSU

There were applications of acoustic technology that were both exciting to consider and important to advancing the state of the art in this field. Due to limited time, it was not possible to truly understand the technical accomplishments of the technologists, yet their ideas were intriguing and their concepts novel. More should be done to fully understand many of these efforts.

As mentioned previously, one of the questions that constantly surfaced was how far specific applications had been taken. It was not clear at times whether a concept being discussed had yet moved to hardware or prototype development stages, whether it had been evaluated in a real world setting, or whether it had already become available as a product.

Sometimes it was also unclear what the future held for specific applications that were discussed. With limited resources and a very dynamic environment, the future of an idea is uncertain. Many of the applications discussed could well be moved

into viable products readily sought after in the world marketplace. Whether they will reach that goal is not clear.

It was recognized by many members of the WTEC team that solutions to technological problems had been implemented on computer hardware of limited capability. Emphasis was placed on efficient algorithms and clearly understanding the principles of the problems. Many can remember how their first efforts at applying microcomputers to instrumentation forced the use of machine languages and complex interface programming. This is not unlike what seems to be the norm in Russia and Ukraine today. The benefit of this has been to develop unique solutions to complex programming problems.

There is a genuine desire for cooperation and collaboration. On one hand this is obvious since funding and equipment are lacking. More importantly, however, is the perception that technologists in Russia and Ukraine truly believe that cooperation and collaboration will bring new insights and further advance their technological interests. The individuals involved in the visits were very talented technical people. Much would be gained by the synergism resulting from true cooperation.

The current environment in the FSU is allowing technologists the freedom to choose their own research directions. In addition, many technologists are starting small businesses to privatize their talents and products. This has not been possible in the past since funding and resources were directed at specific projects planned outside of the various institutions. It is clear that this new freedom will allow researchers to consider directions that were not available in the past.

The WTEC team agreed unanimously that the time available for the visits did not allow for in-depth discussions. This was probably inevitable for this first series of visits, but should be corrected during future visits. There is much to learn concerning acoustic applications in Russia and Ukraine. Learning is always a slow process that follows a less than straight path. Future visits should allow time for technical discussions with the actual professionals involved in moving applications from concept to reality.

### **System Engineering**

Europe. Underwater vehicles and marine technologies are very important to the European countries visited. This is evidenced by government-funded programs, such as the Marine Technology Directorate (MTD) program, sponsored by the United Kingdom's Science and Engineering Research Council (SERC) and France's IFREMER program. Also, a European-wide focus is offered by the Marine Science and Technology program. European marine technology and underwater vehicle (UV) activities are well planned and focused, and funding, though never enough, is adequate. The bottom line is that the Europeans are making good progress in developing AUVs, and are moving toward some very useful national and regional



objectives in ocean research. Good work is also in progress toward development of ROVs for the offshore oil industry.

The organizations involved in UV development and marine research are well equipped for research, engineering, and overall system integration. The computer equipment and test facilities are modern and as capable as any in the United States.

*Former Soviet Union.* Labor and materials are still cheap in Russia and Ukraine, and the availability of micro-electronics is limited. This has led in the past to an emphasis on manned UVs rather than unmanned units. Manned UVs are easier to integrate and maintain, and use low-cost labor to good effect. This trend will probably continue into the near future, until the industrial sector begins to mature and costs drive it toward unmanned systems. In the West, the high cost of labor and the risk of litigation and insurance penalties have driven scientists toward unmanned solutions. However, the same cost of labor has made sophistication and high technology expensive. The United States has improved performance and minimized man-dependency, but in some cases has violated the basic rules: "keep it simple" and "sufficient is good enough." The United States is too often enamored of the whiz-bang solution rather than the simplest one.

Fundamental science in Russia and Ukraine is impressive and based on sound theory. Due to lack of computational capabilities, there has been a focus on empirical validation rather than in-depth analysis. This will continue during the process of economic, political, and defense conversion.

FSU scientists and engineers have been very creative in applied research, and have many accomplishments that equal or exceed those of the West. Some examples include manned submersibles, acoustic tomography, nonacoustic ASW, high-speed underwater projectiles, and materials development for the marine environment.

Engineering in Russia and Ukraine is generally behind that of the West in sophistication, but not necessarily in results. Some engineering and integration achievements there include the following:

- o Numerous and very good research test facilities
- o Short development spans based on a theory of build it, field it, and then improve it
- o Avoidance of the analysis paralysis that slows progress in the West
- o Lack of preoccupation with aesthetics; systems are built stout to last and simple for easy maintenance

**Navigation, Communication, Automation, and Control**

There is limited technology in the former Soviet Union in the areas of automation in underwater vehicle technology. The control technology is based primarily on manual operation. Navigation and communication systems in the former Soviet Union use technologies that are currently available worldwide. There are a large number of well-trained engineers and scientists in the FSU who are underutilized because of the current funding situation. There are several very nice design, test, and fabrication facilities in the former Soviet Union. Russia and Ukraine would like to make these facilities available in some form to be used in the world market. The engineers said that access to computers, computer-aided design and simulation software, and more reliable electronics, would make them more effective.

France is the leader in the field of underwater vehicle technology. French programs in the integration of local sensor data for navigation and control have the potential of opening up new capabilities for underwater vehicles.

The United Kingdom is leading a European Community effort in developing long-range underwater vehicles. This program is pushing the limits in underwater vehicle technology in automation, navigation, and control.

## **CHAPTER 1**

# **INTRODUCTION AND OVERVIEW OF RESEARCH SUBMERSIBLES AND UNDERSEA TECHNOLOGIES IN RUSSIA, UKRAINE, AND WESTERN EUROPE**

**Richard J. Seymour**

### **SCOPE OF THE STUDY**

The initial meeting of the World Technology Evaluation Center (WTEC) panel on Research Submersibles and Undersea Technologies was held at the National Science Foundation (NSF) in Washington, D.C. on November 19, 1992. Paul Herer and Norman Caplan of NSF, a principal sponsor of the study, presented their agency's interests in nonmilitary submersibles and subsea technology. The participants formulated the general plan for the study, generated an initial list of target sites to visit, and established the dates and basic itinerary. This plan was refined in a series of conference calls over the next several months. Subsequent consultation with the Advanced Research Projects Agency (ARPA), the other major sponsor of this study, led to further refinement of the scope.

At the first meeting, the subject areas selected for investigation were: sensors and instrumentation; control, automation, and communication; hydrodynamics, power, and propulsion; manned systems, unmanned systems, and applications of acoustics; and systems engineering and integration. Each subject area was assigned to one panel member, who was responsible for documenting the panel's findings in this report with respect to that area. The panel's conclusions in the executive summary follow this breakdown, as do the subsequent chapters.

Budget constraints and the limited time available for panelist participation severely restricted the scope of the study. Initially, it was hoped to cover all of Europe, East and West. It became clear that countries such as Norway, Germany, Italy, and others with capabilities in submarines and subsea technologies could not be adequately surveyed. Further, there were so many potential sites in Russia and Ukraine that a substantial selection process was required. For example, there was strong interest among panel members in visiting Vladivostok, but the costs and time to do this were prohibitive. Similarly, transportation difficulties in Ukraine prevented visiting both Sevastopol and Odessa in the allotted time, forcing a choice in favor of Sevastopol.

The two teams visiting the United Kingdom and France (a subset of the full panel) completed their visits during the week of May 10 to 14, 1983, and the entire panel met in Frankfurt, Germany on May 18 prior to the eastern Europe visits during the week of May 17 to 21. One team traveled to Finland and to the St. Petersburg area in Russia, two teams covered Moscow and vicinity, and another team was principally in Ukraine. The entire panel reassembled in Frankfurt on May 22 prior to returning to the United States.

There was considerable reluctance among many of the potential organizations selected for visiting. This seemed to stem from either a concern for commercial (or national) secrecy or an inability to see any advantage to the host institution in spending time and resources to accommodate the visiting panelists. A statement of WTEC's purpose, either in English or in Russian, short biographies of the panel members, and a list of questions representing the panel's interests were distributed to the prospective sites in advance. Some desired sites in Russia were not available to the panel, and one location was canceled on the morning of the visit because of a failure to secure the necessary government clearances. In spite of these difficulties, panel members were quite impressed with the quality of the sites that were made available to them.

A total of 38 sites were investigated: 1 in Finland, 3 in France, 19 in Russia, 5 in Ukraine, and 10 in the United Kingdom. Of these, 4 were academic institutions, 10 were involved in basic research, 3 were trade groups, 19 undertook applied research, and 3 conducted operations. (A list of the sites visited is contained in the Table of Contents of this report.)

In spite of long workdays, the visits were necessarily of short duration. There was always a great deal more to see and discuss than time allowed. Further, the discussions were -- for the most part -- led by the hosts, with little opportunity for the panelists to steer towards other topics of interest. This meant that panelists were almost always precluded from technically rigorous discussions, and often were given only general-purpose written material. This lack of technical depth was a source of concern and frustration to the panel, but it was generally agreed that without

drastically narrowing the technical and geographical scope, there really was no solution to this problem.

Another limitation arose from the amount of time devoted to tours of laboratories and facilities at the expense of discussion time. On occasion, panelists saw unique and impressive facilities during these tours. For the most part, however, the tours were highly repetitive and relatively unproductive.

Language barriers were an obvious restraint to communication in most host countries. Language differences also limited the technical depth that could be reached. Translated written materials, good technical translators (there was simultaneous translation on one occasion in Ukraine!), and solid advance field work lessened the impact of the language barrier, but it remained a significant restraint, particularly in the former Soviet Union (FSU).

The effects of defense conversion activities were evident at most of the sites the panel visited, but most markedly in Russia and Ukraine. New companies or trade groups in these countries, lacking previous experience in or close ties to free market activities, appeared to have difficulty deciding on appropriate civil applications for their extensive defense technology. The panel observed, for example, a surprisingly large number of agencies in Russia designing or proposing tourist submarines in competition with each other for a world market that is already close to saturation. In addition to defense conversion, Russian and Ukrainian scientific institutions are attempting to convert to commercial objectives, including the development of marine resources and improvement of environmental conditions. There appeared to be very little planned activity at many institutions. It appears that many valuable assets, human and physical, may be in danger of being lost because of the severity of the economic problems.

One of the interesting problems that arose from some of the visits in Russia and Ukraine occurred because of the hosts' decisions to disclose information and technology that had been declassified only very recently. Many of the panel members are aware of complementary work in the United States that remains classified. However, Russia and Ukraine possess impressive, and in some cases unique, facilities for physical testing. These facilities are underutilized and offer opportunities for Western nations.

Researchers in Russia and Ukraine have extremely limited computing facilities compared to Western engineers in this field. As a result, Russian and Ukrainian researchers have taken a strong theoretical or analytical approach to most problems, which appears to have been very valuable. It has resulted in an ability to write extremely efficient computer code to facilitate numerical analyses and signal processing on limited computer platforms. Given the ready availability of large platforms in the West and the greater difficulties in maintaining tightly coded

programs, it is not clear that this capability represents a technological asset to the rest of the world.

Russia and Ukraine possess extensive fleets of seagoing research vessels capable of long voyages. These vessels possess state-of-the-art facilities for conducting oceanographic investigations. Except for vessels under contract to Western nations, these vessels are largely inactive at this time.

Russia and Ukraine have adopted a philosophy of including human presence in nearly all subsea geophysical and oceanographic investigations. They have produced an impressive variety of manned research submersibles that also are largely unused at this time. The beginning of research on autonomous vehicles in Russian means that country has, in effect, largely skipped over the development of the conventional cable-controlled remotely operated vehicles (ROVs).

The panel principally visited government entities in Russia. In a few cases, it was possible to visit newly formed commercial companies associated with such centers. It became apparent that large numbers of companies with shared personnel and objectives have been established surrounding many of the mother research and development facilities, and that these companies form sources of technology and commercial capability that were not adequately assessed by the panel.

Many of the panel's observations can be assumed to represent only the general state of the art in the research and development laboratories in that country. That is, there are almost certainly more advanced facilities that the panel was not able to visit.

## **CHAPTER 2**

# **SENSORS AND INSTRUMENTATION**

**Algis N. Kalvaitis**

### **INTRODUCTION**

Underwater vehicles and sensor systems are essential to conducting research and working in the ocean. Over the past several decades, the use of these vehicles, both manned and unmanned, has increased dramatically to conduct significant work associated with offshore oil development, defense activities, salvage, and undersea research.

One of the major goals of this study is to identify and assess European research and development and technology in manned, teleoperated, and autonomous vehicles and associated systems. This chapter focuses on sensors, measurements, and sampling capability using these vehicles. Instrumentation used for ocean studies as well as remote sensing capability will also be discussed.

### **DATA COLLECTION COSTS AND JUSTIFICATIONS**

The collection of marine and oceanographic related data is costly; however, these measurements and observations are necessary for various user sectors on a worldwide basis. These include data on the ocean floor, coastal seas, living resources, health of the oceans, shipping, defense, and climate. Obtaining ocean data often involves using large ships whose operational costs range from \$10,000 to \$50,000 per day. Because of these costs, it is imperative that the data collection

capability be greatly increased. Therefore, the measurement and sampling capabilities of undersea vehicles, platforms, and instrumentation must be improved for maximum effectiveness and efficiency.

Since there is little likelihood of an increase in the number of ships for ocean research and monitoring, novel approaches are needed. There has been a trend toward the development of alternate methods of data collection. For example, various automatic systems have recently been developed, such as moored and drifting instrument platforms for international programs like Tropic Ocean Global Atmospheric (TOGA) and the World Ocean Circulation Experiment (WOCE). During the next decade, long-range autonomous underwater vehicles (AUVs) capable of measuring and sampling to full ocean depths will probably be developed. Instrumentation and sensors are being continually enhanced for automatic operation on various ocean platforms. In addition, improvements are being made to remote sensing techniques such as the acoustic Doppler profiling current meter.

New technology development, including sensors and instrumentation, is fundamental to international programs such as Global Ocean Observing Systems (GOOS), a multinational fifteen-year study that is presently in the concept evaluation and feasibility study phase. Eventual operating costs are estimated to be \$2 billion per year once this program is fully implemented.

### **SENSOR SYSTEMS AND VEHICLES/PLATFORMS**

This assessment focused on several major sensor systems that are utilized from various deep ocean vehicles and platforms. These sensors include remote, oceanographic, and scientific/other, and may be used or deployed from ships, submersibles, remotely operated vehicles, or autonomous undersea vehicles. The temporal and spatial sampling from the various data acquisition platforms are summarized in Table 2.1. This matrix provides a listing of platform, the maximum time of sampling, and the horizontal and vertical (depth) excursion capability (Dickey 1991). Note that this table reflects the present capability and may soon be updated with new systems, such as the Japanese *KAIKO* 10,000 m remotely operated vehicle (ROV), which was undergoing sea trials during the summer of 1993.

### **MANNED SUBMERSIBLES, SENSOR SYSTEMS, AND EQUIPMENT**

Most shallow submersibles were originally developed for offshore commercial projects to perform a wide variety of underwater tasks, including survey, inspection, construction, and search and recovery. A major portion of this work was related to the oil industry, although some shallow submersibles have been configured for science activities.



**Table 2.1**  
**Time and Space Sampling from Data Acquisition Platforms**  
 (Modified from Dickey)

PLATFORM DESCRIPTION	SAMPLING DOMAINS		
	TIME	HORIZONTAL	VERTICAL
Moorings	1 min - years	centimeters (cms)	At fixed depths: 10s m - 100s m
Ship on Station	<1 hr - 4 weeks	On station: cms Inter-station: kms	<1 m - 100s m
Ship Mapping/Fixed Depth	1.5 days - 4 weeks	<1 m - 100s km	± Few meters upper 100s m
Ship Tow-yo's	1.5 days - 4 weeks	0.5 km - 100s km	<1 m - 100s m
Drifters/Fixed Depth	1 min - 6 months	<1 m - 100s km	± Few meters upper 10s m
Planes	1 day - 1 week	10s m - 1,000s km	Upper few meters (opt. atten. depth)
Satellites	1 day - years	1 km - global	Upper few meters (opt. atten. depth)
AUV Systems	1 min - weeks	cms - 300 km	Variable over range 1 m - 6,000 m
ROV Systems	min - 1 week	cms - 100 km	To 7,500 m
Submersibles	min - 12 hours	cms - 10 km	To 6,800 m

Scientific and research applications for manned submersibles generally increase as a function of depth. Extensive oceanographic and undersea research using manned submersibles was initiated in the early 1970s during Project FAMOUS (French-American Mid-Ocean Study) on the Mid-Atlantic Ridge at depths of 3,050 m (10,000 ft), during which over 100,000 photographs were made and nearly 1,300 kg (3,000 lbs) of carefully selected geological samples were collected by *Alvin* and two French submersibles. In addition, water samples were collected and a data logger was developed to automatically record depth, altitude, heading, and time (Karahl 1990). Since that time, numerous submersibles have been developed by various countries (specifically France, Russia, Japan, and the United States), including several having 6,000 m capability. The French and Russian scientific-type submersibles, consisting of the *Cyana*, *Nautilie*, and *Mir* submersibles, will be described in the following section. Other Russian and Ukrainian submersibles are discussed in other chapters.

The French manned deep-sea submersibles *Cyana* (3,000 m) and *Nautilus* (6,000 m) have conducted extensive subsea projects because of their manipulative capabilities and various work packages. A large variety of equipment has been developed for scientific purposes, including rock, sediment, water sampling, and in-situ measurements.

*Nautilus* is a relatively low weight (18.5 tons), titanium-hulled submersible designed by IFREMER and DTGN, and has been used extensively for undersea research. It has two manipulators and a retractable sample basket. The high payload of 500 kg allows the installation of extra equipment, tools, and sampling capability. Sensors and instrumentation include Doppler log, pressure sensor, subbottom profiler, and sonar. To date, the *Nautilus* has conducted approximately 700 dives with around 120 dives per year scheduled. *Cyana* has a single five-function manipulator and a sample basket with a 80 kg payload. Sensors and equipment include an echosounder and scanning sonar. *Cyana* has made approximately 1,500 dives.

Both French submersibles have a large variety of tools, equipment, and instruments to carry out complex operations and experiments. These include: water samplers, temperature and conductivity probes, a sediment corer, a hydraulic hammer for rocks, a rock corer, a vacuum sampler, a tracer injector, and miscellaneous cutting tools (Michel et al. 1989).

Russia and Ukraine presently own and operate 20 or more submersibles, and have several deep versions (two 4,000 m and one 6,000 m) under construction that have been delayed by funding. These are discussed in Chapter 4 of this report. *Mir I* and *Mir II*, among the world's deepest diving submersibles (6,000 m class), were delivered to the USSR Academy of Sciences by Rauma Oceanics of Tampere, Finland, in December 1987, when they underwent successful sea trials to 6,170 m.

These submersibles are constructed from high-strength maraging steel and have a 100 kWh battery capacity that provides extensive (in excess of 14 hours) on-bottom time, considerably longer than any other deep diving submersible. The *Mir* submersibles are effective platforms for deep water activities; each can be equipped with a wide range of scientific equipment and sensors, depending on intended use (Mikhailov 1989). Table 2.2 is a listing of sensors, samplers, and equipment. It is believed that most of the equipment and sensors were obtained from international suppliers. The collected data can be recorded by an integrated data acquisition and navigation recording system. Side scan sonar and a subbottom profiler provide geological information. It is the opinion of some scientists that the *Mir* submersibles and their support ship, the *R/V Keldysh*, comprise the best equipped and most capable research tool for deep-sea research (Johnson 1993).

**Table 2.2**  
***Mir* Submersibles**

<b>SENSORS, INSTRUMENTATION AND IN-SITU CAPABILITIES</b>
Neil Brown CTD
DO Sensor
High-Temp Sensor (Up to 400°C)
3-Axis Current Velocity
3-Axis Magnetometer
pH Sensor
Sound Speed
Radioactivity Probe
Two 7-Function Manipulators
Core Drill
Water Sampler, Niskin

### **REMOTELY OPERATED VEHICLES**

Generally speaking, most of the remotely operated vehicles available in Europe and the former Soviet Union (FSU) are work vehicles for the offshore industry. These are discussed in detail in Chapter 8 of this report. However, there were several specialty ROVs that have been designed or are being developed for scientific and unique applications. These include the Intershelf *Fish-103* series of ROVs, developed for assessment of the environmental effects from the sunken *Komsomolets* nuclear submarine. These compact ROVs have been used to make observations and measurements using a tether management system on the *Mir* submersibles.

In addition to the 6,000 m and 3,000 m submersibles, IFREMER is developing a 6,000 m ROV that is scheduled for sea trials in 1995. This \$7 million project (manpower costs excluded) will incorporate scientific requirements, including sensors and instrumentation from undersea researchers. This ROV will utilize a fiber optic umbilical and a 300 m tether with three tool packages, including biological, geological, and ocean sensor configurations. These tool packages will be interchangeable with the scientific ROVs operated by the Monterey Bay Research Institute (MBARI), Monterey, California, allowing broader accessibility to the world undersea science community.

## AUTONOMOUS UNDERWATER VEHICLES

Autonomous underwater vehicles have enormous potential for studying the world's oceans. Several major AUV programs are presently under way in Europe that will provide extensive data gathering capability for various research missions. These AUV designs and their sensor systems are described in the following section.

The British government's Department of Trade and Industry (DTI) is sponsoring a collaborative effort by Marconi Underwater Systems, Ltd. (MUSL), Moog Controls, Chelsea Instruments, and Alupower/Alan International to produce an autonomous underwater vehicle specifically for oceanographic research. The *Oceanographic Data Acquisition System (ODAS) AUV* makes extensive use of off-the-shelf hardware, including advanced torpedo technology, and thus is an excellent example of military-to-civilian conversion. End use of the AUV is to collect data to ocean depths of 100 m while transmitting under the polar ice cap. Sensor design maximizes reliability and performance in the hostile environment (Neal 1992).

Core sensors include the most commonly measured oceanographic parameters, conductivity, temperature, and depth (CTD), and also chlorophyll-a fluorescence. Core sensors will require five data channels, two channels for housekeeping, and nine data channels for externally mounted sensors that would be mission specific, that is, fluorimeters, nephelometers, and transmissometers. Table 2.3 provides range, accuracy, and resolution specifications for the ODAS sensors.

Table 2.3  
ODAS AUV Sensor Suite Specifications

PARAMETER	RANGE	ACCURACY	RESOLUTION	COMMENTS
Temperature (°C)	-2 to +32	±0.02	0.002	Platinum resistance thermometer
Depth dbar (m)	0 to 100	±0.25	0.002	Silicon strain gauge transducer
Conductivity (msh/cm)	1 to 50	±0.02	0.005	300 m at 1 m/sec inductive cell
Chlorophyll-a Fluorescence (gm.cm <sup>-3</sup> )	10 <sup>-11</sup> to 10 <sup>-7</sup>		10 <sup>-11</sup>	Measurements are referenced to chlorophyll-a extracted from spinach

Environmental design considerations include minimum air temperature, thermal shock, icing, fouling, low temperature sealing integrity, and corrosion. To withstand Arctic operations, circuit designs are rated to  $-40^{\circ}\text{C}$  operational and  $-65^{\circ}\text{C}$  storage. Sensors and filters are highly stable, and are designed for cold temperatures and thermal shocks.

AUVs are being developed by the Institute of Oceanographic Sciences' Deacon Laboratory (IOSDL) as part of the Autosub project of the United Kingdom's National Environment Research Council (NERC). Deacon Laboratory is leading this project. The Autosub project will involve the development of three AUVs (Babb 1993). The first is the Demonstrator Test Vehicle, which will be a full ocean depth (6,000 m) demonstration and learning AUV. Additional long-term concepts under consideration include *DOLPHIN* (*Deep Ocean Long Path Hydrographic Instrument*), a 6,000 m depth capable AUV that would follow a vertically undulating path taking oceanographic measurements in the water column and a range target of 7,000 km, surfacing every 30 km to fix its position by global positioning satellite (GPS) and transmit its data. Another AUV concept is *DOGGIE* (*Deep Ocean Geological and Geophysical Instrumented Explorer*), which would be used for geological survey using acoustic imaging sensors of the seabed.

Development of the *DOLPHIN* AUV during the next decade represents an ideal technique for automatic wide-area hydrographic data collection in the deep oceans and under ice. By conducting comprehensive surveys across ocean basins, *DOLPHIN* would complement surface observations using satellites, buoys at fixed locations, and other measurement platforms. *DOLPHIN* is designed to provide a set of measurements with sufficient accuracy and resolution (water density resolved to  $10^{-5}$ ) that when assimilated, along with other data, into four-dimensional models, would permit computation of global transport of heat and moisture by the oceans, a critical factor in global change.

*DOGGIE* would be a geologic survey vehicle that could provide highly detailed maps using acoustic imaging sensors of the seabed for a total track length of 1,000 km in a 80 km x 70 km rectangle. Specific study sites would include hydrothermal vent fields associated with ore deposits near midocean ridges. Because it is designed as a multisensor vehicle, *DOGGIE* carries side scan sonars, a subbottom profiler, a magnetometer, and chemical sensors. This AUV is therefore capable of providing a wealth of data on geophysical and geological properties of particular sites.

In addition to its activities under the U.K.'s Autosub project, IOSDL is also leading an EC Marine Science and Technology (MAST II) program with six other European partners (including IFREMER). This has the title "Advanced Systems Research for Unmanned Autonomous Underwater Vehicles" and is focussed on generic subsystems research. This is almost certainly the same program referred to during

the WTEC team's visit to IFREMER in Toulon, France. IFREMER representatives mentioned then that they are engaged in an EC project to develop key technologies for a 6,000 m abyssal survey vehicle (ASV) for survey and mapping of deep ocean regions. Subsequent correspondence from IFREMER (November 1993) noted that this project tends towards the same objectives as the *DOGGIE AUV*. IFREMER quoted a figure for total funding of approximately \$2.5 million for the EC-supported ASV project, which will result in a feasibility study and preliminary design in 1995.

## REMOTE SENSING SYSTEMS

Numerous techniques have been developed for remote sensing of the ocean. Some techniques that the team encountered during the trip included: a multipurpose airborne laser system Lidar, for oil spill detection and ocean thermocline research; radars for wind-wave research; and acoustic Doppler current profilers (ADCP) for ocean current measurement at various depths. (Additional information on the Lidar and wind-wave radars may be found in the site reports on the General Physics Institute and the Institute of Applied Physics in Appendix B.) The following section describes the ADCP capabilities noted during the site visits.

During the past ten years, acoustic Doppler current profilers have progressed from an alternative method to an established technique for measuring the ocean's horizontal flow field at various depths. ADCPs provide high quality data for requirements as diverse as oil production, fisheries development, and environmental monitoring. The ADCP is basically a multibeam (there are typically three or four beams) pulsed, range-gated sonar that employs the acoustic Doppler principle to remotely measure vertical profiles of horizontal water currents from a moving vessel, buoy, or the seafloor. In areas where the water depth is within the ADCP bottom tracking range, the sonar also measures the earth-referenced vessel velocity.

The Institute of Applied Physics, Nizhny Novgorod, Russia, has developed a universal ADCP that can provide real-time measurements of three components of flow velocity at different depth cells. These measurements can be made from a stationary platform, from the sea bottom, from ice, or from a ship. When operating at depths of 300 m to 400 m, ship speed relative to the bottom can be measured. Table 2.4 summarizes the technical specifications for the institute's ADCP.

This ADCP system also includes an IBM-PC/AT with appropriate peripheral equipment and software. The mean values of the calculated velocity profiles are depicted on the computer monitor and as data files on the hard disk. Also incorporated in the design is a sound velocimeter that provides measurements of sound speed to allow corrections in the ADCP data. The shipboard version also includes a gyre sensor for pitch and roll measurement, and a digital adapter for the ship gyrocompass. Analysis of these specifications indicates that this narrow-beam

version has capabilities comparable to a commercially available ADCP (e.g., RD Instruments, Inc.).

**Table 2.4**  
**Institute of Applied Physics**  
**Acoustic Doppler Current Profiler Specifications**

Operating Frequency	220 kHz
Beam Description	3 beams, 30° off vertical in 120° increments
Velocity Range	±3 m/sec ±10 m/sec (shipboard version)
Current Profiling Depth	200 m to 300 m
Depth Cell Length	4, 8, 16 m
One-Pulse Measuring Error	10, 5, 2.5 cm/sec
Averaging Interval for 1 cm/sec Accuracy	2 minutes
Bias	<0.25% of mean velocity
Number of Depth Cells	up to 100
Operating Pressure	10 atmospheres

A broadband version of the ADCP with enhanced capabilities was developed two years ago by the same company. The broadband design implements advanced signal processing technology known as pulse-to-pulse coherent sonar. On receipt of the broadband signal, it is amplified and digitized. This design provides a four-fold resolution increase, an order of magnitude faster updates, shallower operating depths, and highly accurate Doppler velocity log capabilities when compared to the narrowband ADCP version (Spain and Gordon 1992).

## **OCEANOGRAPHIC SENSORS AND INSTRUMENTATION**

The following section describes various oceanographic sensors and instrumentation developed by Ukrainian and Russian institutes. Most of the instruments described were developed at the Marine Hydrophysical Institute (MHI), Ukrainian Academy of Sciences, in Sevastopol, Ukraine. The other major source of oceanographic instrumentation in the FSU is the Institute of Oceanology, Russian Academy of

Sensors, Moscow. Instrument configurations allow for towed, profiling, and moored conditions. Basically the sensors and instrumentation can be grouped in current meters, CTDs, DO, pH, transmissometers, geomagnetic compasses, and various others.

Numerous design configurations for current meters have been developed by MHI, including rotating elements (propeller, impeller) and nonmoving parts (acoustic and electromagnetic). Most of these current meters record the time series measurements data internally for periods up to a year depending on the sampling, or in some cases vector averaging, interval. Depth capabilities range from 50 m to 6,000 m, depending on application. Several designs allow for data processing on an IBM-compatible personal computer (PC). MHI has concentrated on acoustic current sensors that measure small scale (10s of cm) velocities based on acoustic travel time instead of the acoustic Doppler current profilers that measure over a much longer scale (100s of m). It appears that this technology and the capabilities of the MHI acoustic current meters are similar to the NBS ACM developed in the United States and at Christian Michelsen Institute, Bergen, Norway, in the 1970s. Electromagnetic current meters were introduced by Marsh and McBinney, Inc., in the 1970s, and have demonstrated applications in the marine environment and in other environments.

MHI has also developed various other instrumentation, such as those measuring conductivity, temperature, and depth for physical oceanographic studies. CTD designs include both towed and lowered (sounding) or profiling versions. One version, the MGI-1201, is capable of CTD measurements at speeds to 15 kt with depths to 1,500 m, allowing surveys over a large area. Another towed version, the MGI-9201, has control surfaces and can be maneuvered in three dimensions at towing speeds up to 12 kt. The shape of the vehicle is radically different from that of other towed vehicles, such as the *Sea Spar* or *Bullfinch*, which are used for similar ocean research (Dugan and Jendro 1993). In addition to the CTD capability, this unit measures light attenuation (transmissometer) at two wavelengths, and chlorophyll-a fluorescence. The towed body trajectory may be controlled by an operator or an onboard computer. This instrument was designed to study frontal boundary zones, internal waves, and fine structure of the upper ocean.

MHI has developed a series of profiling systems lowered by cable and utilized from ships of opportunity. Some of these instruments (MHI-4103, MGI-4116) have CTD, DO, pH, turbidity, sound speed, and light attenuation sensors and, in some versions, current measurement capability. Several designs incorporate sampling of up to 26 samples. Several models have 6,000 m depth capability. A deck unit provides readouts of sensor values, computation of secondary parameters, and data output into chart recorders, printers, and computers. There are also self-contained designs that record data on magnetic tape. Additional information on these miscellaneous oceanographic instruments may be found in the site report on MHI (Appendix C) and in MHI's specification catalog (Marine Hydrophysical Institute 1993).



Much of the instrumentation developed in Russia and Ukraine has had questionable data quality, and the accuracy and reliability has not been on a level with comparable Western ocean sensors (Dugan and Jendro 1993). Numerous cooperative intercalibration experiments, both in the laboratory and the field, have revealed measurement anomalies outside the reported accuracy bounds of the sensors. It is unclear if this can be attributed to instrument quality, calibration procedures, laboratory standards, or routine maintenance. Data of known quality is an important product from international global experiments.

### MISCELLANEOUS MEASUREMENT CAPABILITY

The sinking of the *Komsomolets* submarine off Norway in 1989 resulted in several in-situ investigations of the submarine and surrounding area by Russian research institutions and scientists. In order to effectively carry out these studies (see Table 2.5), equipment, instrumentation, and sensors have been developed by Russia's Central Design Bureau for Marine Engineering (RUBIN) to enable researchers to assess the contamination effects from the nuclear reactor and nuclear missiles. For example, two small ROVs were developed by Intershelf for deployment from the *Mir* submersibles to allow closer inspection of the submarine. These neutrally buoyant ROVs have a depth capability of 6,000 m, two TV cameras, and a radiometer.

**Table 2.5**  
***Komsomolets* Submarine Investigations**

Sank 4-7-89 in Norwegian Sea in 1,700 m water
Nuclear Reactor and Torpedoes
Three Expeditions to Date <ul style="list-style-type: none"> <li>- Completed 12 submersible dives, 120 hours</li> <li>- Towed camera and AUV surveys</li> <li>- Obtained 200 sediment and soil samples</li> <li>- Developed gamma spectrometers</li> <li>- Used submersible deployed ROVs</li> <li>- Obtained 2,000 measurements</li> </ul>

Because of absorption of alpha and beta emissions by almost any intervening material (seawater, hull, etc.), radiation measurements from seabed sources or sunken vehicles is almost exclusively monitored by the use of gamma spectrometry. In response to the *Komsomolets* submarine's sinking on April 7, 1989, the Russian Research Center's Kurchatov Institute developed several versions of a gamma

spectrometer deployed or used from the *Mir* submersibles (Nejdanov 1993). Basically, gamma rays emit between 0 and 3 Mev (mega electron volts) in the spectrum, and the point in the spectrum where a peak occurs directly identifies the isotope (in this case, Ce-137) causing the radiation.

Gamma radiation is measured using a sodium iodide scintillation detector that emits flashes of light when struck by gamma radiation. These are converted to electrical pulses by a photomultiplier tube coupled to the end of the detector. The pulses are amplified and recorded in the submersible. The brightness of the light flashes, and hence the size of the electrical pulses, is directly proportional to the energy of the gamma radiation striking the detector.

Several different gamma spectrometers were developed for use from the *Mir* submersibles, as well as a version that can be utilized from a ship. The minimum detectable activity of Ce-137 in seawater is claimed to be 0.5 pCi/l. The spectrometers are designed for minimal weight and size, and maximum sensitivity for undersea measurement use. Figure 2.1 depicts a model REM-2 gamma spectrometer that was deployed near the *Komсомолец* submarine with the *Mir* submersibles. Figure 2.2 shows some typical Ce-137 measurements, while the K-40 peak is the radiation signal detected in most seawater. An autonomous, self-contained version has been developed that allows deployment for longer time measurements. These instruments are not unique; similar designs of portable NaI crystal gamma spectrometers have been available commercially for approximately a decade, that is, at Exploranium G.S. Limited, Toronto, Canada.

## SUMMARY AND CONCLUSIONS

Deep ocean submersibles such as the *Mir* and *Nautilus* continue to be effective platforms for undersea work and research because of their extensive sensor, instrumentation, and manipulative capability. The *Mir* submersibles are considered by some scientists to be the best equipped and most capable research tools for deep sea (6,000 m) research.

Although Russia and Ukraine have developed limited remote sensing capability for ocean studies using Lidar and acoustic Doppler current profilers, these designs are not unique and are within the current state of practice.

Oceanographic instruments (CTDs, current meters, etc.) are being marketed by Russia and Ukraine. Their data quality is unknown, and intercalibrations should be conducted to determine measurement capabilities. Other factors, such as price, reliability, and maintainability, must also be addressed.

conducted to determine measurement capabilities. Other factors, such as price, reliability, and maintainability, must also be addressed.

Research-type ROVs and AUVs are being actively developed by several European countries outside of the FSU. Unmanned platforms for undersea and oceanographic research using enhanced sensors and samplers are being supported as major programs by the EEC. This is in marked contrast to the United States, where there is no major focused thrust for developing scientific AUVs.

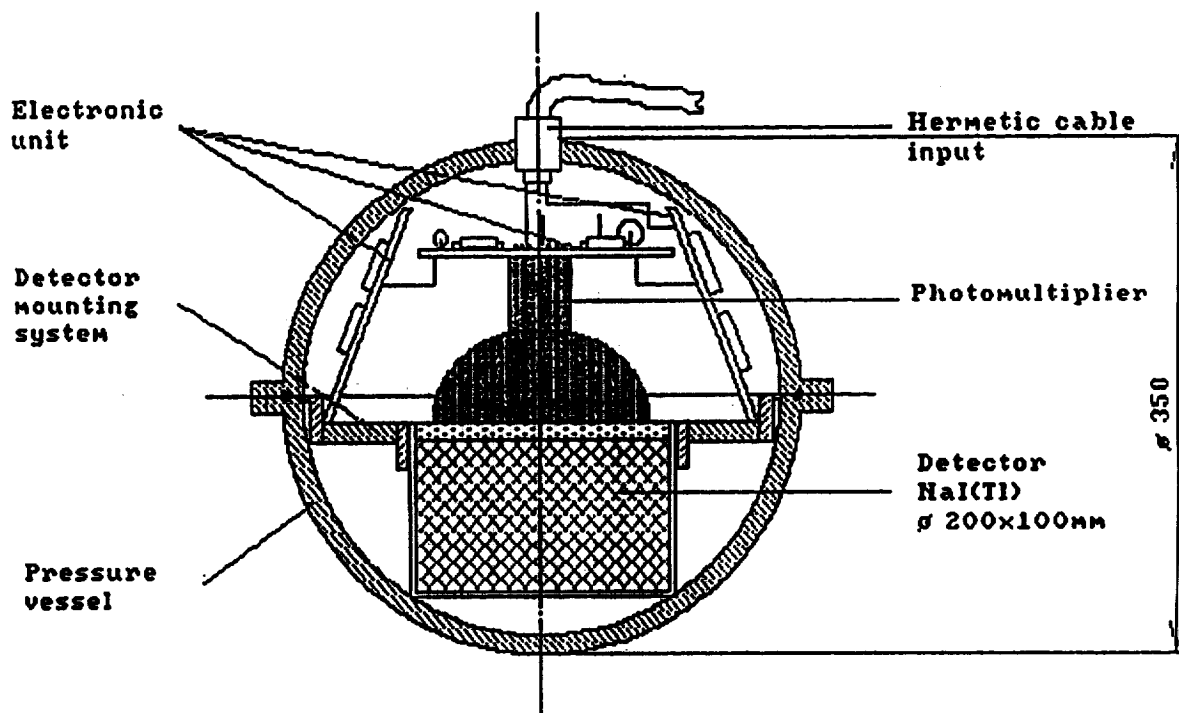


Figure 2.1. Gamma Spectrometer REM-2

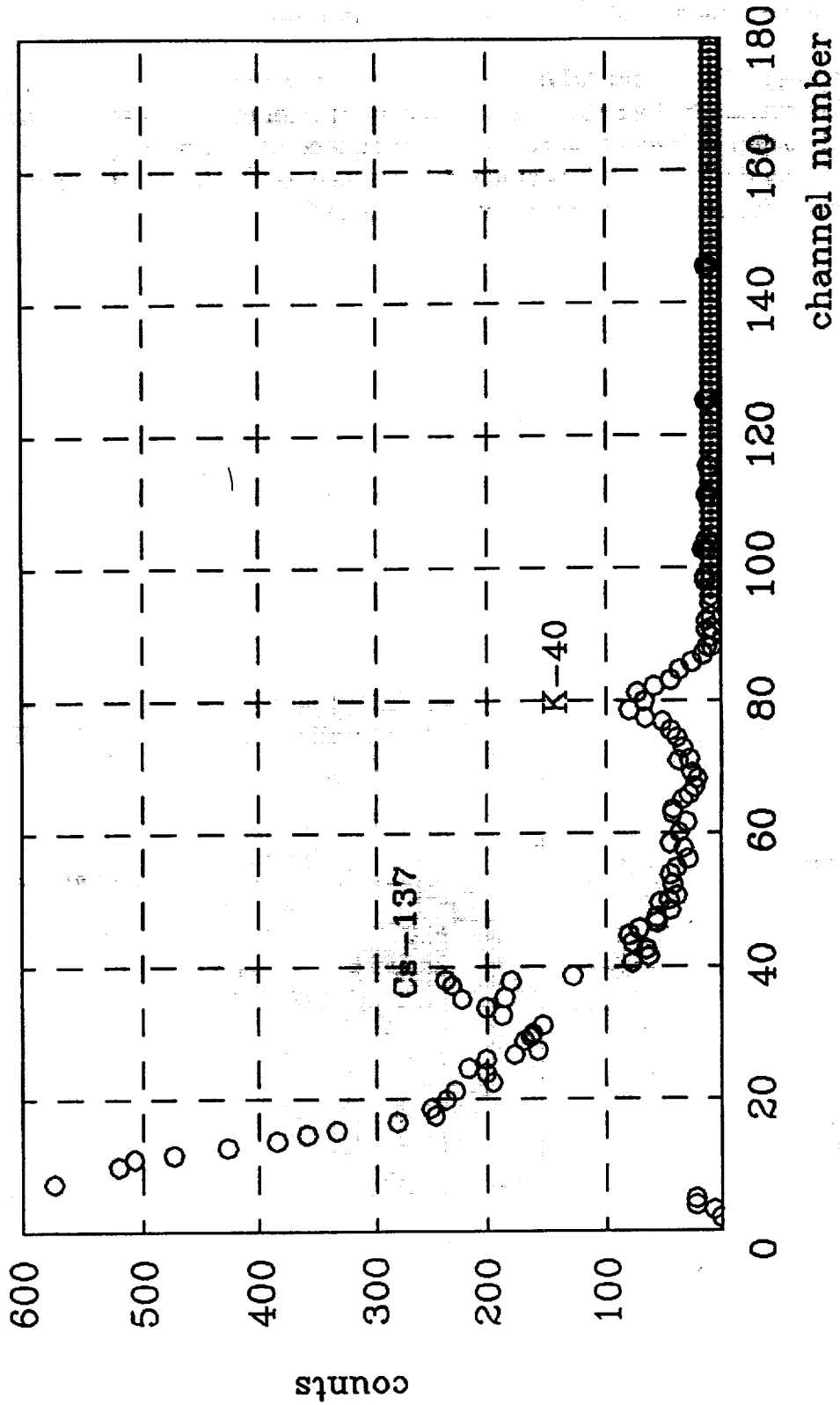


Figure 2.2. Gamma-Radiation Spectrum of Water in the Vicinity of Reactor Compartment

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## CHAPTER 3

# ENERGY, PROPULSION, AND HYDRODYNAMICS

Don Walsh

### INTRODUCTION

The countries of the former Soviet Union collectively have the world's largest nuclear submarine force, both in absolute numbers and diversity of designs. With the end of the Cold War and the dissolution of the USSR, this capability represents an enormous technology base for underwater applications.

Understandably, until less than two years ago, these were considered sensitive technical areas that were discussed with few Soviet citizens and were not discussed at all with foreign visitors. Now, with a solid and urgent commitment to defense conversion prevalent in Russia and Ukraine, the WTEC team was shown a great many applications for nuclear power sources reactors but few technical details. The same was true for other power systems, hydrodynamics and propulsion systems.

Time was extremely limited at each stop on the trip, a matter mentioned as often by the hosts as by the WTEC team members. Therefore it is not clear whether the lack of technical details was due to insufficient time or a residual reluctance to reveal details of former military research work. What is clear is that the team members have all received invitations to visit most of the sites again, and for longer time periods.

It was not appreciated until recently that there had been a wide variety and number of manned deep submersible vehicles (DSV) designed and built in the former Soviet Union. Prior to the dissolution of the Soviet Union it was believed that no more than a handful of relatively simple submersibles had been built. It appeared that the most

advanced DSVs, such as the two 2,000 m *Pisces* and the two 6,000 m *Mirs*, were procured from the West. Now it appears that between 30 and 40 Soviet-designed DSVs have either been built or are in the process of construction. From the information supplied to WTEC teams, the energy systems used in these sources are fairly conventional storage batteries. Again, time limitations prevented a more in-depth review of DSV energy sources.

In short, much more was discovered than had been anticipated during the planning of this trip. A major technology base in submarines and submersibles has supported a wide range of technical development in all of the areas of interest to the WTEC team.

Concurrent with nuclear submarine development, the Soviet Union also maintained a program of development for diesel-electric submarines. Within this program there was some experimentation on air-independent propulsion (AIP) energy sources.

In the following section on energy and power systems, several Russian nuclear reactor concepts are discussed. Clearly, most of this work has come from submarine programs. There are also descriptions and specifications for various types of fuel cells, as well as primary and secondary battery systems. The specifications are shown in tables for clarity. However, these are not complete brochure-type specifications, but rather a sample of each power unit's parameters and capabilities.

Perhaps the most useful baseline specification for undersea vehicles power and energy sources is its energy density in terms of watt hours per kilogram of weight (Wh/kg). This value has been given for almost every unit cited. But giving Wh/kg without a calibration reference may not be very useful. Therefore, Table 3.1 compares various types of energy sources. Note that these are sample relative values; designs within each category may have slightly different energy densities.

The second major section of this chapter is hydrodynamics. As a result of military development programs it was evident that a lot of USSR research work was done on high speed vehicles (i.e., submarines and weapons with speeds up to 75 kt). However, this does not have much carryover value for manned submersibles, remotely operated vehicles or most AUV designs. For long-duration mission AUVs (up to 30 days is forecast), the skin drag reduction and hull shape developments shown to the WTEC teams can be important where energy efficiency and conservation are prime concerns for the designer.



**Table 3.1**  
**Some Sample Energy Densities for Power Sources**

Lead-Acid Battery	30 Wh/kg
Nicad Battery	44 Wh/kg
Sodium-Sulfur	100 Wh/kg
Silver-Zinc	112 Wh/kg
Sterling Engine	259 Wh/kg
Al-O <sub>2</sub> (Air) Cell	278 Wh/kg
Hydrogen-Oxygen Fuel Cell	300 Wh/kg
Li-Thionyl Cl <sub>2</sub>	396 Wh/kg

Propulsion, an area of particular relevance to submersibles, is the subject for the third section of this chapter. To use the aviation analogy, most underwater vehicles do not fly underwater by use of propeller(s) and lifting and control surfaces. In general, submersibles are dynamically positioned by use of thrust vectors. Horizontal movements are in the order of a few thousands of meters. Thus, the energy efficiency of thrusters is a key design consideration in development of a vehicle's overall energy budget. The ideal thruster develops high thrust with minimal energy consumption. This conservation permits mission tradeoffs where onboard energy can be allocated to a longer mission time or the carriage of more electrically powered equipment.

The emphasis in the following sections will be on developments in Russia and the Ukraine. European developments that are discussed generally represent technologies that are readily available in the open literature. In the case of Russia and Ukraine, almost everything the WTEC teams saw was new.

In many -- if not most -- visits to Russian and Ukrainian organizations, the degree of technical information provided to the WTEC team tended to be superficial. This was mostly due to time limitations and a general lack of printed materials. This lack of technical detail should not be an excuse for not at least citing developments of interest at places visited, even though the information is more anecdotal than technical. Further, the mention of a development at a specific location can help provide a roadmap for others who wish to follow up on this information.

**ENERGY AND POWER SYSTEMS****Nuclear Power**

**Russian Research Center Kurchatov (Moscow).** RRC Kurchatov has seven active reactors at this site, including the first reactor in Europe (1947). Ten thousand people are employed here to design, construct, and operate nuclear power reactors. The WTEC team was told that this is one of two institutes in Russia that develops reactors for military submarines.

The WTEC team was shown Gamma, an operating prototype of a nuclear-powered thermoelectric power source. This unit is designed for unattended operation on the seafloor to water depths of to 6,000 m. Table 3.2 shows Gamma's general specifications.

**Table 3.2**  
**Gamma Nuclear-Thermoelectric Power Source**

<b>Output</b>	6 kWe electrical and 200 W of heat
<b>Size</b>	6 m high x 2.5 m diameter
<b>Weight</b>	10 to 12 t
<b>Design Life</b>	10 years
<b>Fuel</b>	UO <sub>2</sub> with less than 20% enrichment
<b>Design Work Began</b>	1970
<b>Began Testing</b>	1972
<b>Principal Construction Material</b>	Titanium
<b>Cooling</b>	Natural Circulation

No field installations have been made, and this prototype test unit will soon reach the end of its design life. However, in this case Gamma will last about twelve years, since it has not been operated continuously at full power.

RRC Kurchatov also has developed Helena, a design concept for a larger unit of 100 kWe that employs the same basic fuel elements and design approach as Gamma. None of this type has been built. Table 3.3 gives Helena's specifications.

**Table 3.3  
Helena Nuclear-Thermoelectric Power Source**

<b>Output</b>	100 kWe electric and 3,000 kW of heat energy
<b>Maximum Operating Depth</b>	6,000 m
<b>Weight</b>	200 t
<b>Size</b>	height 12 m x diameter 4.5 m
<b>Design Life</b>	25 years
<b>Price</b>	\$6 to 8 million

**Lazurit/Kurchatov ROSSHELF Joint Program.** Lazurit is one of three organizations in Russia that does military submarine and submersible designs for the navy. Their defense conversion efforts are focused on development of a wide variety of non-military undersea vehicles, submarines and seafloor structures. None have been built yet.

ROSSHELF is a newly created company proposing to build a seafloor-based oil and gas production complex (maximum operating depth of 500 m) involving the design and technical cooperation of several Russian organizations. The Lazurit Central Design Bureau is proposing to design and engineer the seafloor structures while RRC Kurchatov would be responsible for designing the two nuclear reactors (turboelectric conversion) that will power the complex. There is a continuing, close tie between these two organizations.

Each of the two reactors will be rated for 6,000 kW. They will be highly automated, requiring only one supervising operator. These power sources will be located in the ROSSHELF Control and Power Unit (CPU), which will be in the form of two cylindrical pressure hulls. Reactor design life is estimated to be 30 years with major refit (refueling) being done every 10 years.

Existing design and fabrication technologies for pressure hulls and propulsion developed for the Soviet Navy nuclear submarine program will be used throughout the ROSSHELF complex. This may include the operating team for the reactors.

However, this is not straight defense conversion. Design, construction, and operation of a virtually unattended, seafloor-mounted, underwater nuclear power reactor of this size is most certainly a major new development program. To date, no one has developed a seafloor-sited nuclear power plant.

The full ROSSHELF concept also includes a nuclear-powered (15,000 kW) service-support submarine for the seafloor complex for tasks such as crew transfers, inspections, maintenance, repairs, and emergency evacuation. The submarine will be equipped to carry both a manned submersible and a fly-off remotely operated vehicle. A second manned submersible will be built as a rescue vehicle in case personnel have to be evacuated from any of the seafloor modules.

The program outline for ROSSHELF states that it will take from eight to ten years and about \$2 billion to develop the prototype/pilot seafloor system, even though many of the basic technologies involved will be transferred from the defense area.

*Lazurit Central Design Bureau (Mishin Novgorod).* In addition to ROSSHELF, some of Lazurit's defense conversion efforts apply the bureau's military nuclear submarine design expertise to commercial practice. One concept discussed with the WTEC team was a nuclear submarine container ship of 190,000 tons displacement. The cargo capacity is 1,000 TEUs (80-foot equivalent containers), which is small by surface ship standards, where 2,000 to 3,000 TEU vessels are common. The power plant will produce 45,000 kW.

A second nonmilitary nuclear-powered submarine project that has been worked on by Lazurit is *Ocean Shuttle*. This is a small submarine (about 1,000 tons) that is designed for oceanographic and commercial ocean work tasks.

Originally this was a joint project between Lazurit and the ECS Group in Canada. Lazurit would design the submarine hull and major systems, while ECS would provide and install the small (100 kW) reactor to power it. Because of the breakup of the Soviet Union, and difficulty getting funding from the Canadian side, this project was put on hold.

Lazurit is still interested in doing this project, and claims that use of a Russian reactor would reduce the program cost (originally about \$100 million) by more than one-third. Of interest is the fact that this nuclear power system would represent an entirely new design, since *Ocean Shuttle's* power system is intended to be relatively low powered, to be fail safe, to have low temperature and pressures, and to operate virtually unattended.

*Krylov Shipbuilding Research Institute (St. Petersburg).* This is the principal shipbuilding research organization in the former Soviet Union. The institute's Marine Power Plants and Nuclear Power Plant divisions are concerned with marine power and energy systems. Unfortunately, the WTEC team was not given information about these activities at Krylov. It may be that Krylov's Nuclear Power Plant Division is only concerned with large installations for submarine and surface ship applications.

However, Krylov has been responsible for the design of several deep submersibles. Krylov also has the national responsibility for developing recommendations for classification rules for the design, construction, and maintenance of all Russian manned submersibles. Therefore, with this degree of experience, there is reason to believe that the institute also has contributed to the development of power systems for submersibles.

### Fuel Cells

*Energia Space Corporation (Moscow).* Energia is a key institute for manned spaceflight vehicles and large payload rockets. The institute also has developed Russia's version of the space shuttle *Buran*.

Energia has developed a hydrogen-oxygen ( $H_2-O_2$ ) fuel cell (designated by Energia as an "electrochemical generator" or "EG"), called "Foton" (Photon) for its space shuttle, which carries four of these cells. Energia says that its unit is similar to NASA's fuel cell in the U.S. Space Shuttle. Energia has manufactured 100 Photon EGs since 1987. In test programs and on actual missions, these cells have accumulated a total of 80,000 hours of operational experience. Table 3.4 gives the parameters for Photon.

**Table 3.4**  
**Energia Photon Fuel Cell for Space Applications**

Power	1 to 15 kW
Voltage	27 to 34 VDC
Energy Density	750 to 1,000 Wh/kg
Life	10,000 hours
Efficiency	65 to 70%
Weight	160 kg (empty)
Byproduct	Distilled water

Based on the Photon development program, ENERGIA now offers two modified versions for undersea applications. The first is a hydrogen-oxygen power unit fuel cell and the second is a hydrogen-oxygen electrical battery (HOBUE). Both are based on the Photon developments. Tables 3.5 and 3.6 provide the general specifications for these units.

**Table 3.5**  
**Energia Hydrogen-Oxygen Power Fuel Cell for Submarines**

Power	Up to 30 kW
Voltage	34, 36, 110 VDC
Energy Density	300 Wh/kg
Life	10,000 hours
Efficiency	65 to 70%
Weight	1,060 kg (empty)
Weight of Reactants	160 kg
Byproduct	Distilled water

Energia representatives state that they can design, develop, and manufacture prototype units within 1.5 to 3 years once an order has been received.

**Table 3.6**  
**Energia HOBV Hydrogen-Oxygen Battery**

Output	1,000 AH
Power	6 kW
Voltage	27 ( $\pm 3$ ) VDC
Energy Density	100 Wh/kg
Life	1,000 cycles
Efficiency	60%
Weight	270 kg

Energia also has proposed a cell that would use phosphoric acid and natural gas as the reactants. However, this would be intended for fixed applications on land.

Finally, the company has helped develop a design for 10-passenger tourist submarines with the Russian Intershef J.P. Kenny Company. J.P. Kenny is considering using Energia's fuel cell (or HOBV battery) to power it.

**Lazurit Central Design Bureau (Nizhny Novgorod).** About five years ago, Lazurit designed a conversion of an older diesel-electric submarine to  $H_2-O_2$  propulsion. Some features of this installation were:

- o Liquefied gases were carried in large external tanks topside.
- o Weight compensation was achieved by removing most of the storage batteries.
- o Sea testing ended in 1991 (panelists were shown a video of some of these tests).
- o Lazurit said that the submarine's submerged endurance increased five to ten times.

The submarine has been taken out of service and scrapped in the Ukraine.

**State Nautical University (St. Petersburg).** The university has developed a water-activated, semi-fuel cell, magnesium-water energy system, which has a 200 Wh/kg energy density. These units have been built and tested in various sizes. No additional specifications were provided to the WTEC team. The panel believes this design might be similar to the Alupower (United States) aluminum-oxygen semi-fuel cells (see section below).

**Marconi/Alupower (United Kingdom/United States).** Alupower Inc. (Warren, New Jersey), part of the Aluminum Company of Canada, has developed an aluminum-air (oxygen) semi-fuel cell. The battery uses very pure (99.999 percent) aluminum plates, potassium hydroxide as the electrolyte, and air (oxygen) as the reactant materials.

Compared to other types of batteries, this energy source is of long duration and therefore of particular interest to developers of AUVs where extended mission times are desired. An Alupower energy system, AUV XP-21, by Advanced Remote Technologies in San Diego, California, is presently being sea tested in the United States. To conform to the shape of the AUV, the cell stacks are 21 inches in diameter.

Installation in Marconi's *ODAS* will greatly reduce space required for the battery system and thus will provide more mission payload space. At the same time this unit will significantly increase mission time. *ODAS* will use half an XP-21 cell. Table 3.7 provides the specifications for the aluminum-air battery.

## **Batteries**

**State Nautical University (St. Petersburg).** The university has designed and tested a full pressure compensation system for large numbers of alkaline cells. Compliant battery cases and oil-filled cables are used to isolate seawater from the system. It

is not clear whether or not the university has developed any new battery systems or has just been involved in repackaging existing units. The WTEC team was not provided with detailed information on this development.

**Table 3.7**  
**Alupower Aluminum Oxygen Battery**

Capacity	50 kWh
Voltage	120 VDC
Life of Al Stacks	40 hr
Energy Density	260 Wh/kg
Temperature Range	60 to 80°C

*Deacon Laboratory, Institute of Oceanographic Science (United Kingdom).* Deacon Laboratory of the Institute for Oceanographic Sciences is responsible for managing a multi-organization project, Autosub, which will develop two AUV systems for long-duration research tasks. To ensure that all contributing technologies are optimized, a "Demonstrator Test Vehicle" AUV will be built and sea tested.

Lithium-sulphur dioxide (Li-SO<sub>2</sub>) batteries are under consideration for the Demonstrator Test Vehicle's propulsion -- other technologies may also be considered depending on the mission. Initially, for trials and short missions, secondary batteries will be used. The Li-SO<sub>2</sub> battery should be sufficient for the vehicle's 1,200 range. However, this will not be sufficient for the *DOLPHIN* and *DOGGIE* long-duration AUV missions (up to 30 days and 7,000 km transits). Energy-dense power system choices could include a fuel cell or semi-fuel cell such as the Alupower unit (see Table 3.7).

*Marconi Underwater Systems Ltd. (United Kingdom).* Marconi's *Ocean Data Acquisition System AUV* is operational and uses sodium-sulphur batteries. These batteries were developed several years ago by the automotive industry for electric vehicles. Therefore, they are of moderately proven design with fairly low technical risk. A limitation is that they must operate at a high temperature (~300°C). Table 3.8 describes the battery system for the *ODAS AUV*.

*Rauma Nickel-Iron (Ni-Fe) Storage Battery (Finland).* This is the type of battery developed by Rauma Geoservices for the two 6,000 m submersibles built for the USSR Academy of Sciences. This development took place when the Shirshov Institute decided not to use hydrazine gas generators as the primary power source onboard these submersibles.



**Table 3.8**  
**Sodium-Sulfur Battery for ODAS**

Capacity	200 AH
Power Rating	37 kWh
Voltage	48 VDC
Life	>300 cycles
Weight	103 kg
Energy Density	100 Wh/kg
Optimum Operating Temperature	300°C

These cells have been used for several hundred dives onboard the *Mirs* and have been thoroughly field tested. The Shirshov Institute has reported that the cells have been very reliable and that their capacity has permitted mission times up to 18 hours with a generous power reserve remaining. Table 3.9 gives the specifications for this battery, which are commercial units offered for sale by Rauma Oceanics.

**Table 3.9**  
**Rauma Nickel-Iron Battery**

Capacity Per Unit	41 kWh
Pressure Compensation	6,000 m
Voltage	1.2 V (Voltage of each cell) to 120 VDC
Life	1,000+ charge/discharge cycles
Energy Density	40 Wh/kg (25 for lead-acid)
Optimum Operating Temperature	8°C

### Other

*Bauman Institute of Underwater Devices and Robotics (Moscow)*. Bauman is part of Moscow State Technical University, the oldest institute in Russia. Primarily an

educational organization, the Institute of Underwater Devices and Robotics has developed a solid propellant that uses water as an oxidizer. The gas generated is intended to power submersibles, probably by the use of turboelectric generators. Since Bauman indicated that its unit uses solid fuel, it is clear that the fuel is not a hydrazine-based energy source (see section on Rauma Oceanics below for this type of development in Finland). This appears to be a unique means of power generation for undersea applications.

Bauman has operationally tested a unit onboard one of the navy's four *Poseidon* submarine rescue submersibles. This is a particularly good application for a long-duration power system due to the time-critical nature of the mission. Bauman is also working on a unit to replace batteries on other types of manned submersibles.

*Morsplotekhnika (MTT) Scientific Research Institute (St. Petersburg)*. MTT was founded in 1946 with captured German experts to do research and development in underwater technologies. In recent years the focus of the staff of 200 has been on high performance (i.e., military) undersea vehicles.

The WTEC team visit to MTT was canceled upon arrival in Russia. However, the team received a one-page summary of MTT's activities. According to this information, MTT has been responsible for development of power systems for undersea vehicles and probably small submarines.

MTT's primary developmental line in energy sources has been thermal systems, using various fuel types that are quiet and capable of operating at great depths. According to MTT's paper, a series of power plants have been built and tested at sea.

*State Nautical University (St. Petersburg)*. Primarily an academic institution (8,000 students), the research conducted by faculty (800 plus 300 researchers) and graduate students has included energy systems for undersea vehicles. Work has been conducted on Sterling cycle engines; however, WTEC was given no specific details.

*IFREMER/COMEX Saga Submarine (Marseille/Toulon)*. Built by COMEX in France in 1987, *Saga* is powered submerged by a two-Sterling cycle engine that was built in Sweden. Conventional lead acid batteries, with a capacity of 0.8 MWh, provide energy backup. A diesel engine is installed for surface operations and recharging the batteries. Table 3.10 gives some specifications for the Sterling Cycle power system.

*Saga* underwent successful sea trials in 1991, but is presently in storage at Marseille due to lack of work. The French national ocean agency, IFREMER, provided the majority of funding for this program. Through its laboratory in Toulon, IFREMER has operational control of *Saga*.

**Table 3.10**  
**Saga Sterling Engines**

Number of Engines	2
Power Output	75 kW each
Recoverable Heat from Engines	28 kW each
Working Fluid	Helium
Fuel	Diesel oil + O <sub>2</sub> (carried as LOX)
Working Temperature	800°C
Efficiency	31%

**DCN AIP For Military Submarines (Toulon).** The French Naval Arsenal at Toulon (DCN) has an active project to develop and test an air independent propulsion (AIP) system for military submarines. Discussions have been held with IFREMER to use *Saga* as a test bed for the Navy's experimental AIP system.

**Rauma Oceanics (Finland).** Rauma has developed and tested a hydrazine hydrate gas energy source. The original intent was to provide 200 kWh of power for a proposed 6,000 m research submersible, the *Akademik*. These hydrazine gas generators could also be used for emergency ballast blowing at depths greater than 6,000 m.

This was a joint Rauma Repola (now Rauma Oceanics) - USSR development that began in 1985, although the first suggestion to use hydrazine came from Canada in the late 1970s. The USSR side was the P.P. Shirshov Institute of Oceanology, which set specifications and funded the submersible development.

By the time the construction contract was let, the companies had decided to build two 6,000 m submersibles that would be called *Mir* (i.e., "peace") I and II. The Shirshov Institute also made a conservative design decision, and storage batteries, providing 100 kWh, were used by Rauma Oceanics. The submersibles were delivered by Rauma in 1987.

As part of the original construction contract, Rauma was to develop a prototype hydrazine power unit. It was built in the early 1990s and successfully tested at sea in 1993. Table 3.11 gives its specifications. The next generation unit (RDP-100) increased power output to 50 kW with an increase in total system weight to 950 kg.

**Table 3.11**  
**Rauma Rankine Cycle Engine**

Type of System	Turboelectric, closed circuit Rankine Cycle
Power Output	20-25 kW
System Weight	600 kg (in air, without fuel)
Fuel	Hydrazine hydrate
Working Fluid	Toluene
Maximum Working Depth	6,000 m
Exhaust Effluent	Primarily ammonia
System Efficiency	30%

*Rauma RDP-100 Power Pack (Finland).* This hydrazine power unit was developed from the *Mir* developmental program and is advertised for sale by Rauma. The specifications are similar to those of the unit described in Table 3.11. The primary difference is that the RDP-100 product is adaptable to many different types of fuels (e.g., hydrazine, kerosene, jet fuel, etc.). The units are also pressure compensated and operational to a depth of 6,000 m.

Correspondence to the panel from IFREMER in the Fall of 1993 mentioned the Rankine engine "MESMA," developed by the BERTIN Company, which was previously unknown to this author.

## HYDRODYNAMICS

### Russia

*Morteploshchinka Scientific Research Institute (St. Petersburg).* Although a WTEC team did not visit this site, in the one-page summary of the institute's activities, MTT stated that it has designed, constructed, and delivered high speed (to 75 kt) underwater apparatuses. If so, this implies an advanced in-house hydrodynamics capability, but no further information was available.

*State Nautical University (St. Petersburg).* This academic institution uses its faculty and graduate students to do a variety of marine technical research projects. The university has a major hydrodynamic design and testing capability. Research

projects have included work on the control of boundary layers on submersible vehicles through suction, injection of liquid (water-soluble polymers), and elastic (compliant) coatings. University researchers have also developed a design concept that optimizes hydrodynamic hull-propeller interaction to reduce drag and increase propulsive efficiency.

The university has extensive hydrodynamic test facilities that are described in Chapter 7 of this report. A review of the characteristics of the facilities available will provide some indications of the types of hydrodynamic programs in progress at the university. In addition to the test facilities, the university has extensive programs in computer-aided mathematical modeling of various hydrodynamic problems.

*Krylov Shipbuilding Research Institute (St. Petersburg).* This is Russia's principal shipbuilding research institute. The WTEC team was told that this organization, the most comprehensive of the hydrodynamics research organizations visited by the WTEC teams, characterizes itself as the equivalent of the U.S. Navy's David Taylor Naval Research and Development Center in Carderock, Maryland. One of the seven divisions is Hydro and Air Mechanics, which does both design and testing in these fields.

## **Ukraine**

*Institute of Hydromechanics.* This institute, which is under the Department of Mechanics of the Ukrainian Academy of Sciences, has a total staff of 300 persons, 150 of whom are research personnel. The types of hydrodynamics work can be seen by examining the titles of the institute's 12 departments:

- o Hydrodynamic Acoustics
- o Vortex Motions
- o Hydrobionics and Boundary Layer Control
- o Free Boundary Flows
- o Hydrothermal Processes Modeling
- o Hydrodynamic Processes Control
- o Technical Hydromechanics
- o Applied Hydrodynamics
- o Hydrodynamics of Wave Processes
- o Hydrodynamics of Hydraulic-Engineering Structures
- o Dynamics of Elastic Systems
- o Stratified Flows

Current areas of investigation related to the hydrodynamics of undersea vehicles are:

- o Boundary layer control through methods such as compliant surfaces, polymer injection, and Coanda Effect ducts

- o Resistance coefficients in unsteady flows
- o Wave-structure interactions
- o Hydrodynamic acoustics
- o Vibration control and other methods for drag reduction

The institute has several sophisticated test facilities (see Chapter 7).

Of special interest are the following research projects:

- o Studies of fish propulsion and drag reduction and how to develop mechanical analogs of these. Various fish shapes have been modeled and tested to determine how animals reduce drag forces. (See section on the development of the propulsion analog in Propulsion Systems, below.)
- o High velocity projectile shapes fired into tanks at speeds approaching Mach 1. Design of the nose/entrance section of the projectile permits establishment of a specific cavitation vapor chamber that decreases drag at the higher speeds. The test projectiles used were approximately 10 cm long x 1 cm in diameter. The institute's theoretical work shows that Mach 2 velocities may be attainable.

While both developments are remarkable from a hydrodynamics point of view, there seems to be little potential application to the design of deep submersibles.

### **United Kingdom**

*Deacon Laboratory of the National Environmental Research Council.* The general, preliminary outline design for the Autosub project was done by Vickers Shipbuilding and Engineering, Ltd. However, the hydrodynamics research on optimum vehicle shapes is being done through the Department of Mechanical Engineering at the University of Surrey. The hydrodynamics work began in 1990.

Hull design work has concentrated on a laminar flow shape with the propeller integrated into the body shape as much as possible to reduce drag-inducing interaction with the hull. Wind tunnel tests were initially used to test various low drag shapes.

A major unknown at this point is the effect of smaller scale ocean turbulence and particulate matter in seawater on the performance of the low drag hull. Deacon Laboratory has conducted model work at sea to test low drag performance of the hull shapes, and to better understand ocean turbulence and particulates effects on it. Full scale shapes have been released for buoyant ascent from water depths as great as 1,000 m.

## **PROPULSION SYSTEMS**

### **Russia**

As might be expected, most thruster and propeller work is being done by the same institutions that do hydrodynamics of hulls and underwater shapes.

*Bauman Institute of Underwater Devices and Robotics (Moscow).* Four areas of propulsion work were discussed with WTEC team members:

- o Electrohydraulic drive systems and associated controls
- o Electric drive systems that use brushless motors
- o Magnus effect propulsion, which has been used on a towed system at a depth of 2,000 m
- o Adoptive propulsion, using totally regulatable hydraulic motors that select operating parameters to maximize propulsive efficiency

Because the visit was brief, there was not time to get into much technical detail with regard to these propulsion research projects.

*RRC Kurchatov (Moscow).* The Kurchatov Research Center has teamed with the Institute for High Temperatures and the Institute of Power Engineering to develop a magneto-hydrodynamic (MHD) propulsion system. Cryogenically pumped superconducting magnets create an extremely powerful magnetic field that can create water (acting as an electrical conductor) movement through an enclosed tube or tunnel, resulting in a propulsive force with no moving parts (propellers, jetpumps, etc.). While such a system would not be feasible for a submersible, the attractiveness for submarines is obvious.

This work has taken place over the past several years and a prototype system is operating in a laboratory. The Russians have said that at least three more years of effort will be required to have a system ready for testing at sea. The most advanced MHD operational system in the world is in the Japanese experimental vessel *Yamato*. The power level of the Russian prototype is said to be twice that of the unit in the *Yamato*.

*Krylov Institute (St. Petersburg).* As a major naval architecture and marine engineering institute, Krylov has the capability and facilities to design and test conventional propellers. However, it is not known if any of this work has been for deep submersibles. The WTEC team was not informed about any specific research and development work being done in this area.

**State Nautical Engineering University (St. Petersburg).** As noted in the previous discussion on hydrodynamics, this institution has several projects concerned with propulsion. Some of these are:

- o Dual-circuit waterjet propulsion with a noise level 10 to 12 db lower than an equivalent screw-type propeller
- o Sound isolation of the drive system from the environment
- o Nontraditional rotational, ducted propeller-rudder units for underwater vehicles and for precision steering, and studies of various duct systems to improve efficiency
- o Engineering tests of a screw propeller-Grin's wheel system
- o Research and development for a waterjet, stream-ejection system propeller
- o Various conventional propellers for very small underwater vehicles and tourist submarines

### **Ukraine**

**Institute of Hydromechanics (Kiev).** The institute has developed an oscillating wing propulsion system that is being tested at sea on a large scale model. It appears that the concept behind the system is to produce a rough mechanical analog of fish propulsive motion.

### **United Kingdom**

**Deacon Laboratory of the IOS.** Within the Autosub project, the responsibility for propulsion research and development is shared between Moog Controls, Ltd. (motor design), Deacon Laboratory (testing), and the Defense Research Agency -- Haslar -- (propeller design).

The current design approach for the propulsion motor is to use a contra rotating DC brushless unit. This direct drive unit has two propeller hubs connected directly to the rotors of the motors. Seawater-lubricated ceramic bearings are used instead of shaft seals. A single rotation version of this motor is installed on the Marconi ODAS AUV.

The contra rotating propellers are under design development. Preliminary estimates indicate a diameter of 0.6 m for a 1.5 revolutions per second rotational blade speed.

### **SUMMARY AND CONCLUSIONS**

The WTEC team did not see much that was new or revolutionary. Most of the technologies presented to the team were conventional. However, one must keep in mind the fact that an extremely time-limited and busy visit schedule permitted very



little in-depth discussions with the hosts. What was impressive was the numbers of units either built or designed.

Another problem in attributing developments to specific organizations was the question of whether the organizations were simply systems integrators or had technologies transferred to them for other reasons. Thus if an institute claimed to be using a certain type of energy system, it was not always clear whether the system was that organization's original development. This is the kind of detail that surely would have emerged if more time had been available at the sites.

### **Energy and Power Systems**

A wide variety of energy and power systems were shown to the WTEC team. Most of this work was not state of the art. The WTEC team was shown or made aware of 30 to 40 manned submersible/submarine concepts or actual hardware. In almost every case, conventional batteries were the chosen energy source. This is also validated by the fact that none of the team members was briefed on any details of battery developments.

With respect to nuclear power sources, the situation was somewhat different. Team members were briefed on reactor applications from 45,000 kW to 6 kWe, and actually saw the 6 kWe thermoelectric unit in operation. Among the unique, seriously proposed applications were a large (6,000 kW) unattended seafloor system (ROSSHELF) and a small simple unit built for a research submarine (*Ocean Shuttle*). In addition, a 15,000 kW reactor has been proposed for the service and maintenance submarine for the ROSSHELF complex. All of this design activity for nuclear reactors is not surprising considering the extensive numbers and varieties of nuclear submarines that were developed for the Soviet Navy. Defense conversion is now bringing much of all this knowledge into the civil sector.

Fuel cell development in the countries visited did not show significant advancements over the state of the art. Energia seems to have acquired numerous hours on units developed for the space program. This base of experience could help the company develop cost-effective, reliable units for commercial applications.

### **Hydrodynamics**

The most interesting visit in this technical area was to the Hydromechanics Institute at Kiev, Ukraine. The institute's work in developing and testing high-speed projectiles in water is very advanced. However, it does not have much application to deep submersibles. It is difficult to see how movement of a body at speeds of Mach 1 would have a commercial application.

In the United Kingdom, hydrodynamics work for the Autosub project is important for getting hull shapes for long-duration mission vehicles. Reduction of drag converts to longer mission times and/or less energy usage. However, even this hydrodynamics work is pretty much state of the art. Perhaps the new aspect of this work is open ocean testing to determine drag induced by particulates in the sea, marine growth during long missions, and the effect of small-scale turbulence on the vehicle.

### **Propulsion**

The WTEC teams saw, or were told about, a wide variety of design approaches for propulsion systems (propellers, thrusters, ducted devices, etc.). However, most of it was not particularly new. An exception may be the MHD work being done by RRC Kurchatov, which is interesting because the power levels are said to be much higher than those of the Japanese system being tested in the experimental vessel *Yamato*.

The Institute of Hydromechanics in Kiev, Ukraine is doing imaginative work in developing a mechanical analog of fish propulsion. While this general line of work has been done many times before, it has seldom resulted in a large-scale, seagoing test model like the one developed by the institute. Unfortunately, the WTEC team was not briefed on the specific performance of this unit, so efficiency is unknown.

Deacon Laboratory's Autosub program in the U.K. has resulted in some excellent advancements in propulsion motors for vehicles. Moog Controls' contra rotating motor and the design of its ceramic seals will be useful contributions to the development of other submersibles.

## CHAPTER 4

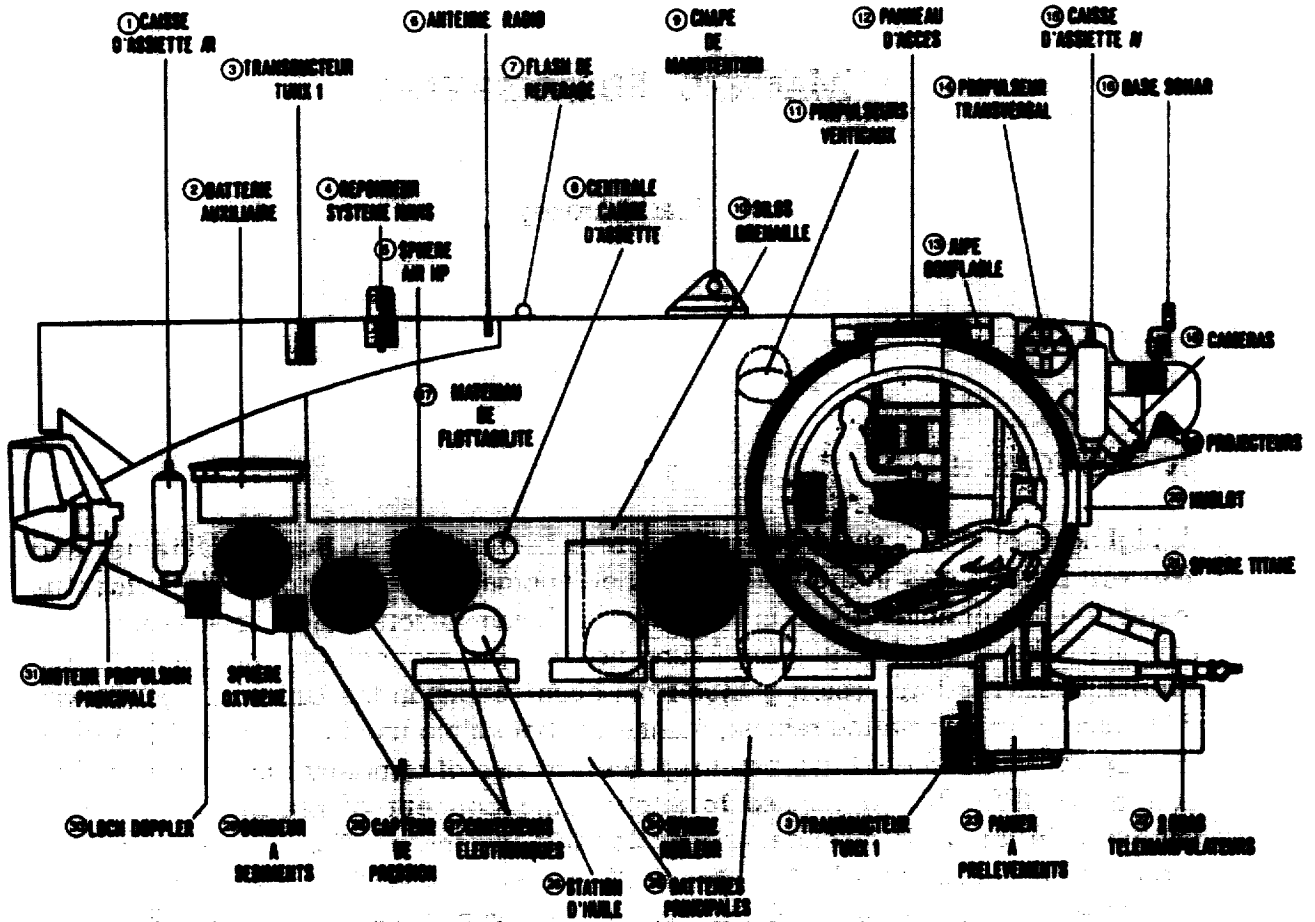
# MANNED SUBMERSIBLES

Brad Mooney

### INTRODUCTION

A highlight of the assessment of undersea technology in Russia, Ukraine, and Western Europe was in the area of manned submersibles. Not only did numerous manned submersibles exist in the former Soviet Union (FSU), but vision was exhibited there in planning for future use of this technology, including tourist submarines. The impression gained from observations in the United Kingdom was that, except for submarine rescue, manned submersible use in the United Kingdom in support of offshore oil has been replaced by use of remotely operated vehicles. In France, IFREMER continues to support the concept of placing a man in a submersible for work, science, and exploration purposes. The *Nautilie* serves the French well in this regard. A sketch of *Nautilie* systems and sensor suite is shown in Figure 4.1. Technical specifications are displayed in Tables 4.1 and 4.2.

Of the 25 projects visited in Russia and Ukraine, 11 are involved in the design, fabrication (e.g., of components and sensors), and operation of manned submersibles. The eight organizations with projects most closely related to manned submersibles at this time are discussed in this chapter.



caractéristiques principales :  
 longueur totale : 8,00 m  
 largeur : 2,70 m  
 hauteur : 3,45 m  
 masse : 18,5 t  
 immersion : 6000 m  
 vitesse maximum : 2,5 nds  
 durée mission :  
 - normale 13 h  
 - survie 130 h  
 charge utile : 200 kg

- ① aft trim tank
- ② auxiliary battery
- ③ transducer
- ④ "NAVIS" transponder
- ⑤ high pressure air tank
- ⑥ radio antenna
- ⑦ flash-light
- ⑧ trim control
- ⑨ hook-up part
- ⑩ ballast tanks
- ⑪ vertical thrusters

- ⑫ hatch
- ⑬ inflatable conning tower
- ⑭ lateral thruster
- ⑮ fore trim tank
- ⑯ sonar transducer
- ⑰ buoyancy material
- ⑱ cameras
- ⑲ lights
- ⑳ view port
- ㉑ titanium hull
- ㉒ 2 mechanical arms

- ㉓ sampling basket
- ㉔ variable ballast tank
- ㉕ main battery
- ㉖ hydraulic power unit
- ㉗ electronics housing
- ㉘ pressure sensor
- ㉙ sub-bottom profiler
- ㉚ doppler speedometer
- ㉛ main propeller

Figure 4.1. 6,000 m Diving Submersible (Courtesy IFREMER)

**Table 4.1**  
**Technical Specifications of 6,000 m Diving Submersible Nautilus**

<b>MAIN CHARACTERISTICS</b>		
Depth Rating		6,000 m
Weight in Air		18.5 t
Dimensions: Length Width Height		800 m 270 m 348 m
Payload		200 kg
Manned Sphere		
Crew	Men	3
Inside Diameter		210 m
Sphere Material	Titanium Alloy	
Viewports	Number Diameter	3 120 mm
Pitch and Trim Control	Mercury Pump	$\pm 12^\circ$
<b>AUTONOMY</b>		
Usual Mission	Hours	13
Safety	Hours	130
<b>TELEMANIPULATION (DEGREES OF FREEDOM)</b>		
Gripping Arm (5)	Arms	2
Manipulator (7)	Arms	
<b>POWER SYSTEM</b>		
Power System	Pb Battery	50 kWh
<b>PROPULSION</b>		
Main Propulsion	Axial Motor	1
Auxiliary Propulsion	Vertical Thrusters	2
	Lateral Thrusters (forward)	1
High Speed	Knots	2.5
	Nautical Miles	8

**Table 4.2**  
**Communications and Miscellaneous Equipment of Nantle**

<b>COMMUNICATIONS</b>	
Underwater Telephone	1
Video-Pictures	
Acoustic Transmission	
<b>MISCELLANEOUS EQUIPMENT</b>	
Scanning Sonar	1
TV Camera	1
Photo Cameras	2
External Lights	6 (3,000 W)
Subbottom Profiler	1
Dead Reckoning	1

## **DESIGN, FABRICATION, AND OPERATING ACTIVITIES**

### **Intershelf (Moscow/St. Petersburg)**

J.P. Kenny Intershelf is a joint venture of Russia and the British firm J.P. Kenny. Intershelf has never built a submersible. However, the company has experience in designing and operating bottom crawlers, diver systems, and small ROVs. Intershelf now proposes to produce *Sub Tour 10/100*, a tourist submarine. This 10-person vehicle with 100 m depth capability is advertised by Intershelf as costing \$900,000. Intershelf indicates it can deliver this submarine 18 months after a contract is signed. *Sub Tour 10/100* would be built for Intershelf at Energia, a Russian institute normally involved in development and construction of manned space flight systems.

### **Kharax (St. Petersburg)**

Kharax Company Ltd. is one of the first private companies in Russia focused on building a business around manned submersible technology. This entrepreneurial organization has a cadre of six talented, experienced, and innovative people. Another 180 technicians are employed on a jobshop basis.

To date Kharax has focused on a *Leisure Submersible Apparatus (LAS)*, or tourist submarine. The *LAS* is designed to carry six persons and a crew of two to a depth of 300 m. Kharax is asking \$750,000 for the submarine, including its launch and

recovery system. Additionally, Kharax will provide operators, operations support, maintenance, logistics, and planning support for the submersible system.

A center for underwater tourism (CAT) is another concept that Kharax is exploring. CAT is basically a large ship with observation rooms that accommodate 40 people, an underwater restaurant and diving facilities on the lower level.

Kharax provides technical equipment for a variety of subsea expeditions. One of the first efforts for this new enterprise was the expedition to look for the lost Korean 747 airliner.

### **Krylov (St. Petersburg)**

The Krylov Shipbuilding Research Institute is the principal shipbuilding research institute in Russia. It originally worked only for the Navy, but presently is focused on all disciplines of ship science. This facility performs research similar to that of the David Taylor Naval Research and Development Center in Carderock, Maryland.

The facilities for structural, pressure, and temperature testing at Krylov are extensive. Those related to manned submersibles include: a 1.4 km linear tow tank; a 3.2 m diameter pressure test tank that is 9.5 m deep, and capable of testing to 1,000 atmospheres; and a 1.8 m diameter pressure test tank that is 5.5 m deep, capable of testing to 1,500 atmospheres.

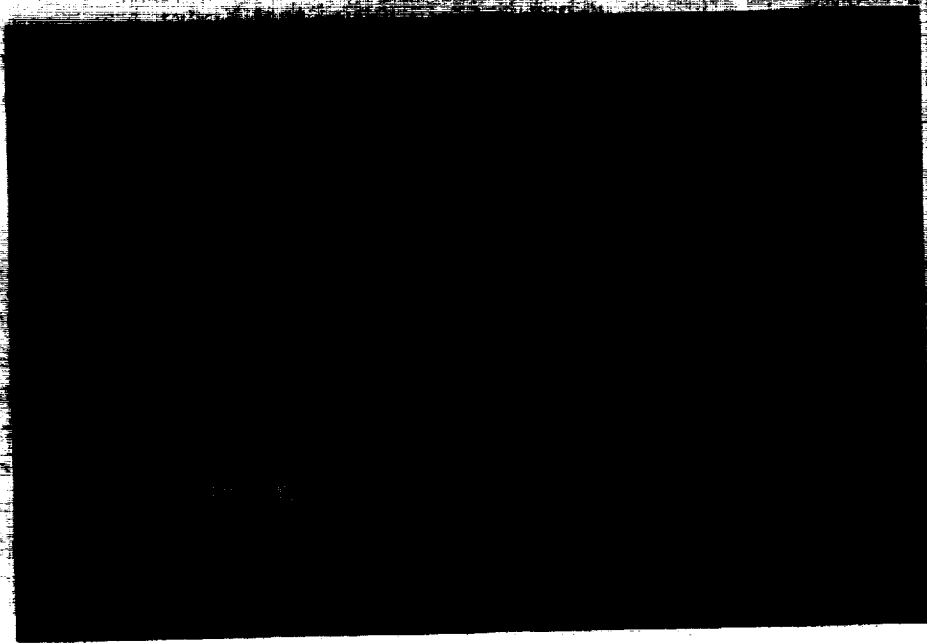
The engineers at Krylov displayed a 2.4 m diameter titanium sphere, certified for a 4,000 m depth by the Russian registry, for \$1 million. Figure 4.2 is a picture of this sphere at Krylov. In addition, it has been reported that Krylov has been testing a composite (including glass reinforced plastic and acrylic plastic) hulls for use in tourist submarines. According to Malachite, this technology originated at the "Prometey Institute."

### **Lazurit (Nizhny Novgorod)**

The Lazurit Central Design Bureau is one of three design bureaus in the FSU that designed military submarines. The other two are Malachite and RUBIN, both in St. Petersburg. Of the 30 manned submersibles operating in Russia, 24 were designed by Lazurit. About 11 models of manned submersibles and tourist submarines were on display at Lazurit (see Figures 4.3 and 4.4). Diagrams or drawings for another six to eight models were displayed along a conference room wall. The only one recognizable by the visiting WTEC team was the *Poseidon* deep submergence rescue vehicle. This is similar to the U.S. Navy's deep submergence rescue vehicles (DSRVs). Four *Poseidons* are in service.



**Figure 4.2. Titanium Sphere Displayed at Krylov**



**Figure 4.3. CBD Director Kvasha with Manned Submersible Models**



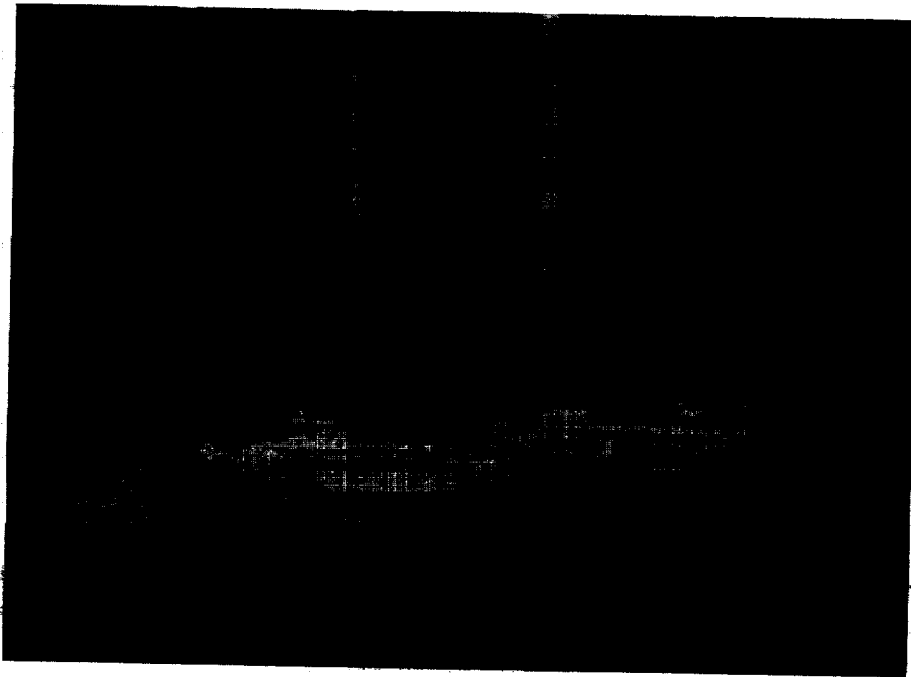


Figure 4.4. CBD Director Kvasha (right) with Tourist Submarine Models

As part of the Russian policy of defense conversion, Lazurit is trying to commercialize its capabilities. The bureau's focus is on an array of small research and work submersibles, and on tourist submarines utilizing various undersea technologies that are the expertise of Lazurit. The designs range from a one-person recreational submersible to a 130,000 ton nuclear-powered submarine container ship capable of carrying 1,000 standard 20-foot containers. Between these two ends of the spectrum are several proposed manned undersea vehicles of various sizes and capabilities.

Currently there appears to be considerable interest in the United States for a nuclear-powered oceanographic research submarine for use primarily in the Arctic. Lazurit proposes a built-for-this-purpose submarine named *Ocean Shuttle*.

Of the six to eight tourist submarines proposed by Lazurit, the one that has generated the most interest was a glass-hulled submarine. The term "glass" was originally described to the WTEC team as "composite organic and silicon glass," material reportedly developed in cooperation with Krylov.

The innovative concept of a submarine lifeboat, to be used as an escape mechanism from a properly designed offshore oil platform, was discussed. Personnel could escape from an endangered platform down through the inside of a hollow platform leg to the submarine, which would be mated to the leg.

Lazurit is involved in several concepts related to projects proposed by ROSSHELF. ROSSHELF proposes to build a complete oil and gas production complex on the sea floor in the Russian Arctic beneath the largest icebergs in the area. Lazurit has been designated as the leading organization within ROSSHELF regarding the development of underwater oil and gas production complexes.

The bureau's proposed submarines and submersibles are described in greater detail in the Lazurit site visit report, which is included in Appendix B.

### **Malachite (St. Petersburg)**

Malachite Marine Engineering Bureau is one of the leading Russian firms in underwater shipbuilding. Malachite built the first Soviet nuclear submarine. Malachite's experience in small submersibles is limited to *Thetis*, a towed manned submersible. *Thetis* is designed so that the operator can peer the submersible, to a degree, to the right and left or up and down to best observe the trawl nets of fishermen. There are several versions of the *Thetis* (sometimes spelled "*Tetis*") towed manned submersibles. The *Thetis H*, operated by Mariscoprom, weighs 3 tons, has a length of 3.3 m, operating depth when towed of 300 m, and a submerged speed of 2 to 6 kt for 6 hours. *Thetis H* carries two people and has a positive reserve buoyancy of 50 kg. In addition to assisting trawling fishermen, *Thetis* class vehicles have been used to estimate fish stock within the water column of a given region of the world, for underwater filming and observation of underwater structures, and for underwater transmission of video observations to a surface station. The occupants can communicate with its support and towing ship by radio and telephone. *Thetis* vehicles are equipped with several viewports (depending on the model) and an automatic flash camera system.

Malachite has also been active in a closely related underwater intervention field, a man-in-the-sea effort. The bureau's research has included the design of the *Benthos-300* vehicle, which can dive to 300 m and accommodate up to 12 scientists and crew. Special equipment built by Malachite for *Benthos-300* facilitates long-duration tests on animals aimed at medical issues associated with possible future underwater habitats.

*RUS*, a 6,000 m submersible, is being built by Malachite for the Ministry of Geology. *RUS* will use silver zinc batteries, Russian manufactured syntactic foam, and a welded titanium hull. Malachite has considerable experience in welding thick titanium.

Two test tanks are available at another facility with which Malachite has close contacts. The smaller 2.2 m diameter tank has a depth capability of 6 km. The larger 2.9 m diameter tank has a depth capability of 4 km.

In addition, Malachite proposes to design a submersible oil tanker that could transport oil under Arctic ice from North America to Asia. The bureau is also interested in designing various types of tourist submarines. The *North 2*, a 2,000 m submarine, was designed by Malachite. The status of *North 2* was not determined during the whirlwind visit to Malachite. Literature for several undersea vehicle projects proposed by Malachite are listed in the Bibliography section of the Malachite site report (Appendix B).

### **RUBIN (St. Petersburg)**

The Central Design Bureau for Marine Engineering (RUBIN) specializes in submarines and other underwater technologies. Several years ago, RUBIN was a secret institute that could not be mentioned openly. The *Typhoon*, *Oscar*, and *Komsomolets* submarines were designed there. Because of recent conversion efforts, approximately 40 percent of the work is presently defense related, with major thrusts in the past several years concentrating on high-speed train development, nonmilitary submarines, and tourist submersibles.

The bureau designed and built *Neptun*, the only Russian tourist submersible now in service, which began operations in 1993 at the island of Antigua in the Caribbean.

### **Mariecoprom (Sevastopol)**

The Mariecoprom Scientific Industrial Association, located in Sevastopol, is the operating arm of the Ukrainian Academy of Science. It operates ten submersibles and nine support ships, most of which are converted fishing vessels varying in size from 1,200 tons to 4,000 tons. These vessels conduct oceanographic and geophysical research worldwide. The current undersea interests of Mariecoprom are centered in the Ukrainian portions of the Black Sea. Mariecoprom does not operate unmanned vehicles. The staff at the association strongly believe that the best science is accomplished in situ by knowledgeable and trained scientists. The submersibles operated by Mariecoprom vary in size and capability from the very large twelve-person *Benthos-300* to the small, towed, three-person *Tetis-H*. Mariecoprom is able to provide qualified operating crews at very low daily rates. Mariecoprom does not conduct research and development directly, but operates and maintains support ships and submersibles for the Ukrainian government and its Academy of Science institutes. (The submersible support ships operated by Mariecoprom are described in Chapter 7.) The submersibles operated by Mariecoprom are: *Sever-2*, *Sever-2 Bis*, *Benthos-300*, *Omar*, *Langust*, *Tinro-2*, *Tetis-H*, and *Rif*. (See Figures 4.5 through 4.10 and Tables 4.3 through 4.14.)

**Table 4.3**  
**Sever-2 and Sever-2 R Tactical Characteristics and Specifications**

<b>Surface Displacement (dry weight)</b>	<b>39.7 t</b>
<b>Overall Length</b>	<b>12 m</b>
<b>Breadth</b>	<b>2.64 m</b>
<b>Depth</b>	<b>4.05 m</b>
<b>Operating Depth</b>	<b>to 2,000 m</b>
<b>Crew (2 pilots and 3 operators/observers)</b>	<b>5 persons</b>
<b>Maximum Submerged Speed</b>	<b>3 kt</b>
<b>Active Submerged Worktime</b>	<b>6 hr</b>
<b>Passive Submerged Period</b>	<b>72 hr</b>
<b>Power Supply</b>	<b>Accumulator battery</b>



**Figure 4.8. Submersible Sever-2**

**Table 4.4**  
***Sever-2 and Sever-2 Bis Operating Capabilities***

The submersibles are intended for use wherever there is need of underwater technical and research operations, such as:

1. Support for the construction, control, and technical servicing of underwater pipelines, cable routes, and hydrotechnical structures.
2. Search, detection, marking on the ground, and support for the recovery of sunken objects.
3. Data acquisition and mapping of bottom landscapes in seas and oceans.
4. Search for underwater deposits and participation in their exploitation.
5. Support for emergency-rescue operations.
6. Underwater teleshooting, filming, and photography.
7. Search and recording of fishery objects, and prediction and estimation of their stock.
8. Studies of hydrobiont behavior and distribution as affected by environmental factors.
9. Sampling of water, soil, and benthos when submerged.
10. Additional research and underwater activities.

The submersibles are designed and their units arranged to provide a dramatic view of diameter of a bow portion of the outboard space, through 3 portholes 140 mm in diameter and 4 portholes 60 mm in diameter in the presence of outboard lamps of permanent and pulse glow. The submersibles are equipped with a system of automatic and manual control. Their system for life-support is reliable. The emergency-rescue devices are adjusted. The electrical radio-navigation equipment offers a stable two-way communication with these submersibles, with the support vessel ensuring search missions and navigation safety of the submersibles. They are also equipped with electrohydraulic manipulators made of titanium alloy with 7 degrees of freedom and a kit of renewable instruments. These features enhance the effective utilization of the submersibles.

The submersible is able to embark (both inside and outside the pressure hull) some additional technical and scientific equipment weighing up to 500 kg. Sufficient quantities of spare multicore inputs and hydraulic pipe connections allow one to include this equipment in the electric network and hydrosystem of the submersible.

The vessels *Odissey* and *Ikhtiandr*, operated by the research and production association Mariecoprom, are the support vessels for the submersibles *Sever-2* and *Sever-2 Bis*.

**Table 4.8**  
**Tinro-2 Tactical Characteristics and Specifications**

<b>Displacement</b>	<b>10.5 t</b>
<b>Overall Length</b>	<b>7.11 m</b>
<b>Breadth</b>	<b>2.49 m</b>
<b>Maximum Depth</b>	<b>2.71 m</b>
<b>Diving Depth</b>	<b>to 400 m</b>
<b>Crew (1 pilot and 1 operator/observer)</b>	<b>2 persons</b>
<b>Maximum Submerged Speed</b>	<b>2.7 kt</b>
<b>Submerged Worktime</b>	<b>6 to 7 hr</b>
<b>Emergency Endurance</b>	<b>72 hr</b>
<b>Power Supply</b>	<b>Accumulator battery</b>



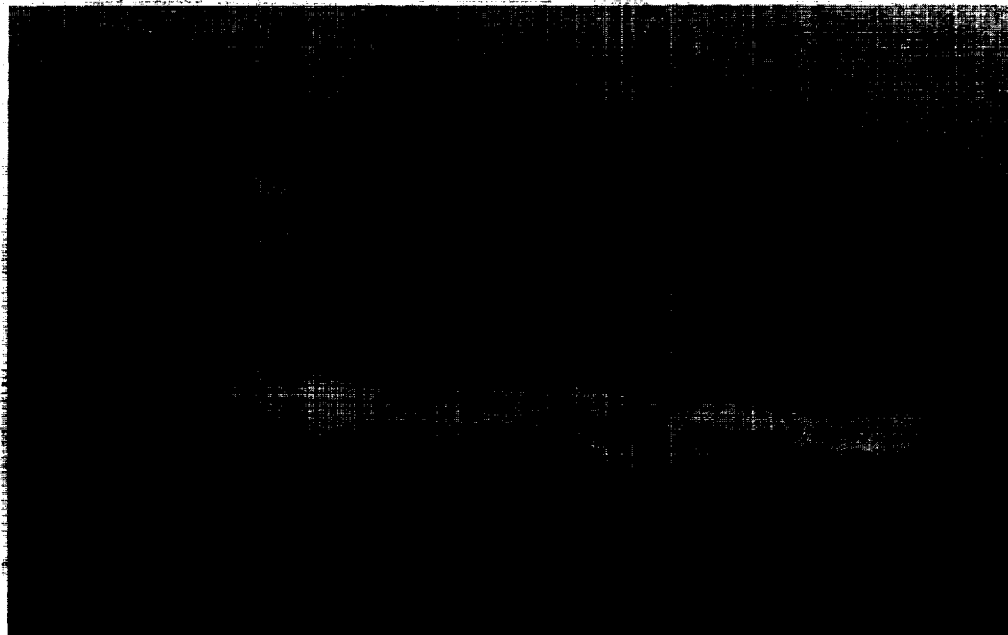
**Figure 4.6. Submersible Tinro-2**

**Table 4.6**  
**Tinro-2 Operating Capabilities**

<p>The apparatus is designed to accomplish several undersea technical and research activities, notably:</p> <ol style="list-style-type: none"> <li>1. Visual observation of the construction and monitoring of the state of underwater pipelines, cable routes, and various hydrotechnical structures.</li> <li>2. Search, recoding, and recovery of objects not exceeding 300 kg.</li> <li>3. Visual inspection of supposed sites of deposits of mineral resources, with the ability to take specimens from the surface of the sea floor.</li> <li>4. Visual control of emergency-rescue operation with sunken floating aids.</li> <li>5. Search and recoding of fishery objects, studies of the hydrobiont behavior, and distribution as affected by environmental factors.</li> <li>6. Underwater teleshooting, filming, and photography.</li> </ol>
<p>The apparatus can be equipped with more instruments and gear, which will increase the technical range of the apparatus implementation. The reserve cable lead-ins can be used to do this (technical capabilities of the apparatus permit the embarking of an additional 200 kg). As a result, the following operations will be possible:</p> <ul style="list-style-type: none"> <li>- sampling of soil, water, and benthos, when submerged;</li> <li>- data acquisition and mapping of bottom landscapes on the shelf and continental slope</li> </ul>
<p>The submersible operates from a support vessel equipped with a special launching-lifting assembly that has a 15 t load-lifting capacity, as well as from floating cranes or other floating facilities of suitable displacement, satisfying the requirements of standard support vessel.</p>
<p>The apparatus is capable of horizontal and vertical maneuvering within a water column, smoothly varying its position at a given distance from the ground until coming to a position of rest.</p>
<p>Viewing of the overboard field is effected through 6 portholes, 140 mm in diameter in the bow portion of the hull, and 3 portholes, 60 mm in diameter.</p>
<p>The submersible has simple and reliable equipment for underwater orientation and an up-to-date electric radio-navigation system that enables continuous communication with a support vessel.</p>
<p>The submersible possesses an electrohydraulic manipulator with 7 degrees of freedom.</p>

**Table 4.7**  
**Benthos-300 (Nos. 1 and 2) Tactical Characteristics and Specifications**

Surface/Submerged Displacement	605/630 t
Overall Length	30.3 m
Breadth	6.6 m
Depth	11.5 m
Draught	6.12 m
Diving Depth	320 m
Crew (7 to 8 hydro-nauts and 5 operators or scientists)	12 persons
Submerged Speed	1.5 kt
Surface/Submerged Towing Speed	6/4 kt
Submerged Endurance	7 days
Power Source	Accumulator battery



**Figure 4.7. Submersible Benthos-300**



**Table 4.8**  
**Benthos-300 (Nos. 1 & 2) Operational Capabilities**

1. Long-term observations of underwater objects under both stationary and dynamic conditions.
2. Control over the construction and technical state of underwater pipelines, cable routes, and other hydrotechnical structures.
3. Search, discovery, and marking on the ground of sunken objects, as well as providing for their recovery.
4. Data acquisition and mapping of sea floor landscapes on the shelf when erecting appropriate facilities.
5. Light-diving operations ensuring divers entering and going out down to a depth of 60 m.
6. Support to accomplish emergency and rescue operations.
7. Submarine teleshooting, filming, and photography.
8. Various research and other submarine activities.
9. Search and recording of fishery objects, and prediction and estimation of their stock.
10. Studies of hydrobiont behavior and distribution as affected by some environmental factors.
11. Sampling of water, gas, soil, ichthyofauna, and plankton when submerged (provided that the required equipment is installed), and initial processing of samples on board.
12. Fixation of hydrological parameters of the environment (salinity, temperature, etc.) of the ground using the on-board electronic computer.

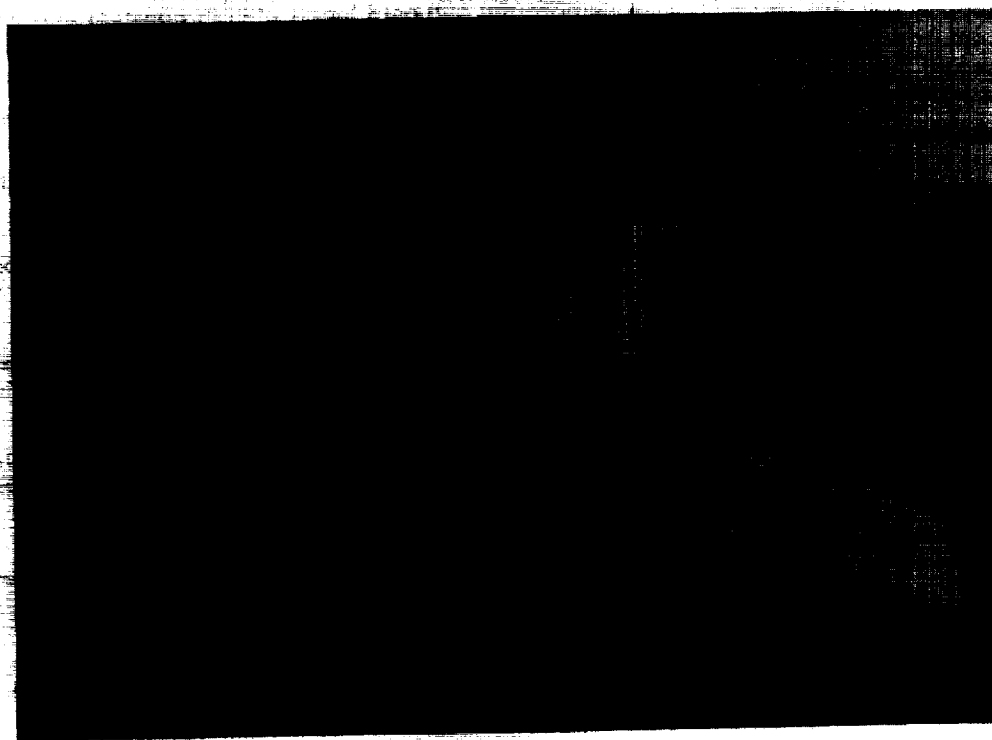
The laboratory has long-term submerged endurance with a simultaneous capability of maintaining more experts on board (in comfortable four-berthed cabins), wide viewing of outboard space through 12 portholes, 190 mm in diameter, and 15 portholes, 140 mm in diameter, in the presence of numerous powerful outboard lamps of both constant and pulse glow, an own-water system with a decompression chamber that makes it possible for divers to go out and enter down to a depth of 60 m, a reliable life-support system for the crew and passengers, adjusted emergency-rescue appliances, and an electric radio-navigation system that enables steady two-way communication with a support vessel and solution of search problems, and provides navigational safety. It is also possible to load the laboratory with some additional technical and scientific equipment weighing many tons.

One can substantially increase operational capabilities of the laboratory by installing more equipment, that is:

- to apply the laboratory as a unique underwater device capable of lifting from the sea floor loads of up to 100 tons, subsequently transporting them under the bottom of the laboratory to shallow water.
- to perform operations of the EPROM type: underwater electric welding and cutting, and hydraulic washout of the ground using a jet with a pressure of 8 kg/cm<sup>2</sup> with a water jet efficiency of 40 m<sup>3</sup>/hr.
- to use a tourist version of the laboratory and participate in underwater filming.

**Table 4.9**  
**Tetis-H Tactical Characteristics and Specifications**

Dry Weight	3 t
Lifted Mass (with Surplus Water in Permeable Portions)	3.6 t
Overall Length	3.3 m
Extreme Breadth (Wing Span)	3.2 m
Extreme Depth	2.1 m
Operating Depth When Towed Under Hydrostat Conditions	200 m 300 m
Submerged Speed When Towed	2 - 6 kt
Submerged Work	6 hr
Crew (1 pilot and 1 operator/observer)	2 persons
Emergency Endurance	24 hr
Power Supply	No power supply. Electrical power is supplied by means of a cable from a support vessel. Additionally, emergency accumulator battery.



**Figure 4.8. Towed Submersible Tetis-H**

**Table 4.10**  
***Tetis-II* Operating Capabilities**

<p>The apparatus is intended for use wherever there is need for the following undersea technical and research activities:</p> <ol style="list-style-type: none"> <li>1. Detection and estimation of the fish stock in the water column of a given region in the world's oceans.</li> <li>2. Maintaining control over fishing gear of fishing vessels.</li> <li>3. Underwater filming and photography, and visual observations of underwater objects and structures.</li> <li>4. Underwater transmission of operative video information to the monitor to screen on board the support vessel.</li> </ol>
<p>The submersible can be exploited under one of two regimes, the submerged towage regime or the hydrostatic regime, depending on the task.</p>
<p>The submersible has a simple and rational design and control system. It is miniature and reliable. Its additional safety is due to positive reserve buoyancy (on the order of 80 kg).</p>
<p>The apparatus is equipped with a radio and telephone communication system as well as an automatic camera with a flash. Wide viewing of the outboard space is carried out through 3 portholes that are 300 mm in diameter, and 3 portholes that are 140 mm in diameter.</p>
<p>As a support vessel, the <i>Tetis</i> can utilize the vessel equipped with launching and lifting arrangement (load-carrying capacity 4 - 8 t), a special towing winch and low above-water board.</p>

**Table 4.11**  
***Omar* and *Langst* Tactical Characteristics and Specifications**

Dry Weight	9.4 t
Overall Length	5.6 m
Breadth	2.54 m
Depth	3.5 m
Diving Depth	to 540 m
Crew (1 pilot and 2 operators/observers)	3 persons
Maximum Submerged Speed	2.1 kt
Active Submerged Worktime	6 hr
Passive Submerged	72 hr
Power Supply	Accumulator battery

**Table 4.12**  
**Omar and Langust Operating Capabilities**

The aforementioned submersibles are intended for use wherever there is need for underwater research, such as:

1. Support for the construction, control, and technical servicing of underwater pipelines, cable routes, and hydrotechnical structures.
2. Search, detection, marking on the ground and support for the recovery of sunken objects.
3. Data acquisition and mapping of bottom landscapes on the shelf and continental slope.
4. Search for deposits on the shelf and participation in their exploitation.
5. Support for emergency-rescue operations.
6. Underwater tele-shooting, filming, and photography.
7. Search, recoding of the fishery objects, and prediction and estimation of the stock.
8. Studies of hydrobiotic behavior and distribution as affected by environmental factors.
9. Sampling of water, soil, and benthos, when submerged.
10. Various scientific and other underwater investigations.

These submersibles are rationally designed, and their units and mechanisms are optimally arranged. They are highly maneuverable and provide a wide view of the outboard space through 9 portholes, 200 mm in diameter, and 6 portholes, 100 mm in diameter in the presence of powerful lamps. The submersibles are simple and reliable to operate. They offer a good life-support system for the crew. The up-to-date electric radio-navigation equipment provides stable two-way communication with a support vessel. The submersibles accomplish search missions and contribute to navigation safety. The submersibles are equipped with an electrohydraulic manipulator with 7 degrees of freedom. These features contribute to the highly effective use of the submersibles.

The submersibles are able to embark additional technical and scientific equipment weighing up to 250 kg. Seven reserve multicore cable inputs permit connecting the equipment with the electric network of the submersibles.

The fishing vessels *Gidronavi* and *Mariacoprom* are the support vessels for the submersibles *Omar* and *Langust*. Also, a ship with an assembly capable of launching and lifting less than 20 t, and having a place to house a submersible, can be a support vessel for the described submersibles.



Figure 4.9. Submersible *Langust*

**Table 4.13**  
**Rif Tactical Characteristics and Specifications**

Dry Weight	2.6 t
Overall Length	4.2 m
Breadth	1.8 m
Depth	2 m
Operating Depth	to 85 m
Crew (1 Pilot and 1 Operator/Observer)	2 persons
Maximum Submerged Speed	2.5 kt
Active Submerged Worktime	4 hr
Passive Submerged Period	72 hr
Power Supply	Accumulator battery

**Table 4.14**  
**RZ Operating Capabilities**

The submersible is intended for use wherever undersea technical and research activities are needed, namely:

1. Support to build and maintain control of the state of underwater pipelines, cable routes, and hydrotechnical structures, and their technical servicing.
2. Search, detection, marking on the ground, and support for the recovery of sunken objects.
3. Data acquisition and mapping of bottom landscapes in seas and oceans.
4. Discovery of the offshore deposits of mineral resources and participation in their exploitation.
5. Support for emergency and rescue operations.
6. Underwater telebroadcasting, filming, and photography.
7. Search and recording of fishery objects, and production and estimation of the stock.
8. Investigations of hydrobiotic behavior and distribution as affected by environmental factors.
9. Studies of man-made reefs and plantations of mollusks.
10. Sampling of water (into a pressure hull), soil, and benthos, when submerged.
11. Research and other underwater activities.

The apparatus is rationally designed, and its units and mechanisms are optimally arranged. It is highly maneuverable and provides a panoramic view of the outboard space through two portholes, 400 mm in diameter, in the presence of underwater lamps. The submersible is easy and reliable to operate. It possesses a high quality life-support system for the crew; up-to-date electric and radio-navigation equipment ensuring a stable, continuous submersible-to-support vessel communication, search targets and navigation safety of the apparatus. The submersible is equipped with an electrohydraulic manipulator with 7 degrees of freedom, with renewable instruments and cassette of samplers. All that and a relatively small and easily transportable mass enhances its highly effective use.

The submersible is able to embark additional technical and scientific equipment weighing up to 25 kg. Three reserve multicore cable lead-ins assure its inclusion into the electric network of the apparatus.

An important advantage of the RZ is its possible exploitation as a shore-based version. All the required equipment is available. The only thing needed would be 380 V, 7 kW alternating current. The submersible is transported by a motor vehicle to its base site. Its loading and unloading is performed with the help of a truck-mounted crane.

As a support vessel for the RZ, one can employ either the sea tug *Akhil'ar*, operated by the research and production association *Maricoproim*, or some other vessel equipped with gear capable of lifting no less than 5 t, as well as some place to house and store the submersible.

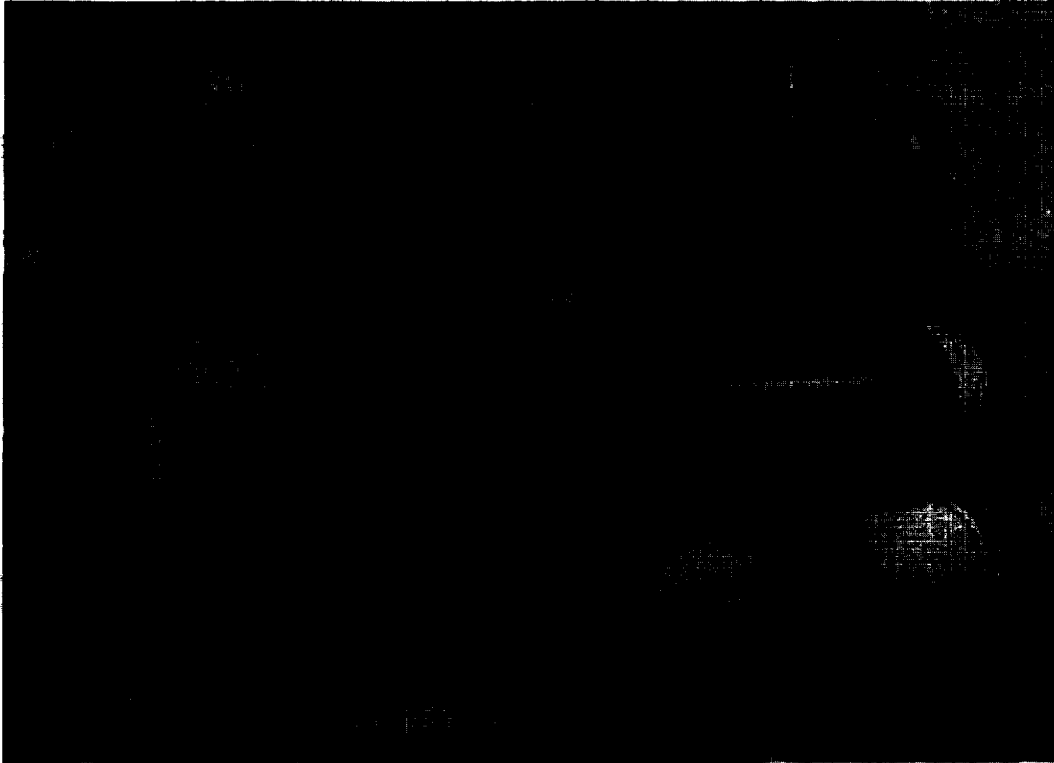


Figure 4.10. Submersible *Rif*

### **P.P. Shirshov Institute of Oceanology (Moscow)**

The P.P. Shirshov Institute is part of the Russian Academy of Science. Divisions of Shirshov are in St. Petersburg, Kaliningrad (Baltic Base), Gbelendzhik (Black Sea Base), and Moscow (headquarters). The institute operates ten research ships. Six are oceanographic research ships and two are submersible support ships. Shirshov has six submersibles. Two *Mir* class steel hulled, 6,000 m depth capable submersibles were built in Finland by Rauma-Ripola Corporation. Two *Pisces* class 2,000 m depth capable submersibles were built in Canada by HYCO Ltd. The *Argus* 600 m depth capable submersible operates primarily in the Black Sea. *Osmotr*, with a 300 m depth capability, is located in Gbelendzhik on the Black Sea and is for sale.

### **Experimental Design Bureau of Oceanological Engineering (Moscow)**

The Bureau of Oceanological Engineering is a spin-off of the P.P. Shirshov Institute. The people who now direct this bureau designed and built the *Argus 600* and

*Osmotr* when they were part of Shirshov. This bureau now is building two *Rift* class 4,000 m submersibles that are 85 percent complete. The institute, which is seeking \$2 million in Western hard currency to complete the two submersibles, has also indicated that it would give the funding source one of the submersibles. Table 4.15 describes the *Rift* submersibles. Figures 4.11 and 4.12 are pictures of the incomplete *Rift* submersibles. The Experimental Design Bureau of Oceanological Engineering and *Rift* Co., Ltd. have developed two designs for tourist submarines, *Angara TS 6/600* and *TS 20/100*, which cost \$400,000 and \$880,000 respectively. (See Table 4.16.)

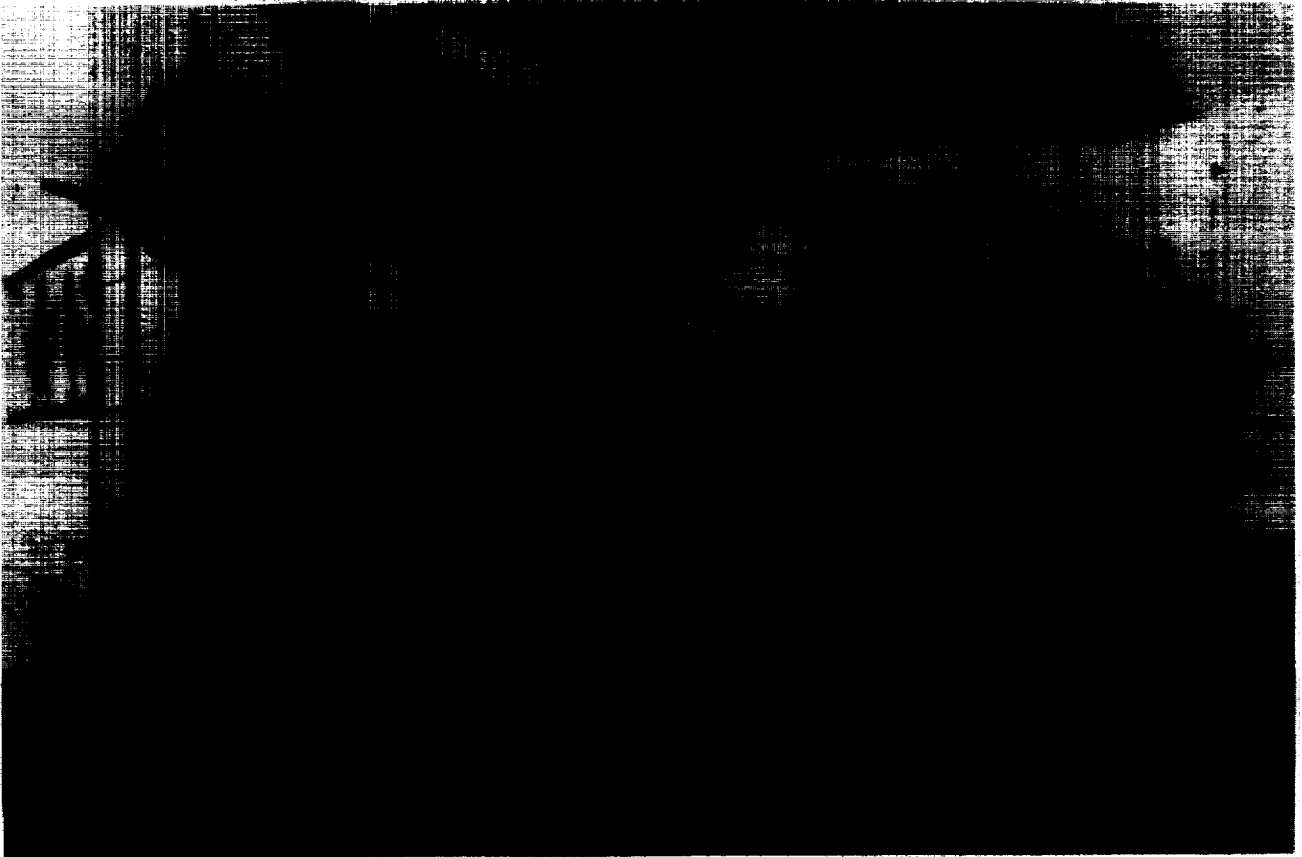


Figure 4.11. *Rift* Submersible (1)



**Table 4.16**  
**DSV *Rift***  
(Two Being Built Simultaneously)

Depth	4 km
Displacement	18 t
Crew (1 Pilot, 1 Copilot, and 1 Scientist)	3 persons
Dive Time	10 to 12 hr 8 to 6 bottom time
Material: pressure hulls and components exposed to sea water	Titanium
Length	7 m
Width	3.2 m
Height	3.7 m
Cruise Speed	3 kt
Life Support Endurance	246 man-hr
Battery Capacity	87 kWh
Payload at 4,000 m	50 kg



Figure 4.12. *Rift* Submersible (2)

**Table 4.16**  
**Tourist Subs by Rift Co., Ltd.**

<b>Proposals for 2 Tourist Subs</b>	
<p><b>Tourist Sub 20/100</b>            20 passengers            100 m depth            Displacement 80 t            Crew 2 to 3            Power 160 kWh            Length 12.5 m            Width 3.8 m            Height 3.8 m            Excursion endurance 1 hour            Launched 2 yrs after contract            Price \$850,000</p>	<p><b>Tourist Sub 6/600</b>            6 passengers            600 m depth            Displacement 25 t            Crew 2            Power 79 kWh            Length 8.2 m            Width 3.2 m            Height 3.3 m            Speed 1.5 kt            Endurance 8 hr            Price \$400,000</p>

## **SUMMARY AND CONCLUSIONS**

Existing and proposed noncombatant manned undersea vehicles in Russia and Ukraine, both submersibles and submarines, are fundamental, straightforward, low cost, uncomplicated, reliable, and tested. Concepts that work well are retained; those that do not work well are corrected. Many of the existing submersibles are available for lease. Anyone contemplating lease of these vehicles should do so cautiously. The WTEC team only briefly examined the relationships between Russian Registry Certification, Lloyds of London, the American Bureau of Shipping, Det Norske Veritas, and U.S. Navy standards of certification. If contracts or insurance require any of these types of certification, one should check carefully before assuming that Russian certification is acceptable.

Some of the designers of manned systems in Russia and Ukraine are now moving slowly into autonomous systems. There does not appear to be an evolutionary transition from manned to ROV to AUV, as is the case in the United States. To date the desire to place man physically in situ persists in the countries of the former Soviet Union. Possible liability considerations and insurance costs have not yet driven their operators to seriously examine alternatives to use of manned vehicles.

The extensive use of titanium is very impressive. The use of the term "glass" mentioned during the WTEC team's visits at Lazurit and Krylov deserves further evaluation. Subsequent correspondence to WTEC from Malachite described these materials as "glass-reinforced plastic and acrylic plastic."

**The optimistic view of the tourist submarine market at most design and fabrication activities as well as in operating groups needs to be questioned and resolved by conducting a thorough market analysis.**

**Greater computing capabilities and the introduction of such tools as computer aided design will enhance undersea vehicle efforts in the FSU. The horizons of scientists and engineers there have been limited and their perspectives conditioned by lack of computing tools.**

**The manned submersible potential in Russia and Ukraine is large. Academically, industrially, and operationally, the existing base is impressive. Opportunities for joint ventures are numerous.**

Manned Submersibles

The first manned submersible was the Trieste, which was used to reach the bottom of the Challenger Deep in the Mariana Trench in 1960. It was a bathyscaphe, a type of submersible that consists of a spherical pressure hull and a large, inflatable float. The Trieste was designed by the Italian Navy and was used for several deep-sea dives. It was the only manned bathyscaphe to reach the bottom of the Challenger Deep.

Other manned submersibles include the Alvin, which is used for deep-sea research, and the DeepSEA, which is used for deep-sea mining. The Alvin is a manned submersible that is used for deep-sea research. It was designed by the Woods Hole Oceanographic Institution and is used for a variety of deep-sea research projects. The DeepSEA is a manned submersible that is used for deep-sea mining. It was designed by the University of Washington and is used for deep-sea mining research.

The Trieste was the first manned submersible to reach the bottom of the Challenger Deep. It was used for several deep-sea dives and was the only manned bathyscaphe to reach the bottom of the Challenger Deep. The Trieste was designed by the Italian Navy and was used for several deep-sea dives. It was the only manned bathyscaphe to reach the bottom of the Challenger Deep.

## CHAPTER 5

# UNMANNED SYSTEMS

Claude P. Brancart

### INTRODUCTION

The purpose of the site visits was to quantify and evaluate the research submarines and undersea technologies in Western Europe, Russia, and Ukraine. The diversity of these regions was so great, especially when considering the needs, attitudes, and levels of technological commercialization, that it seemed unwise to review the status of unmanned systems with all entities in a single group. Therefore, this chapter has been divided into two sections: Great Britain and France, and Russia and Ukraine.

Unmanned systems include any hardware that is self-powered and operated autonomously (AUVs); self or surface powered, and operated with man-in-the-loop (ROVs); or towed through the water. Systems considered include free swimming vehicles and bottom crawler (tracked or wheeled) vehicles. Table 5.1 gives the major parameters for each system that will be considered in this chapter.

The motivating force for the development of unmanned systems must be considered. Since development of commercial systems is driven by the profit motive, system developers have a direct and immediate application to a commercial need. Scientific unmanned systems are driven to acquire knowledge of the undersea environment through the collection of data (chemical, geological, biological, and others) as a function of position and time. Therefore, in this chapter, unmanned systems have been segregated into commercial and scientific categories where possible.

**Table 8.1  
Major Parameters To Be Considered**

<b>Physical</b>	<b>Size Weight (dry/wet) Energy Source</b>
<b>Operation</b>	<b>Control Navigation</b>
<b>Payload</b>	<b>Size and Weight (dry/wet) Sensors Others</b>

Next, the present position of this technology relative to the rest of the market place and the prevailing trends of the facilities visited are evaluated. Finally, an attempt is made to compare present position and trends to those of their U.S. counterparts.

The views presented are based on two- to three-hour visits to commercial and scientific facilities in Western Europe, Russia, and Ukraine. There are many other facilities in the region, but the findings presented should approximate the status of the prevailing technology.

## **GREAT BRITAIN AND FRANCE**

### **Motivation**

The motivating force in the United Kingdom for the commercialization of unmanned systems is North Sea oil, which is a major national asset. Consequently, systems and subsystems components are developed to assist the offshore oil business. Of a secondary nature would be the support of non-oil requirements, including undersea cable deployment and burial, surveys, waste outfalls, salvage, and others. The driving force to develop scientific unmanned systems is the same as that in the rest of the world -- to acquire information. The water column is always of interest, but one area may be more interested in subsea geological or seismic information, while another may seek information on the fisheries potential.

### **Commercial Unmanned Systems**

The major producer of working ROVs in Great Britain is Slingsby Engineering Ltd. (SEL). This small company of 80 people, located in the English countryside between

London and Newcastle, has cornered a major portion of the large ROV business. Other ROV-producing companies in the U.K. are no longer in business.

SEL has been in operation since the 1970s. During the earlier years the company designed and fabricated the Submarine Escape and Rescue Vehicles (LRS); the one-atmosphere JIM suit, a carbon-fiber-skin diving suit rated for 1,500 ft operating depth; and *Scarab III* vehicles with water jet systems for cable burial, bottom crawlers with trenching capabilities, and other heavy duty work systems for ocean use. SEL has also undertaken special design studies, for example, the *10K DOLPHIN* project, a 10,000 m ROV system for Japan.

SEL now concentrates on large ROVs. The company first started with the *Trojan* series, which was redesigned to become the *Multi-Role Vehicle (MRV)*. The market for these vehicles is small. Thirteen *Trojans* were built, but the last one remains unsold because the first *MRV* made its debut. Presently SEL is working on *MRV* number 5. The basic parameters of these two large ROVs are given in Table 5.2.

**Table 5.2**  
**Basic Parameters of Trojan and MRV ROVs**

	<i>Trojan</i>	<i>MRV</i>
Length	2.2 m	2 m
Width	1.6 m	1.5 m
Height	1.6 m	1.5 m
Weight/Air	3,970 lbs	1.5 to 2.2 t
Performance	2.5 kt	2.5 kt +
Power	30 to 38 kW	28 to 45 kW
Payload	91 kg	180 kg +
Operating Depth	1,000 m	600 to 2,000 m

There is a great deal of similarity between the two vehicle designs, but the basic design philosophy is different. In 1990, SEL surveyed the market place and concluded that the future for large ROVs was a multipurpose vehicle system that would have the power, structure, strength and integrity, and flexibility that other ROVs did not have. The result was the *MRV* -- a basic core vehicle with the capability of incorporating a variety of payload packages based on customer

demand. The modular building-block approach must be cost-effective. The *Mobil-FSSL* project presented later emphasizes this concept.

SEL only incorporates field-proven components in its vehicles. What is not available, the company designs and builds. Consequently, although SEL has designed a number of special tools, the company is known for its manipulators, namely, TA9, a seven-function master/slave position feedback manipulator; TA16, a five-function rate control manipulator/grabber; and TR33, a nine-function spatially correspondent manipulator. The company also has designed its own hydraulic power packages and thrusters. SEL has the capability to test all of the systems and components at their rated operating depths.

Commercial customers want to purchase complete ROV systems. Consequently, SEL sells a complete ROV system that includes dual manipulators and necessary spares and documentation; a Tether Management System (TMS/garage), a deck-handling winch, and an A-Frame; and a North Sea duty control van with system controls, video displays, and recording capabilities. An auxiliary power generator system is included. For the complete 600 m MRV system, including operator training, the purchase price is £1,230,000, or about \$2 million.

Mobil North Sea Limited of Aberdeen, Scotland, is a user of the technology and hardware developed by firms with ocean-related products. Because of the small market, they can direct where the technology should go. The *Mobil-FSSL Diverless Intervention System* is a prime example of this approach.

The capability requirements of the *Mobil-FSSL* system are to replace components, operate valves, conduct valve maintenance and pressure testing, and execute control umbilicals and flowline installations in 1,000 m of sea water. To achieve this goal, the company starts with a core ROV, the SEL MRV, and adds peripheral components (see Table 5.3). These components have been or are being designed by Mobil, SEL, and others. It is a multiyear program with defined milestones to assure system reliability and success.

The justifications for this approach to operating and maintaining a subsea completion system are cost savings and reliability. The cost advantage is demonstrated by two examples presented in Table 5.4.

The reliability advantage is exemplified by the trend of removing the human element (diver) from the underwater work tasks and replacing him with a tested, proven, and known work package.

*Present Position.* SEL is undoubtedly the major large ROV supplier in Great Britain. On the world market, the possible competition SEL has is Perry Tritech, a Florida-based company owned by the French company Colteq, with its *RECON*, *Triton*, and *Scorpion* vehicles, and International Submarine Engineering Ltd. (ISE), of Port Moody, B.C., Canada, and its series of large ROVs -- *Hysub*, *Hydra*, and others.



**Table 5.3  
Peripheral Components**

<b>SIM</b>	The Skid Interface Module is the component that controls the work modules and interfaces with the ROV.
<b>TIM</b>	The Tooling Intervention Module provides the capability for subsea completion tree valve operation, valve greasing, and pressure testing.
<b>HLM</b>	The Heavy Lift Module is employed to install or retrieve control pods, choke inserts, or tree caps. The unit can position a 1,400 pound load.
<b>UPIM</b>	The Umbilical Pull-In Module is to be used to install both control umbilicals and small flowlines into subsea trees and templates.

**Table 5.4  
Cost Advantage of Diver and ROV**

ITEM	DIVER		ROV	
	\$/Day	Cost	\$/Day	Cost
<b>Planned Maintenance Intervention, 20 Days on Location</b>				
Mobilization		240,000		112,000
Field Work	64,000	1,280,000	24,000	480,000
Demobilization		160,000		
<b>TOTALS</b>		<b>1,680,000</b>		<b>592,000</b>
		<b>Total Saved</b>	<b>\$1,088,000</b>	
<b>Single Unplanned Intervention, 2 Days on Location</b>				
Mobilization		240,000		112,000
Field Work	64,000	128,000	24,000	48,000
Demobilization		160,000		
<b>TOTALS</b>		<b>528,000</b>		<b>160,000</b>
		<b>Total Saved</b>	<b>\$368,000</b>	

**Trends.** SEL identifies customer needs and designs the hardware accordingly, for example, the *MKV* ROV. Where needed, the company continues to improve the components. SEL will remain a small organization because the customer market is small and more user/service companies are fabricating their own special purpose ROVs.

The *Mobil-FSSL* project is a typical example of a major oil company working with equipment suppliers toward a common goal. It also exemplifies the trend toward removing the human element from the ocean. Twenty years ago, the offshore oil market was serviced by manned submersibles and divers. Now, there is not a single manned submersible in operation for the offshore oil companies, and diver tasks are continually being reduced in depth and function. The reliability of a diver versus a proven and tested work system is considered to be low, and the cost and potential liabilities extremely high. This trend will continue.

### Scientific Unmanned Systems

A major ongoing program to develop unmanned systems for the scientific community is the Autosub project. This project is being led by the Institute of Oceanographic Science Deacon Laboratory, located in Godalming, Surrey, south of London. The project seeks to use the most appropriate experience and skills available in the United Kingdom's science and technology communities. Consequently, university departments, industry, and laboratories of the Defence Research Agency have been directly involved.

The Autosub program envisions two operational vehicles, *DOLPHIN* and *DOGGIE*. The *DOLPHIN*, or *Deep Ocean Long Path Hydrographic Instrument* vehicle, is a long-path undulator for hydrographic work to full ocean depths. The vehicle would quantify the vertical ocean profile with spatial and temporal sampling of the ocean volume to determine the distribution of heat and fresh water, carbon dioxide content, air-sea fluxes, plankton distribution and nutrients, and others, surfacing every 30 km to fix its position via global positioning satellite and return data to appropriate shore facilities. The motivation for the development of *DOLPHIN* is the automation of routine data gathering, for example in the North Atlantic Ocean. It has been estimated that the North Atlantic heat flux, which is vital for maintaining the mild climate for the United Kingdom and Europe, could possibly be monitored and predicted with data obtained from 10 transocean *DOLPHIN* sections carried out routinely at specific times yearly. This data would be of great interest to programs like Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS).

Information on the deep sea floor gathered from surface platforms, though of excellent quality, is on a large scale. Scientists need higher resolution data obtainable only from higher frequency instruments mounted on deep towed, or

autonomous, platforms deployed much closer to the sea floor. The *DOGGIE* vehicle would cover the ocean bottom at 5 to 6 kt with 5 to 6 km side scan swaths with 1 m resolution. The vehicle would also support subbottom profiler, magnetometer, and chemical sensors. All data would be temporally and spatially recorded.

The Autosub program, begun in 1988, incorporates four phases over a ten-year period, as shown in Table 5.5.

**Table 5.5**  
**Four Phases of Autosub Project**

Phase I	Year 0 to 2	Conduct Subsystem Studies - pressure hull - buoyancy control - propulsion - hydrodynamics
Phase II	Years 2 to 6	Vehicle Subsystem Development
Phase III	Years 4 to 8	Demonstration Test Vehicle
Phase IV	Year 6 onwards	<i>DOLPHIN</i> and <i>DOGGIE</i> Systems

Presently, the dual propulsion motors have been designed and tested under load at full operating depth. A one-half scale of the laminar flow hull for *DOLPHIN* has been built and tested in water depths to 1,000 m. The hull design is underway. Sea water exhibits compression of 2.8 percent between the surface and a depth of 6,000 m. Any material that is less compressible (steel exhibits 1/70 the compressibility of sea water) must be compensated or counteracted to maintain a neutrally buoyant system. The search for proper materials, both metallic and nonmetallic, and structural design is ongoing. Control logic for autonomous vehicle operations is being studied. Autosub is at the halfway point, and the demonstration test vehicle is behind schedule. The goals are ambitious, but the real issue is the availability of funds to complete the program.

Heriot-Watt University is located in Edinburgh, Scotland. The university is greatly influenced by the needs of the North Sea oil industries. In the 1970s, Heriot-Watt developed the *Angus* class of ROVs. *Angus-1* was the first deep operating (300+ m)

ROV in Europe. *Angus-2* and *Angus-3* were improved versions of the original design. *Angus-3* incorporated *Bover*, a small ROV. *Angus-4* was designed but never built. A lack of funds was the main reason, but the changing nature of the underwater service industry required rethinking the ROV's design. *Angus-4* was to be powered from the surface but diver operated, and was to act as a staging and power source platform from which divers would operate.

It appears that the university is redirecting its goals from complete vehicles to specific underwater vehicle functions, for example, autonomous interaction control for two seven-function manipulators using video, very high resolution sonar and laser triangulation sensors to provide reliable motion control in the manipulator work volume.

Marconi Underwater Systems, located in Waterlooville, is an operating company within GEC-Marconi, a large, primarily defense-oriented firm. Eighteen months ago, Marconi started the *Ocean Data Acquisition System (ODAS)* vehicle, an autonomous vehicle based on technology developed for a number of heavy torpedo projects. Marconi representatives believe that most of the *ODAS* vehicle is a totally new design.

The basic vehicle is the same size and weight as a heavy torpedo. It has an operating depth of 300 m. The propulsor used is the Deacon Laboratory propulsor design single shaft version. The power source is a sodium-sulphur battery, a high temperature (300°C) battery developed by the Germans for use in an electric car. The 37 kWh battery, divided 65 percent for propulsion and 35 percent for payload, enables the vehicle to travel just under 8 kt for 36 hours, resulting in an operating range of 300 km. Payload is 45 kg wet and 90 kg dry. System sensors include a Chelsea instrumentation package, an upward looking side scan sonar, and an echosounder (reconfigurable to be downward looking). Marconi has developed a novel launch-and-recovery system that is simple, is low cost, can operate in high sea states, and appears to be reliable. Marconi suggests that the *ODAS* system should be priced in the \$100,000 to \$200,000 range.

The Institut Francais de Recherche pour L'Exploitation de la Mer, or IFREMER, is in the process of designing a science-dedicated ROV. The vehicle would have major ocean depth capability (6,000 m), use fiber optics for high data rate transfer for communications with other surface entities, and would operate from a garage (TMS) from a 300 m tether. The payload would be three interchangeable packages: biological, geological, and other sensors, and two manipulators. Propulsion would be from 25 hp (five 5 hp) thrusters. The system would be tracked via ultrashort baseline and long baseline systems. IFREMER estimated the cost of the ROV to be \$7 million without labor. The program began in 1993 with conceptual studies. Subsystem designs are scheduled for 1994, and the vehicle will be assembled and tested in 1995. To minimize risk, *VORTEX (Versatile Ocean Subsea Robot for*

*Technical Experiments*), a testbed ROV for validating hardware and concepts, has been built and is operational.

*Present Position.* Relative to the Western world, the United Kingdom is equal to or slightly behind in scientific unmanned systems, but only because of funding constraints. The Autosub project is very ambitious; it will take five or more years to see the results. However, with low-cost obstacle avoidance and navigation systems, the inexpensive Marconi *ODAS* vehicle could be of great interest to the scientific community.

*Trends.* Universities are taking a narrower view of technology development because of funding constraints. Long-term projects like Autosub may survive. What is interesting is the cooperative nature of technology development, not just within the country, but within the European Community. A prime example is the European Community Marine Science and Technology (MAST) research programs. Recently, two new MAST programs have been initiated with a goal of furthering autonomous underwater vehicle technology, namely:

- o Advanced Systems Research for Unmanned Autonomous Underwater Vehicles and
- o Autonomous Underwater Vehicle for Coastal Surveys.

The first project concentrates on generic AUV technology in direct support of individual major vehicle projects at the British and French national oceanographic research institutes. The participants in this project include the Institute of Ocean Sciences Deacon Laboratory, Defence Research Agency (DRA) from the United Kingdom, IFREMER, Societe ECA, and Institut National de Recherche en Informatique et en Automatique (INRIA) from France, National Technical University of Athens from Greece, and Instituto Hidrográfico (IH) from Portugal. The second project, DRA, is actually building a vehicle, *MARIUS*, or *Marine Utility Vehicle System*, for coastal seabed and environmental surveys. The key participants in this program are from Portugal, Denmark, and France. The *MARIUS* vehicle is designed for seabed inspections and environmental surveys in coastal water less than 600 m deep. The vehicle is capable of hovering and retrieving bottom samples. The hull has been completed and initial sea trials are expected off Portugal in late 1993. It is planned to be fully operational in 1994.

The major point to bring forth is the trend toward international cooperation on major projects. There may be something to learn from this mode of technology development, especially in a tight money environment.

## **FORMER SOVIET UNION**

### **Motivation**

The past and present conditions both Russia and Ukraine have a strong impact on the trend toward unmanned systems. Except for Intersheif in Russia and Rauma in Finland, the facilities that WTEC visited were and are government-funded and directed. These facilities were tightly controlled. Goals and objectives were determined not necessarily by the scientific community, but based on national needs. Some facilities were so tightly secured that communications with other agencies or institutions either did not exist or were very difficult. Also, establishing knowledge of what the rest of the world was doing was difficult if not impossible. The situation has completely changed, but the lack of funds and facilities in the infrastructure for establishing communications links has still proven to be very difficult to overcome.

Russian scientists have always felt that good science requires that the scientist be present. That is why they have designed and built a large number of manned submersibles, many more than previously known in the West. The need for ROVs did not exist and consequently was not pursued, with a few exceptions that will be noted.

The drive to commercialize products is very high in the countries of the former Soviet Union (FSU) because of the need for funds. The problem is that the Russians do not have an understanding of the world market place, with regard to either the needs of potential customers or the competition. The pricing of an object is very difficult. The profit motive never existed, consequently the cost of an object was not critical. The price structure has no resemblance to that in the Western world. (For example, the salary for a senior scientist is approximately \$40 per month.) Therefore, the only way they have been pricing objects or systems for the world market is to find a Western counterpart and price their object the same (see discussion of Fish-102 and 103 below under Low-Cost and Deep ROVs). The motivation for a westerner to purchase Russian or Ukrainian hardware is probably low because of the lack of documentation and parts, and because of the logistics for repairs. The domestic market in these countries is very small because of a lack of funds.

Lastly, the level of sophistication of some of the unmanned systems may be too low for the Western scientist. Computer technology is 10 to 15 years behind that in the West. On a positive note, the basic engineering design of hardware is generally simple, reliable, and field repairable. This condition was vividly exhibited in the manned submersibles that the WTEC panel saw.

The unmanned systems observed at the Russian and Ukrainian sites visited can be broken down into the following categories:

- o Low-cost ROVs
- o Deep ROVs
- o AUVs
- o Specialty ROVs

### **Low-Cost ROVs**

These ROVs are the "eye-ball" types, a controllable platform with a video system that is generally black and white. Examples of these are the *Polus* and *Adeline* ROVs from the Institute of Hydromechanics (UAS), in Kiev, Ukraine. These are 100-pound ROVs for 100 m water depths. The *Fish-102* (36 pounds, 100 m water depth) from Intershelf is very similar to the early *Phantom* ROVs from Deep Ocean Technology. Based on this similarity, Intershelf has priced the unit at \$14,000, and has been negotiating with a Western distributor. These vehicles are probably 10 to 15 years behind prevailing hardware designs.

### **Deep ROVs**

One interesting trend was observed. ROVs operated either in shallow water, that is, 100 meters, or "full-ocean-depth," that is, 6,000 meters. An example of the deep ROVs are the *Uran* vehicle from the Krylov Institute of Ship Research in St. Petersburg. The *Uran*, built two years ago, is a large ROV with a smaller one tethered to it. The Intershelf *Fish-103* (100 pounds weight and 1 kW power) has an operating depth of 6,000 m, but it must operate from a separate platform via a 30 m tether. This ROV was used on the third expedition to the *Komsomolets* submarine that sank in 1,700 m of water off Norway in 1989. Subsequent to the WTEC panel's visit, *Fish 103* was used in three additional dives to *Komsomolets* during August of 1993, penetrating into the submarine's first compartment, operating there for a total of five hours and recording four hours of video. *Fish-103* has been priced at \$50,000.

### **AUVs**

The only AUV observed was the *Scaros* vehicle at the Bauman Institute of Underwater Devices and Robotics in Moscow. The vehicle is very similar in function and size to the recently retired French *Epaulard*. The *Scaros* is 80 percent complete, but was put on hold because of a lack of funds. Another AUV, the *MT-88* from the Institute of Marine Technology Problems in Vladivostock, exists but was not seen. This vehicle can operate to 6,000 m, has a range of 15 km, and is approximately 3 feet in diameter, 12 feet long, and 2,000 pounds. The vehicle is tracked acoustically and can be controlled from an acoustic command link. The *MT-88* conducted the first survey of the *Komsomolets* submarine.

### Specialty ROVs

There are numerous examples of specialty ROVs. The Shirshov Institute of Oceanography (RAS) in Moscow has a deep ocean tow sled that can operate at 6,000 m from a 10,000 m umbilical. Sensors are a side scan sonar, low light level black-and-white video, and a color stereo camera. This system was used on the second *Komsomolets* survey.

The Marine Hydrophysical Institute (UAS) in Sevastopol, Ukraine, has developed a towed CTD that can be maneuvered while under tow. This institute is known for its physical oceanographic sensors. Some of its systems can operate at 2,500 m, and can measure dissolved oxygen, pH, turbidity, chlorophyll fluorescence, CTD, and distance to the bottom.

Bauman designed and built numerous specialty vehicles, for example, a bottom crawler, an object (torpedo?) retriever, the *Manta* and *Aquator* (circa 1978) ROVs, and *Triton*. No specifications were made available, but the author has the impression that they are 10- to 15-year-old systems.

Intershelf designed a series of bottom-tracked devices: *Alpha* at 1 ton, *Beta* at 8 tons, and *Gamma* at 80 tons. They are controllable platforms capable of handling various types of payload work packages to a water depth of 400 m. One unit, an 8-ton *Beta*, was built, tested, and completely modularized for easy transport anywhere.

**Present Position.** Establishing a present position relative to the Western world is very difficult. The low-cost ROVs are definitely old technology. The deep ROVs are another matter. The West has very little experience with ROVs operating in 6,000 m of water. The AUVs are not impressive except for the fact that the *MT-88* can operate in 6,000 m of water. There was nothing technologically exciting about the specialty ROVs. Unmanned systems have not been the forte of the Russians or Ukrainians.

**Trends.** Out of necessity, the various facilities and individual members have formed private ventures in an effort to generate badly needed funds. The main problem that exists is that they are not market wise. For example, there are numerous ventures for developing tourist submarines. However, a detailed study of the world market for tourist submarines indicates that a need exists for only 10 to 15 more submarines.

Intershelf exemplifies another trend where a foreign firm, J.P. Kenny, formulates teaming agreements with individuals and facilities to conduct business on a worldwide basis.

The first market for unmanned systems will be in the countries of the FSU, but the prevailing economic situation there will have to become more stable and stronger.



## **CHAPTER 6**

# **APPLICATIONS OF ACOUSTIC TECHNOLOGY**

**Richard Blidberg**

### **INTRODUCTION**

This chapter explores the applications of various acoustic techniques that were discussed during the trip. The WTEC team saw many systems and research interests in the United Kingdom, France, and Russia. This discussion is not meant to represent all such applications being undertaken in all of the countries referenced. Many more are undoubtedly underway. The applications mentioned, however, do give a sense of the relative breadth and level of technology being worked within each of those countries. This summary of activities is considered to be a snapshot and suffers from limited technical depth and scope.

### **GOALS OF THE ASSESSMENT**

A set of objectives were established to help organize the information gathered during the visits and, hopefully, guide the discussions. Although all of the objectives were not met, many insights and new knowledge of capabilities were gleaned from the discussions. The objectives established to allow consideration of the applications of acoustic technology were as follows:

1. Begin to document applications of acoustic technology
2. Assess the maturity of those applications
3. Relate those activities to similar ones in the United States
4. Identify unique concepts or applications

It is clear that much activity, in terms of both basic research and development, is underway in both Eastern and Western Europe. It is hard to quantify differences in the level of technology since current conditions in the former Soviet Union (FSU) and Western Europe are so different. Certainly the market for these applications is much more mature in Western Europe. The specific applications under consideration may be more diverse in the FSU. Previously, the focus was almost exclusively on military need. Now the interest is on more commercial applications. Technologists are searching for unique applications of their capabilities.

Acoustic applications in France and the United Kingdom, for the most part, have matured to a point where products have been defined or specific needs established. In Russia and Ukraine, the maturity of the work discussed varied from functioning hardware to esoteric consideration. Although it would be foolhardy to state that this visit clarified the questions related to concept maturity, it was possible to gain an initial understanding.

There is a marked difference between developments in the United States and the FSU. There is also some difference between what was seen in France and the United Kingdom and in the United States, although those differences were far less pronounced.

To identify unique applications, it must first be understood that some applications discussed during the WTEC team's visits in Russia and Ukraine may exist in the United States in classified programs. All assessments of the uniqueness of work are made with no understanding of possible similarities of application in classified programs or activities in the United States. It may be better to assume that applications described as unique may be more accurately described as interesting.

## MATRIX OF APPLICATIONS

For purposes of this report, it is appropriate to separate the activities of Western Europe from those found in Russia and Ukraine. The maturity of the market for acoustic systems being developed in France and the United Kingdom is clear. Products are the main focus. Also, research into acoustic applications in Western Europe is far more product and need oriented. Efforts underway in Russia and Ukraine are far less driven by quantified need. Indeed, much effort is being expended to consider possible new areas of application and product development.

Table 6.1 gives the names, locations, and primary types of activity of the organizations that the team visited where acoustic applications were discussed. It is clear from discussions with some of our hosts after the WTEC visit to Russia and Ukraine (during the WTEC workshop held in Washington, D.C.) that other activities exist that were not discussed.

**Table 6.1**  
**Organizations Where Acoustics Applications Were Discussed**

<b>ORGANIZATION</b>	<b>LOCATION</b>	<b>TYPE</b>	<b>APPLICATIONS</b>
General Physics Institute	Moscow, Russia	RES, DEV	Acoustic Propagation Studies
Andreev Acoustics Institute	Moscow, Russia	RES	Various Research
Marine Hydrophysical Institute	Sevastopol, Ukraine	RES, OPS	Acoustic Current Meter
Shirshov Institute	Moscow, Russia	RES, DEV	Arrays, Xnducrs, Small Beacon
Institute of Applied Physics	Nizhny Novgorod, Russia	RES, DEV	ADCP, Arrays, Processing
NIIVK	Moscow, Russia	RES, (DEV)	CPU Hdwr/Sftw, Applications
St. Petersburg State University	St. Petersburg, Russia	RES, EDU	USB Tracking System
Oceanpribor	St. Petersburg, Russia	RES, MAN	Various Applications
Bureau of Oceanological Engineering	Moscow, Russia	RES, MAN	Various Applications
Geoton Company	Dubna, Russia	COM	Seismic Data Acquisition
Peleng Company	Dubna, Russia	COM	Low Frequency Sources
ROS Company	Dubna, Russia	COM	Minisocus
INFRAD Company	Dubna, Russia	COM	Sonar Tomography
Heriot-Watt University	Edinburgh, UK	RES, EDU	Various Research
Tritech International	Aberdeen, UK	COM	Low-Cost Sonar Systems
Reson	Aberdeen, UK	COM	Volume Scanning Sonar System
Marconi UDI*	Aberdeen, UK	COM	Xnducrs, Tools, Systems
Marconi Underwater Systems	Waterlooville, UK	COM	Various Products
IFREMER	Toulon, France	RES, DEV	Various Applications Research

\* Marconi UDI was sold in August 1993, and is now known as Fugro-UDI Limited.

**SUMMARY OF INSTITUTIONS UNDERTAKING ACOUSTIC ACTIVITIES**

Many of the institutions visited mentioned that they were involved in various acoustics applications. The brevity of the discussions did not allow documentation of many of the technical details. Because of this lack of complete information the following discussions may be brief, but the associated tables will help to clarify where applications were mentioned. When possible, more detailed information will be presented. For more information, contact the specific institute representatives named in the site reports (Appendices B through F).

**General Physics Institute (Moscow)**

*Low Frequency Acoustics.* Although the institute has nine departments, the WTEC visit was primarily concerned with the institute's work in devices for oceanographic research. While several of the departments contribute to marine related research, the majority of that work is done in the Department of Wave Phenomena.

The institute's Acoustic Ocean Sounding laboratory has been using a towed fish, equipped with two transducers, in the Barents Sea to do sound path research at 100 Hz and 300 Hz frequencies at output powers of 100 W and 300 W, respectively. In conjunction with these acoustic sources, an array consisting of 12 hydrophones is used for receiving the acoustic signals. The array, 70 m in length, can be towed from a ship or mounted on the sea floor where it is battery powered (operating depth of 500 m). The array has sensors to measure depth and tilt angle to compensate for these variables in signal processing. Through the use of buoys, the received data can be transmitted to a remote location up to 10 miles away.

Using this system, researchers have sent acoustic signals over a 500 km path to determine losses for both vertical and horizontal paths. This work has been used in conjunction with acoustic tomography efforts in the United States. The institute hopes to continue this work in the Arctic Basin for long-range tomography experiments. The institute also hopes to do some shallow water work with this system in the Barents Sea.

*Atmosphere - Ocean Communications.* An interesting application was discussed where communications between an aircraft and a submarine would be accomplished using high-powered lasers and acoustics. The aerial platform would use a very high-powered, modulated laser directed at a very small area of the ocean surface. The power output of the laser would be high enough to create mechanical surface roughness that could be sensed by the submerged platform. Through analysis of the generated surface roughness, the information transmitted would be detected.

Conversely, the submerged platform would use an upward directed very high frequency sound source to create similar roughness on the sea surface. This

roughness would then be detected by a cross-polarized radar. This concept has been tested from a low flying aircraft.

### **Andreev Acoustics Institute (Moscow)**

The Andreev Acoustics Institute is a research institute and considers first principles related to acoustic applications. Although the institute does not build systems, it becomes involved in the testing and evaluation of systems after they have been developed.

The institute focuses on basic research of sound propagation in the sea, although it is now considering air acoustics as well as a number of other application areas. The institute is involved with scientific research, not prototype development. It is involved in five areas of acoustic research: (1) ocean, (2) oil and gas, (3) medical, (4) ecological, and (5) air acoustics. This is a technical institute and, as such, previously worked only on problems provided by the user community. Recently it has been given more freedom to choose its research directions, but has far less support to accomplish that research.

The following nine acoustic applications were mentioned, a few of which were discussed in some technical depth:

- o Transponder system development
- o Bottom referenced positioning system
- o Bore hole reentry system
- o Sound vision system
- o Parametric sonar system
- o Pulsed acoustics for pollution monitoring
- o Matched field processing activities
- o Communications
- o Marine mammals research

**Transponder System Development.** The institute is interested in undersea transponders with extended durations. Some work has been undertaken directed at the development of transponders that would extend their endurance through the use of a sleep mode. One year or more lifetime with wake up mode is expected.

The institute has been investigating the design of a multibeam receiver for obtaining accurate range and bearing determination using transponders. Investigations suggest bearing accuracies of 1°. The institute has not built these receivers, but has completed the design investigations.

**Bottom Referenced Positioning System.** This project uses bathymetric data to monitor the movement of slow moving objects such as oil rigs. Andreev Institute compared data acquired from a multibeam sonar with previous data to get motion accuracy of  $\pm 1$  cm. The institute has a multibeam sonar of 100 1° beams.

**Bore Hole Reentry System.** Andreev Institute is considering using stationary arrays to monitor the positions of oil drilling heads. Processing will eliminate the noise associated with the drilling process and allow for range and bearing to drill head.

**Sound Vision System.** This effort is focused on medical applications. An acoustic imaging system was discussed that uses 1 MHz and a  $100 \times 100$  array with  $1^\circ$  beams. The beams are electronically formed from the array data.

**Parametric Sonar Systems.** The institute is working on parametric sonar techniques for different applications. One such application is for oil exploration; the sediment is used to mix carriers around 300 kHz to get a 600 Hz difference in frequency for subbottom profiling/seismic analysis.

**Pulsed Acoustics for Pollution Monitoring.** The institute's scientists believe that they can obtain pollutant concentrations by analyzing received pulses over small volumes of water (1 to 10 m) paths. They have run some experiments to obtain understanding of changes in concentrations of pollutants to 1 part per  $10^6$ .

**Matched Field Processing.** The institute has been working on matched field processing for years, and is now applying that technique to various problems. They are working on, or at least interested in:

1. Long path acoustic current meters. The matched field techniques minimize errors introduced by the bottom and surface reverberations in shallow water channels. This increases the accuracy of measurements of fluid flow in long, shallow water channels.
2. Internal wave structure of a channel. Scientists feel that they can analyze the health of a body of water by understanding the flow of water entering and exiting that body.
3. Underwater acoustic holography. The institute is using optical waveguide techniques to better understand underwater sound channels.
4. Sediment measurements. Andreev's representatives mentioned a project to measure sediment properties through the use of acoustics. By measuring the effect of an acoustic wave as it propagates through the marine sediment, various parameters can be determined.

**Communications.** The institute's scientists and engineers have worked on some communication systems that they cannot discuss. They have looked at some filter processing techniques being applied to underwater communications. They believed that there was a need for long range communications at low data rates (2,000 km to 3,000 km). The same techniques can be applied to shorter ranges with

correspondingly higher data rates (e.g., 20 Hz  $\pm$  10 for ranges of 1,000 km to 2,000 km using a receiver with 18 bit resolution). With regard to bore head telemetry, the institute wants to use its techniques for implementing a low data rate telemetry system from the drill head to the surface without cables.

*Marine Mammals Research.* Andreev is researching dolphins' and other marine animals' sonar capabilities, with an interest in understanding what can be applied to sonar systems. Marine mammals such as the dolphin have a sonar system that is a "whole" system, that is, the physiological characteristics of the animal as well as its behavior are part of the entire sonar system. Much may be learned from this: it has been said that 5 to 100 neurons can sometimes have the equivalent processing capability of a million computers.

The institute is investigating some basic issues associated with neural networks, specifically, how a group of neurons with msec response times can be connected so that the group can detect msec variations. The research effort in this area is not large.

#### **Marine Hydrophysical Institute (Sevastopol)**

*Acoustic Current Meters - Special Instrumentation.* The Marine Hydrophysical Institute is principally focused on the study of physical oceanography. Scientists there have a substantial design, development, and manufacturing capability to support the development of instrumentation required for their activities. There is an acoustics facility at Odessa, but there was not enough time for the team to visit it.

The institute has developed a number of acoustic current meters for its needs. It has concentrated on acoustic current meters that measure velocity components at a point rather than utilizing the range gated Doppler system concept. No other unique applications of acoustic technology were reported; however, others may well exist.

#### **Shirshov Institute (Moscow)**

The Shirshov Institute is involved with the production of platform and instrumentation systems needed to support its oceanographic research. Since there was limited availability of Western equipment, the institute's scientists and engineers were forced to develop their own instruments. While this activity was driven by necessity, it also helped to stimulate the development of some unique devices. The applications mentioned were:

- o An AUV simulator with forward-looking and vertical sonar
- o Sonar information processing
- o Transducer elements for side scan sonar and acoustic imaging
- o Hydroacoustic beacon/transponder for divers/mammals

o **Geophysical towed arrays**

**Sonar Information Processing.** The little about sonar information processing that was discussed appeared to be related to side scan sonar imagery.

**Transducer Elements for Side Scan Sonar and Acoustic Imaging.** The work on side scan sonar transducers and imaging systems focused on the development of transducers rated for 6,000 m.

**Hydroacoustic Beacon/Transponder.** This effort focused on the development of a beacon/transponder system for attachment to divers and marine mammals. In both cases, physiological and location data could be sent back to a remote station. It was suggested that this system could be used to control the activities of marine mammals via long distance communications.

**Geophysical Towed Arrays.** Mr. Meridin discussed his development of a smaller, lower-cost geophysical seismic system. Pointing out that existing 3-D systems are large and expensive, his goal is to achieve similar results with much less complexity by developing a 5 km towed array using sensors that are only 20 to 25 mm in diameter. A microjet transmitter would transmit a complex broadband signal as a source for seismic analysis of returns.

**Additional Information.** Additional information can be obtained from a publication developed by the Office of Naval Research, European Office (NAVSO P-3678). This publication mentions acoustic applications under investigation at the Laboratory of Acoustic Noise and Sound Fluctuations and the Acoustic Wave Propagation Laboratory of the institute. These include free-floating acoustic recording capsules, bottom tomography, various arrays, and a portable acoustic positioning system with baseline distances in the 20 to 25 km range.

**Institute of Applied Physics (Nizhny Novgorod)**

Discussions during the WTEC team's visit focused on the Department of Hydrophysics and Hydroacoustics for work related to acoustic applications, where most of this institute's ocean-related work takes place. Although little technical detail was discussed, several projects were mentioned, including:

- o Remote diagnostics of ocean phenomena
- o Submarine location using acoustic and nonacoustic means
- o Low frequency acoustics in the sea
- o Phased arrays in sound transmission and reception
- o Signal processing
- o Physical and mathematical modelling of the oceans
- o Environmental monitoring



- o Acoustic Doppler current profiler, 3 beams; 30° or 120°
- o Mobile linear array

**Low Frequency Sources.** One example of work on low frequency sources was the testing of a compact electromagnetic monopole source in conjunction with the Woods Hole Oceanographic Institute (published in WHOI-93-09). The titanium source, developed at IAP RAS, has a mass of 123 kg and a diameter of .54 m. The system has a center frequency of 225 Hz, a bandwidth of about 50 Hz, an associated pulse resolution of about 200 msec, and a sources level of 198 Db re 1  $\mu$ Pa at 1 m, with an efficiency of about 50 percent. This source is being considered for use in monitoring the ocean to understand more about global ocean processes and their impact on the world's climate.

**Mobile Linear Array.** This 200 m long mobile linear array consists of 64 hydrophones spaced 3 m apart (300 m operating depth). The system is capable of making very accurate acoustic spectrum measurements from 20 to 300 Hz. The upper range can be extended to 2,000 Hz. Included with this system, which is available for sale at \$20,000, is signal processing software, which otherwise costs an additional \$12,500.

**Acoustic Doppler Current Profiler.** This instrument is a three-beam (30° beams oriented 30° off vertical in 120° azimuthal increments), 220 kHz system for operation in water depths to 400 m (200 to 300 m for current profiling, and 300 to 400 m for ship velocity measurements). The system is configured with an IBM/AT for processing. It is believed to be superior to the RD Instruments system.

### **Scientific Research Institute of Computer Complexes (NIIVK)**

NIIVK was represented as the institute responsible for designing computer hardware and systems software. In accomplishing this task, NIIVK scientists developed algorithms for sonar systems. Much of this work was originally classified (and some still remains so) but is now unclassified. Efforts are underway to commercialize several acoustic applications that have evolved from the work at NIIVK. The following describes some of those concepts.

**Fish Monitoring Sonar System.** This system is designed for low-tonnage vessels fishing in any open ocean areas. It is aimed at detecting pelagic and bottom fish shoals to determine their location while the vessel is operating at full speed in seas up to sea state 4. The system is used in low-tonnage vessels for fish objects detection (fish, crustaceans, mollusks) in active and/or passive (on receiving bioacoustic signals) sonar mode.

The unique feature of the system is its use in a passive sonar mode, which assists in the detection and classification of living resources on or in the bottom layer, which

is a favorite location of crustaceans and mollusks. The Fish Monitoring Sonar System includes a receiving-transmitting transducer (antenna), a signal processor, and displaying, recording, and control devices. The use of a standard recorder and a standard display is possible, as well. Receiving-transmitting and control devices should be installed in a pilot house.

The sonar system range is nominally 16 km, but depends on sea depth, sound speed dependence, bottom and surface acoustic parameters, and equivalent radius of a fish shoal.

At 1 Pa total acoustic noise (reduced to reference conditions: 1 kHz frequency, 1 Hz bandwidth, and a concentration factor equal to 1) at the site of the transducer, the range for a shelf zone must be more than 6,000 m for pelagic fish shoals (at an equivalent sphere radius  $R = 2$  m), and 200 m for a single fish at a bottom layer ( $R = 0.1$  m).  $R$  is given for a frequency of 15 kHz. At a signal occurrence probability equal to 0.4, a signal detection probability must be not less than 0.8.

Depending on operational needs, fish shoal search may be carried out in sector or in circular view mode. In the sector scan mode, the system scans  $\pm 165^\circ$  in the azimuth plane and 0 to  $90^\circ$  in the elevation plane (bottom direction). Accuracy of fish object location in the azimuth and elevation guidance mode is not less than 3 percent. Less precision is permitted in the search mode.

Classification of objects detected in passive mode is implemented automatically. The probability of species and subspecies valid classification achieves 0.7 to 0.8 for relatively high values of signal/noise ratio. The results of the classification are displayed in a form suitable for operator perception.

A receiving-transmitting antenna is a 0.9 m height and near 2 m diameter cylinder. The antenna is installed under a keel in a glass-fiber-plastic or a metal sonar dome. The antenna may also be placed in a lifting-sliding facility or may be lowered from a helicopter. This facility must lower the antenna 1 m lower than a keel. In an idle state the antenna should be retracted into a trunk inside a vessel hull. The antenna displacement control is remote, automatic, and manual.

Display, signal, and control processors are based on 286 (386, 486) and TMS 320C30 processors. The required performance of the signal processor is about 800 MDPS.

*Compact Sonar System for the Nearest Water Area Viewing.* This compact sonar system is designed for underwater apparatus used in shelf zones for applications such as exploration of mineral deposits, laying cable, surveying platform sites, and investigating ice covers. General system specifications are given in Table 6.2.

This parametric sonar system has a transmitting array of  $0.2 \text{ m}^2$  in the angular sector. A parallel-sequential spatial view is obtained by the system.

**Table 6.2**  
**General System Specifications -- Nearest Water Area Viewing**

Range	0.1 to 2 km
View Sector in azimuth in elevation	$\pm 45^\circ$ $\pm 15^\circ$
Distance Resolution	0.2 m
Angular Resolution	$1^\circ$ to $3^\circ$
Antenna Square	0.2 to $0.6 \text{ m}^2$
Equipment Volume	0.2 to $0.6 \text{ m}^3$
Submergence Depth	up to 500 m
Power Consumption	0.5 kW

The receiving array ( $0.6 \text{ m}^2$ ) receives a noise and valid signal mixture. The amplified, filtered, and digitized signals are sent to the computing facilities. Signal processing includes the following:

- o Multibeam forming in the spectral region
- o Reverberation noise suppression
- o Matched filtration
- o Signal detection and signal parameters measurement
- o Primary signal classification
- o Data preparation for displaying
- o Processing results archiving

The processing results are displayed. An operator analyzes the image and, taking into account primary classification data, identifies the object under observation.

Design specifications of this system are available. The main design concepts have been analyzed, simulated, and tested in natural conditions, and the array breadboarding has been accomplished. Proposals for cooperation with foreign participants are being sought.

**Multiship Fish Monitoring Sonar System.** This compact system is designed for fish shoals search and classification in the shelf zone and in the open ocean. General system specifications are given in Table 6.3.

The pseudo random signal transmitting antenna is towed by the most forward fishing vessel. The receiving array is towed by one or two fishing ships, moving parallel with the major vessel. The arrays receive a noise and valid signal mixture. These signals are amplified, filtered, digitized, and sent to the computing facility. Signal processing includes:

**Table 6.3**  
**General System Specifications -- Multiship Fish Monitoring**

Range in the shelf zone in the ocean	5 to 10 km 3 to 5 km
Shoal Detection Accuracy distance accuracy angle accuracy	5% of a distance 5°
Classification Probability	0.8 to 0.9

- Forming multibeam directivity diagram in the spectral region
- Filtration, matched with moving underwater objects
- Measuring signal detection and signal parameters
- Classifying initial signals
- Preparing data for display
- Filing processing results

The processing results are displayed. An operator analyzes the image and, taking into account initial classification data, identifies the object under observation. Data concerning new objects are then loaded into the classification database.

Scientific analysis of detection methods and underwater moving objects classification are available. Proposals for cooperation are being sought.

**Sonar System for Beam Structure Parameters of Undersea Acoustic Fields.** This system is aimed at acquiring parameters of undersea acoustic fields and comparing empirical data with calculated parameters. The system can measure the following:

- Propagation beams
- Beams focusing factors

- o Angles of arrival in the vertical and horizontal planes
- o Time delays between beams
- o Correlation factors between beams
- o Spatial intervals of beams coherence in the vertical and horizontal planes
- o Time intervals of beams coherence
- o Bottom and surface reflection factors
- o The ocean noise spectrum and spatial characteristics

General system specifications are given in Table 6.4.

The antenna, installed at the transmitting ship, transmits a pseudorandom signal. The array at the receiving ship can be placed in the vertical or horizontal position. It receives a noise and valid signal mixture. Amplified, filtered, and digitized signals are sent to the computing facilities. The computer evaluates the beam structure parameters of sea acoustic fields. The use of special algorithms provides beam super resolution. Computer system software includes beam structure evaluation of acoustic fields and the comparison of theoretical and experimental results.

In order to make measurements more accurate, the receiving array is automatically calibrated at regular intervals. Processing results are displayed and loaded into a database. This measurement method has been experimentally verified in the Atlantic Ocean. Proposals for cooperation are being sought.

**Table 6.4**  
**General System Specifications -- Beam Structure Parameters**

Antenna Length	36 m
Frequency Band	1 to 6 kHz
Number of Resolution Beam Clusters	up to 16
Number of Resolution Beams in a Cluster	up to 3
Angle of Arrival Measurement Accuracy	1 to 3 minutes
Time Delay Measurement Accuracy	$10^{-4}$ sec
Focusing Factors Measurement Accuracy	5%

### **St. Petersburg State University (St. Petersburg)**

The university has some interest in an ultrashort baseline underwater tracing system with a range of 1 km. Not much was discussed relating to other acoustic applications, although there may be other work underway.

### **Oceanpribor (St. Petersburg)**

Oceanpribor is the largest Russian company specializing in the design and manufacture of hydroacoustic systems. The company has developed and is selling transponders and transducers as well as hydroacoustic systems for various applications under the trademark "Korvet." Hence the company is sometimes known as Korvet Oceanpribor. Table 6.5 summarizes some of its offerings.

### **Bureau of Oceanological Engineering (Moscow)**

The bureau's primary function is to design, build, and test samplers, sensors, and instrumentation for oceanographic research. Its activities in acoustic applications seem consistent with the types of instruments commonly found in the ocean community. The following applications/acoustic instruments were mentioned:

- o Acoustic releases
- o Long and short baseline navigation systems
- o Transponders for the navigation systems
- o Communications between submersibles and surface vessels

### **Dubna International Centre of Research and Technology Development (TECHNOPOLE)**

TECHNOPOLE is a trade group that represents several startup companies that have spun off the technologies developed at Atoll Scientific Research Institute in Dubna. Four companies discussed their products and ideas for products, as summarized below.

#### **Geoton Company (Dubna)**

*Acoustic Data Acquisition System.* Geoton (in existence for about two years) presented a multichannel seismic system to explore for oil and gas. The unique feature of the Geoton system is its multichannel capability for data acquisition and processing. Up to 10,000 channels are possible in the system, which can enable three-dimensional views and greater accuracy for location of test drilling sites. Geoton claims that this will reduce the number of test wells by one-third. With the Geoton system in place it is also possible to estimate undepleted reserves in productive oil and gas fields.

**Table 6.5**  
**Oceanprbor's Transponders, Antennae and Systems**

SYSTEM TYPE	FREQUENCY	ENDURANCE	DEPTH	COMMENTS
Transponder	8 - 30 kHz	280 hrs - 120 days; 3 yrs	1,000 - 6,000 m	family of transponders
Transponder	14 - 19.8 kHz int. 8 - 13.8 kHz res.	10 days - 180 days; 3 yrs	6,000 m	various reply strategies
Transponder	7.75 - 12.25 kHz int. 28/38 kHz res.	2 yrs - 3 yrs	1,000 m	
Transponder	21.55 - 26.46 kHz fixed freq. int. 27.17 - 32.47 kHz fixed freq. res.	2 yrs	1,000 m	
Transponder	38.8 or 39.8 kHz fixed freq. int. 37.8 kHz fixed freq. int.	2 yrs	1,000 m	
Transceiver array	10 - 20 kHz Xmit 7 - 14 kHz Rcvr			30, 45, 90 deg. beams
Transceiver array	70 kHz		unlimited	0.75 deg. beams "cosec"
Transceiver array	80 kHz		6,000 m	3.5 deg. beams "cosec"
Transceiver array	400 kHz		unlimited	1 deg. sector
Transmitting array	14 - 20 kHz 3 - 7 kHz		1800 m	7 deg. beam 9-25 min. beam (prototype)
Hydrophones	various		100 - 1800 m	
Multipurpose scanning sonar	90 kHz		6,000 m	7.5, 15, 30 deg.
Hydroacoustic telephone communication systems	30 - 40 kHz	10,000 hrs	380 m	range 2,000 m
	82 - 88 kHz	10 hrs	60 m	range 250 m
Digital communication system over hydroacoustic channel	Multibeam channel			2,000; 800 bit/s  range up to 15 km
Ship positioning system	7 - 12 kHz int. 28 or 38 kHz reply		30 - 800 m 80 - 6000 m	12 km range (or more)
Sonar Doppler log	255 kHz		6000 m	4 x 3.5 deg.

Geoton has built components for its system and tested them in the laboratory. Systems have been developed around the TMS 320 processor using algorithms developed solely in Russia, since the company has had no access to the computer technology of the West. The Institute of Oil and Gas has deployed and tested a 12-channel system with good results. Although Geoton does not manufacture, it will form partnerships with other Russian companies to produce the system. Geoton representatives believe they are well positioned to serve companies that will be conducting oil and gas exploration in the fields of Siberia, and are looking for clients with that same interest.

### **ROS Company (Dubna)**

*Passive Sonar System (minicosus).* The ROS Company, which may be the oldest of the four companies, was a company with a product that was developed and ready for sale: a seabed passive sonar system. This low-frequency system uses from less than 1 Hz up to 5 kHz, and has a sensitivity of 250 microvolt/Pa.

The wet part of the system consisted of multiple hydrophone arrays, each array in a straight-line with multiple arrays ganged onto an underwater data transmission line. The arrays might have 30 or 80 hydrophones. From four to eight arrays would make up the underwater systems. Analog to digital signal conversion was provided at each hydrophone, and electronic to optical signal conversion occurred in a regenerator at the array level to enable fiber optic transmission to the shore station.

The dry part of the system consisted of a remote-controlled power supply and an acoustic data analysis and display system that used an 80486 microcomputer. Very efficient data sampling, and compression and analysis algorithms were claimed for the system, which together with TMS 320 S-30 chips for each four arrays enabled effective and timely processing with a 486 microcomputer. Frequency, bearing, time, and target location (depending on array layout) could be displayed for up to five simultaneous targets per display. A database for classification of shipping targets is available from ROS. Larger projection displays could be incorporated if desired. The wet system could be retrieved and redeployed. The dry system is compact enough to reside in a mobile van. Other characteristics are in Figure Dubna.1 in the TECHNOPOLE/Dubna site report (see Appendix B). Figures Dubna.2 and Dubna.3, also in the site report, are photos that show the hydrophone piezoceramic of about 1.5 inch diameter, and the hydrophone housing, which is approximately 12" x 5" x 2", and contains the hydrophone and the a/d signal converter.

### **Peleng Company (Dubna)**

*Low Frequency Acoustic Sources.* The Peleng Company specializes in high power, low frequency (below 1,000 Hz) acoustic emitters. Mr. Polevik is a senior scientist there with many years of experience in emitter design, and holds approximately 80



patents for acoustic devices. He discussed the design of sparker, boomer, electrodynamic, and hydraulic-type emitters. Finally, he discussed the characteristics of a patented cylindrical emitter, created especially for use in seismic operations.

The problem of more durable electrodes in the sparker device has been solved by encapsulating them in a special liquid in which the high powered electric discharge takes place. The power in a single pulse from this large device, which is 1.2 m by .6 m and weighs 300 kg, is 5 kJ, which is hydraulically transmitted through the encapsulation to the surrounding sea. The operational depth of the device is up to 200 m.

*High Powered Boomer-Type Induction Pulsing Emitter.* A high powered boomer-type induction pulsing emitter with a tunable frequency response was described. The device was tunable to provide maximum amplitude in the low frequencies -- 50 to 700 Hz. It was claimed to be the first such design available for deep water use, that is, up to 300 m.

*Pulse Resonant Transmitter With High Frequency Response.* A working model of a new pulse resonant transmitter with high frequency response has been completed. The transmitter has a flat characteristic curve in the 10 to 300 Hz range through the use of reactive compensation, and has output power in the 3 kJ range. The transmitter is electrohydraulic; it is purely electric at low power and can be purely hydraulic at high power.

*Low Frequency Active Array.* A developmental concept was discussed for a low frequency active array of cylindrical shapes that might be used for searching out oil and gas fields. The array would be arranged to fit down an oil and gas well casing and would operate in the 50 to 100 Hz range with control to produce a directed beam pattern along a horizontal plane. The total system would also include a multichannel receiver array.

### **INFRAD Company (Dubna)**

*Fish School Detection Using a Passive Sonar System - ARGUS System.* A senior scientist from INFRAD described the ARGUS system, which is being developed in partnership with other companies in the Dubna region. The ARGUS system proposes using sonar emission tomography to detect fish shoals, currents and underwater waves, and sediment fallout rates. The proposed system would be purely passive and would have a maximum depth of 1,000 m, with a monitoring base line of 150 m that lies up to 200 km offshore. The pattern of surface noise would be understood through array processing as fish, currents, or sediment, and could be characterized as to depth, density, and school size of fish. The processing by each array would require the characteristics of the conditions in situ. The spokesperson for INFRAD explained that for about one year, there had been basic work exploring

the fine structure of hydroacoustic fields to support the concept of sonar tomography, but as yet there had been no funding to support experiments.

### **Heriot-Watt University (Aberdeen)**

The discussions at Heriot-Watt University focused on two groups involved with research directly related to underwater systems. The Ocean Systems Laboratory, headed by Professor George Russell, is investigating several different areas, three of which focus on sonar applications. The second group, headed by Dr. L.M. Linnett, was investigating sonar signal processing. The following topics were discussed:

- o Multisensor fusion
- o Subsea communications
- o Digitally focused sonar system
- o Object detection
- o Pipeline inspection
- o Seabed characteristics
- o Sonar data compression
- o Sonar simulation

**Multisensor Fusion.** This investigation studies methods of sensing three-dimensional environments in which subsea robotics activities take place, providing the precise positional information required by combining signals from optical sensors and acoustic sensors to increase realizable accuracies.

**Subsea Communications.** These studies investigate mathematical models of underwater acoustic propagation channels and the validation of these models through field demonstrations. The purpose of these efforts is to provide design information for high data rate communications for autonomous underwater vehicles.

**Digitally Focused Sonar System.** This project seeks to develop methods of creating high definition images by the digital processing of signals from sonar arrays, with application to the detailed survey of seabed features, texture classification, object detection by surface vessels and underwater vehicles, obstacle avoidance, and navigation of AUVs.

**Object Detection.** The group's years of work on object detection has advanced to a stage where excellent detection rates have been achieved for many different seabed types. The work is now aimed at assessing the probability of detection against different backgrounds.

**Pipeline Inspection.** A system has been developed for inspecting subsea pipelines using side scan sonar techniques to detect spalls (unsupported sections of a pipe). A system that performs real-time processing of the data has been successfully produced.

***Seabed Characterization.*** This work has reached the stage where excellent characterization of complex seabeds from side scan sonar records has been achieved. The present aim is towards a database of seabed types covering most areas of the seabed. With the increase in data rates from sonar equipment, the ability to accurately analyze data quickly is essential. To this end, a system has been developed for performing on-line segmentation of seabed types. This has application in hydrography where it is possible to perform seabed comparison over very short time scales. This could be of major importance in times of conflict.

***Sonar Data Compression.*** With the increase in resolution of modern sonars, gigabytes of data are now being gathered in side scan surveys. Techniques have been developed that are capable of compressing the information by many orders of magnitude. This has obvious benefits for the storage, manipulation, and transmission of such data. Work is continuing on techniques for real-time handling of acoustic data.

***Sonar Simulation.*** The group is developing mathematical and graphical techniques for synthesizing side scan data. The aim is to develop a system to allow the study of the sonar process, which will aid analysis and detection work.

#### **Marine Technology Directorate Ltd. (United Kingdom)**

The Marine Technology Directorate (MTD) is a United Kingdom-based association with international membership. The members have significant interests and capabilities in ocean-related technologies and come from industry, government, research establishments, academic institutions, the United Kingdom's Science and Engineering Research Council, and the Royal Academy of Engineering.

MTD funds research programs that relate to undersea vehicle technology. One, the Technology for Unmanned Underwater Vehicles (TUUV) program, covers a broad spectrum of technology problems in six main areas: sensing, control, communication, navigation, propulsion, and analysis. Three of those projects reflect types of activities related to acoustic applications in the undersea environment.

MTD advances research and development through its funding of marine research. MTD also encourages communication in the marine community by organizing discussions with companies whose interests relate to the objectives of the WTEC study. A description of three TUUV projects funded by MTD follows:

***Techniques for Processing Side Scan Sonar Data from Large Data Sets (Heriot-Watt University).*** In recent years, there has been an increase in the demand for high quality side scan sonar data for mapping sediments on the seafloor. Coupled with this demand has been increasingly sophisticated sonar equipment capable of obtaining high resolution images of the seafloor. These factors have led to an abundance of data that must be examined by trained personnel in a subjective and

time-consuming process. Techniques must be developed to more fully automate this process.

***A New Underwater Vision System (Strathclyde University).*** The goal of this project is to investigate a new vision system for working underwater. It combines the complementary characteristics of stereo optics with three-dimensional acoustic imaging. A 2-D matrix ultrasonic array, fixed relative to a pair of underwater cameras operating in stereo mode, will generate spatial and depth information to a target. This data will then be used to update and optimize a stereo matching algorithm to provide accurate 3-D optical vision. The objectives of the project are: (1) to merge acoustic data with 3-D optical data; (2) to design and evaluate a 2-D matrix ultrasonic array; (3) to create and implement stereo matching algorithms by fusing acoustic and optical data; and (4) to evaluate a prototype system.

***High Data Rate Subsea Acoustic Communications for UUVs (Newcastle University).*** The goal of this project is to better understand the potential for using acoustics to achieve 20 kbit/sec data transmission in shallow water environments. The objectives of this effort are: (1) to determine the fundamental limitations relating to the use of m-ary phase shift keying (PSK), beamforming, and adaptive equalization in the subsea environment; (2) to develop a half-duplex acoustic telemetry link using simultaneous beamforming at the transmitter and receiver; and (3) to demonstrate the practicality of high data rate acoustic communications systems operating in real conditions.

#### ***Tritech International Ltd. (Aberdeen)***

Tritech produces a range of advanced, high performance, and compact scanning sonar heads, all of which can be operated from the SCU-3 Multitasking Surface Control Unit. The heads are available in three different frequencies to satisfy the majority of underwater requirements.

The ST 325 long range scanning sonar is used throughout the world. It is an all-around sonar with a 200 m range capability. It is generally used for obstacle avoidance and navigation on small and large vehicles. The ST 525 high resolution, imaging sonar combines long range (100 m) with high resolution making it suitable for most ROV applications, including target acquisition and debris survey. The ST 725 very high resolution sonar is a high resolution, mid-range (50 m) imaging sonar used where higher resolution images are needed in preference to long operation.

The scanning heads for these sonar systems are available in three different configurations (vertical, horizontal, and big top) to allow installation in available spaces. The big top version has a larger transducer than the standard vertical and horizontal heads. This design produces a narrower and more concentrated sonar beam, resulting in higher angular resolution beam patterns.

**Table 6.6**  
**Specifications of Tritech Sonars**

<b>SPECIFICATIONS</b>	<b>ST 325</b>	<b>ST 525</b>	<b>ST 725</b>
Frequency	325 kHz	525 kHz	
Bandwidth, normal	4.5° x 24°	4.5° x 24°	2° x 24°
Beamwidth, Big Top	2.5° x 24°	1.2° x 24°	N/A
Maximum Range	200 m	100 m	50 m
Pulse width	60 - 1,000 μsec	60 - 1,000 μsec	60 - 1,000 μsec
Scan rate	8 - 40° sec	8 - 40° sec	8 - 40° sec
Depth rating	3,000 m	3,000 m	3,000 m

The sonar heads share a common power supply requirement and data communication protocol that enable the connection of multiple devices, including sonar, profilers, and altimeters, to the SCU-3 via a single twisted pair.

The SCU-3 is a powerful yet simple to operate multitasking acoustic processor. In addition to controlling ST sonars, it also operates Tritech ST 1000 scanning profilers, displays real-time video, and shows information from other sensors, such as a TSS 340 Pipetracker and eastings and northings from a navigation computer, all on the same monitor simultaneously. Data may be logged to and replayed from disk.

Images may be taken from SCU-3 and entered into desktop publishing packages to assist in creating post-operation reports.

#### **Reson Systems UK (Aberdeen)**

The SEABAT 9001 system is a multibeam sonar system that carries out profiling operations. It consists of a low weight (5 kg in water) multibeam sonar head, a 19-inch rack mounted processor, a high resolution monitor, and a track-ball with which to control the system (all functions are menu driven).

The SEABAT 9001 transmits a 90° x 1.5° fan beam consisting of sixty 455 kHz individual beams (1.5° x 1.5°) in one single pulse. All the beams are formed using a curved face transducer that minimizes background noise.

Because a single pulse is transmitted, undistorted profiles are generated, accurately portraying even the most complex sea bed features. Also, due to the single

transmission pulse, the full 90° profile is updated at 30 times per second at 25 m range or below, reducing to 7 times per second at 100 m.

The SEABAT 9001 exports the XYZ coordinates as a data stream twice per second to be integrated with roll, heave, pitch, and heading sensor information via a data acquisition program to provide an XYZ data stream that is combined with the positioning information supplied via the navigation program and passed through a digital terrain modelling program to provide the specified charts.

The SEABAT 6012 is a 485 kHz electronically scanning minisonar. It was especially designed as a principal ROV sensor for mine warfare. It is a 90° forward-looking sonar used for detection, relocation, and classification of mine-like objects located on the seabed or in the mid-water column.

The SEABAT 6012 functions in real-time with a visual window of 90° horizontally and 15° vertically. This, in effect, is similar to a wide angle camera view. Because the SEABAT displays static and moving objects dynamically in real-time, the sonar head can be set on a pan and tilt mount, as you would a video camera, to follow an area of interest while maintaining orientation. This is particularly useful when monitoring installation or positioning procedures in visibility that precludes the use of video.

The 6012 has a maximum usable range of 200 m and a minimum set range of 2.5 m. The speed of update is controlled by the range selected and is dependent on the speed of sound through water. For example, at ranges from 2.5 to 25 m, the update is 30 times per second. The image displayed is optically correct, with the objects viewed appearing without dimensional distortion. This remains the case regardless of the speed of movement of the supporting platform or the object being viewed. The SEABAT 6012 has been operated satisfactorily at towed speeds of up to 10 kt.

### **Marconi UDI (Aberdeen)**

Marconi UDI [now Fugro UDI Limited] is a relatively small company focused on the development and application of sonar systems. The company has a strong focus on the development of acoustic transducers, and has expanded that focus into different projects. Marconi has a modular building block concept where the company packages standard blocks of transducers into large arrays. The following summaries describe some of the systems discussed.

**Sonavision 4000.** Sonavision 4000 is the first commercial high frequency scanning sonar to use UDI's newly developed composite array technology. The use of these arrays results in a wider bandwidth and much greater efficiency in the conversion of electrical energy into mechanical energy.

The Sonavision 4000 transmitter and receiver electronics are fully tunable via software from 150 kHz to 1.5 MHz. Therefore various beam angles and frequencies are available, that is, 1 MHz profile and 2,000 kHz long range search. See Table 6.7 for specifications.

In one application, the standard Sonavision 4000 sonar product was modified to take a 1.2° 500 kHz sonar array. The computer graphics card in the display system was modified to store up to 10 sonar pictures and the OS9-based control software was adjusted accordingly. Software was also supplied for personal computer control of the sonar system, enabling the operator to store sonar images to disc.

*1-3 Connectivity Piezoelectric Materials for High Frequency Sonar.* UDI and Strathclyde University have spent three years developing new materials for sonar applications. In brief, the material consists of piezoelectric ceramic pillars embedded in a polymer matrix. In general, the combination of long, tall ceramic pillars and polymer materials enhances the electromechanical conversion efficiency and reduces the acoustic impedance to provide a better match to water. The results have enabled phased arrays to be manufactured at a fraction of their price, and for special sonar transducers to be supplied at little additional cost to clients.

**Table 6.7**  
**Specifications of Sonavision 4000 at 500 kHz**

Transmit	27° vertical x 2.1° horizontal
Receive	27° vertical x 3.0° horizontal
M.D.S.	72 db
Source Level	210 db re 1 micropascal at 1 m
Pulse Length	100 $\mu$ sec
Bandwidth	10 kHz
Scan Rates (Menu Selectable)	Slow, normal, fast, super fast

*Cavitation Cleaning Sonar.* UDI built a technical demonstrator sonar consisting of a 400 mm diameter multi-ring 270-element phased array, and racks of 45 power amplifiers. The system was designed to produce a focused beam capable of cavitating a small volume of water. The cavitation effect can be used to clean rust off metals. Investigations are underway into its capabilities against marine growth.

**Mirror Sonar.** The company participated in the design and manufacture of the arrays and subsea electronics for a low cost mirror sonar. High frequency multi-element sonar receive and transmit arrays were designed and built into a focused acoustic mirror housing. Electronics from UDI's modular sonar designs were incorporated to provide a 24-channel sonar system.

**Modular Arrays.** UDI has developed a modular construction technique for a sonar phased array. Using this technique, 8 array modules of 16 elements each were mounted onto a frame, producing a 128 element array. Electronic pods containing power amplifiers and preamplifiers were also delivered. Electronics costs were kept to a minimum by using UDI standard sonar building blocks that use surface mount devices.

### **Marconi Underwater Systems (Watadooille)**

In conjunction with its product development, Marconi Underwater Systems has developed acoustic systems. During the visit of the WTEC team, a few of those applications were discussed briefly, as summarized below.

**Communication Between Divers and Between Diver and Surface.** A sealed divers electronic module (DEM) has been designed for use down to 100 m. Divers using gloves can carry out simple battery changes. Communication is achieved using high frequency acoustic waves transmitted through water between acoustic transducers attached to the DEMs. Each DEM uses a single sideband, a suppressed carrier, transmitters, and receivers.

A two-way simplex communication is available; each transmission is preceded by a short tone-burst. The operation of the press-to-talk (PTT) switch causes the changeover from receive to transmit. To enable diver-to-surface communication, an adaptive headset is used for the surface operator, while the diver uses bone conduction earphones and microphones.

A minimum effective distance of 1 km can be achieved when the DEM is selected at long range. A facility exists to reduce the effective range to short range (less than 100 m), depending on prevailing propagation conditions for use in complex missions. Any number of divers can be involved with the controlling surface station.

**A Hull Mounted High Definition Scanning Sonar for Surveying Inshore Coastal Waters.** The transmitting and receiving arrays assembled within the sonar head are mounted beneath the vessel. The scanned sector can be depressed to any angle from the horizontal and can be rotated to any position in azimuth, in either the vertical or horizontal mode.



The sonar head is mounted on a dynamic, stable platform that relates the beam to a fixed spatial reference independent of roll, pitch, and yaw by the vessel. The 60° insonified sector is scanned electronically by a very narrow beam to generate a high definition video image. Each echoed pulse represents angle and range data for processing by the computer. The received echoes are digitized and subjected to modern image processing techniques. These enhance the composite video and eliminate flicker. Performance has been demonstrated up to speeds of 10 kt and sea state 4.

The Mark II Hydrossearch outputs standard CCIR TV format. This permits the use of a wide range of devices, such as TV monitors, line scan recorders, video recorders, and output printers.

*Bathyscan Swath Echo Sounding System.* Bathyscan is a 100/300 kHz swath echo sounder based on the principle of acoustic interferometry. In the 100 kHz mode the system will operate in continental shelf water depths and can map a swath up to 500 m wide, while at 300 kHz it offers high resolution surveys in rivers, harbors, and estuaries.

*Advanced Models of Sound Propagation in the Ocean.* Marconi Underwater Systems is engaged in research on the propagation of sound in the oceans in order to further develop the company's knowledge of the complex underwater environment. Computer models of sound propagation play an important part in this research and allow the user to predict the distribution of sound intensity given prior knowledge of the physical properties of the ocean, such as its sound speed profile.

#### **IFREMER (Toulon, France)**

IFREMER, a French government agency with scientific, industrial, and commercial roles, directs, funds, and promotes ocean research and development. The agency often develops system concepts, then works with industry to build the system and evaluate its operation. The Toulon facility is focused on the operation of many of the developed systems. The Brest facility, however, has established an acoustics development laboratory. The following applications were mentioned, although few details were gathered during this visit: (1) acoustic data transmission; (2) acoustic determination of seabed characteristics; (3) development of very low frequency transducers; and (4) array processing (acoustic tomography).

Further information is readily available by contacting the Brest laboratory.

## SUMMARY OF SYSTEMS AND APPLICATIONS

Tables 6.8 and 6.9 summarize the information gathered during the visits. Table 6.8 summarizes the organizations working on or developing specific acoustic systems. It is not felt to be a complete representation of the institutes, but rather a reflection of the information discussed during the WTEC visits. Table 6.9 also summarizes the results of those discussions in terms of the specific application areas considered at the institutes. The users defined in the tables are those implied by the researchers during the visits.

### Trends

As with any effort such as this, there are undoubtedly omissions and mistakes, especially when the data obtained during the site visits was far from complete. It is possible, however, to draw some conclusions regarding perceptions of trends in technology and the interests of the organizations visited.

Ecological and environmental applications are a primary area under consideration for applying existing and new technology. Current awareness and concern for environmental issues in Russia and Ukraine was apparent in several visits. The environment is seen as an area where existing technology can solve some problems that exist there. Water quality, noise pollution, acceptable standards for the impact of technology and industry on the environment, and a number of other issues were discussed.

*Low Cost Systems.* It was clear during the discussions in both the FSU and in Western Europe that the cost of technology was a factor to be considered in future applications. The low cost sonar systems offered by Tritech were of interest to all. The technology has advanced to a point where new techniques and hardware promise significant capability at a far lower cost than has been the case for existing sonar systems and other acoustic equipment. In Russia and Ukraine there was a clear sensitivity to price and its importance to Western markets. Actual costing of possible systems to be produced in the FSU seemed nonexistent. The proposed price of a system seemed to be an arbitrary figure somehow related to the current pricing structure outside of the FSU. Nevertheless, the cost of a system was recognized as of primary concern. In Europe, the Marconi ODAS system development efforts focus on a low price tag.

*Long Endurance.* As is shown in the previous tables, some transponder systems have quoted endurance of multiple years. In some of the institutes visited, projects were directed at increasing the endurance of other autonomous instrumentation. In Europe, the Autosub program seeks 7,000 km transits; the French have focused some of their work on long range systems. Endurance is an important design consideration for acoustic transponders and other instrumentation under development.

**Table 6.8**  
**A Summary of Application Focus and User Community**

<b>SYSTEM</b>	<b>USES / USER COMMUNITY</b>	<b>ORGANIZATIONS INVOLVED</b>
Acoustic Arrays	Oil and Gas Science Maritime	Shir, IAP, Kor*
Transponders	Instrumentation Various Applications	And, Shir, Kor, BuO
Transducers	Instrumentation Various Applications	Shir, Kor, UDI, IFRE, Pel, (Kiev?)
Sonar Imaging Systems	Oil and Gas Medical Seabed Characterization	And, NII, Kor, HW, TriT, Res, UDI, Marc
Communication Systems	Maritime Oil and Gas	GPI, And, Kor, HW, Marc, IFRE
Position / Navigation	Maritime	And, Shir, St.PU, BuO, HW, Kor
Parametric Sonar	Oil and Gas Science	And
Acoustic Releases	Science	Shir, BuO
Acoustic Current Meters	Oceanographic Community	MHI, Kor
ADCP Systems	Science - Oceanographic Research Maritime	IAP

\* Kor = Oceanpribor (Korvet Oceanpribor)

**Higher Resolution.** Several institutions focused on higher resolution acoustic information. In Europe, interest in higher resolution sonar imaging systems is very visible. At Strathclyde University, MTD is funding an effort to develop more accurate position data for undersea tasks. In Russia and Ukraine, the term "super resolution" acoustic data was emphasized. Improvements to existing technology are clearly focused on increasing the resolution of acoustic systems either with new hardware techniques or with advanced sonar signal processing and high-speed algorithms.

**Efficient Sonar Signal Processing.** Computer hardware available to researchers in Russia and Ukraine has been limited. Researchers have had to understand clearly the problems they encountered, adjusting their techniques to optimize the processing that had to be accomplished. This has led to development of new methods for processing acoustic data that seem to be more efficient than those in the United States and other countries.

**Table 8.9**  
**A Summary of Organizations Involved in System Design**

<b>APPLICATIONS</b>	<b>USER FOCUS</b>	<b>ORGANIZATIONS INVOLVED</b>
Array Processing	Fisheries Government Maritime Science	IAP, NII, Ros, INFRAD, GPI, Kor
Environmental Monitoring	Environment	And, IAP
Ocean Acoustic Studies	Environment	And, Shir, IAP, NII, GPI, Kor
Matched Field Processing	Various	And, (others?)
Seismic Data Acquisition	Oil and Gas	GEO
Sonar Simulation	Oil and Gas Maritime Science	Shir, HW, Kor
Holography	Materials Sediment Class Communications	And, GPI
Tomography	Science	And, IFRE, GPI, Shir
Sonar Image Processing	Various	And, HW, Shir, Kor
Marine Mammals Research	Research	And, Shir
Physical Oceanography	Science	MHI
Sediment Analysis	Environment Oil and Gas Maritime	And, IFRE, Kor

## **FINDINGS AND OBSERVATIONS**

Although all of the objectives of the site visit were not met, many insights were gleaned from the visits and the discussions, as summarized below.

### **Relative Level of Technology**

In Western Europe the technology developments are very similar to those efforts in the United States. Some of the sonar imaging systems are more interesting than similar units manufactured in the United States due to price/performance issues. However, the situation is different in Russia and Ukraine.

***Understanding of Basic Theory.*** The researchers participating in the discussions were clearly aware of the basic principles of the technology with which they were involved. The limitation of computer capability and the need for efficient problem solutions may have forced this need for in-depth basic understanding. The situation in the United States is clearly different, where computer capability and the cost of people may force development to proceed along different lines, where an engineering solution may be more important than reaching a total understanding of all aspects of a problem.

***Application Ideas.*** New applications are under consideration by researchers in Russia and Ukraine. Some of these ideas had not been considered in the United States, at least within the circles represented by the members of the WTEC team. It may well be that the new freedom to consider research directions has allowed researchers to consider novel applications of technology. It may also be that having to compete in a world marketplace demands new products and ideas.

***Implementation Software and Implementation Hardware.*** Research in Russia and Ukraine has been undertaken in an environment with limited computer hardware capability. However, this limitation has probably resulted in an emphasis on efficient algorithms and highly capable microprogramming in the development of Russian software.

***Maturity of Applications.*** Although Russia and Ukraine have explored applications of technology that are interesting and novel, the actual maturity of those applications is not clear. Many of the technological concepts discussed were in their conceptual stages only. With limited financial resources, it is unclear just how many of those applications will come to fruition.

***Infrastructure.*** The changes in the FSU have had a strong impact on the technology infrastructure. Communications among various groups is unclear. Also, the method for moving from concept to final prototype was controlled very completely in the past; the resources needed to accomplish a development effort were planned and in place. It seems that this is no longer the case. It will take time for a new infrastructure to evolve in the present environment.

### **Perceived Needs**

A number of factors impacting technology development in the FSU were apparent during the WTEC team's visits and discussions in Russia and Ukraine. These are not necessarily related to technology development, but are rather important to the process used to develop technology. The following sections identify some of those issues.

***Publishing in Professional Journals.*** It was clear from discussions with the WTEC team's hosts in Russia and Ukraine that technologists there do not understand how to publish their work in professional journals, or which journals best suit their interests and technological focus. Many researchers in the FSU realize that they should publish their work to make the results of their efforts more widely known. There has been little need in the past to do this since their efforts were part of a coordinated plan. It is far more important now, and there is much interest in doing so.

***Acquire Better Computer Hardware.*** There is a limited amount of computer capability for implementing new ideas. The need for more capable computer systems hardware is clear. Access to that hardware by a larger group of individual researchers would have a profound effect on technological developments in the FSU.

***Establish Better Communication Channels.*** Discussions at specific institutes often referred to cooperative efforts outside of the organization. There seemed, however, to be little substantive communication between many of the people working on a specific project and outside researchers. It has been suggested that there was little need for this in the past. Recent changes make the need for this far more important. How this evolves and at what level communication channels are put in place will directly affect future technological developments. The Russian and Ukrainian technical communities are being heavily affected by the dynamics of ongoing change. Effective communication will temper the impact of that change.

***Better Understand How To Do Business With the West.*** The Western countries represent a marketplace for the technological capabilities that exist in Russia and Ukraine. Many of the acoustic applications mentioned in the discussions would most definitely be of interest to potential users in the United States and other countries. How business is conducted in these countries and the factors that guide business decisions are not well understood in the FSU. This lack of understanding must be dealt with if products, application concepts, and technical capability are to be marketed in the Western countries.

***Better Understand Technology Outside of the FSU.*** In some of the institutions, it was clear that individuals were aware of technical developments in the United States and other countries. For the most part, however, the current level of technology existing outside the FSU was not well understood. Much of this undoubtedly lies in the fact that access to professional journals and individual contacts is limited. As this understanding increases, the level of technological development will be more clearly understood.

## **SUMMARY AND CONCLUSIONS**

It is impossible to understand just what the most important results of this visit were. There were a number of applications of acoustic technology that were both exciting to consider and important to advancing the state of the art in this field. Due to limited time, it was not possible to truly understand the technical accomplishments of the technologists. Yet, their ideas were intriguing and their concepts novel. More should be done to fully understand many of these efforts.

One question that surfaced repeatedly was how far specific applications had been taken. It was not clear, at times, whether a discussion was of a concept not yet moved to hardware; a concept for which a prototype had been developed; a concept that had been evaluated in a real world setting; or a concept that had already advanced to a product.

It was also unclear, at times, what the future held for specific applications that were being discussed. With limited resources and a very dynamic environment, the future of an idea is uncertain. Many of the applications discussed could well be moved into viable products readily sought after in the world marketplace. Whether they will reach the marketplace is not clear.

It was recognized by many members of the WTEC team that solutions to technological problems had been implemented on computer hardware of limited capability. Emphasis was placed on efficient algorithms and clearly understanding the principles of the problem. Many in the West can remember how their first efforts at applying microcomputers to instrumentation forced the use of machine languages and complex interface programming. This is not unlike what seems to be the norm in the FSU. The benefit of this has been that technologists in the FSU developed unique solutions to complex programming problems.

There is a genuine desire for cooperation and collaboration. On one hand, this is obvious since funding and equipment resources are lacking. More importantly, however, is the perception that technologists in Russia and Ukraine truly believe that cooperation and collaboration will bring new insights and further advance their technological interests. The individuals involved in the visits were very talented technical people. Much would be benefitted by the synergism that results from true cooperation.

An interesting factor recognized during many discussions was that the current environment in Russia and Ukraine allows technologists the freedom to choose their own research directions. This has not been possible in the past since resources were directed at specific projects planned outside of the various institutions. It is clear that this change will allow researchers to consider new directions not possible in the past.

One recommendation that should be made results from the WTEC team's unanimous agreement that the time available for the visits did not allow for in-depth discussions. This was probably inevitable for this first series of visits, but should, most certainly, be corrected during future visits. There is much to learn in the FSU regarding acoustic applications. Learning is always a slow process that follows a less than straightforward path. Future visits should allow time for technical discussions with the actual professionals involved in moving applications from concept to reality.



## CHAPTER 7

# SYSTEMS ENGINEERING AND INTEGRATION

Larry L. Gentry

### INTRODUCTION

Systems engineering and integration (SE&I) is the discipline that brings together technologies and hardware/software into an efficient product to satisfy operational needs. As such, it is an appropriate wrap-up of the foregoing chapters that have described the state of practice relating to underwater vehicles (UVs) and related subsystems and technologies. For the following discussion, SE&I is separated into four main topics that describe the process from emerging technologies through development of the overall system and finally to mission operations. In each of these topics the methodology and general state of practice are described where they could be observed, and unique features are presented. Where possible, comparisons and contrasts are drawn between the approaches employed in Western Europe, the former Soviet Union (FSU) and the United States. Value judgements of "better" or "best" are not appropriate in this comparison since both the West and the countries of the FSU have been successful in meeting their objectives in the development of subsea systems and technologies.

Numerous factors have conspired to limit the validity and scope of the team's understanding of how SE&I is practiced at the many locations visited. This is particularly the case in Russia and Ukraine, but is also true to a lesser degree in Western Europe. These factors include the lack of time at each site; the lack of common understanding of SE&I; the necessity for splitting into teams, so that the author of each topic in this report had to rely on data acquired by others on the panel; and the unevenness of the visits. Some of the visits focused on real hardware and others on general discussions. Some meetings were strongly orchestrated by

the hosts, with little freedom for interchange. This was not due to the hosts' lack of openness as much as their uncertainty about the team's interests and the language barriers. The result is that very often perceptions were obtained, rather than solid evidence and facts. Consequently, the following discussions are more a starting point than a closed set of conclusions.

### **The Role of System Integration**

SE&I is a somewhat arcane engineering discipline, but is one that is critical to the successful operation of any system comprised of multiple and interdependent subsystems and functions. It is practiced in different ways and on different levels by each developer of UVs and related technologies. In some cases the UV systems are sufficiently simple that SE&I is almost an unconscious part of the design, fabrication, and test process. In more complex systems, where larger teams of engineers are required and a broad range of advanced technologies are employed, the process is more formal and rigorous and often requires a separate systems engineering organization. In all cases it is the process that defines and controls the various technologies and disciplines that are required, and the interfaces that enable the subsystems and functions to work effectively together. Ultimately, the SE&I process must identify and resolve all conflicts and interferences that might otherwise render the system ineffective.

### **The Importance of System Integration**

SE&I, which has evolved primarily in the United States, has become an important part of the development process. This is especially the case in projects conducted by and for the U.S. Government, although SE&I is pervasive in the marine and offshore industries. Part of the reason SE&I has become a major emphasis in the United States is due to the following:

- o A desire to perform more complicated underwater tasks
- o An increased consciousness of the inherent personnel risks involved in the subsea environment, and a consequent trend toward unmanned systems
- o Increased cost of insurance and litigation
- o Significantly increased labor and material costs
- o A preoccupation with high technology and a desire to include the very latest and very best in each new system

The result has been something of a "Catch 22." As the United States moves toward unmanned and more complicated operations, there is an attendant increase in hardware and software complexity and thus development and maintenance costs. This, in turn, fuels the search for more efficiency in the UV systems and the processes by which they are developed. The result is a spiralling of high

technology, increased costs, and time-consuming engineering refinement and optimization. It is not uncommon for development of a new UV to cost from tens to even hundreds of millions of dollars, and to take four years or more to make it ready for operations. In some cases, due to rapidly changing economics, politics, and technologies, the need for the system and/or the technology base may be obsolete before the system is ready for use. SE&I has become one of the main ways of seeking improved development efficiency and lowered costs.

Early on, the WTEC panel decided that to obtain an end-to-end perspective of underwater vehicle capabilities, SE&I had to be included in the technology evaluations of Europe, Russia, and Ukraine. The topic is divided into four phases of SE&I: technology evolution, system design and development, assembly and test, and field test. The following sections describe the methodologies and provide an assessment of the tools and support systems that are available.

## **TECHNOLOGY EVOLUTION**

In the West, the impetus for advanced research and development in undersea technologies has come from a mixture of the military, industry, and science sectors. The military sector has most often been the initiating source, with industry and academia adopting and refining the resulting advances for lower-cost applications in commerce and research. This is very much the same in Western Europe, although the strength of the North Sea oil and gas industry has resulted in the commercial sector being a stronger initiator of new technologies than is the case in the United States. In the FSU, however, the federal funding process was slanted heavily toward military needs; only recently has the process of conversion to the civil and research sectors begun in earnest. This process has been made extremely difficult by the breakup of the Soviet Union and by the numerous and often competitive institutes that are in place. The Soviet Academy of Science no longer exists; smaller academies of science and independent research institutes within each country of the FSU are now forced to compete for funding and direction from other sources. It should be noted that numerous and very capable test facilities developed under the Soviet government are still available in many of the institutes for use by entities outside the FSU. Table 7.1 lists and summarizes the primary activities of the basic and applied research institutes that the team visited in Western Europe, Russia, and Ukraine. (For detailed descriptions, see the site reports in Appendices B through F.)

### **The European Programs**

As mentioned earlier, Europe employs the same basic approach and tools as does the United States for advanced research and development. Work stations and high capacity computational systems allow a heavy emphasis on analysis and simulation, and a concerted effort to develop autonomous systems and smart sensors (see LIFIA

**Table 7.1**  
**Summary of R&D Sites Visited in Western Europe, Russia, and Ukraine**

SITE/LOCATION	TYPE OF RESEARCH
<b>Europe</b>	
Heriot-Watt University / Edinburgh, Scotland	Robotics, acoustics, and vehicle automation. Participant in MAST and SERC programs
LAFIA / France	Artificial intelligence, robotics, and active vision systems. Support IPREMER vehicle systems development
INRIA / France	UV guidance and control architecture R&D. Support IPREMER vehicle systems development
Inst. of Oceanographic Science (Deacon Labs) / England	Deep water oceanography and general marine science. Member of MAST programs and lead in Autosub project
<b>Russia</b>	
Andreev Institute / Moscow	Ocean sound propagation; nonlinear acoustics; U/W communications and acoustic signal processing
Bauman Institute (MSTU) / Moscow	Propulsion systems; robotics; gas dynamic energy systems
General Physics Inst. / Moscow	Hydrophysics; nonequilibrium microfluidics; nonacoustic ASW; laser and low frequency acoustics for communications and physical oceanography
Inst. of Applied Physics / Nizhny Novgorod	Oceanography and ocean modelling; acoustic and nonacoustic ASW; low frequency acoustics; radar and laser systems
P.P. Sheshov Inst. of Oceanology / Moscow	Oceanological R&D in biology, geology, hydrophysics, hydroacoustics, and ocean instrumentation
St. Petersburg State Univ. of Ocean Engng. / St. Petersburg	Vehicle guidance, control and navigation; hydroacoustics and U/W communications; robotics
Oceangribor / St. Petersburg	Sonar systems; research and signal processing; real-time information systems; applied hydroacoustics
Scientific Research Inst. of Computer Complexes (NIVE) / Moscow	Semiconductor and computer architectures; computer Algorithm development; acoustic field modelling and signal processing algorithms
<b>Ukraine</b>	
E.O. Paton Welding Inst. / Kiev	Metallurgy and welding R&D; nonmetallic materials development (composites, ceramics); U/W welding
Inst. of Geological Science / Kiev	Geology and geomorphology studies of worldwide seabeds; biological and geological interaction
Inst. of Hydromechanics / Kiev	Hydrodynamic and fluid flow processes; wave loads and motions; hydroacoustics; high velocity U/W projectiles
Marine Hydrophysical Inst. / Sevastopol	Full range of oceanology for deep oceans, shelves and coastal zones; ocean-atmospheric interaction; optical and acoustic systems

and Heriot-Watt University site reports in Appendices D and E, respectively). One strong point in the European programs is their ability to focus advanced research across a number of countries. This has been accomplished through the Marine Science and Technology (MAST) programs, which have established European joint research objectives and funded cooperative activities at institutes and organizations in each country. MAST II, a ten-year program in oceanographic research and development, funds and/or links together such programs as AMADEUS and Autosub in the U.K. and others across Europe. These programs will develop technologies, sensors, and underwater vehicles to do work and research in the deep ocean as well as in shallow, near-shore areas (see Heriot-Watt University, INRIA, IFREMER, and Deacon Laboratory site reports in Appendices D and E). The U.S. programs, by comparison, are more independent, with each research and development entity setting its own objectives and seeking separate funding. In this time of limited funding in the United States, an approach like that of MAST may be helpful in achieving national objectives for ocean research and development.

### **Russian and Ukrainian Programs**

Since the collapse of the Soviet Union, each state in the Confederation of Independent States (CIS) independently conducts its own programs in undersea technology. The WTEC team visited only Russia and Ukraine, but found many similarities in how their scientists conduct research and development for advanced marine and undersea technology. Research and development in Russia and Ukraine are characterized by strong theoretical work. The fundamental processes and mathematical models are well understood and emphasized. On the other hand, the lack of high capacity computational platforms limits the analytical work necessary to validate the theory. Hence simulation and analysis are performed at a level that can be supported on IBM or equivalent PCs (see Andreev Institute and Dubna site reports in Appendix B). IBM 386 and, very recently, a few 486 machines were the only computers observed or mentioned at the various institutes; in fact, the need for better computers and software was frequently mentioned. The result seems to be that research and development is taken to the laboratory and the field much sooner than is generally the case in the West. Thus, much of the scientific verification is done empirically.

Under the previous Soviet system, the relatively low cost of labor and materials compared to the West led to a proliferation of very capable and often similar test facilities throughout the Academy of Science organizations. The low labor costs also resulted in large staffs of qualified scientists at many of the institutions. Populations ranging from 5,000 to 25,000 people have not been uncommon in the past. Presently, however, large reductions in the numbers of scientists and support personnel are occurring at most of the institutions due to lack of funding. Unless funding is acquired soon, the extensive science capabilities in both facilities and people will be lost. It has been said that major reductions in the CIS military R&D sector are

inevitable, and the amount of collaborative use or direct aid the West can provide to prevent this from occurring is insignificant. All institutes will reduce in size and scope, and only the best will survive.

One other general observation is that much of the R&D that the WTEC team observed was of an applied nature. This is most likely due to the fact that it was largely intended for military and defense purposes. Since funding and direction were entirely from the Soviet government, it is not surprising that the research activities observed had an applied flavor rather than one of pure science. This applied emphasis has a beneficial effect in that many of the institutes seem to be involved not only in science but also in the engineering, manufacturing, and testing of the resulting systems. This close coupling allows underwater vehicle systems and research requirements to be well focused and integrated, in contrast to situations in the United States, where there is sometimes a conscious effort to decouple the research and engineering disciplines.

### Technology Developments of Interest

A few of the sites visited by the panel had ongoing technology activities that were unique and worthy of special comment.

- The Institute of Applied Physics at Nizhny Novgorod conducts R&D in acoustic and nonacoustic ASW (see Institute of Applied Physics site report in Appendix B). Scientists there have two test tanks that permit investigation of two-layer, stratified fluid systems. The layers have separate thermal and circulation controls plus wind and wave-making capability. Tow carriages allow for experimentation with moving bodies at different depths to measure remote detectability via surface and internal wave effects.
- The Institute of Hydromechanics at Kiev, Ukraine, has conducted unique work in high velocity underwater projectiles (see Institute of Hydromechanics site report in Appendix C). Experimental results in small, explosively launched projectiles (see Figure 7.1) have been obtained for velocities in excess of 1,000 m/sec. Theoretical research has been completed for velocities approaching Mach 2 (2,700 m/sec). The projectiles, due to shape and a surrounding cavitation field, exhibit very low drag (less than the projectile would experience at the same velocity in air).
- At the Scientific Institute of Computer Complexes in Moscow, research has been conducted in advanced acoustic propagation modeling and signal processing (see Scientific Research Institute of Computer Complexes site report in Appendix B). A family of supercomputers has been developed at this institute over the past thirty years in support of the Soviet missile defense system. These same computers have been creatively applied to both radar and sonar system research.



**Figure 7.1. High Velocity Test Chamber (top), Projectiles (middle), Projectiles in Water Cavities (bottom)**

- o Paton Welding Institute in Kiev conducts basic research in materials and welding technologies for military and civil applications (see E.O. Paton Electric site report in Appendix C). Although the WPAIC team saw little of the institute's actual work, Paton claimed to be doing advanced materials and welding research in titanium, ceramics, and composites. The institute's representatives talked of having perfected a technique for welding ceramics to metals. The institute has an ongoing program of research in underwater welding, using a flux core wire in a gaseous environment. This was demonstrated by both divers and automated equipment in Paton's test facilities.

## SYSTEM DESIGN AND DEVELOPMENT

Many of the engineering and fabrication sites visited are also involved in applied research in support of their products (see Table 7.2). In Europe as in the United States, an infrastructure of small entrepreneurial companies is engaged in the development of components for underwater vehicles. This is the result of our free enterprise society. In Russia and Ukraine this infrastructure is lacking, although the beginnings can be found in groups that have separated from the traditional institutions and now offer products and services that used to be totally controlled by the state. As these fledgling commercial companies mature and learn to market and price for the rest of the world, there probably will be a move by industry and academia toward the structure present in the West. The Academy of Science and its institutes will do science, and industry will deliver product. However, at present the institutes are still the primary force in Russia and Ukraine in deciding what direction the marine industry will take.

### Europe

The sites visited were well equipped with state-of-the-art engineering tools. CAD systems and integrated analytical codes are used on workstations. Workstation software development environments such as VXworks are commonplace, and implement advanced algorithms and modern code for simulating systems and components. In short, the engineering and manufacturing work places and processes are much like in the United States.

In the United Kingdom, the Marine Technology Directorate (see Marine Technology Directorate site report in Appendix E) plays a unique role in funding and coordinating development of new technologies for underwater vehicles. A number of small companies and universities are supported in this manner to produce needed advances in acoustic and video sensors, automation and robotics, and other technologies. The end objective is to integrate and test these UV elements into operating systems. In France (see IFREMER site report in Appendix D), IFREMER plays a government role, funding and coordinating research and development at five different centers, and integrating the products into useful UVs.



**Table 7.2**  
**Summary of Engineering Sites Visited in Europe, Russia, and Ukraine**

SITE / LOCATION	PRODUCTS AND APPLIED RESEARCH
<b>Europe</b>	
Camera Alive / Scotland	U/W high resolution digital array stereo video systems and signal processing for ROVs
IFREMER Research Inst. / France	ROV/AUV development programs; coordinate research at other institutes in France (e.g., LIFIA, INRIA)
Marconi Underwater Systems / England	Develop, integrate, and operate small (torpedo-size) AUVs (i.e., ODAS); defense and commercial contractor
Mobil North Sea Ltd. / Scotland	Oil and gas exploration and production; fund and direct ROV technology development for subsea operations
Rauma Oceanics Ltd. / Finland	Shipbuilding and research; built <i>Mir</i> submarines for Russia
Reson Systems Ltd. / Scotland	Develop SEABAT sonars; acoustic transducers and arrays
Slingsby Engineering Ltd. / England	Develop and integrate commercial ROVs for the oil industry; develop manipulators and ROV components
Tritech International / Scotland	Develop low-cost scanning sonars for ROVs
UDI / Scotland	Build high resolution mechanical sonars for ROVs
<b>Russia</b>	
Bureau of Oceanological Engineering / Moscow	Design and produce UVs – primarily submarines (i.e., <i>Argus</i> , <i>Osmotr</i> , and <i>Rif</i> )
Dubna International Centre of R&D (TECHNOPOLE) / Dubna	Acoustic communications, seismic systems, and acoustic tomography
Energia Space Firm / Moscow	Space agency; develop manned spacecraft; advanced controls, communication, and energy systems (fuel cells)
Kharax / St. Petersburg	Design, build, and operate submarines; tourist submarines
Krylov Shipbuilding Inst. / St. Petersburg	Hull form design for surface ships and related technologies; submarine pressure vessels; structural design
RRC Kurchatov Inst. / Moscow	Design and fabrication of nuclear reactors for marine applications. ROSSHELF is latest project
Lasarit Central Design Bureau / Nizhny Novgorod	Design and fabricate submarines; fabricator for ROSSHELF
Malachite Central Design Bureau / St. Petersburg	Design and fabricate submarines. Manned submarine ( <i>Tetis-H</i> , <i>Rus</i> , and tourist submarines)
NIIVK Computer Research Inst. / Moscow	Design and build advanced computer systems for defense applications. Produced Russian supercomputers
Oceanpribor / St. Petersburg	Acoustic systems; communications; sonars and systems; seismic devices; passive antenna arrays; navigation and positioning systems, XBTs
Rubin Central Design Bureau / St. Petersburg	Design and fabricate submarines. <i>Typhoon</i> , <i>Oscar</i> , and <i>Mike</i> ; tourist submarines

## Russia and Ukraine

The WTEC team saw little of the engineering spaces in Russia and Ukraine. As a result, the team obtained little direct evidence of how the engineers work and what software and hardware design tools are available. However, much of the engineering is done manually. The computer support is exclusively on PCs; more than once, CAD and analytical software were mentioned as the most needed engineering tools (see Malachite Central Design Bureau site report in Appendix B). The engineering exhibited in the manned submersibles observed at Sevastopol (see Mariacoprom site report in Appendix B) also supports the conclusion that engineering in these two countries is basic but adequate. Optimization and aesthetics were obviously not important in the engineering approach. Structurally the submersibles were clearly over-designed rather than over-analyzed. Rather than minimizing weight through endless engineering, displacement is added and the size is accepted as a reasonable penalty. The most rudimentary manual controls are used instead of computer controlled systems. No navigation sensors were found, although obstacle avoidance sonars were used. Observation is by eyeball through view ports rather than by using external video systems. Even the latest of the submersibles, the *Omar* (1990) and *Langust* (1999), exhibited the same engineering and construction techniques. The philosophy seems to be to stay with what works and not to change unless necessary. This philosophy can also be detected from the lack of unmanned vehicles. Manned vehicles have accomplished what is required and the additional complexity of unmanned systems has been eschewed. The result is large and unsophisticated submersibles that are reliable and easy to maintain.

These submersibles are being offered for lease at low cost to users in the West, and may be an attractive alternative to vehicles presently used for science. A few problems, however, will have to be overcome. Certification of these submersibles for manned occupancy will not be easy. Previously produced vehicles are typically difficult to certify after the fact. Insurance and litigation concerns for uncertified vehicles will limit the value to Western industry and academia. Vehicles that are now in development, such as the *Rif* submersibles, are being coordinated with certification agencies such as Lloyds of London, DNV, or ABS. This level of certification will be acceptable to industry and academia but probably not to the U.S. Navy. One additional problem is the maturity of unmanned vehicles in the West. Years ago Western industry moved away from manned vehicles to ROVs, and the support infrastructure is well entrenched. It is unlikely that the oil industry, the biggest user of ROVs, will change to manned systems at this juncture.

## FACTORY INTEGRATION AND TEST

Testing plays a very important role in the integration of underwater vehicles and technologies before delivery for operational use. Both European and FSU

developers stress a bottoms up factory test approach that tests components, subsystems, and finally complete systems. European developers that the WTEC team visited employ test methods very similar to those used in the United States. Russia and Ukraine differ from the United States only in the sophistication of test equipment in use. In the West, simulation testing is often used as an overall final factory acceptance test. It couples environmental and mission simulation modules with system hardware and man in the loop to perform end-to-end functional acceptance tests. Simulation testing is most often performed dry, but can also be done in suitable wet tanks or pressure chambers, if available. Automated test equipment (ATE) is used extensively in the West, and provides a preprogrammed, computer-controlled capability for high volume test sequences such as life cycle testing and production testing of complicated electronic equipment. Simulation and automatic testing require more capable computer assets than are generally available to most developers in the FSU, hence, the lack of this kind of test activity was anticipated. One exception was at Krylov, where advanced automated test facilities were observed. In general, very capable test facilities are available in both Europe and the FSU for the type of applications and vehicles that are in use. Tables 7.3a and 7.3b summarize the test activities and facilities that were observed or described to the panel. Some of the more unique facilities are discussed in the following paragraphs.

## **Europe**

In both the United Kingdom and France there are very capable physical and functional test facilities in use. Simulation laboratories and automated test equipment were observed (see Heriot-Watt University, LIFIA, and Marine Technology Directorate site reports in Appendices D and E); they are used to test systems and components for underwater vehicles.

Pressure chambers of various sizes and depth capabilities are available in Europe. The most impressive was found at Slingsby Engineering Ltd. Slingsby has a 3 m diameter horizontal chamber (see Figure 7.2) with a unique, half-cylinder support carriage that allows for entry of test articles nearly the size of the full diameter of the chamber. In this manner, the company can functionally test even its largest ROVs to depths of 7,500 feet. Large chambers capable of testing complete vehicles to full ocean depth (6,000 m or more) were not found, but may be available at other locations. Handouts at Rauma Oceanics in Finland listed a reasonably large (2.5 m diameter) chamber good to 7,500 m, but the team was not allowed to tour any of the company's facilities.

**Table 7.3a**  
**Test Facilities Observed or Available in Europe, Russia, and Ukraine (1)**

ITEM	DESCRIPTION	CHARACTERISTIC	UNIQUE FEATURES	STATUS
<b>MARCOINI UNDERWATER SYSTEMS, LTD; England</b>				
1	Vehicle Test Facility	Automated Test Equipment for Small Vehicles	Torpedo Production and Component Test Equipment in Use for Commercial UVs (e.g., ODAS)	Operational
2	Pressure Chamber			
<b>INSTITUTE OF OCEANOGRAPHIC SCIENCES; England</b>				
1.	Pressure Test Chbr (2)	6,000 m Depth	Component Testing and Field Compression Measurement	Operational
2.	Propeller Test	Dynamometer at Depth	Measure Thrust at Depth	
<b>SLINGBY ENGINEERING LTD; England</b>				
1.	Pressure Test Chbr	3 m Dia x 8 m Lg	ROV Testing - Full Function at 7,500 ft. Depth	Operational
2.	Wet Tank	8 m Dia x 3 m x 3.5 m		
<b>RAUMA OCEANICS LTD; Finland</b>				
1.	Pressure Chbr	2.5 m Dia x 6 m Lg	Pressure to 7,500 m (several other chambers to 18,000 m)	Operational
2.	Pressure Chbr	4 m Dia x 12 m Lg	Pressure to 11,000 m	
<b>MALACHITE MARINE DESIGN BUREAU (associated plant); St. Petersburg</b>				
1.	Pressure Chbr (2)	2.2 m Dia 2.8 m Dia	4,000 m Depth 4,500 m Depth	Operational
<b>KRYLOV SHIPBUILDING INSTITUTE; St. Petersburg</b>				
1.	Linear Tow Tank	1.4 km Long	Longest Known Tow Tank - Carriage Speeds to 16 m/s	World Class Facilities; Operational and Available for Lease
2.	Propeller Test Tank	Ship Propeller Design	Air-Water Interaction	
3.	Pressure Test Chbr	1.8 m Dia x 8.5 m Deep 1,500 ATM 3.2 m Dia x 8.5 m Deep 1,000 ATM	3,000 Channel DAC, Automated Computer Control	
4.	Miscellaneous Tanks	High Speed & Maneuvering; Ice Breaker; Seafaring	Hydrofoils, Ice Breakers, Ground Effects Vehicles	
5.	Fatigue Test Fixture	Life Cycle Test for Full-Scale Ship Structures	Accommodates Major Ship Structural Sections, 3000 Channel DAC, Automated Computer Control	

**Table 7.3b**  
**Test Facilities Observed or Available in Europe, Russia, and Ukraine (2)**

ITEM	SITE/DESCRIPTION	CHARACTERISTIC	UNIQUE FEATURES	STATUS
<b>OCEANPRIBOR; St. Petersburg</b>				
1.	Acoustic Test Basin	80 m x 14 m x 10 m Freq. 0.2 to 600 KHz	Testing of Active and Passive Acoustic Products	Operational
2.	Pressure Test Chbrs. (3)	Various Sizes and Depths to 3,000 m	Acoustic Transducer Testing	Operational
<b>NIVK, INSTITUTE OF COMPUTER SCIENCE; Moscow</b>				
1.	Super Computer Facilities	4th or 5th Generation Super Computer for Signal Processing	Signal Processing and Simulation for Radar and Acoustic Data	Operational
<b>INSTITUTE OF APPLIED PHYSICS; Nizhny Novgorod</b>				
1.	Stratified Fluids Basin	8.5 m x 3.3 m x 2.7 m	Thermally Layered Fluids for ASW Testing Using Laser and Radar Detection Systems	Operational
2.	Stratified Fluids Basin	30 m x 4 m x 2 m		
<b>HYDROMECHANICS INSTITUTE; Kiev</b>				
1.	Tow Basin	140 m x 3 m x 1.8 m	High Speed (28 m/s) Carriage	Operational But Inactive
2.	Tow Basin	30 m x 8 m x 3 m	Wind and Wave Generation	
3.	High Velocity Tunnel	70 m long	Mach 1 Projectile Test	
4.	Fluid Flow Test Stand	Small	Fluid Dynamics	
<b>IFREMER; Brest &amp; Toulon</b>				
1.	Wave Tank/Tow Basin	50 m x 12.5 m x 20 m		Operational
2.	Hyperbaric testing complex		Multiple Chambers; Pressures up to 2400 Bars	Operational
3.	Robotics research lab.		Tests Manipulators & Autonomous Robotics	Operational
<b>PATON ELECTRIC WELDING INSTITUTE; Kiev</b>				
1.	Materials & Welding Test Facilities	World Class Test Equipment	Welding of Metals to Non-Metallics	Not Observed
2.	U/W Welding Test Facilities	Pressure Chbrs for Diver and Automated Welding	Gas-Free, Flux Core ROD U/W Welding	Demonstrated

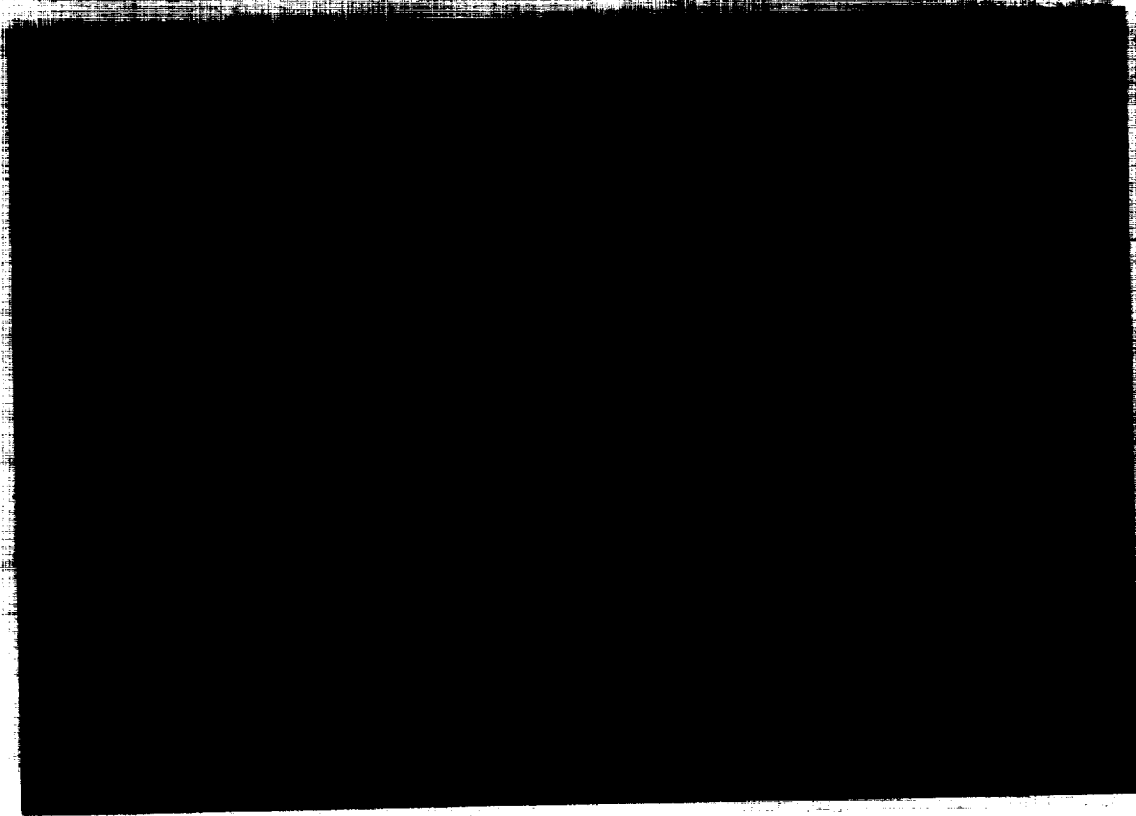


Figure 7.2. Pressure Test Facility at Slingsby

### Russia and Ukraine

The emphasis on testing in the FSU has led to a plethora of very capable test facilities for both ocean research and development test of underwater vehicles in these two countries. The most unique were clearly found at Krylov Shipbuilding Institute in St. Petersburg (see Krylov Shipbuilding Institute site report in Appendix B). Krylov is Russia's equivalent to the David Taylor Research Center (DTRC) at Carderock, Maryland. In fact, Krylov's test facilities are more extensive and in many ways superior to DTRC's. The very long tow tank (1.4 km) and massive pressure test chambers are truly world class. Krylov's largest chamber is over 3 m in diameter and capable of testing to 1,000 atmospheres (14,700 psi or > 33,000 ft). The slightly smaller chamber (1.8 m diameter) is rated at 1,500 atmospheres, which is well beyond full ocean depth. Krylov is unique in the FSU in that it has computer

controlled test facilities. The structural test facility (see Figure 7.3) can life cycle test full-sized ship panels by hydraulically applying simulated loads in numerous positions at temperatures down to  $-110^{\circ}\text{C}$  and measuring up to 3,000 data points to monitor fatigue and cracking.



Figure 7.3. Structural Facility at Krylov

Other test facilities observed in Russia and Ukraine, while not as impressive as those at Krylov, were still very capable and have been used extensively in developing advanced marine technologies. As summarized in Tables 7.3a and 7.3b, acoustic, hydrodynamic, and pressure test facilities were found at many institutes and were adequate for both research and component development. However, the only facility that appeared to be large enough to test a complete manned submersible hull was

the facility at Krylov. Computer controls, automated test equipment, and modern data acquisition equipment were not observed at any of the other test facilities.

Integrated test of completed vehicles does not appear to be emphasized in Russia or Ukraine as it is in the West. This is probably due to the less complicated vehicles that have been developed. Simple manned vehicles, without high-tech controls and subsystems, translate into simple test equipment and approaches.

### **OPERATIONAL DEMONSTRATION AND TEST**

The final phase of integration is field test and demonstration in the ocean environment. This requires support vessels and test ranges that are equipped to evaluate performance. In the West, the U.S. Navy and other agencies of the government are properly outfitted for operational testing. In addition, many commercial companies and universities have support vessels and can adequately conduct at-sea tests. The same is largely true of Europe. Russia and Ukraine have a wealth of support systems and ranges for at-sea testing, and clearly appreciate the need for proving the systems in the environment. Table 7.4 summarizes some of the support capabilities that were observed in Europe, Russia, and Ukraine.

#### **Europe**

While the WTEC team observed none of the field test capabilities at the European sites, it is well established that companies like Saab, Marconi, and IFREMER are well equipped and experienced at field testing. The companies have support vessels and test ranges.

Heriot-Watt University also has a long history of field testing the Angus class of ROVs. A new range is being installed by Heriot-Watt University in the Firth of Forth. It will allow acoustic propagation and communication studies in a real-time mode with the laboratory, which is some fifteen miles away. Linked by acoustics and microwave, the scientists and engineers in the laboratory will be able to monitor and influence the sensors and vehicles under test in the Firth.

#### **Russia and Ukraine**

Support vessels and test ranges are available for UV operation. In fact, Russia and Ukraine have an enviable fleet of dozens of research ships that are capable of operating manned and unmanned vehicles in any part of the world. These vessels are very large by Western standards, ranging up to 10,000 tons or more, and have the capability of long missions and great distances. They are well equipped for research and because of their size are able to carry large submersibles and large crews for research and operations. The team visited the *Ikhilandr*, a medium-sized



**Table 7.4**  
**Field Test and Demonstration Capabilities**

ITEM	SITE/DESCRIPTION	CHARACTERISTIC	UNIQUE FEATURES	STATUS
<b>HERIOT-WATT UNIVERSITY; Scotland</b>				
1.	Acoustic Test Range	Acoustic Research in Firth of Forth for Sonar and Communications	Real-time Acoustic Research from Range to Laboratory	Will be Operational This Fall
<b>ANDREEV INSTITUTE; Moscow</b>				
1.	Research Ships	2 ea. @ 10,000 Tons	Configured for Acoustic Research	Not Operating at Present
<b>GENERAL PHYSICS INSTITUTE; Moscow</b>				
1.	Field Testing in Arctic and Pacific	Helicopters and Ship Platforms	Laser and Acoustic Research in Ocean Processes for ASW	Not Operating at Present
2.	Long Range Acoustic Sensing Facility	Frans Joseph Land	Acoustic Tomography Testing for Global Climate Study	To Be Installed
<b>P.P. SHIRSHOV INSTITUTE; Moscow</b>				
1.	Research Ships	10 ea. up to 10,000 Tons; Baltic, Black Sea and Far East	Configured for Oceanologic Research & Submersible OPS	Some Leased to European Industry for Passenger Trade
2.	Field Laboratory on Black Sea	Located at Ghalendzhik	Submersible Test Range For AUV and others	Status Unknown
<b>OCEANPRIBOR; St. Petersburg</b>				
1.	Acoustic Test Range	Test Range on Lake for Acoustic/Sonar System Measurement	Have a Non-Self-Propelled Hydrolaboratory	Operational, but not Observed
<b>MARINE HYDROPHYSICAL INSTITUTE; Sevastopol</b>				
1.	Research Ships	2 ea. - Océangoing 3 ea. - Black Sea	Located at Odessa and Katsival for Physical Oceanography and Acoustics Research	Unknown
<b>MARIECOPROM; Sevastopol</b>				
1.	Research Ships	2 ea. @ 3,800 Tons	Support for Diving and Submersible Operations for 10 Manned Vehicles	Operational But in Need of Maintenance
2.	"	1 ea. @ 3,480 Tons		
3.	"	2 ea. @ 1,800 Tons		
4.	"	3 ea. @ 1,220 Tons		
5.	Research Submersibles	2 ea. <i>Benthos-300</i>	Diving and Seafloor Research	Operational

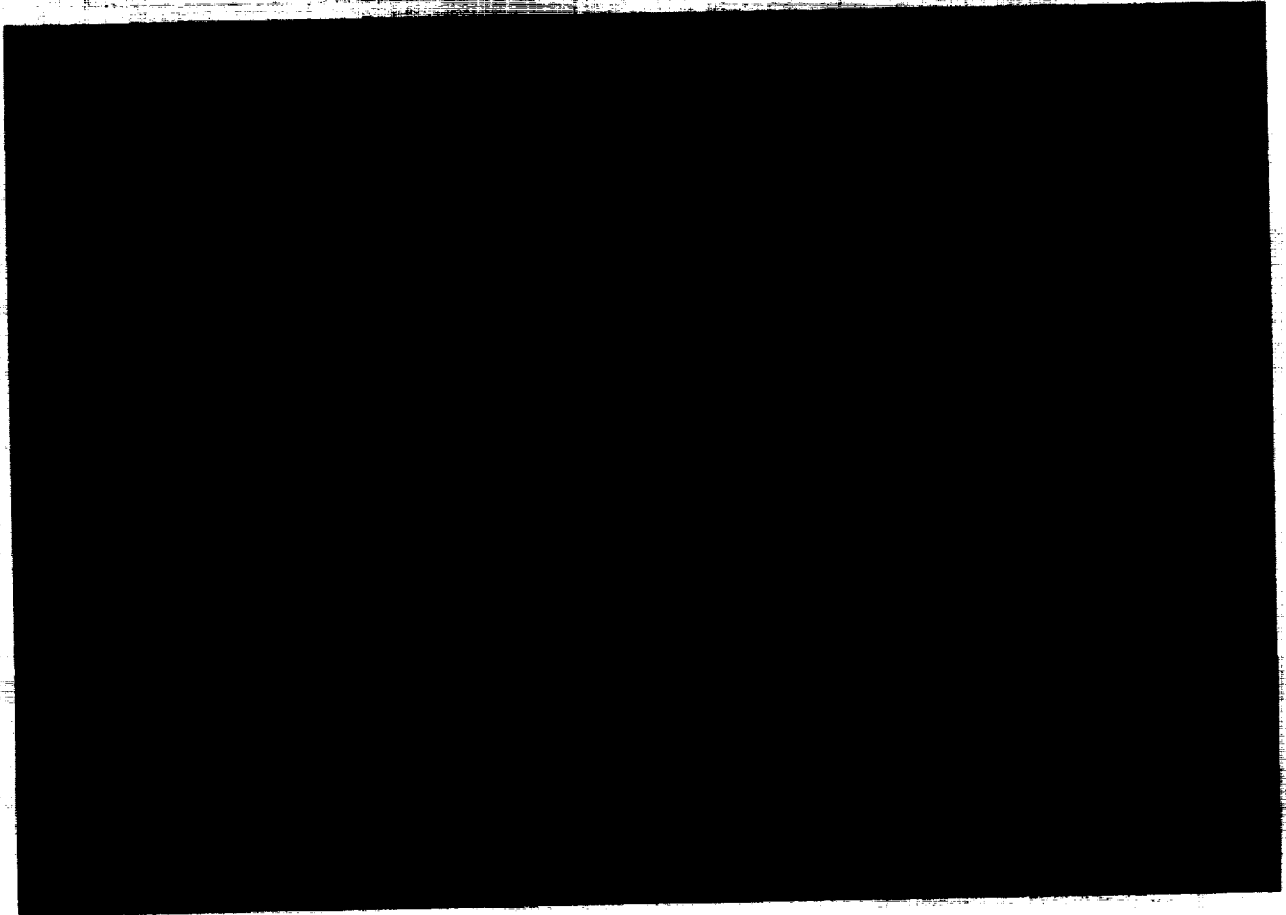


Figure 7.4. *Ikhtianr* and *Sever-2* Submersible

(4,000 t) converted fishing trawler with the 38.5 t *Sever-2* manned submersible (see Figure 7.4). The size and stability of vessels like the *Ikhtianr* allow over-the-side launch and recovery operations. As can be seen, the *Sever-2* is stowed on the port side in a maintenance bay equipped with sliding doors to provide all weather maintenance. It is handled into the water with dual bridge cranes. The operators claim to routinely conduct launch and recovery operations in state 5 sea conditions.

The vessels that the team observed at Sevastopol were largely idle and poorly maintained due to funding problems. Some of the larger vessels owned by Shirshov Institute have been unable to continue operation and are being subleased for

European passenger transportation until other funds become available. The personnel at Mariecoprom (see Mariecoprom site report in Appendix C) were anxious for partners in research in the Black Sea or anywhere the partner desires. The *Ikhtiandr* and *Sever-2*, fully crewed, would lease for about \$600/day. Even with fuel and provisions as extra, this is a very low cost.

## **SUMMARY AND CONCLUSIONS**

### **Europe**

Underwater vehicles and marine technologies are very important to the European countries visited. This is evidenced by government sponsored and funded programs such as the Marine Technology Directorate program sponsored by the United Kingdom's Science and Engineering Research Council and France's IFREMER program. There is also a European-wide focus through the Marine Science and Technology program. European marine technology and UV activities are well planned and focused, and funding, though never enough, is adequate. The bottom line is that the Europeans are making good progress in developing AUVs toward some very useful national and regional objectives in ocean research. Good work is also in progress toward development of ROVs for the offshore oil industry.

The organizations involved in UV development and marine research are just as well equipped for research, engineering, and overall system integration. Their computer equipment and test facilities are as modern and capable as any in the United States.

### **Russia and Ukraine**

To summarize:

- o Labor and materials are still inexpensive. This has led in the past to an emphasis on manned UVs rather than unmanned units because it is easier to integrate, maintain, and use the low-cost labor to good effect. This trend will probably continue into the near future until the industrial sector in these countries begins to mature and costs drive them toward unmanned systems. In the West, the high cost of labor and the risk of litigation and insurance penalties have driven the United States toward unmanned solutions. However, the same cost of labor has made sophistication and high technology expensive. The United States has improved performance and minimized man-dependency, but in some cases has violated the basic rules of "keep it simple" and "sufficient is good enough." U.S. researchers are too often enamored of the whiz-bang solution rather than the simplest solution.

- o **Fundamental science in Russia and Ukraine is impressive and based on sound theory. Due to lack of computational capabilities, there has been a focus on empirical validation rather than in-depth analysis. This will continue during the settling out process of economic, political, and defense conversion.**
- o **Researchers in Russia and Ukraine have been very creative in applied research, and have many accomplishments that equal or exceed what has been achieved in the West. Some examples include manned submersibles, acoustic tomography, nonacoustic ASW, high-speed underwater projectiles, and materials development for the marine environment.**
- o **Engineering is generally behind that of the West in sophistication but not necessarily in results. Some engineering and integration that Russian and Ukrainian engineers have done well include the following:**
  - **Numerous and very good research test facilities**
  - **Short development spans based on the build it, field it, and then improve it theory**
  - **Avoiding the analysis paralysis that slows progress in the West**
  - **Lack of preoccupation with aesthetics. Equipment and systems are built stout to last and simple for easy maintenance.**

## CHAPTER 8

# NAVIGATION, COMMUNICATION, AUTOMATION, AND CONTROL

Michael J. Lee

### INTRODUCTION

Navigation, communication, automation, and control are important technologies in underwater vehicles. The ability to navigate and control a vehicle is essential to all underwater vehicle activities. Automation and communication are enabling technologies that are prerequisites for advanced capabilities, such as autonomous operation and remotely controlled work environments. Basic capabilities allow vehicles to be used as observation platforms. Higher level capabilities allow for use of the vehicles in missions that are oriented more towards experimentation and manipulation. Communication technology enables remotely operated vehicles, remote observation, and/or experimentation platforms, and also the ability to extend the number of people who are involved in and interact with an underwater activity. Automation provides two functions. First of all, automation can take tasks that are tedious and require a lot of manpower and accomplish or help accomplish these tasks using a machine or a computer. This allows more tasks to be accomplished with a fixed amount of manpower. Secondly, some tasks can be done more efficiently (that is, faster, more accurately, and more repeatably) by an automated system than manually. This allows objectives to be accomplished that otherwise could not be achieved.

The WTEC team looked at the application of automation and control technologies in the research and development laboratories as well as in underwater systems.

Automation of design, test, and fabrication processes is an important component of the competitiveness of underwater vehicle programs.

## NAVIGATION

### Background

Navigation is the process of determining the position of a vehicle or object with respect to some exterior reference system. Global navigation systems determine position with respect to world coordinates. Local navigation systems determine position with respect to a local object or a set of transducers that are not referenced to world coordinates. Integrated navigation systems measure the position of the vehicle with respect to a local reference, and then transform the output into global coordinates.

A common technique for navigating submersible and autonomous or remotely operated vehicles is to determine the position of the support ship using a global navigation system (such as GPS), simultaneously determining the position of the vehicle with respect to the ship, using an acoustic positioning system employing short or ultrashort baseline technology. These measurements can then be integrated to form a global position or used separately. Another common method is to calibrate a long baseline system with respect to ship position, and then to determine the position of the vehicle with respect to the long baseline. Other technologies can be used to increase the accuracy of navigation systems or to fill in the gaps during the periods of time that information is not available from other systems. These technologies include the use of acoustic Doppler to determine vehicle velocity, inertial motion reference systems to determine changes in position, and correlation sonar to determine changes in position with respect to the sea bottom. Another type of navigation is positioning with respect to a local environment. This is accomplished by using vision or sonar to sense objects in the local environment, then positioning the vehicle or manipulator with respect to those objects.

### Overview

Acoustic positioning techniques of long baseline, short baseline, and ultrashort baseline are available and commonly used in the former Soviet Union (FSU), Western Europe, and the United States. Integration of acoustic positioning systems and GPS or similar systems are also commonly available. Technologies to fill in information to augment acoustic positioning are becoming available but are still expensive, large, and/or power hungry. Techniques applicable to submersibles, or ROVs or AUVs, for navigation using sensors of local terrain and integrated inertial navigation systems, are being researched.

### **Country-by-Country Assessment**

**Russia and Ukraine.** Several institutions in Russia and Ukraine are working on the development of transponders for subsea navigation. At the Andreev Institute there are several projects developing this technology (see Andreev Institute site report - Appendix B). The scientists' focus is on extending the duration of the transponders. This can be accomplished by increasing the efficiency of the power transfer from electrical energy to acoustical energy. It can also be accomplished by putting the transponder to sleep, waking it up only when power is needed. Another method is to focus on failure modes and to increase the mean time between failure of the transponder. Oceanpribor is developing low, medium, and high power transponders. A test facility is used there to test transponders and navigation systems. The company has developed long, short, and ultrashort baseline navigation systems, some of which have capabilities similar to the Honeywell and Simrad systems (see Oceanpribor site report - Appendix B). The Bureau of Oceanological Engineering is developing transponders for two systems: a long baseline system and an ultrashort baseline system (see Bureau of Oceanological Engineering site report - Appendix B). St. Petersburg State University has been working on ultrashort baseline underwater tracking systems and the corresponding transponders (see St. Petersburg State University site report - Appendix B). Transponder design (for navigation, communication, and sensing) is an area that was described to the WTEC team as an area of strength in the FSU. Russia and Ukraine have impressive test facilities and a large experience base to offer in this area.

The Andreev Institute is working on bottom referenced navigation (see Andreev Institute site report - Appendix B). This includes correlation sonar and multibeam sonar. These systems use multibeam transmitters to insonify a large area and then correlate the response with a reference image. Another system under development uses a multibeam receiver to track the position of a remote transponder.

At the Bauman Institute in Moscow, there is a research program to develop a low drift integrated inertial navigation system based on some very high accuracy accelerometers (see Bauman site report - Appendix B).

**France.** In France, several programs are focused on using locally sensed data in the navigation system of an undersea, or any robotic, vehicle. At LIFIA, in Grenoble, the French are using a multibeam sonar to sense the local environment (see LIFIA site report - Appendix D). This data is then matched to a world model. The position of the vehicle, as well as any new obstacles, can be determined from this data. A path on how to proceed to the objective can then be calculated. Figure 8.1 shows the output of the user interface showing the vehicle and the position that it has calculated with respect to the walls of the laboratory.

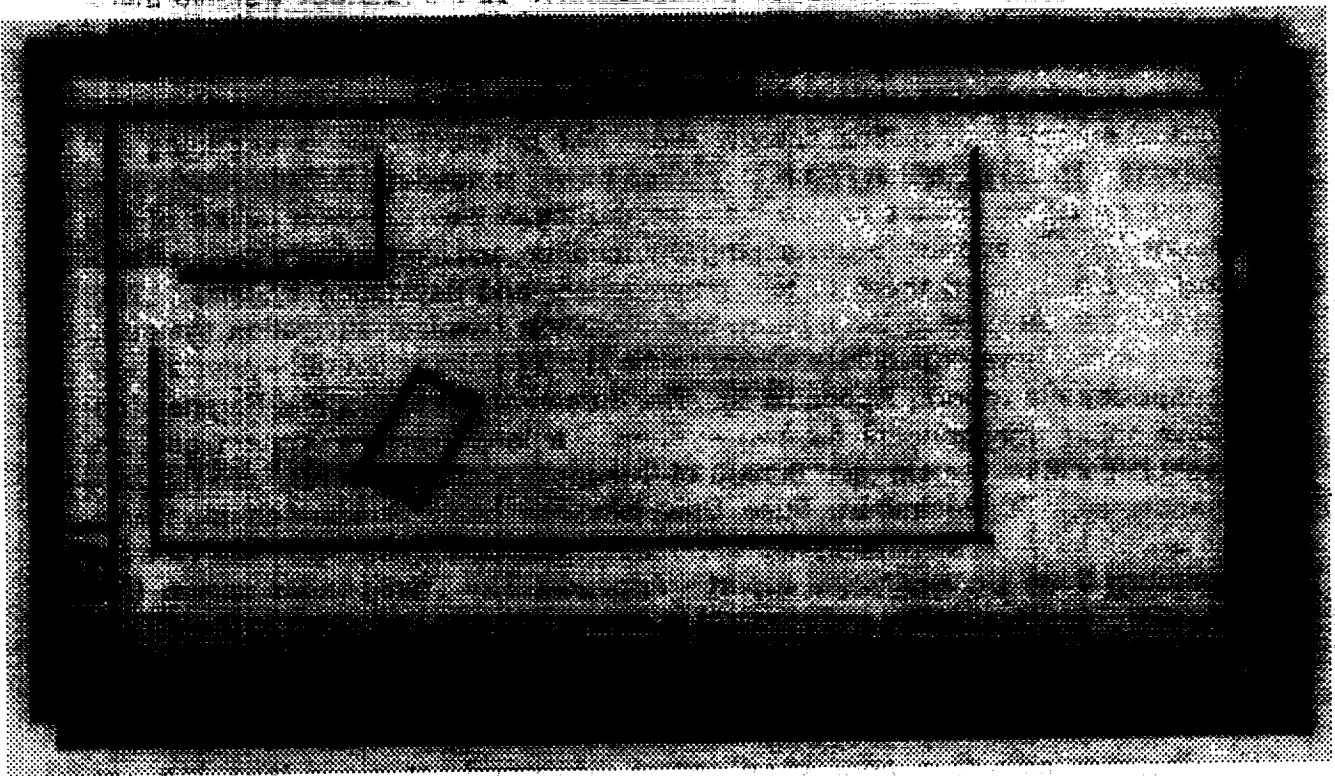


Figure 8.1. 2-D Local World Model and Vehicle From LIFIA System

**IFREMER and INRIA are working on the use of video in navigation (see IFREMER and INRIA site reports - Appendix D). They use an image from a video camera to determine the position of a vehicle relative to a wellhead. They then use the signal to guide the vehicle to reenter the well. IFREMER has been involved in subsea navigation systems of various types for several years.**

**United Kingdom.** There are several projects in the U.K. that focus on navigation in such man-made structures as oil rigs or nuclear power plants (see Marine Technology Directorate site report - Appendix E). At Strathclyde University a system is being developed that uses a model from a CAD drawing as a reference. It then correlates the actual sonar image with the expected image, which is calculated by simulating the projection of sonar on the CAD drawing. The information is used to determine a most likely position within the structure of the vehicle. Then this position is used to navigate the vehicle.



## Summary

For newer vehicles, navigation systems are acquired internationally so that their performance is not limited to regional or national capabilities. Two vehicles that have been used extensively by the worldwide scientific community are the two *Mir* submersibles that were designed and built in Finland by Rauma Oceanics. The navigation and communications equipment onboard the *Mir* submersibles is built in Finland by a Rauma subcontractor (see Rauma site report - Appendix F).

In the area of navigation, research programs in the FSU, Western Europe, and the United States all use similar technologies (Figure 8.2). In Russia and Ukraine, there are: (1) a large number of engineers who are trained and working in this area; (2) an infrastructure for the development, testing, and evaluation of navigation technologies; and (3) a focus on the development of hardware, on the development of algorithms, and on testing and evaluating navigation technologies.

**Table 8.1**  
**Availability of Navigation Technologies**

	Russia & Ukraine	Western Europe	United States
Long Baseline Acoustic Navigation	C	C	C
Short Baseline Acoustic Navigation	C	C	C
Ultrashort Baseline Acoustic Navigation	C	C	C
Correlation Sonar	A	A	A
Integrated GPS - Acoustic	A	A	A
Inertial - Dead Reckoning	A	A	A
Video Navigation		R	R

**Key:**  
 C = Commonly available in science ROV submersibles  
 A = Available / under development  
 R = Research

## COMMUNICATION

### Introduction

Communication technologies are important for underwater vehicles and underwater systems. Communication links are used to interconnect vehicles, both manned and unmanned, with the surface and with remote control stations. Communication links are also used to interconnect benthic and midwater instrumentation to the remote control and data acquisition systems.

Acoustic communication, fiber optic communication and, over short ranges, optical transmission techniques are generally available in the PGI, Western Europe, and the United States. Extending the range and bandwidth of the communication links seems to be the primary focus of current research. Making systems that are capable of working in multipath environments is also an area of interest. There seems to be interest in Russia and Ukraine in participating in the follow-on projects to the Heard Island Experiment of 1991. This test demonstrated the ability to communicate sound very long distances around the world through the sound channel.

Since many of the communication projects that were being worked on are still classified, hosts were not able to provide in-depth information on the current state of their research.

### Country-by-Country Assessment

*Russia and Ukraine.* Several organizations are working on acoustic communication systems. Andreev Institute is working on communication from a drill head to the surface control vessel. Scientists at the institute would like to be able to track and monitor data from the drill head as it operates beneath the ocean's bottom. They are also interested in technology for long range (2,000 to 3,000 km) communication (see Andreev Institute site report). Communication between submersibles and surface vehicles is also an area of research. In addition to data and control, Oceanpribor is working on sending compressed video over acoustic communication links (see Oceanpribor site report).

There is a general feeling in the institutes that the team visited that they have a strength in the development of algorithms for communication systems. Scientists at the institute feel that they have been limited in their access to fast computers, so they have compensated for this by developing very efficient algorithms. Also, many researchers seem to be involved in the development and theory of algorithms (see Table 8.2).

**Table 8.2**  
**Algorithm Development**

<b>Strengths</b>
Limited speed and memory in computer platforms forced developers to focus on efficient algorithms.
Large number of engineers and scientists are trained and have been working in algorithm development.
Algorithm development has been a priority due to military applications.
<b>Limitations</b>
Many of the theoretical concepts have not been tested.
Computer capability to stimulate algorithms is limited.
Effects of tradeoffs between maintainability and efficiency of code have not been evaluated.

Fiber optic communication systems seem to be an available technology (see Dubna/TECHNOPOLE and Energia site reports - Appendix B). These systems are used to link offshore surveillance systems to the land. The team did not see any fiber optic communication tethered to remotely operated vehicles.

In the General Physics Institute, a unique communication system was described (see General Physics Institute site report - Appendix B). This system is designed to communicate between submarines and aircraft. The aerial platform would use a very high power, modulated laser directed at a very small area of the sea surface. The power output of the laser would be high enough to create mechanical surface roughness variations that could be picked up by a sonar, decoding the signal by using signature analysis techniques. The submarine would use an upward directed, very high frequency sound source to create similar roughness on the sea surface. This surface roughness variation would be detected by a high frequency cross-polarized radar (Figure 8.2).

*France.* IFREMER has developed the TIVA acoustic modem system and operated it for the last five years (see IFREMER site report). TIVA is a 20 kbaud communication link that passes both data and compressed video between a submersible and a support vessel. This system has been transferred to a commercial company and is now available for sale.

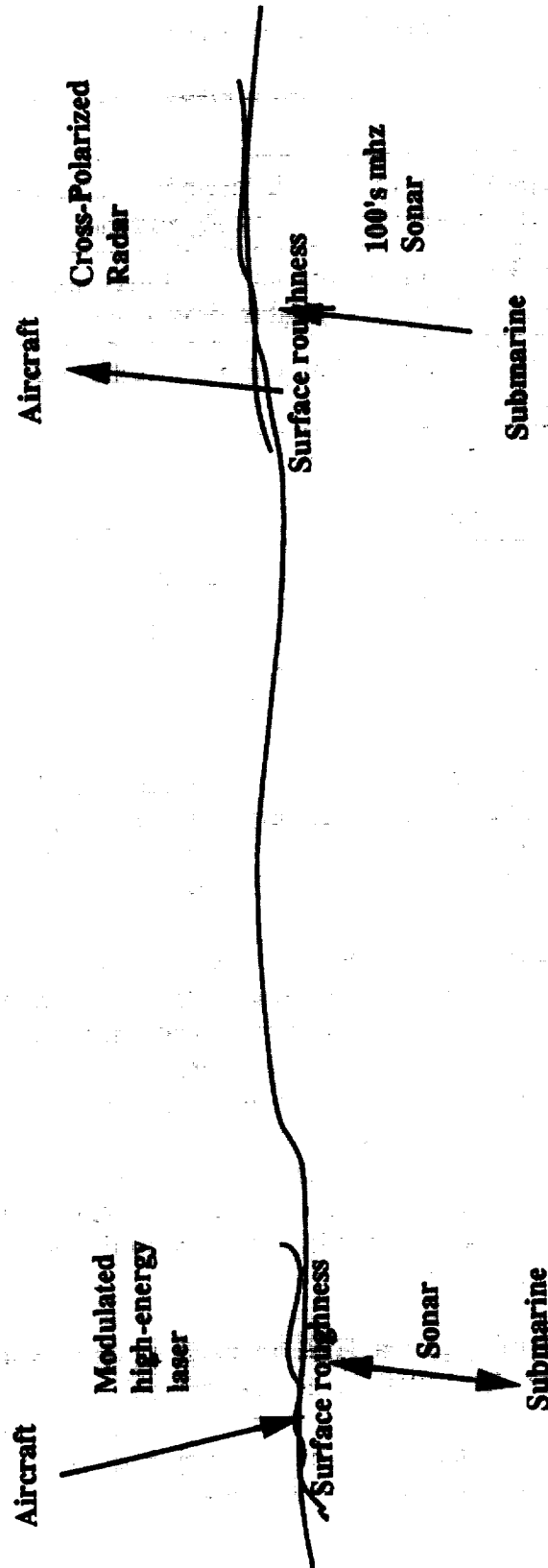


Figure 8.2. Atmosphere - Ocean Laser Communications

*United Kingdom.* EEVMAC is a European Community supported project to develop underwater communication technology. One of the goals is the development of high data rate communication systems for AUVs. EEVMAC is developing a very large acoustic communications test range in the Firth of Forth. This range will be fully instrumented so that the data can be evaluated in real time in the laboratories (see Heriot-Watt University site report - Appendix E).

## **Conclusions**

Communications technologies and research programs are generally consistent across Russia and Ukraine, Western Europe, and the United States. The main focus seems to have been on communication with submarines, which has provided spin-off technology that is now being made available to the nonmilitary community. Communication tools are generally available to research and development programs in each of the countries. The current push is for longer range, higher speed, and more robustness.

Communication is an area where the focus on simple efficient algorithms, which we have seen in Russia and Ukraine, may pay off. Researchers in the FSU have focused on algorithm development and less computationally intensive solutions. Techniques using these algorithms could have advantages over other techniques used in Western countries.

## **AUTOMATION AND CONTROL**

### **Introduction**

Automation and control are important technologies for underwater vehicles. Automation can pertain to a range of capabilities, from simple systems that assist the operators in performing only basic tasks to fully autonomous systems which are capable of going to sea with little or no communication and performing a task. With basic levels of control technology, a vehicle can be an effective observational platform. To use underwater vehicles for manipulative and experimental functions, the vehicle and its instrumentation need to have a more advanced level of control. Advanced vehicles that are capable of autonomous or semiautonomous functions need a fairly sophisticated controller because they need to be able to sense and respond to their environment. If properly applied, higher levels of automation and control in vehicles are useful because they increase the safety and effectiveness of the vehicle, allow the vehicle to function in ways that would not be possible if it were not automated, and provide a more cost-effective solution to accomplishing a task.

### **Assessment of Russia and Ukraine**

There is little automation on the vehicle systems that the WTEC team observed in Russia and Ukraine. The systems tended to be manually controlled and operated. This is different from what you see in the United States, where the systems tend to be more and more autonomous in operation. Many of the vehicles in Russia and Ukraine (both manned and remotely operated) have no computer systems onboard. The manual systems in these vehicles seem to be reliable and to meet their specified objectives. In Western countries, automated control systems have reached the point where, for many applications, they are much more reliable than manual control systems.

An example of what can be considered an advanced vehicle automation system in the FSU is the *Rus* vehicle (Figure 8.3). This vehicle has an autopilot that receives input from a navigation system and controls the actuators to automatically fly through waypoints (see Malachite site report - Appendix B).

Another vehicle that has some automated systems is an autonomous unmanned vehicle, the *MTS88*, which was designed in Vladivostok. This vehicle has the capability to dive, execute a survey, and return under automated control.

Some of the potential causes for the lack of automation in Russia and Ukraine are lack of access to computers, the reliability of the electronics, and the relative cost of labor versus capital there.

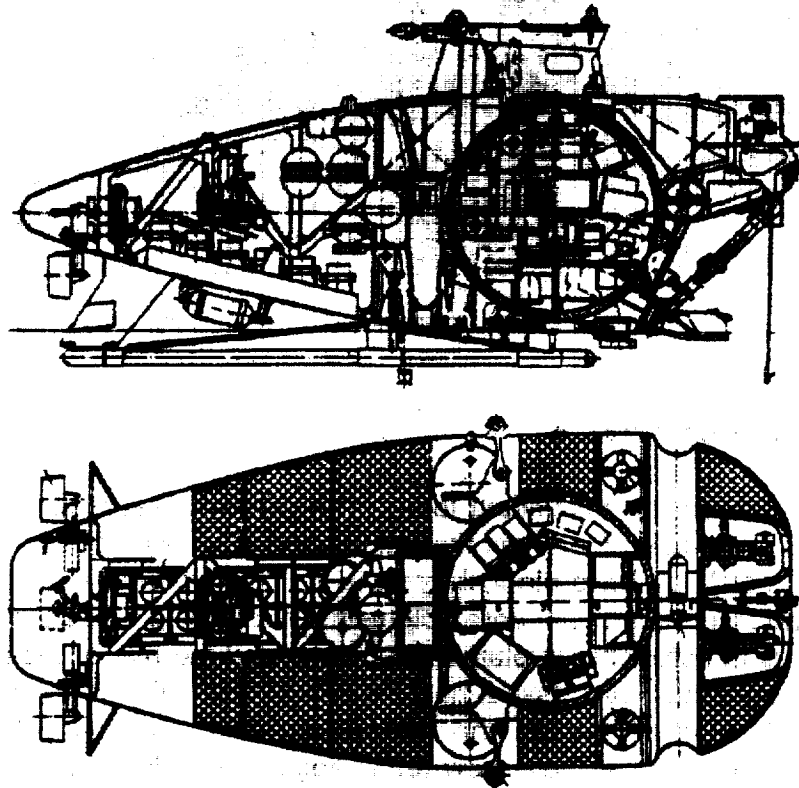
### **Facility Automation**

Most of the facilities that the team observed in Russia and Ukraine have almost no automation. The facility that seemed the most automated was the Krylov Shipbuilding Research Institute (see Krylov Shipbuilding Research Institute site report - Appendix B). Figure 8.4 is a picture of one of the pressure test facilities at Krylov. The pressure chamber is 3.2 m in diameter and can test pressure vessels at up to 1,000 atmospheres. This pressure test facility can automatically control the test through multiple pressure cycles, and can monitor the deformation of the test component in real time. The separate structural fatigue test facilities at Krylov automatically sequence 96 channels and measure 3,000 data points.

Computers and computer-aided-design software tools were identified by several organizations in Russia and Ukraine as the most important contribution that would make them more effective. Rauma Oceanics in Finland showed the company's extensive computer-aided-design and simulation facilities to the team. That company's scientists expressed the view that this capability is one of the major strengths that they bring to the underwater vehicle field.

 **MALACHITE**  
SAINT-PETERSBURG MARINE ENGINEERING BUREAU

**RUS**  
**Autonomous Manned Submersible**



**Figure 8.3. An Autonomous Manned Submersible**

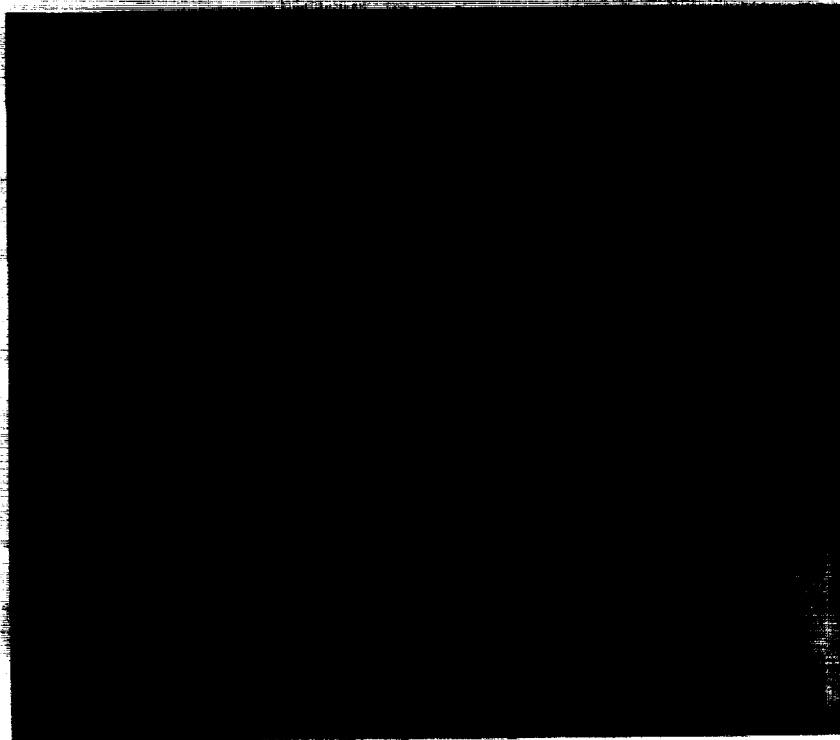


Figure 8.4. Krylov Pressure Test Facility

### **Control From Local Sensors**

Vehicle automation is a significant focus in the French research laboratories. One program that was described was the automation of oil well bore hole reentry (see INRIA site report). In this project, they try to use an automatically controlled vehicle to center and insert a tool in a bore hole using locally sensed data. The French also have projects in autonomous planning systems and the use of local sensors in the decision and planning process. A new French ROV is being designed that will have a fairly high level of integration and automation. The test vehicle *VORTEX* is being used to develop and test these new technologies (see IFREMER site report).

### **Manipulator Control**

At Heriot-Watt University, a program is underway to develop higher levels of control for manipulator arms (see Heriot-Watt University site report). Scientists there are working to allow multiple arms to operate in the same workspace without collisions. This involves multisensor fusion and autonomous decision making within the robot control system itself. They have a demonstration of two robot arms moving in the same workspace. In the future there is the prospect of intelligent robots able to



autonomously visualize, plan, and control manipulative tasks with a minimum of operator involvement.

At the Bauman Institute, scientists are working on manipulators and manipulator control. They are working on high positional accuracy (0.1 mm) manipulator control systems (see Bauman site report). Their control systems are consistent with other control systems that the panel saw in Russia and Ukraine that use joystick input to control either rate or force on a manipulator axis.

### **Software Architecture**

In the Western European programs there is a significant focus on architectures for control of underwater vehicles. The goal of these programs seems to be to find methodologies that provide structures for data transfer within the vehicle system, and that provide clean, maintainable software that can function at increasingly higher levels of autonomy (see INRIA site report).

At INRIA, scientists are working on automatic generation of software for vehicle control (see INRIA site report). They have an automated robot design system to let them design the mechanical configuration of a robotic system using computer-aided-design tools. They then input the configuration from the CAD to an automated software design system. The system is configured by specifying modules, such as data sources and control filters. These modules are then connected together by data paths. C code is then generated that will run in a specified hardware and software environment. The code is simulated line-by-line and the performance verified.

### **Autonomous Vehicles**

MAST II is a European Community program including two projects relating to AUVs. One of these, entitled "Advanced Systems Research for Unmanned Autonomous Vehicles," is being coordinated by Deacon Laboratory in the United Kingdom. Deacon Laboratory is also coordinating Autosub, a U.K.-funded program aimed at developing vehicles that can autonomously make transoceanic crossings and gather data and samples. This program is pushing the technology in long distance navigation, as well as in automation and control (see Chapter 5 and the Deacon Laboratory site report in Appendix E).

### **Conclusions**

The level of automation in the vehicle systems and in the development laboratories and test environments is much lower in Russia and Ukraine than in Western Europe or in the United States. The infrastructure to develop automation and advanced control techniques is 10 to 20 years behind that in the West. There has been little

or no emphasis on development of automation systems. There is little confidence in automation and little understanding of the pros and cons of its application. The autonomous control technology has not yet made its way into the vehicle programs of Russia or Ukraine, either in space or under water. Control systems tend to be hard-wired direct links to human operators.

Most of the test facilities in Russia and Ukraine are operated manually. There are a few test facilities that have automated data acquisition and test sequencing. There is no evidence of any software automation or hardware design. There was a consistent request from the designers for computer-aided-design and simulation tools.

The level of automation in the vehicle systems and in the development laboratories in Western Europe is similar to that in the United States. France has put a specific focus on control from local sensors, and the United Kingdom has put a focus on very long-range autonomous vehicles and the technologies that would enable them.

## **SUMMARY AND CONCLUSIONS**

In Russia and Ukraine there is limited technology in the area of automation in underwater vehicle technology. The control technology is based primarily on manual operation. Navigation and communication systems in these countries use technologies that are currently available worldwide. There are many well-trained engineers and scientists there who are underutilized because of the current funding situation. There are also several very nice design, test, and fabrication facilities. The Russians and Ukrainians would like to make these facilities available in some form to be used in the world market. The areas that engineers said would be most useful at making them more effective are access to computers, computer aided design and simulation software, and more reliable electronics.

France is a leader in the field of underwater vehicle technology. French programs in the integration of local sensor data for navigation and control have the potential of opening up new capabilities for underwater vehicles.

The United Kingdom is also pioneering the development of long range underwater vehicles through its Autosub program. This program is pushing the limits in underwater vehicle technology in automation, navigation, and control.

## APPENDICES

### APPENDIX A PROFESSIONAL EXPERIENCE OF PANELISTS AND OTHER TEAM MEMBERS

#### PANEL MEMBERS

**Richard J. Seymour**, Chair of the WTEC Panel on Research Submersibles and Undersea Technologies, is Director of the Offshore Research Center and Senior Chair in Ocean Engineering at Texas A&M University.

Dr. Seymour heads the only U.S. national engineering research center that is dedicated to ocean engineering research. The mission of the Center is basic research that will assist economical oil and gas production at great depths (2 to 3 km). The Center's research activity has included fluid/structures interaction, advanced composites for deep ocean applications, and seafloor engineering, with particular emphasis on innovative foundations and structural reliability. Formerly, Dr. Seymour headed ocean engineering research at the Scripps Institution of Oceanography of the University of California, San Diego. In addition, he has headed a number of major ocean engineering research programs, and has published over 150 papers, books, and reports in his field.

A graduate of the U.S. Naval Academy, Dr. Seymour obtained his Ph.D. at Scripps. He is a member of the Marine Board of the U.S. National Research Council and is active in the Marine Technology Society, the American Society of Civil Engineers, and the American Society of Mechanical Engineers.

**D. Richard Blidberg** is the Director of the Marine Systems Engineering Laboratory at Northeastern University's Marine Science Center in East Point Nahant, Massachusetts.

Mr. Blidberg has been involved in the development of autonomous underwater vehicle systems for over 20 years. He began his career in industry, where he was involved in the development of underwater acoustic systems and their applications in the polar regions. He subsequently assisted in the founding of the Marine Systems Engineering Laboratory of the University of New Hampshire. In that laboratory's new home at Northeastern University, Mr. Blidberg continues to focus on the development of intelligent systems technology for undersea applications, particularly architectures for intelligent control. He has been responsible for the current EA VE system architecture program since 1976. Mr. Blidberg has served on a number of committees focused on undersea systems technology, and has

organized a series of international symposia on Unmanned Untethered Submersible Technology. Mr. Blidberg has published over 40 papers and technical reports, and has consulted for a number of companies on AUV technology development.

Mr. Blidberg is a graduate of the University of New Hampshire, where he received his Bachelor of Science degree in Electrical Engineering. He has served on the board of directors for the Association for Unmanned Vehicle Systems, and has been involved in many activities of the IEEE Oceanic Engineering Society and the Marine Technical Society.

**Larry L. Gentry** is a Program Manager for underwater vehicles in the Marine Systems Group at Lockheed Missiles and Space Company, Inc., in Sunnyvale, California.

Mr. Gentry has 30 years experience in the subsea and marine industry. From 1983 to the present, he has managed a number of underwater vehicle development programs. He has been responsible for fabrication and testing of UVs, and for planning and supervising research and development projects for advanced technologies, including autonomous command and control, acoustic and optic communications, advanced structural materials, and precision inertial navigation. Formerly, he was involved in the development and installation of subsea oil and gas production systems, and was one of the inventors of Lockheed's one-atmosphere subsea completion and production system. He has designed and operated both manned and unmanned undersea systems. Mr. Gentry holds nine patents or patents pending for marine systems and equipment.

Mr. Gentry has a Bachelor's degree in Electrical Engineering from Oregon State University and a Master's degree in Electrical Engineering from San Jose State University. He is a past member of the Marine Board of the U.S. National Research Council, and has served on submersible and diving consulting panels for the American Bureau of Shipping and Det Norske Veritas.

**Algis N. Kalvaitis** is the Senior Engineer and Operations Director for the U.S. National Oceanic and Atmospheric Administration's National Undersea Research Program (NURP).

Mr. Kalvaitis is responsible for providing technical support and guidance on undersea vehicles to ensure that the NURP's undersea research objectives are technically feasible, safe, cost-effective, and efficient. He previously managed several major projects associated with the Ocean Thermal Energy Conversion Program, which explored the ocean as a renewable power source. He has also been involved in the design, testing, and evaluation of instrumentation systems and

platforms for oceanographic and meteorological measurements. Mr. Kalvaitis has published articles on undersea technology developments and platforms, ocean thermal energy conversion, data quality assurance, and marine instrumentation.

Mr. Kalvaitis received his Bachelor's degree in Mechanical Engineering from the University of Maine, Orono. He is a member of the Marine Technology Society's Undersea Vehicles/ROV Committee, and of the Current Measurement Technology Committee of the Institute of Electrical and Electronics Engineers. In addition, he is a member of the Engineering Committee on Oceanic Resources Working Group for Marine Robotics.

**Michael J. Lee** is a Senior Engineer with the Monterey Bay Aquarium Research Institute of Monterey, California.

Mr. Lee is involved in research in task-level controlled unmanned underwater vehicle systems. He developed and managed the institute's research programs for underwater remotely operated vehicles and underwater instruments. He was instrumental in developing the scientific ROV *Ventana*, which has conducted over 500 scientific research missions off the coast of California. Formerly with Hewlett Packard Laboratories, where he headed the Control Systems Department, Mr. Lee is experienced in research in electromechanical systems, including printers, plotters, instruments, and robotics. Moreover, he managed the Laboratories' efforts in manufacturing technology, including robotics, design for manufacturability, and computer-integrated manufacturing.

Mr. Lee received his Bachelor's degree in Electrical Engineering from Massachusetts Institute of Technology and his Master's degree in Electrical Engineering from Stanford University. He is a member of the Marine Technology Society and of the American Society of Mechanical Engineers.

**John B. "Brad" Mooney Jr.**, a Retired Admiral in the U.S. Navy, is an independent consultant to ocean engineering and research managers.

Admiral Mooney is a member of the Board of Directors of Coltec Industries; a member of the Marine Board of the U.S. National Research Council; a member of the Board of Directors of the National Association of Marine Laboratories; and serves on the Naval Studies and Ocean Studies panels of the U.S. National Academy of Sciences. He is a former President of the U.S. Marine Technology Society, and is the former President and Managing Director of Harbor Branch Oceanographic Institution, Inc. of Fort Pierce, Florida. Admiral Mooney retired from the U.S. Navy in 1987. His 34 years of commissioned military service included numerous assignments involving ocean engineering and research and development. He served

in several submarines and commanded one. He is a former Officer in Charge of the bathyscaphe *Trieste II*. He piloted *Trieste II* when it located the submarine *Thresher*. He was Chief of U.S. Naval Research and served as Oceanographer of the U.S. Navy, directing the Navy's Oceanography, Meteorology, and Hydrographic Survey Organization. In addition, he has served in an advisory capacity for oceanographic technology issues to both the White House and the U.S. Congress.

Admiral Mooney is a graduate of the U.S. Naval Academy. He is a member of the U.S. National Academy of Engineering and the U.S. National Engineering Honor Society.

Don Walsh is President of International Maritime Incorporated (IMI), a marine industry consulting company located in Los Angeles Harbor, California.

Dr. Walsh has been associated with ocean science, engineering, and marine policy for over 30 years. He served as an officer in the U.S. Navy and held the rank of captain at the time of his retirement. He spent 16 years at sea, mostly in submarines, and was the commanding officer of a submarine. In addition, he worked in ocean-related research and development for the U.S. Navy. A former Dean of Marine Programs and Professor of Ocean Engineering at the University of Southern California, Dr. Walsh founded and directed the university's Institute for Marine and Coastal Studies. In 1989, his company, International Maritime Incorporated, formed a joint venture with the P.P. Shirshov Institute of Oceanology to establish an underwater maintenance company, Soyuz Marine Service, which continues to operate in the Russian Federation.

Dr. Walsh has a Bachelor's degree in Engineering from the U.S. Naval Academy, a Master's degree in Political Science from San Diego State University, and a Master's degree and a Ph.D. in Physical Oceanography from Texas A&M University. He was appointed by Presidents Carter and Reagan to the U.S. National Advisory Committee on Oceans and Atmosphere, was a member of the Law of the Sea Advisory Committee for the U.S. Department of State, and served as a member of the Marine Board of the U.S. National Research Council from 1990 to 1993.

#### **OTHER MEMBERS OF THE TEAM**

Norman Caplan is the Head of the Bioengineering and Environmental Systems Section of the U.S. National Science Foundation.

Mr. Caplan supervises a Section of the National Science Foundation that supports U.S. research in several bioengineering disciplines involving ocean systems engineering. The Foundation's Ocean Systems Engineering Program focuses on

research in subsea technology and coastal zone utilization. In addition, Mr. Caplan has been actively engaged in promoting the Foundation's international activities, and served as the Chairman of the Foundation's Coordinating Committee for Research in Intelligent Robotics Systems. Prior to joining the Foundation in 1973, Mr. Caplan held positions with U.S. academia and U.S. companies involved in research in undersea technology, ocean vehicles, and advanced naval communications.

Mr. Caplan received his Bachelor's and Master's degrees in Electrical Engineering from New York University. He is a member of the Institute of Electrical and Electronic Engineers (IEEE), is Past President of the Robotics and Automation Society, and is active in the Marine Technology Society (MTS). He is the U.S. Delegate to the International Advance Robotics Program and to the International Ocean Technology Congress.

**Michael J. DeHaemer** is the Director of the Japanese Technology Evaluation Center/World Technology Evaluation Center at Loyola College, Baltimore, Maryland.

Dr. DeHaemer is a former Captain in the U.S. Navy and submarine commander. He is founder and Director of the Lattanze Human Computer Interface Laboratory and is a specialist in the applications of synthesized speech and automated voice recognition systems as computer interface output and input. On the faculty of the Sellinger School of Business and Management at Loyola College, he is the Chairman of the Information Systems and Decision Sciences Department, where he currently teaches Information Technology and Strategy, the Human-Computer Interface, Applications of Expert Systems and Neural Networks, and Production Management. Dr. DeHaemer has research interests in business applications of artificial intelligence and the methodology of technology assessment.

Dr. DeHaemer received his Bachelor's degree in Physics from the University of Notre Dame, Master's degree in Operations Research from the Naval Postgraduate School, Master's degree in Business Administration and Industrial Engineering, and Ph.D. in Management Information Systems from Rensselaer Polytechnic Institute.

**APPENDIX B. SITE REPORTS - RUSSIA**

**Site:** **Andreev Institute**  
**Chernik #4**  
**Moscow 117038**  
**Russia**  
**Telephone: 120-2401**  
**Fax: 120-6411**  
**Email: DUBNOV@NSU.AC.OBS.MKRSU**

**Date Visited:** **May 11, 1993**

**Report Author:** **D. Blidberg**

**ATTENDEES****WTBC:****D. Blidberg****HOSTS:****Nikolai Dubrovsky****Director****BACKGROUND**

Andreev Institute has traditionally focused on basic research into sound propagation in the sea, although it is now considering air acoustics and other applications. The institute is concerned with scientific research, not prototype development. It is involved in five areas of acoustic research: (1) ocean, (2) oil and gas, (3) medical, (4) ecological, and (5) air acoustics.

A technical institute, Andreev has previously worked only on problems provided by the user community. Recently the institute's scientists have been given more freedom to choose their research directions, but they have far less support to accomplish that research. Recently Andreev's two-building complex has experienced reductions to the point where part of one building is used by a commercial company. Mr. Nikolai Dubrovsky's lab has been reduced from thirty-five people to eight in the last eight years.

The institute has two large ships, ranging up to 10,000 tons, that are configured for acoustics research. The ships are not in use now, but the institute is trying to find



companies with which to form joint ventures in order to have the funding required to return the ships to operation.

Applications include: drag reduction, sound and vibration, bionic research, neural networks, navigation, ultrasound, ecological, nonlinear acoustics, algorithmic processing of data, underwater communications, and bore head telemetry.

### **Drag Reduction**

The institute did some work in the 1970s on drag reduction, but subsequently stopped. Since then the personnel involved have left the institute.

### **Sound and Vibration**

Andreev has worked on developing materials and coatings to reduce sound, investigating methods of determining where to place the materials for optimum noise reduction.

### **Bionic Research**

Research into dolphins and other marine animals' sonar capabilities has sparked interest in understanding what can be applied to sonar systems. Marine mammals like the dolphin have a sonar system that is a "whole" system, that is, the physiological characteristics of the animal and its behavior are part of the entire sonar system. Scientists have learned from this that 5 to 100 neurons can sometimes have a processing capability that is equivalent to a million computers.

### **Neural Networks**

The institute is investigating some basic issues associated with neural networks. The institute's scientists want to know how a group of neurons with m/sec response times can be connected so that the group can detect m/sec variations. Andreev does not have a large research effort in the neural networks area at this time.

### **Navigation**

The Andreev Institute is interested in undersea transponders with extended durations. Some work has been undertaken that is directed at the development of transponders -- extending transponder endurance through the use of a sleep mode. The institute's scientists expect to extend the life of transponders by one or more years by using a wake up mode.

The institute has been investigating the design of a multibeam receiver for obtaining accurate range and bearing determination using transponders. The institute's

investigations suggest bearing accuracies of  $1^\circ$ . Andreev's scientists have not built these receivers, but they have completed the design investigations.

**Bottom referenced navigation.** This project focused on using bathymetric data to monitor the movement of slow moving objects such as oil rigs. Researchers compared data acquired from a multibeam sonar with previous data to obtain motion accuracy of  $\pm 1$  cm. The institute has a multibeam sonar of 100  $1^\circ$  beams.

**Bore hole localisation.** The institute's scientists are considering using stationary arrays to monitor the drilling head position for oil. Their processing will eliminate the noise associated with drilling and will allow for range and boring to drill head.

### Ultrasound

This effort is focused on medical applications. Sound Vision System, an acoustic imaging system that uses 1 MHz and a 100 x 100 array with  $1^\circ$  beams was discussed. The beams are electronically formed from the array data.

### Ecological

The institute is investigating such environmental applications as the following:

- o cleaning water and air of pollutants (e.g., oil films on the surface of water)
- o urban noise (level of noise pollution in the air; active and passive reduction of noise; damping noise by application of coating materials; and establishment of standards for noise levels in cars, trains, airplanes)

### Nonlinear Acoustics

The institute is working on parametric sonar techniques for different applications.

1. For oil exploration, the institute's scientists are using sediment to mix carriers around 300 kHz to obtain a 600 Hz difference in frequency for subbottom profiling and seismic analysis.
2. The institute's scientists believe that they can obtain pollutant concentrations by analyzing received pulses over small volumes of water (1 m to 10 m) paths. They have conducted some experiments to understand changes in concentrations of pollutants to 1 part in  $10^9$ .

### Algorithmic Processing of Data

After years of working on matched field processing, the institute is either applying or exploring application of that technique to the following problems:

1. Long path acoustic current meter. Here the matched field techniques minimize the errors introduced by bottom and surface reverberations in shallow water channels. The technique increases the accuracy of fluid flow measurements in long, shallow water channels.
2. Understanding the internal wave structure of a channel. Andreev's scientists feel that they can understand the health of a body of water by determining flows in and out of that water as described by the structure of water in the channel.
3. Underwater acoustic holography, using optical waveguide techniques to better understand underwater sound channels.
4. Sediment measurements through a project to measure sediment properties by using acoustics. By measuring the effect of an acoustic wave as it propagates through the marine sediment, various parameters can be determined.

### **Underwater Communications**

The institute's scientists have worked on some communication systems that they cannot discuss. They also have examined some of the filter processing techniques being applied to underwater communications. They believed there was a need for long range (2,000 to 3,000 km) communications at low data rates. The same techniques can be applied to shorter ranges with correspondingly higher data rates (e.g., 20 Hz  $\pm$ 10 for ranges of 1,000 to 2,000 km using a receiver with 18 bit resolution).

### **Bore Head Telemetry**

Scientists at the institute want to use their techniques for implementing a telemetry system from the drill head to the surface by using a low data rate system without cables.

### **SUMMARY**

In summary, in the area of research projects, the institute's focus is on basic research. The institute also is involved with the actual development of systems. Although several projects are being considered, the status of those projects is not clear.

The institute works with personal computer (PC)-type workstations and develops some of the applications using DSP chips. Andreev Institute's scientists recognize their need for more capable computer hardware, but have accomplished much with existing processing capabilities.

**Site:**

**Bauman Institute of Underwater  
Devices and Robotics  
Moscow State Technical University  
Gaspinsky, 10  
Moscow 107008  
Russia  
Telephone: 261 36 14 or 263 67 64  
Fax: 267 66 66  
Telex: 417661 Moscow GRACH**

**Date Visited:**

May 18, 1993

**Report Author:**

C. Brancart

**ATTENDEES****WTEC:**

D. Blidberg  
C. Brancart  
L. Gentry  
J. Mooney

**HOSTS:**

Vladimir A. Chelyshev

Head of Department, Underwater Devices  
and Robotics

Vadim V. Veltischev  
Dr. Peter A. Zinoviev

Head of Department  
President, Institute of Composite Structures

**BACKGROUND**

The Bauman Institute of Underwater Devices and Robotics is part of Moscow State Technical University, the oldest institute in Russia; it also is one of the largest. Before the Revolution it was called the "Imperial High School."

The Institute of Underwater Devices and Robotics employs 600, not including teachers and students. About 20 students are enrolled in the institute each year. The institute is the only source on manipulator systems in the country. One year ago, the institute was closed to the public because of classified work.

Bauman Institute works with other institutes and agencies on common projects. Their specialties are: manipulator systems, propulsion systems, operating systems and controls, and complete underwater vehicles.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

Although the WTEC team members were unable to undertake any in-depth discussions on the Bauman Institute's capabilities, they were able to highlight the general areas of the institute's expertise.

### **Propulsion**

*Electrohydraulic drive systems and associated controls.* The institute's scientists and engineers claim that their servo valves are the best (i.e., comparable to Westinghouse's hydraulic amplifiers).

*Electric drive systems.* These systems have brushless motors and magnetics, and tend to be very expensive.

*Mangus propulsion.* These rotating cylinders are used on a towed system at 2,000 m depth.

*Adoptive propulsion.* These are totally regulatable hydraulic motors that select operating parameters to maximize propulsive efficiency.

### **Energy Systems**

*Gas Dynamics.* The institute has a solid propellant that uses water as the oxidizer. This is different from torpedo technology because this propellant is ecologically pure. This technology has been used on the institute's rescue submarine. Bauman's scientists and engineers are working on a power package that would replace the batteries on manned submersibles.

*Nuclear.* Bauman is not working on any nuclear power systems. The institute's personnel would like to develop nuclear systems, but they are not allowed to.

### **Manipulators**

Manipulators are the Bauman Institute's area of expertise. The WTEC team visited a laboratory that had just one manipulator instead of the large variety of manipulators that the team's members expected. Some of the major accomplishments in manipulators have been:

- o Servo systems to control manipulator position to within  $\pm 0.1$  mm of setting;
- o Rotary motors without reducers that have 90° rotation, generally used at arm joints;
- o Use of position feedback for control, not forced feedback;
- o Joystick control for rate and force level; and
- o Autonomous control. The institute's scientists wrote the software for the Buran orbiter for an unmanned landing when the vehicle was being tested. They used British computers with parallel processing. All work on autonomous control has been stopped because of lack of funds.

### **Materials**

The institute's scientists have been working with nonmetallic structures, namely carbon, organic, or glass fibers. They have developed models that can predict the damping properties of composite structures and are able to calculate the energy dissipation of composite structures under external loads. They stopped all work in ceramics fifteen years ago because of the low life cycle of the material.

### **Noise**

The major thrust of Bauman's work in this area has been in the use of the constructive resonance concept. In the propulsion area, Bauman's scientists feel that the gas-dynamic system is potentially quieter.

### **Navigation**

Bauman is working on an integrated navigation system that incorporates very accurate accelerometers. The design goal is an accuracy rate of 20 m per hour.

### **Vehicles**

A quick review of Bauman's family of underwater vehicles revealed nothing that could be identified as exceptional. The institute supplied black and white pictures of the vehicles. The *Scaros*, which is very similar to the French *Epauleard*, was the only true autonomous underwater vehicle (AUV). The *Scaros* is 80 percent completed, but work has stopped on the vehicle because of a lack of funds.

## **SUMMARY**

The institute has demonstrated levels of expertise in the area of electrohydraulic system control and devices, and gas-dynamics propulsion. It may be advantageous to pursue the technologies further.

Dr. Peter A. Zinoviev, the institute's director, was very open concerning its present condition: the institute is in a survival mode.

## **REFERENCES**

Bauman Institute representatives passed out black and white photographs of some of the institute's systems, including:

- Triton*, an ROV
- A towed system
- Aquator*, an ROV circa 1978
- A wheeled vehicle
- A grabber vehicle
- Scaros*, an AUV manipulator

**Site:**

**Bureau of Oceanological Engineering  
(Experimental Design)  
Russian Academy of Sciences  
1, Letnaya St.  
Moscow 100087  
Russia**

**Date Visited:**

**May 20, 1993**

**Report Author:**

**D. Walsh**

**ATTENDEES****WTEC:**

**C. Brancart  
B. Mooney  
D. Walsh**

**HOSTS:**

**Victor P. Brovko**

**Director, Science and Technology, designer of manned submersibles; he was formerly with the Manned Submersibles Laboratory of the P.P. Shirshov Institute)**

**Eugene E. Pavijutchenko  
Dr. Alexander M. Podrazhansky**

**Project Chief Designer  
Scientific Ocean Drilling Program, Russian Ministry of Geology (former Senior Research Fellow with the Manned Submersibles Laboratory of the P.P. Shirshov Institute and pilot of the Mir submersibles; now liaison with the Design Bureau)**

**Alexander A. Paramonov**

**Director (he did not attend the site visit, but the WTEC team obtained his card)**

**BACKGROUND**

**The WTEC team spent about three hours at the Experimental Design Bureau. Most of the visit took place in Mr. Victor Brovko's office, where the team was briefed on the various programs. Dr. Walsh was asked to meet separately with Mr. Brovko, Mr. Eugene Pavijutchenko, and Dr. Alexandr Podrazhansky to discuss tourist submarine designs developed by the bureau and its associated private company, Rift Company Ltd. Some team members were shown some of the bureau's hardware.**



The Experimental Design Bureau of Oceanological Engineering was established in 1970 as part of the P.P. Shirshov Institute of Oceanology. The Design Bureau remained a part of the institute until about two years ago. Now it is an independent organization under the Russian Academy of Sciences. However, its two major customers are still the Shirshov Institute and the Ministry of Geology. The bureau is free to sell its devices to any buyers, domestic or foreign.

The bureau's primary function is to design, build, and test sensors, samplers, and instrumentation used for oceanographic research. The bureau's scientists and engineers also design and build manned submersibles. These include *Osmotr*, which was completed in 1985, and the *Rift* class, two of which are under construction. The bureau's recent interest in tourist submarines for the commercial market comes from its experience with oceanographic manned submersibles.

## RESEARCH AND DEVELOPMENT ACTIVITIES

### Oceanographic Instrumentation

In the bureau, there are two major subgroups in the area of oceanographic instrumentation: hydrophysics and hydroacoustics. The bureau's scientists and technologists make a full range of devices for ocean studies, as well as various components such as radio beacons, acoustic releases, physical samplers, and strobe beacons.

They have also been working with the development and construction of both long and ultrashort baseline navigation/positioning systems. This work has included design of the required transponders. Operations with these systems have been conducted in the ocean and in Lake Baikal, where acoustic conditions are very difficult.

Another developmental area is underwater communications between submersibles and surface vessels.

### Manned Submersibles

Manned submersibles have been a mission of the bureau since it was first founded. *Argus* (1975), a 600 m depth vehicle, has made over 1,000 dives, and *Osmotr* (1986), a 300 m vehicle (200 m for diver lockout operations), has made only 20 test dives and "dozens of dives to 50 m" for testing its diver lockout system. It had been offered to Cuba for treasure hunting work, but this project was not realized. *Osmotr*, currently located in the Ukraine, has no programs planned and is presently for sale. Both submersibles were designed and constructed under the direction of the bureau. Also, both have been operated by the Shirshov Institute.

Presently there are two 4,000 m diving depth manned submersibles under construction at the bureau. These are the *Rift* class submersibles, which are of all titanium construction. They are presently 80 to 85 percent complete, but require an additional \$2 million for completion. Mr. Brovko said that the director of Shirshov wants the submersibles completed and in testing by 1994. The initial dive tests will be conducted at their field laboratory at Gholendzhik on the Black Sea.

*Rift's* spherical pressure hull is made up of six major titanium segments that were forged, cut, and welded. There are an additional four inserts for the hatch, viewing ports, and twenty-three hull penetrators.

Mr. Brovko repeated the offer made by the director of Shirshov that a foreign investor who would put in the \$2 million required to complete construction would be given one of the two submersibles.

### **Tourist Submarines**

The Experimental Design Bureau of Oceanological Engineering and *Rift* Co., Ltd. have developed two designs for tourist submarines, the *Angara TS-6/600* and the *TS-20/100*. The former is a \$400,000, 6-passenger submersible that can dive to 600 m. The latter is an \$850,000, 20-passenger submarine that can dive to 100 m. Both submarines are also proposed for underwater oceanographic research platforms.

*Rift* Company Ltd. intends to classify these submersibles with one of the western classification societies, such as the American Bureau of Shipping or Lloyds Register, both of which have offices in St. Petersburg.

The hull design has been completed for *Angara* and the components have been ordered, although construction has not begun. At the present time, *Rift* Ltd. does not have any orders for either submersible. However, there may be a market for the "resort-sized" (six to twenty passengers) tourist submarine. No company in the West has started making these yet; this is a new market opportunity with no competition yet present.

### **SUMMARY**

As was the case with virtually all of the institutes and bureaus visited during the WTEG field trip, most of the Design Bureau's work was severely constrained by lack of funding and customers from those Russian/Former Soviet Union agencies that once supported them. Two years ago, the bureau had 400 employees; today it has 160. A major preoccupation of the Design Bureau's management is finding western customers for its products. In addition, there is an active program to find a western sponsor/investor to put up the \$2 million needed to complete the two *Rift* submersibles.

These marketing efforts are very difficult to pursue since the present state of the Russian economy makes it difficult to secure travel funds to go to the West for this purpose. It was for this reason that Dr. Walsh was asked to make a quick review of their tourist submarine design and marketing strategies and tactics. He has known Mr. Brovko and Dr. Podrazhansky for over ten years, and they have had prior communications about tourist submarines. There is no question that the Bureau/Rift Ltd. combination can do this work. Furthermore, the estimated prices for each of these submarines is well below the estimated cost of an equivalent submersible in the West.

#### **REFERENCES**

*Rift Tourist Submersible 20/100. Brochure.*

*Rift Tourist Submersible 6/600. Brochure.*

**Site:** Dubna International Centre of Research and  
Technology Development (TECHNOPOLE)  
14 Sovetskaya St.  
Dubna, Moscow Region 141980  
Russia

**Date Visited:** May 20, 1993

**Report Author:** M. DeHaemer

**ATTENDEES****WTEC:**

M. DeHaemer

**HOSTS:****Alexander Voronkov**Director, International Centre of Research and  
Technology Development**Valeryi S. Shevchenko**Director, ROS Company  
Entuziastov St., 5A, Rm 02  
Dubna, Moscow Region 141980  
Russia**Sergey Saltykov**

Signal Processing, ROS Company

**Oleg Upensky**Geoton Company  
Box 28 Dubna-1  
Moscow Region 141980  
Russia**Andrey Polevik**Peleng Company, Special Construction Bureau  
Senior scientist  
INFRAD  
c/o TECHNOPOLE**BACKGROUND**

The Dubna International Centre of Research and Technology Development, TECHNOPOLE, is a trade group that represents several new start-up companies that have been spun off to commercialize technologies developed at the Atoll Scientific Research Institute in Dubna, a short distance from Moscow. Atoll appears to have been a center for the development of advanced acoustic systems for military, oil exploration, and oceanographic purposes. Advanced acoustic system hardware

(transducers and signal processors) and analysis software were developed at the institute.

As a result of the downsizing of support for military applications and the reduced support for other purposes in the constricting Russian economy, groups of scientists and engineers have formed small companies in an attempt to commercialize their technical knowledge and/or products for civilian purposes. Representatives from four small acoustic product companies came to Moscow to brief a subgroup of the panel under the TECHNOPOLE umbrella. The discussion of each company follows.

### **ROS Company**

The ROS Company, which may be the oldest of the four companies, was the only company with a product that was developed and ready for sale. ROS was represented by Mr. Valeryi Shevchenko as a company with expertise in subsea surveillance systems and communications systems. He and a colleague met the team at the ROS Company exhibit at a communications equipment trade show. The company exhibit was of hardware and computer displays for a seabed passive sonar system. The system was low frequency -- less than 1 Hz up to 5 kHz, with a sensitivity of 250 microvolt/pascal.

The wet part of the system consisted of multiple hydrophone arrays; each array was in a straight line with multiple arrays ganged onto an underwater data transmission line. Arrays might have thirty or eighty hydrophones. From four to eight arrays would make up the underwater systems. Analog to digital signal conversion was provided at each hydrophone, and electronic to optical signal conversion occurred in a regenerator at the array level to enable fiber-optic transmission to the shore station.

The dry part of the system consisted of a remote controlled power supply and an acoustic data analysis and display system that used an 80486 microcomputer. Very efficient data sampling, compression and analysis algorithms were claimed for the system, which, with TMS 320 S-30 chips for each four arrays, enabled effective and timely processing with a 486 microcomputer. Frequency, bearing, time, and target location (depending on array layout) could be displayed for up to five simultaneous targets per display. A database for classification of shipping targets is available from ROS. Larger projection displays could be incorporated if desired. The wet system could be retrieved and redeployed; the dry system is compact enough to reside in a mobile van. Other characteristics are in Figure Dubna.1 at the end of this site report. Figures Dubna.2 and Dubna.3 are photos that show the hydrophone -- piezoceramic of about 1.5 inch diameter -- and the hydrophone housing -- approximately 12" x 5" x 2" -- which contains the hydrophone and the a/d signal converter.

The ROS Company sees uses for the system as primarily one of surveillance of a national economic zone, that is, detecting the presence of unauthorized fishing vessels, for example. An alternative use might be in connection with seismic exploration for oil.

The company believes that its subsea system will be priced at only one-fifth of the price of such a system from Western countries. A minimum system with only two hydrophone arrays might be arranged for less than \$400,000, exclusive of chartering vessels to deliver it to the site.

The ROS Company expressed great interest in finding both buyers and partners for its system. The company has sold one system and expects to place it in service in the autumn of 1993.

### **Geoton Company**

Mr. Oleg Upensky of Geoton Company presented a multichannel seismic system to explore for oil and gas. Geoton is about two years old, with experience levels among company personnel of up to ten years in undersea digital systems. The unique feature of the Geoton system is its multichannel capability for data acquisition and processing. Up to 10,000 channels are possible in the system, which can enable three-dimensional views and greater accuracy for location of test drilling sites. Geoton claims that this will reduce the number of test wells by one-third. With the Geoton system in place, it is also possible to estimate undepleted reserves in productive oil and gas fields. See Figure Dubna.4.

Geoton has built several components for its system and tested them in the lab. Systems have been developed around the TMS 320 processor using algorithms developed solely in Russia, which has no access to the computer technology of the West. The Institute of Oil and Gas has deployed and tested a 12-channel system with good results.

Although Geoton does not manufacture, it will partner with other Russian companies to produce the system. Geoton believes it is well positioned to serve companies that will be conducting oil and gas exploration in the fields of Siberia and is looking for clients with that same interest.

### **Poleng Company**

Mr. Andrey Polevik represented a newly formed design bureau that specializes in high power, low frequency (below 1,000 Hz), acoustic emitters. Mr. Polevik is a senior scientist with many years of experience in emitter design, and is the holder of approximately 80 patents for acoustic devices. He discussed the designs of a sparker, a boomer, an electrodynamic, and a hydraulic emitter. Finally he discussed

the characteristics of a patented cylindrical emitter, especially for use in seismic operations.

The need for more durable electrodes in the sparker device has been solved by encapsulating them in a special liquid in which the high powered electric discharge takes place. The power in a single pulse from this large device (1.2 m by .6 m and weighing 300 kg) is 5 kJ, which is hydraulically transmitted through the encapsulation to the surrounding sea. Operational depth is up to 200 m. (See photo and specification in Figure Dubna.5.)

A high powered boomer induction pulsing emitter with a tunable frequency response was described. The device was tunable to provide maximum amplitude in the low frequencies -- 50 to 700 Hz. It was claimed to be the first such design available for deep water use, that is, up to 300 m. (See photo and specifications in Figure Dubna.6.)

Mr. Polevik has patented and produced a working model for a pulse resonant transmitter with high efficiency. The transmitter has a flat characteristic curve in the 10 to 300 Hz range through the use of reactive compensation, and has output power in the 3 kJ range. The transmitter shown in Figure Dubna.7 is electrohydraulic; it is purely electric at low power and can be purely hydraulic at high power.

Finally Mr. Polevik discussed the proposed development of a low frequency active array of cylindrical shapes that might be used for searching out oil and gas fields. The array would be arranged to fit down an oil or gas well casing and would operate in the 50 to 1,000 Hz range, with controls to produce a directed beam pattern along a horizontal plane. The total system would also include a multichannel receiver array. See Figure Dubna.8 at the end of this site report.

### **INFRAD Company**

A senior scientist from INFRAD described the Argus system that is being developed in partnership with other companies in the Dubna region. The Argus system proposes to use sonar emission tomography for the detection of fish shoals, currents and underwater waves, and sediment fallout rates. The proposed system would be purely passive and would have a maximum depth of 1,000 m, with a monitoring base line of 150 m that lies up to 200 km offshore. The pattern of surface noise would be understood through array processing as fish, currents, or sediment, and could be characterized as to depth, density, and school size of fish. The processing by each array would require the characteristics of the conditions in situ. The spokesperson for INFRAD explained that for about one year there had been basic work exploring the fine structure of hydroacoustic fields to support the concept of sonar tomography, but as yet there had been no funding to support experiments.

**SUMMARY**

The several private companies that have spun off from the Atoll Scientific Research Institute have strengths in development of low frequency hydroacoustic transmitters and receivers, and in the development of signal processing algorithms. The signal processing algorithms are very likely to be highly efficient since the companies have proposed multichannel receivers with only limited computing requirements. The possibility of sonar tomography for oceanographic data collection is an exciting one. One company, ROS, has manufactured a low frequency surveillance system that is inexpensive compared to similar equipment in the United States and Europe.

These strengths suggest attractiveness and potential for either commercial or research cooperative partnerships with the companies in Dubna.



## APPLICATION

The "Salma" and the "Semga" systems are most effective in continuous all weather monitoring of acoustic noise sources at the sea and in investigation of acoustic properties of marine environment and sea bottom structure.

The systems have the same structure:

- underwater part (hydrophone arrays, digital fiber optic communication line);
- on-shore part (interface, data processing and control center, remote power supply unit).

It's possible to install the on-shore part in premises or in truck (e.g. "KAMAZ").

The "Salma" is intended to detect and to control the activity of fishing boats, seismic prospecting vessels, drilling rigs and to protect 200-miles sea economic zones and state frontiers.

The "Semga" is intended to detect all kinds of vessels (including small motor boats) in marine nature reserve regions, bays, straits, lakes, rivers and its outfalls especially during spawning. Due to its passive mode of operation the "Semga" doesn't influence on marine environment.

The "Semga" system's on-shore part has two modes of operation: 1) manual mode (with one or two operators per shift); 2) autonomous mode (with transmission all necessary information and alarm signals to the data processing and control center using available communication channels).

The system's configuration depends from customer's requirements. The manufactures commit themselves to: delivering system's components to installation site; assembling, installing, tuning and verificating the system; training the personal; providing technical service.

## THE TECHNICAL CHARACTERISTICS:

	"SALMA"	"SEMGA"
— underwater data transmission line	fiber-optic	fiber-optic
— number of arrays, upto	8	4
— number of sensors in a single antenna, upto	80	30
— sampling rate in kHz, upto	1	3
— dynamic range of recieved signals in dB, upto	100	70
— coverage in standard weather conditions (sea-state 3-4, small vessels with radiated noise level about 1 Pa/sq.root(Hz)), km	200	100
— coverage area in the same conditions in sq.km upto	50000	1600
— max. installation depth in m, upto	1000	1000
— power supply in kW, upto	5	1
— on-shore equipment area in sq.m	30	12

## TERMS OF DELIVERY:

	"SALMA"	"SEMGA"
— price (underwater cable cost excluded)	\$3000000	\$1800000
— delivery time in days	300	300

Figure Dubna.1. Seabed Passive Sonar Systems to Monitor Traffic and Environment in Economic and Nature Reserve Regions SALMA and SEMGA

## Приёмник гидроакустический ПРГ-121

*1000m depth testing*

### Назначение:

Приёмник гидроакустический (гидрофон) предназначен для приёма гидроакустических сигналов и преобразования их в электрический сигнал. Приёмник гидроакустический применён в системе "Салма".

### Технические характеристики:

— номинальная чувствительность, мкВ/Па	250
— ёмкость электрическая, нФ	7 ± 1.4
— рабочая глубина, м	до 1000
— верхняя частота рабочего диапазона, кГц	5
— сопротивление изоляции, МОм	не менее 200
— диаметр, мм	46
— длина, мм	45
— рабочий диапазон температур, °С	-10 - +40
— вес, кг	0,3

### Условия поставки:

— стоимость, тыс. руб.	16,0
— срок поставки, дней	30



Figure Dubaa.2. Hydrophone (1)

## Антенный модуль

### Назначение:

Антенный модуль предназначен для размещения измерительного датчика (гидрофона, сейсмодатчика) с электронным блоком (предварительный усилитель, АЦП) на подводном кабеле типа СМПЭВГ и обеспечения герметичности. Антенный модуль применён в системе "Салма".

### Технические характеристики:

— рабочая глубина, м	до 1000
— габариты, мм	70x115x270
— вес, кг	2,5

### Условия поставки:

— стоимость, тыс. руб.	152,0
— срок поставки, дней	100

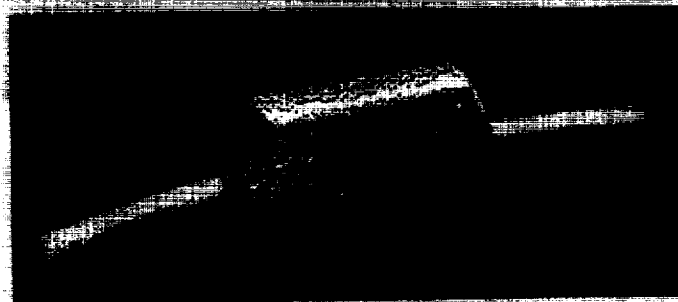
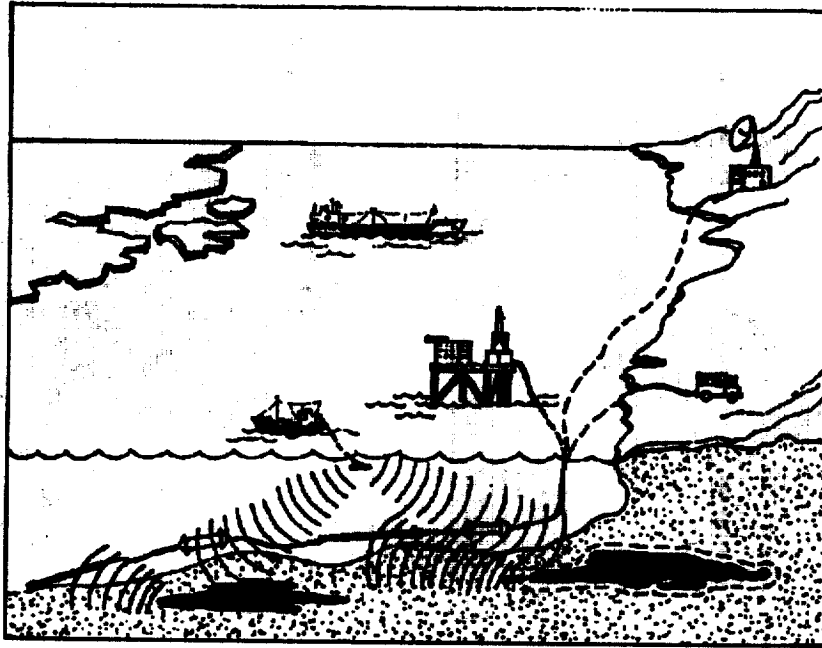


Figure Dubaa.3. Hydrophone (2)

The *Geoton* together with other enterprises from Dubna, possesses everything required to manufacture, deliver and install under a contract the SHELF Sea-Bed Multichannel Seismic System to explore oil and gas on the continental shelf as well as to monitor deposits being exploited.



The SHELF System is highly effective in a number of major activities of seismic exploration on the sea shelf, such as

- detailed seismic exploration, including spacial approaches;
- long-term geophysical prediction;
- exploration under ice and in regions of heavy traffic;
- monitoring of deposits being exploited, including inspection of deposits' outlines, production volumes, etc.

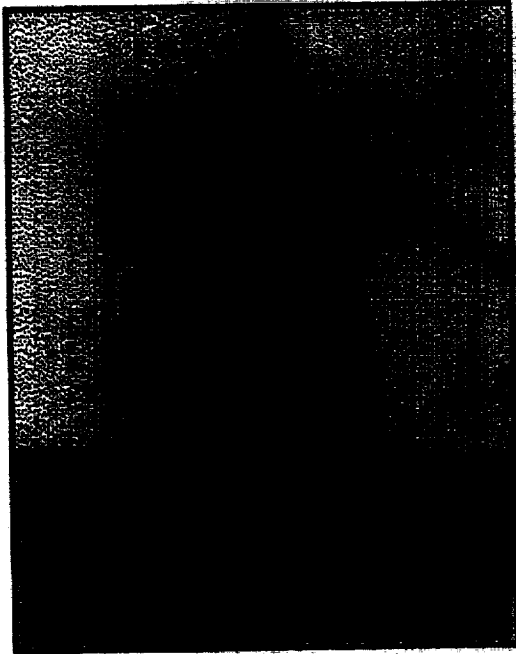
The system consists of:

- extended sea-bed modules comprising a great number of seismic sensors connected with combined devices for analog-to-digital conversion and data compression;
- sea-bed digital data transmission lines with repeaters;
- a built-in checking and diagnostic system;
- field processing equipment to control, check and store information;
- a combined unit to mate the receiving sub-unit with the processor and to supply power.

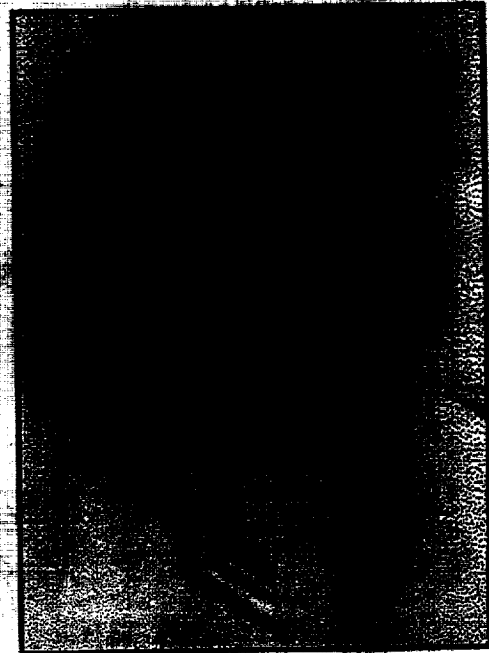
#### Specifications:

<i>Receiving arrays' frequency range</i> .....	<i>from 1 up to several hundreds Hz</i>
<i>Dynamic range of signals to be received</i> .....	<i>up to 115 dB</i>
<i>Number of individual channels</i> .....	<i>up to several ths</i>
<i>A single receiving module: length</i> .....	<i>0.8 km</i>
<i>number of channels</i> .....	<i>32</i>
<i>Wet-end installation depth</i> .....	<i>up to 1,000 m</i>
<i>Area covered</i> .....	<i>up to 1,000 sq.km</i>

Figure Dubna.4. "SHELF" Seabed Multichannel Seismic System to Explore Oil and Gas on the Sea Shelf



**Submersible capsule  
with electrode system  
of electric discharge  
acoustic source**

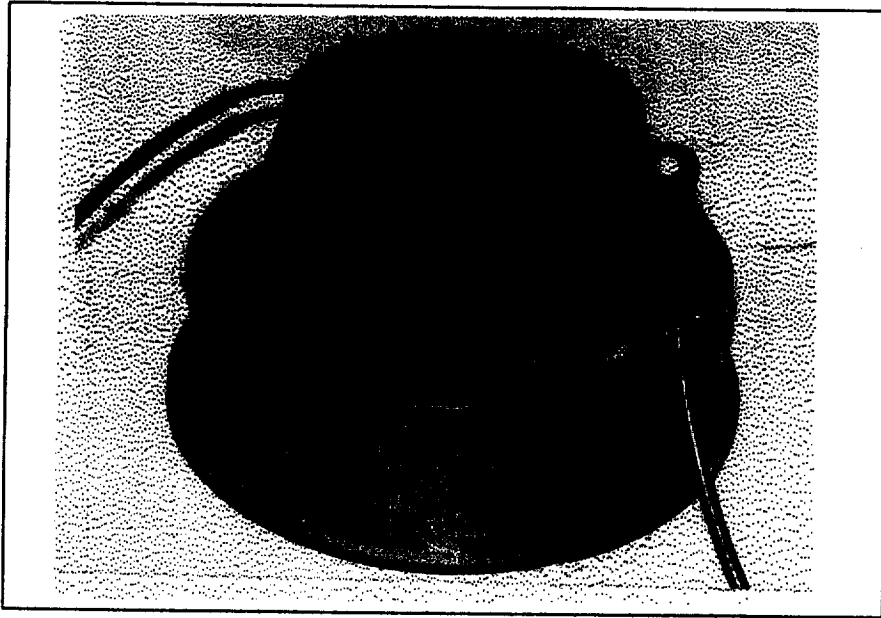


**Electrode system  
being installed  
in submersible capsule**

### Technical characteristics:

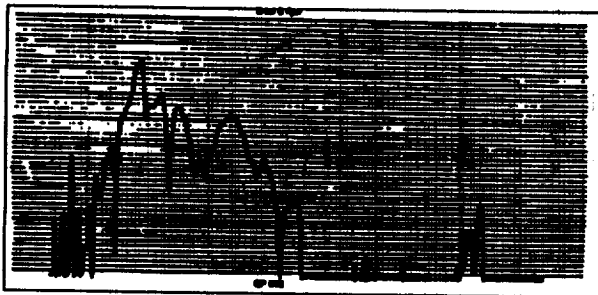
Power in pulse .....	up to 5 kJ
Pulse repetition frequency.....	up to 2 pulses per second
Frequency range .....	50 - 3500 Hz
Operation depth .....	up to 200 m
Voltage on electrode system from pulse current generator ..	20 kV
Weight (in air) .....	300 kg
Height .....	1.2 m
Diameter .....	0.6 m
Resource .....	$10^8$ pulses

**Figure Dubna.5. Underwater Electric Discharge Acoustic Source**

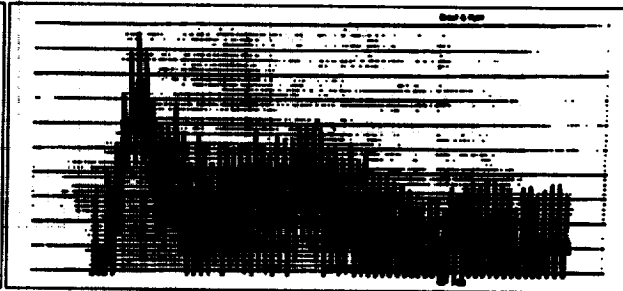


**Technical characteristics:**

- Power in pulse ..... 3  $\mu$ J
- Pulse repetition frequency ..... 10 pulses per second
- Frequency range ..... 50 — 700 Hz
- Continuous operation mode
- Tunable energetic maximum in low frequency range
- Operating depth ..... 300 m
- Weight (in air) ..... 300 kg
- Height ..... 0,4 m
- Diameter ..... 0,6 m



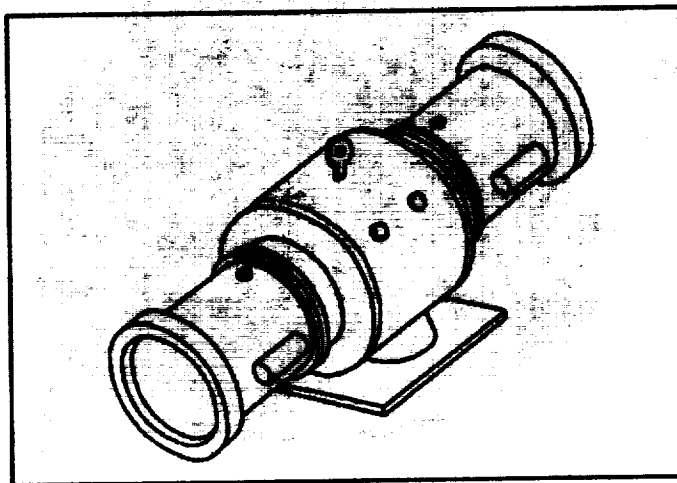
*Energy spectrum in frequency range  
50-300 Hz*



*Energy spectrum in frequency range  
50-700 Hz*

**Figure Dubna.6. Electromagnetic Source of Underwater Acoustic Pulses**

C-3



### Specifications:

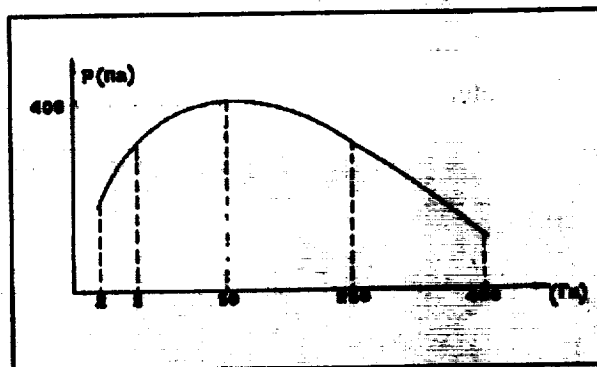
- power consumption - 3kW
- frequency range - 2 - 400 Hz
- effective range - 5 - 250 Hz
- operation depth - up to 300 m
- piston stroke - up to 15 mm
- number of transmitting pistons - 2
- piston diameter - 300 mm
- compensation drum diameter  $R_c$  - 450 mm
- max. height - 550 mm
- length - 700 mm
- weight - 200 kg

### Basic advantages over counterparts available:

- smooth amplitude-frequency response within 5 - 400 Hz range;  $5 - 250 \text{ Hz}$ .
- twice as much radiation efficiency due to impedance reactive component compensation;
- considerably higher specific acoustic power due to more effective use of the magnetic field volume.

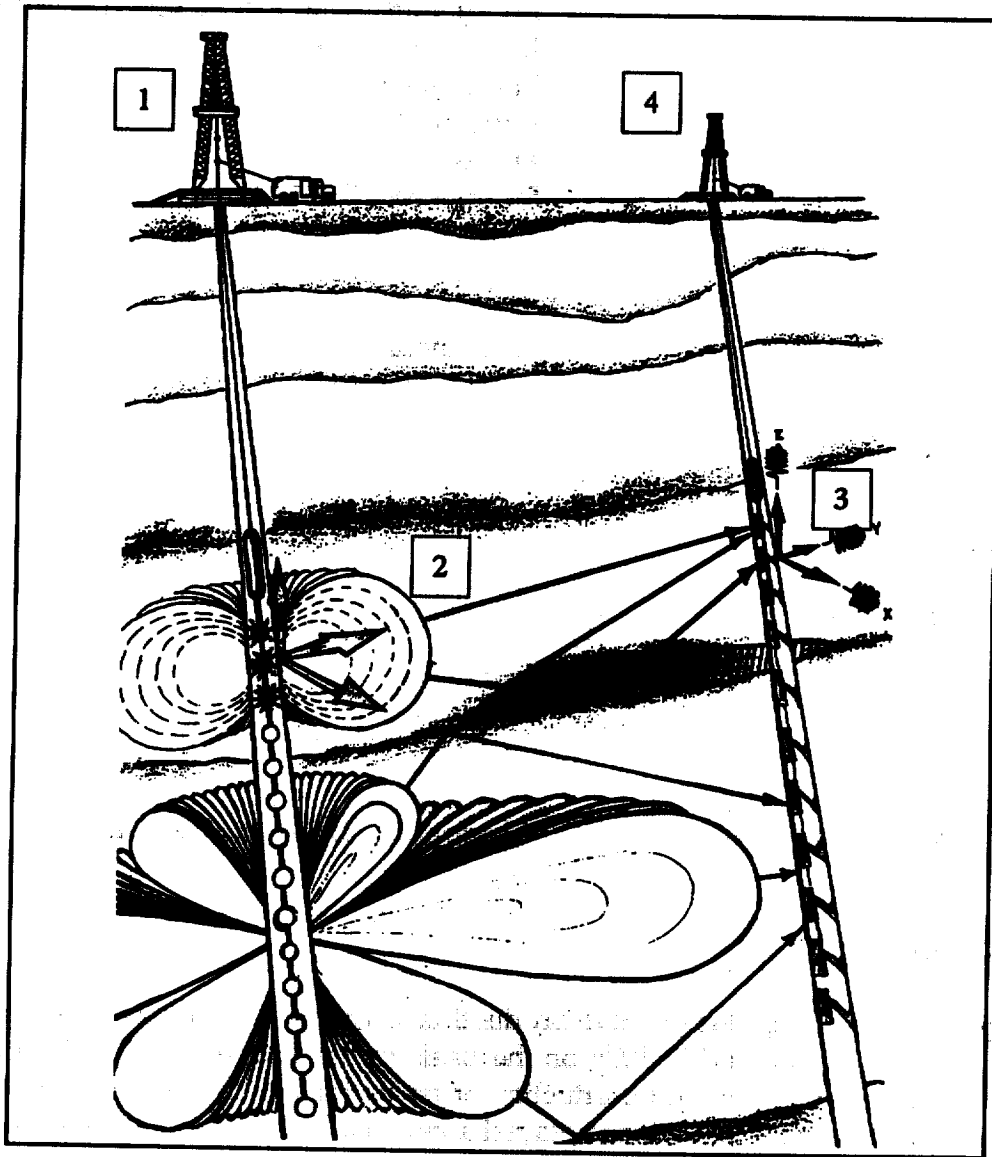
### Application:

Sonar systems verification, investigation of sound propagation in ocean environment etc.



Amplitude-frequency response

Figure Dubna.7. Underwater Magazine-Type Wide-Band Electrodynamic Source With Reactive Component Compensation



**Configuration**

- 1** - transmitting array control subsystem;
- 2** - LF linear transmitting array with vertically controlled directivity pattern;
- 3** - multi-element linear receiving array;
- 4** - computer centre (radiochannel provided).

**Figure Dabna.8. Low Frequency Logging System to Search Oil and Gas**

## Site:

**Energia  
Energia Scientific Production Association  
Lening Ultra 4a  
Kaliningrad  
Moscow 141070  
Russia  
Telephone: 816-24-08**

## Date Visited:

May 17, 1993

## Report Author:

C. Brancart

**ATTENDEES**

## WTEC:

R. Blidberg  
C. Brancart  
D. Walsh

## HOSTS:

Dr. Ing. Vjcheslaw A. Nikitin

Leader of Laboratory, PSS *Buran*

**BACKGROUND**

Energia is a leading design and production organization for the Russian space program. It was founded in 1974 on the basis of the Korolev Design Bureau. The agency is a major design and production organization of space launch vehicles and manned-related spacecraft. It has played a key role in the *Mir* space station and the *Buran* space shuttle.

WTEC panel members understood that the topics of discussion would include:

- o Power and propulsion
- o Communications and sensors
- o Control and automation
- o Fuel cells
- o Telemetry
- o Hull and mechanical robotics (manipulators)

The panel was met by the director of the agency and other association representatives. (The team's contact person was the only person to give team members a business card; his expertise is in the area of fuel cells.) The language barrier proved to be very difficult to overcome. The program plan was to view hardware for one hour and then have discussions for one hour.



The viewing of hardware was very interesting. First panel members saw the museum (open by invitation only) of the space program from *Sputnik I* to the present. There was an impressive array of actual hardware. The panel then went into the plant, a positive pressure volume where white coats were required, to see the shuttle and space capsules for Energia's ongoing space program. This is where the hardware is checked out before going into space.

The general configuration of the hardware was similar to that in the United States. The general area was much smaller than anticipated. Also, the general condition of test equipment and test stands appeared to be dormant and dated; the hardware was in a state of deterioration. The lack of funding was evident.

Following the plant tour, the panel returned to the conference room for discussions. The institute's representatives began the discussion with the question "What problems may we solve for you?" The panel then proceeded to extract information from the group. Panel members advised the Energia representatives of the panel's interest in space technology that could be applied to underwater systems and environments.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

### **Navigation**

The discussion focused on the use of acoustics with GPS updates. There is no new work being done in this area. The best estimate for system accuracy is  $\pm 1$  m in 3 to 4 km.

### **Communications**

Energia is conducting research and development in the area of acoustics, but could not tell the panel any specifics. Tests are now underway in fiber optics.

### **Energy**

The agency's scientists have been in the fuel cell business for twenty years. Their space program has been using alkaline fuel cells. Energia's scientists have been working on a direct current (DC) power supply system based on electrochemical generators with hydrogen-oxygen fuel cells for the *Buran* orbiter. This is the system that the agency plans to use on small submarines. A technical paper on this topic (in English) is listed in the references.

Panel members were also given a paper that summarized different energy sources in Russian. A rough translation of the information presented in the paper is provided in Table Energia.1.

**Table Energia.1  
Energy Sources**

SOURCE	STORED (RESERVE) ENERGY		USEFUL ENERGY (kWh/kg)	EFFICIENCY (%)
	(units)	(kWh/kg)		
NiCd		0.015 - 0.073	0.004 - 0.02	30
silver-Zinc		0.11	-	75
Mg-AgCl (sea water)		0.13	-	
Solid Chemical Compounds		0.09 - 1.40	0.038	5
			0.07	10

### Telemetry

On the space station, Energia has a 26,000 kB/sec data rate and 60,000 kB memory.

### SUMMARY

There were several people in attendance. Attempts to obtain information proved difficult. The director agreed that the association would supply the WTEC team with the names of all attendees and detailed answers to the questions that had been presented to Energia earlier.

A letter to WTEC from Intershelf's Moscow office in early 1994, citing Energia "specialists" as the source, did provide some clarifications and additional information. Intershelf's letter indicated that Energia is involved in the development of a manned submersible for up to 10 passengers with an operating depth of 100 m, and that Energia is active in the development of technologies for extraction of solid mineral resources from the sea floor at depths up to 6,000 m.

### REFERENCES

*Energia and the Space Program.* A general brochure in Russian.

"DC Power Supply System Based on Electrochemical Generators with Hydrogen-Oxygen Fuel Cells for the *Buran* Orbiter." Technical paper in English.

"Comparison of Energy Systems." In Russian.

**Site:** **Energia Space Firm**  
**Pionerskaya St. 4**  
**Kaliningrad 141070**  
**Moscow Region**  
**Russia**  
**Telephone: 095-581-9111**  
**Fax: 095-274-0025**

**Date Visited:** **May 17, 1993**

**Report Author:** **D. Walsh**

### **ATTENDEES**

#### **WTEC:**

**R. Blidberg**  
**C. Brancart**  
**D. Walsh**

#### **HOSTS:**

**Dr. Ing. Vjcheslaw A. Nikitin** **Leader of the Laboratory, PSS *Buran***

### **BACKGROUND**

These comments are a supplement to the report written by Mr. Claude Brancart, the primary author.

### **RESEARCH AND DEVELOPMENT ACTIVITIES**

Energia is the Russian institute for development and construction of manned spaceflight systems (another institute is responsible for unmanned systems). Energia-developed spacecraft such as the *Mir* series have established manned spacecraft mission records of many months. Due to the relatively large size of manned systems, Energia has developed the most powerful launching rockets (e.g., the *Proton* series) in the world.

The WTEC team's interest was in spacecraft systems' components, such as life support, compact energy sources, control designs, and so forth. Also, the team had been informed that Energia was involved in the development of a manned submersible with a company called Intershelf (see the report on the WTEC visit to that company below).

Currently Energia continues work on its *Buran* space shuttle system. The WTEC team had the opportunity to board the prototype of this spacecraft.

### **Life Support Systems**

Energia's life support systems design was conservative and simple.

### **Energy Systems**

Batteries and fuel cells appeared to be similar to those that are state of the art in the West. Energia has been working on fuel cell development for the past twenty years. The latest system, Photon, is onboard *Buran*. This is an  $O_2$ -Alkaline unit similar to that being used by NASA's Space Shuttle Program. The agency's scientists are using nickel-iron primary batteries, which were developed by the LUCH Institute near Moscow (WTEC did not visit LUCH during this trip). They have done some experimentation with hydrazine and gotten as far as prototype testing, but no flight systems have been developed.  $O_2$ - $H_2$  batteries are also in laboratory testing. No nuclear thermionic power systems are used here. (However, the Soviets did have some sort of small nuclear reactor for spacecraft, and they went into space. The United States has even bought one recently, so it is not clear why Energia did not mention this. Perhaps it was developed by a competing institute).

### **Control Systems**

Energia's control systems seem to be less complex (requiring more piloting by the crew) than those used by NASA for manned spacecraft.

## **SUMMARY**

Most of the visit time was occupied by visits to Energia's museum, large prototype construction hall, and hall of history. The museum featured virtually all of the Soviet and Russian manned spacecraft (usually the actual cabins of the vehicles) dating back to the very first *Sputnik*. The time frame represented by the hardware in the museum was nearly a third of a century. The number of vehicles and variety of designs were very impressive and a matter of great pride to Energia.

In the prototype construction hall, the prototypes of all of the currently operational manned spacecraft, including the *Buran* space shuttle, were on display. The team was told that the full operating prototype was set up in this hall to help overcome any in-flight difficulties encountered by the flight vehicle. Energia engineers would attempt to duplicate the problem on the prototype and then advise the cosmonauts about how to fix it in flight. Although the walk-through was fairly brief, it appeared that there were from six to eight prototypes set up in the hall. Only a few people appeared to be working in this area.

After visiting the construction hall, panel members participated in some brief discussions about the WTEC team's goals. Ten Energia representatives were present in the conference room. Team members found that there did not seem to be any technical areas of interest (i.e., applicable to deep submersibles) that could be considered innovative or unknown in the West.

Energia, like virtually all high-technology institutes in the former USSR, is suffering from severe funding cutbacks. For example, their space shuttle has only flown twice, and only once in the manned mode. However, due to the low cost and high efficiency of their launch rockets, there is considerable interest in the West to acquire lower cost launching systems for satellites. Also, Energia has been working with NASA on the redesign of space station *Freedom* in an effort to reduce its cost. While this institute is looking at diversification, the main future for its intellectual and physical assets lies in cooperative (and funded) space programs with the West.

As the team left the institute, members were taken through the hall of history, which displayed some very early photographs, records, and artifacts of Russian/Soviet aeronautical, rocket, and space pioneers.

## CONCLUSIONS

The visit to Energia was very interesting, but it made no contribution to WTEC's requirements. While Energia had received a set of WTEC's technical questions, agency representatives did not directly address them at the meeting. They did promise to send answers to the team in Moscow before the end of the week. Additional information from Energia was relayed several months later via Intershelf, as noted above in Mr. Brancart's site report. This consisted of some corrections to Tables 3.4 through 3.6, with the some additional information on Energia's activities in ROV development and ocean floor mining.

**Site:**

**General Physics Institute  
Russian Academy of Sciences  
1, Lotnaya St.  
Moscow 100987  
Russia**

**Date Visited:**

**May 21, 1993**

**Report Author:**

**D. Walsh**

**ATTENDEES****WTEC:**

**B. Mooney**

**D. Walsh**

**HOSTS:**

**Professor Fiodor Bunkin**

**Corresponding Member, Russian Academy of Sciences; Head, Wave Phenomena Department; Vice Chairman, Hydrophysics Council of the Russian Academy of Sciences**

**Professor Konstantin I. Voliak**

**Head, Hydrophysics Laboratory, Department of Wave Phenomena; Member, Hydrophysics Council of Russian Academy of Sciences; Head, International Programs Commission of the Institute**

**Dr. Valery Petnikov**

**Head, Acoustic Ocean Sounding Laboratory, Department of Wave Phenomena**

**Professor Alexei Bunkin**

**Senior Research Associate**

**Dr. Alexei Maliarovsky**

**Senior Research Associate**

**BACKGROUND**

The Institute of General Physics was founded in 1982. Its director is Academician A.M. Prokhorov, who shared, together with the American Charles Townes, the 1964 Nobel Prize in Physics for their work in developing the laser.

The institute has nine departments, two independent laboratories, an instrumentation design bureau, and a patent division. The team's visit was primarily concerned with the institute's work in devices for oceanographic research. While several of the departments contribute to marine-related research, the majority of the work is done

by the Department of Wave Phenomena. This department is divided into seven laboratories:

- o Hydrophysics
- o Applied Optics and Ultraacoustics
- o Nonequilibrium Macrokinetics
- o Laser Wave Measurement
- o Acoustic Ocean Sounding
- o Physics of Liquid
- o New Radiation Detectors

The team spent about two and a half hours at the institute. The entire visit was conducted in Professor Bunkin's office, where the team was briefed on the oceanographic-related work of the institute. The majority of this work involves the use of lasers and low frequency acoustics to measure ocean processes.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

### **Ocean Remote Sensing by Airborne Laser Systems**

Since beginning work in 1983, the institute has developed and tested a multipurpose airborne laser system that can detect the thermocline in the ocean down to depths of 65 m. The laser platform (helicopter or aircraft) is at an altitude of 500 m. Successful tests have been conducted in the Kara and Barents seas in the Arctic as well as off the Kamchatka Peninsula in the Pacific Ocean. The original purpose of the system was submarine location. This is accomplished by detecting the interference patterns in the surface and subsurface (on the thermocline) wave fields due to passage of a submarine.

The airborne laser for this application is a pulsed Nd:YAG unit with 700 millijoules power output. For thermocline detection the power level is 100 to 150 millijoules (from the third and fourth harmonics of the primary power level) and a wavelength of 532 nm. A 30 cm diameter mirror is used to reflect the laser output signal through a transmitting telescope to the ocean and to receive the return signals.

Over 1,000 hours of airborne testing have been done with this system. Currently it is fitted into a Kamov KA-32 helicopter.

### **Ocean Surface Materials and Processes by Laser**

Through using different parts of its frequency band, this same airborne laser system is capable of several different types of remote ocean-environmental measurements:

- o Location of the thermocline
- o Location of near-surface scattering layers

- o Sensing dissolved organic matter
- o Detection and analysis of sea surface oil films
- o Identification of other substances at sea surface
- o Detection of phytoplankton

Several of these measurements are made by laser energy fluorescing the substances at or near the sea surface. Determination of the type of substance is by spectrographic analysis of the returned signal using a polychromator and a spectro-temporal analyzer.

The complete system consists of several devices that can provide multipath signal outputs to the user:

- o The Lidar (laser)
- o Microwave radiometer
- o Gamma spectrometer
- o Photoacoustical gas analyzer
- o Lidar altimeter

The team was told that just a few days before its visit the institute was able to do plasma excitation of the sea surface with its airborne laser system. This would permit material analysis down to the molecular level.

#### Laser Bathymetry

This system also permits making bathymetric measurements where, depending on clarity, water depth can be as great as 25 m.

#### Low Frequency Acoustics for Ocean Measurements

The institute's Acoustic Ocean Sounding Laboratory has been using a towed fish, equipped with two transducers, in the Barents Sea to do sound path research at 100 Hz and 300 Hz frequencies. The output powers are 100 W and 300 W, respectively.

The institute's scientists can stream this array from a ship or install it on the seafloor (where it is battery powered). The seafloor receiving system consists of 12 hydrophones with a reception band of 10 to 1,000 Hz. The vertically oriented array is 70 m in length and can work as deep as 500 m. The array has sensors to measure depth and tilt angle to compensate for these variables in signal processing. Through use of buoys, the acoustic data can be transmitted by radio to a remote station up to 10 miles away.

The institute's scientists and engineers have sent acoustic signals over a 500 km path to determine losses for both vertical and horizontal paths. These data are useful for development of acoustic tomography. The institute's technical personnel are



cooperating with Dr. Lynch of the Woods Hole Oceanographic Institute (WHOI) in this work. Mr. Craig Dorman, Director of WHOI, and representatives of Science Applications International Inc. (SAIC) have visited this laboratory.

The institute hopes to do work in the Arctic Basin for long range acoustic tomography (perhaps in cooperation with Mr. Walter Munk's program). The Russian equipment will be set up at North Island in Franz Joseph Land. In addition, the institute plans to do shallow water propagation variation studies in the Barents Sea.

### **Atmosphere Ocean Communications**

Academician Alexei Bunkin described some very new work the institute is doing with an optical-acoustic communication system between submarines and aircraft. The aerial platform would use a very high power, modulated laser directed at a very small area of the sea surface. The power output of the laser would be high enough to create mechanical surface roughness that could be sensed by the submerged platform. Through signal analysis of the aperiodic surface roughness, the intelligence would be pulled out of the surface noise.

The submerged platform would use an upward directed very high frequency (100s of MHz) sound source to create a similar roughness on the sea surface. This would be detected by a high frequency, cross-polarized radar. The aperiodic roughness pattern would then be converted into a communications signal.

To date, this concept has been tested from an aircraft at very low altitudes.

### **SUMMARY**

While it is clear that most of the work presented to the team was originally supported by major Soviet Navy efforts to successfully do nonacoustic antisubmarine warfare (ASW), the end of the Cold War has provided an opportunity to channel a lot of this enormous investment into civil applications. If these laser systems can be put into service for a reasonable price, then they could find wide use for commercial fisheries development and marine pollution detection and monitoring.

The low frequency acoustics work, which contributes to the current international effort in acoustic tomography, will be vital in helping to understand the global climate system in terms of ocean warming and cooling.

As with some of the team's other site visits, the information given to the team was very interesting and often surprising. As scientists and engineers, team members could certainly appreciate the emergence of so many things that had not been revealed previously. Unfortunately, much of this information was not relevant to the WTEC charter for assessing deep submergence technologies in the former Soviet

Union. This was not the fault of the institute's representatives, but was due to the team's uncertainty about which organizations do what in present-day Russia.

#### **REFERENCES**

**USSR Academy of Sciences Institute of General Physics. 1990. A descriptive book. The Wave Phenomena Department is described on pages 25 to 29.**

**"Uses of Lidars for ocean remote sensing." Briefing paper.**

**Site:** **Institute of Applied Physics (IAP)**  
**Russian Academy of Sciences**  
**46 Uljanov Street**  
**Nizhny Novgorod 603600**  
**Russia**  
**Telephone: 8312-366669**  
**Telex: 161129 FIZIK SU**  
**Fax: 8312-366717**

**Date Visited:** **May 18, 1993**

**Report Authors:** **B. Mooney and D. Walsh**

### **ATTENDEES**

#### **WTEC:**

**B. Mooney**  
**D. Walsh**

#### **HOSTS:**

**Andrei V. Gapanov-Grekhov**  
**Professor Lev A. Ostrovsky**  
**Dr. Mark M. Slavinsky**

**(Academician) Director, IAP**  
**Head of Laboratory**  
**Deputy Director of Hydrophysics and**  
**Acoustics; Head, Dept. of Ocean Acoustics**  
**Sr. Scientist, Vibroacoustics Laboratory**

**Dr. Victor I. Turchin**  
**Professor Litvak**

### **BACKGROUND**

The first event of the visit was a 45-minute meeting with Academician Gapanov-Grekhov to discuss the WTEC program and, in general, the ocean-related work of his institute. This meeting was also attended by both Professor Lev Ostrovsky and Dr. Mark Slavinsky.

The Institute of Applied Physics (IAP) works in both fundamental and applied research areas. There are five departments in IAP:

- o **Plasma Physics and High Power Electronics**
- o **Hydrophysics and Hydroacoustics**
- o **Solid State Physics**
- o **Engineering and Physical Department**
- o **The Central Department (institutional support)**

The director discussed the ocean-related activities of these departments and provided the panel with a booklet providing the same information.

A major thrust now is to convert as many activities as possible from defense to commercial work. The institute currently has contract work with U.S. companies General Atomics and Varian Associates. The institute also seeks to apply its know-how to detect anomalies in the sea (developed for ASW purposes) through environmental monitoring.

The Department of Hydrophysics and Hydroacoustics, where most of IAP's ocean-related work was concentrated, included:

- o Remote diagnostics of ocean phenomena
- o Submarine location, by acoustic and nonacoustic means
- o Low frequency acoustics in the sea
- o Phased arrays in sound transmission and receiving
- o Signal processing
- o Radar and optical (e.g., laser) systems
- o Physical modeling of the oceans
- o Mathematical models of the oceans

The Solid State Physics department has been working on superconducting materials to develop conductors that will work efficiently at warmer temperatures. The director said they had not been working on magnetohydrodynamic (MHD) propulsion devices.

The director said that IAP used to work extensively in the oceans worldwide; however, the institute has a hard time obtaining access to ships, which are very costly. In particular he mentioned the situation with the P.P. Shirshov vessels *Ioffe* and *Vaviloff*, which his staff had used. As noted in the WTEC report on the Shirshov Institute, *Ioffe* is already on lease to a German company as a passenger vessel. It is feared that *Vaviloff* may have the same fate.

Academician Gapanov-Grekhov also spent some time talking with the panel about the proposed Ocean Shuttle Project, a joint venture between the Soviet Central Design Bureau and the ECS Group of Canada. Planning had been taking place during the final months of the USSR, and this work has not been resumed. Academician Gapanov-Grekhov believes this project should be resumed; he is a strong supporter of the unique work that could be done with a built-for-the-purpose nuclear submarine oceanographic platform. He feels that the Ocean Shuttle concept is more feasible than the alternative of converting a former military submarine for this purpose. Both projects are currently being discussed between the Russian and American oceanographic communities.

Next, the panel embarked on a two-hour tour of several laboratories and offices in the institute where ocean-related work was being conducted.

Prior to leaving the institute, the panel again met at the director's office for final discussions. He mentioned that he is Chairman of the State Committee of Hydrophysics, and that this keeps him involved with related work in other Russian institutes. This also gives him a major voice in the directions that Russian hydrophysics will take.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

In the visits to the laboratories and offices, the team was briefed on the following areas.

### **Stratified Fluid Tanks**

The Hydrophysics Laboratory at the IAP has two tanks that permit experiments in a two-layered stratified fluid system. The smaller tank is 5.5 x 3.3 x 2.7 m and the larger is 20 x 4 x 2 m. In operation, the lower layer of fluid is cooled and the upper is heated to provide a temperature difference of up to 16°C and a maximum gradient of 0.6°C per cm. Once the layers are established, the stratification can remain for prolonged periods without much additional heating and cooling.

In both tanks it is possible to circulate the two layers independently. In the large tank, wave-making devices can excite either or both layers. In this way, internal waves can be induced in the tank. The wave-making device can vary force from a few grams to 1 kg.

A towing carriage permits experimentation with how various shapes (such as submarine hulls) interfere with the stratified system, and whether this interference is measurable at the surface. The panel saw a tow model whose shape appeared quite close to a U.S. Navy SSBN. Carriage tow speeds can be varied from 1 cm/sec to 1 m/sec.

The Department of Hydrophysics and Hydroacoustics is working on remote diagnostic methods of detecting submarines; low frequency ocean instrumentation; low frequency phased arrays, antennae, and projectors; methods of determining depth; and locating submarines and ocean phenomena using radar and optical systems. The department is experimenting with a synthetic aperture radar to detect the surface wave reduction "scar" or "slick" caused by a moving submarine. The scientists and engineers claim that a moving submarine alters the normal internal wave pattern and that by use of a synthetic aperture radar, scatterometer, and passive optical devices, the internal relationships between surface waves and internal waves can be measured.

### **Anechoic Chamber**

This appeared to be a fairly standard chamber for testing acoustic transmissions and for measuring radiated self-noise.

### **Doppler Current Meter**

Doppler current meters and ship speed logs have been in use for several years. The unit that panel members were shown at IAP was designed to be an oceanographic instrument. The device has three beams of either 30° or 120°.

### **Mobile Linear Hydroacoustic Antenna**

This system is capable of making very accurate acoustic spectrum measurements of passing vessels. The 200-m long array is portable and consists of 64 hydrophones spaced 3 m apart; operating depth is 300 m. The frequency range is from 99 to 300 Hz; the upper range can be extended to 2,000 Hz. IAP is offering the array system for \$20,000 with a five-month delivery time. The signal processing software is an additional \$12,500. The system has been successfully field tested in the Barents Sea and near the Kamchatka Peninsula.

### **A Shipboard Multisensor for Ocean Surface Roughness Measurements for Detection of Subsurface Processes**

This system used radar, acoustic, and optical devices to sense the sea surface to detect anomalous perturbations caused by internal processes. This can be the passage of a submarine or natural events such as internal waves.

The Department of Plasma Physics and High Power Electronics is working on the following projects:

- The transfer of high energy over great distances. The energy would be produced by thermonuclear fission. The department is experimenting with current without induction.
- A joint venture with General Atomics in high frequency plasma heating.
- Diagnostic monitoring of the environment to detect impurities. This involves use of radio-acoustics.
- Super conductivity, micro- to nano-structured, X-ray lithography, soft X-rays, long wave X-rays of 100 angstroms, and MHD only in relation to plasma (no MHD work in sea water).
- The nonlinear optics and laser people are working on chaos, mathematics, mathematical physics, nonlinear lasers, wave front reversal, structure of lasers

of  $10^{-16}$  pulse duration, and concentrated energy of  $10^{16}$  W/cm ("Star Wars" technology).

## **SUMMARY**

It was clear that a three-hour visit to the IAP was insufficient to get into very much detail about the programs and devices being developed by this institute. It was also clear that everyone the team met there was most cooperative and interested in informing team members about their work. Due to time constraints, the team was not able to spend much time at each office or laboratory. A detailed visit to IAP should occupy two to three days. The panelists were impressed by everyone's eagerness to establish working arrangements with Western research institutions and commercial companies.

## **REFERENCES**

*Institute of Applied Physics of the Russian Academy of Sciences. Descriptive booklet on the IAP.*

"Hydrophysics Laboratory of the IAP." Description of the IAP's two stratified fluid tanks.

"Universal Acoustic Doppler Current Profiler (ADCP)." Brief description of the system.

"The Acoustic Source Image Reconstruction from the Near-Field Measurements." Theory, design, and description of the mobile acoustic array.

"A Computer Ship Complex of Remote Sensing for Investigation of Ocean Subsurface Processes." Describes the multisensor shipboard system for measuring man-made or natural aperiodic surface roughness.

"Activities and Organization of the Hydrophysics Scientific Council of the Russian Academy of Sciences."

Division of Hydrophysics and Hydroacoustics. Pamphlet.

Deep-Water Self-Sustained Station MDS-48.

On-Board Control System BSU-1,2.

Noise Suppression Problem. Proposal.

**Site:****Intershelf****Koshewnicheskaya St. 11****Moscow 119114****Russia****Telephone: 236 26 93 or 236 25 81****Fax: 236 23 01****Telex: 411782 SHELF SU****Date Visited:****May 17, 1993****Report Author:****C. Brancart****ATTENDEES****WTEC:****R. Blidberg****C. Brancart****D. Walsh****HOSTS:****Sergey Yu. Karev****Director****Andrey V. Nesterov****Moscow Subsidiary Director****Valentina N. Telnova****BACKGROUND**

Intershelf is a joint Russian-British venture led by the British firm of J.P. Kenny. Within J.P. Kenny, there are 12 subsidiaries, 18 offices, and a total of 300 people. In the Commonwealth of Independent States (CIS) there are 10 offices. The office that the WTEC team visited appeared to be a management and engineering office. Fabrication is done elsewhere. The discussions conducted were related to Intershelf's underwater hardware capabilities.

In a development subsequent to the WTEC panel's visit, a new Russian-British company, Elvi-Intershelf, was registered in October of 1993, with Sergey Karev as its Director. All of Intershelf's projects in subsea vehicles, tourist submarines, and all defense conversion contracts have been transferred to the new company. Elvi-Intershelf is looking for additional Western partners, offering access to CIS markets and resources (including the possibility of oil and gas development).



## **RESEARCH AND DEVELOPMENT ACTIVITIES**

Numerous brochures were provided, and the panel viewed a video of Intershelf's underwater crawler program. Information on Intershelf's systems are presented below.

### **Crawlers**

Crawlers are tracked devices with various payload configurations. Intershelf has developed on paper a complete line of underwater crawlers in the one-ton, eight-ton, and thirty-ton categories. Brochures were presented for the various sizes and concepts. In 1991, Intershelf fabricated and tested the Beta unit, an eight-ton vehicle. There appeared to be no sophisticated control or other support systems.

### **ROVs**

Intershelf has developed the *Fish* series of remotely operated vehicles (ROVs). These ROVs are very similar to available hardware.

#### ***FISH 102***

The *Fish 102* is a small ROV with a 100 m operating depth. Its basic dimensions are: 35" x 18" x 14" and 35 lbs in air. Negotiations are underway with a Western distributor. The price was estimated at approximately \$20,000.

#### ***FISH 103***

*Fish 103* is a larger ROV with basic dimensions of 24" x 16" x 10" and 106 lbs in air. It is rated for 6,000 m operating depth. This vehicle has been designed to operate from a large underwater garage assembly or from another manned vehicle because of its 100-ft long umbilical. The vehicle was used to survey the downed Russian submarine *Komsomolets*. The *Fish 103* has a price tag of \$80,000 (presumably without the underwater garage assembly).

### **Others**

*Diver TV*. Intershelf has hard-canned underwater TV systems for use by divers. The black and white version sells for \$2,000 and the color version sells for \$4,000 to \$5,000.

*Tourist Submarines*. Intershelf has designed a ten-seat underwater tourist submarine, the *SubTour 10/100*. The vehicle is available for sale for \$900,000. The submarine is to be certified under Russian guidelines, which the panel was told is comparable to ABS, DNV, and/or Lloyds of London. Intershelf firmly believes that there is a market for these vehicles.

**Designs.** The scientists and engineers have conducted many design studies for underwater restaurants and other underwater tourist facilities. They have not conducted any AUV work, nor do they intend to do so in the near future.

## **SUMMARY**

Intershelf has some interesting products. However, it appears that Intershelf is pricing its products parallel to comparable Western units and not what it would cost the company to fabricate the units. Intershelf's strongest move would be to lower its prices.

The director advised the team that Intershelf is working on a disc that will describe its underwater hardware, design concepts, and capabilities. The panel was advised that the company would send one.

## **REFERENCES**

J.P. Kenny Intershelf. *General Capability Brochure*. Topics include: offshore design and project management, production, marine operations, underwater equipment, and underwater robotic systems.

Concept Drawings. Summary of 1-, 8-, and 30-ton Bottom Crawler Series. Includes: *Alpha* (8 tons), *Beta* (8 tons), and *Gamma* (30 tons).

*Fish 102*. Brochure.

*Fish 103*. Brochure.

*Diver TV System*. Brochure.

*SubTour 10/100*. Underwater Tourist Submarine brochure.

**Site:** Intershelf (J.P. Kenny Intershelf)  
Kozhevnikovskaya St. 11  
Moscow 113114  
Russia  
Telephone: 095-235-9893  
Telex: 411782 SHELF SU  
Fax: 095-235-5287

**Date Visited:** May 17, 1993

**Report Author:** D. Walsh

### **ATTENDEES**

#### **WTEC:**

R. Blidberg  
C. Brancart  
D. Walsh

#### **HOSTS:**

Sergey Yu. Karev  
Andrey V. Nesterov

Director  
Moscow Subsidiary Director

### **BACKGROUND**

J.P. Kenny Intershelf is a joint venture company formed in 1988 by J.P. Kenny Group of Companies of the United Kingdom and two Russian partners, Moscow Institute of Civil Engineering and Promstroibank. Their basic business is to provide engineering, economic, and management services for oil and gas development onshore and offshore in the CIS. Intershelf has 300 employees at nine locations in Russia, Ukraine, Latvia, and Dagestan.

While the CIS joint venture has eight divisions, of specific interest to WTEC are J.P. Kenny Intershelf's Underwater Robotic Systems and Underwater Equipment Divisions. This emphasis in the USSR/CIS began in 1989. While it was not clear from the business cards which division the panel was visiting, the principal discussion topic for the visit was undersea equipment.

This was only an office visit: lunch was provided, but the team saw no equipment or laboratory or production facilities. Although from one to four Intershelf representatives participated at various times in the meeting, Mr. Sergey Yu. Karev acted as host and moderator of the discussions.

## RESEARCH AND DEVELOPMENT ACTIVITIES

### Seafloor Vehicles (Structural Ballance)

Very limited information was provided in this area. Information printed in the J.P. Kenny Intershelf brochure showed one photograph and two drawings of underwater tracked or wheeled vehicles. They appeared to be similar to structurally reliant remotely operated vehicles developed in the United Kingdom for underwater pipeline and telecommunications construction, repair, and inspection. This is not a particularly new technology; such vehicles are operational in the West.

From these discussions, it was not clear if such technologies have been developed in Russia or elsewhere in the CIS.

### ROVs

In addition to the brochure pictures of the seafloor ROV, panel members received product brochures and saw videotapes for two other ROVs, *Fish 102* and *Fish 103*. Work began on these vehicles in the USSR in 1979, so these represented technologies imported into the J.P. Kenny Intershelf joint venture.

*Fish 102* is an open frame ROV that appears similar in design to the early *Phantom* ROVs developed by Deep Ocean Engineering in Oakland, California. Its performance is roughly comparable with the *Phantom 300*. *Fish 102* has a 100-m operating depth and carries a black and white TV camera. The price is roughly \$20,000, and twelve to fourteen have been sold.

*Fish 103* is a deep diving (6,000 m) ROV that was used to explore the wreck of the lost *Mike* class nuclear submarine *Komsomolets* in the Norwegian Sea. For this work, it was carried onboard the *Mir* class manned submersibles (there are two) and used in a fly-off mode with a 30 m umbilical. This ROV is also fitted with a black and white TV camera system. For surface-tended operations, a tether management system is provided. The approximate price of this vehicle is \$50,000. Intershelf has had three purchase inquiries from the United Kingdom.

### Tourist Submarines

In cooperation with Energia (see Energia site reports in this appendix), Intershelf is offering a ten-passenger tourist submarine, *Subtour 10/100*. None have been sold yet; they will be built at Energia and will require eighteen months to construct upon receipt of the order. Mr. Karav said that Intershelf has relations with several possible producers of tourist submarines with passenger capacities from two to fifty people, and depth ratings from 50 m to 600 m. The company is prepared to rent, lease, or joint venture with operators of the submarines.

## **Miscellaneous**

*Underwater TV System.* The team was given a brochure on Intershelf's Diving TV Systems (DTVS). Designed for operations to depths of 80 m, these systems come with a 100 m umbilical. There appear to be three versions of the camera system, with resolutions ranging from 200 to 450 lines per inch. The cameras have a single light mounted on top of the housing. The lowest price for a black and white system is about \$4,000.

*Product Data Diskette.* Mr. Karev said that Intershelf is now producing a data diskette that describes all Russian suppliers of undersea equipment. He hopes this will help in marketing the company's undersea equipment to the West. The panel asked to receive copies of the diskette when available.

## **SUMMARY**

This office of J.P. Kenny Intershelf appeared to be largely concerned with the promotional and marketing aspects of its undersea technologies. With perhaps the exception of the diver TV system, it did not appear that Intershelf had directly developed any of the equipment shown to the panel. Since the major foreign partner is a United Kingdom company, there should be good access to western markets through J.P. Kenny.

Although J.P. Kenny Intershelf showed the panel ideas, concepts, and hardware for ROV and passenger submersibles, no information was provided about autonomous unmanned vehicles. The team assumed that this is not a major commercial development direction for Intershelf at this time.

## **REFERENCES**

*J.P. Kenny Intershelf. Corporate Brochure.*

*Fish 102 ROV. Product information sheet.*

*Fish 103 ROV. Product information sheet.*

*Diving TV Systems. Product information sheet.*

*Subtour 10/100 Tourist Submarine. Brochure.*

**Site:**

**Intershelf  
Ul. Galernaya, 69/71  
St. Petersburg 190000  
Russia**

**Date Visited:**

**May 21, 1993**

**Report Author:**

**M. Lee**

**ATTENDEES****WTEC:**

**N. Caplan  
A. Kalvaitis  
M. Lee**

**HOSTS:**

**Andrei Voronov  
Alexander Finkelshtain**

**Director  
Technical Director**

**BACKGROUND**

**Intershelf is the St. Petersburg division of the Moscow-based company J.P. Kenny Intershelf. It is a joint venture company that pulls together Russian and British interests in underwater technology. The British partner is J.P. Kenny of London. Russian partners include Promstroibank and the Moscow State Building University. The company specializes in subsea vehicles and submersibles, and has a marketing focus on the mining, gas, and oil industries on the continental shelf. The company started in 1990 with three people and has now grown to eleven people. The company currently produces two products: a hand-held TV camera that is used by divers, and a small remotely operated vehicle. Intershelf also designs electromechanical, optical, and acoustic pipeline inspection systems. Intershelf would like to evolve to include environmental monitoring in the future.**

**RESEARCH AND DEVELOPMENT ACTIVITIES**

**The product that was most emphasized was the low cost ROV *Fish 102M*. This ROV sells for \$14,000, including cable handling, topside control, and a spare parts package. It only weighs 16 kg and can be launched by hand by one person. The company has sold fourteen of these vehicles to date.**

Intershelf's other product is a diver-held TV camera and light. This is similar to the camera and light on the *Fish 102* ROV system.

The team also saw a video of the vehicle *Fish 103*. This ROV has an operational depth of 6,000 m. It was installed on the submarine, *Mir*, and has been used on several of the *Mir* dives to inspect the sunken submarine *Komsomolets*. Subsequent to the WTEC panel's visits, in August of 1993, *Fish 103* was involved in three dives to *Komsomolets*, during which time the ROV penetrated the first compartment of the stricken submarine, operating there for a total of 5 hours and recording 4 hours of video. The panel saw the body of this vehicle in the laboratory.

Intershelf builds most of the vehicles, including the electronics, in the company's laboratory.

## **SUMMARY**

Intershelf is a small entrepreneurial division of a Russian-British joint venture. It is positioned to tap into the vast base of skill and knowledge of underwater vehicles that exists in St. Petersburg. It has developed a couple of initial products and is beginning to work with Intershelf's main division on marketing, sales, distribution, and support for its activities.

*Fish 102M* appears to be similar to other current low-cost ROVs on the market.

## **REFERENCES**

Intershelf. St. Petersburg Press Release.

Intershelf. *Diving TV - Systems Specifications*. Brochure.

Intershelf. *Deep-Water Surveillance Complex Fish 103M*. Brochure.

Intershelf. *LC ROV Fish 102M*. Brochure.

Intershelf. *High Resolution Side Scan Sonar*. Brochure.

**Site:** **Kharax Company Ltd.**  
**Gogol St. 18-20**  
**St. Petersburg 190000**  
**Russia**

**Date Visited:** **May 20, 1993**

**Report Author:** **M. Lee**

### **ATTENDEES**

#### **WTEC:**

**N. Caplan**  
**A. Kalvaitis**  
**M. Lee**

#### **HOSTS:**

**Michael Giers**  
**Svetlana Giers**  
**Igor Brazhnikov**  
**Klaprov Rudolf**  
**Professor Glosman Mikhail**  
**Sapelov Pavel**

**Director, Chief-Pilot Submarine**  
**Vice Manager**  
**Vice Manager**  
**Malachite**  
**St. Petersburg Admiralty Shipyard**  
**Giproribflot**

### **BACKGROUND**

Kharax is one of the first private companies in Russia that is engaged in designing submersible vehicles. Kharax also operates, enhances, and maintains previously designed vehicles. The company has pilots and technicians who operate and maintain vehicles from all over the world. Kharax is investigating the concept of building an underwater tourism center. This is basically a large ship with observation rooms and divers rooms underneath. The company provides technical equipment for subsea expeditions of all purposes. One of the first expeditions was to look for the lost Korean 747 airliner. Company representatives gave the panel a book on this operation. The organization has 8 permanent employees and another 180 people who are employed in a jobshop structure.



## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The company's main product is a deep diving tourist submarine. A picture of the model of this vehicle is included below. This vehicle is being designed to hold six persons plus two crew members. The feature that makes this vehicle different from other tourist submersibles is that it is being designed to go to depths of 300 m. The vehicle sells for \$750,000, including the launch and recovery system. Kharax will also provide operators and support for the vehicles. The company's marketing analysis shows that there is demand for such a vehicle.

Kharax also described an underwater tourist center that the company is proposing. This center would have accommodations for more than 40 persons; it would also have an underwater restaurant and diving facilities.

Kharax also provides operations support, maintenance, and logistics and planning support for existing vehicle systems.

## **SUMMARY**

Kharax is an entrepreneurial organization that has brought together talent, experience, and drive, and focused it on the objective of building a business around manned submersible technology. The company has its first product design well underway. Kharax has a small core of people in the organization's base, and jobshops out as many activities as possible. The company has an experience base that includes many innovative new concepts that it feels will bring success in this new enterprise.

## **REFERENCES**

*Leisure Submersible Apparatuses. Brochure.*

*Center for Underwater Tourism. Brochure.*

**Site:** **Committee for Underwater Operations of  
Special Purpose (KOPRON)**  
**Meeting held at:**  
**P.P. Shirshov Institute of Oceanology**  
**3 Baskova St.**  
**Moscow 117851**  
**Russia**

**Date Visited:** **May 17, 1993**

**Report Author:** **L. Gentry**

### **ATTENDEES**

#### **WTEC:**

L. Gentry  
R. Seymour

#### **HOSTS:**

**Dr. Tengiz N. Borisov**

**Chairman, KOPRON, at the Russian  
Federation Government**

**Igor K. Abramov**

**Expert of the Committee on Defense and  
Security of the Supreme Soviet of the  
Russian Federation**

### **BACKGROUND**

The panel met at the Shirshov Institute for a presentation regarding a new committee being formed by the Yeltsin government to deal with the remediation and cleanup of undersea environmental hazards. The meeting was requested by Dr. Tengiz Borisov to appraise the WTEC panel of the plans and present status of this new committee of which he is chairman. The meeting was held at Shirshov only because it was convenient for Dr. Borisov, since his offices are in the Kremlin, which was not a possible meeting site at short notice. Members of the professional staff of the Shirshov Institute were also present, including the director of the institute.

Dr. Borisov was accompanied by Mr. Igor Abramov, who represented the Russian Defense and Security Directorate and who spoke briefly after Dr. Borisov to present a united front for the new committee's message. The team was impressed by the emphasis of the two speakers that a joint concern of both President Yeltsin and

Parliament exists, and that both are agreed about the urgency of doing something soon.

The meeting, which was interpreted, lasted about 40 minutes. No technological information was conveyed. However, the message was clear that the Russian government is serious about the issue of ecological contamination, and also that it sees the problem as an international concern requiring cooperative funding. A brief discussion between the panel and the two committee representatives to clarify issues and identify future activities followed Dr. Borisov's presentation.

### **RESEARCH AND DEVELOPMENT ACTIVITIES**

No details on the committee's plans for research and development were presented, although Dr. Borisov implied that they have opportunities to transfer highly developed military technologies and systems to support KOPRON's work. He specifically mentioned capabilities to locate and encapsulate radioactive debris on the ocean floor. He said he would provide further information on what technologies are available to KOPRON later in the week before the panel left Moscow. Although he attempted to contact the panel later in the week, no additional information was received. He also indicated that he planned to deliver a paper at a conference to be held on 6 June at Woods Hole Oceanographic Institute. A close working relationship has developed between Dr. Borisov and WHOI. He indicated that representatives of KOPRON were expected in Russia the week of May 24, 1993.

### **SUMMARY**

Dr. Borisov described his Committee for Underwater Operations of Special Purpose by making the following points:

- o The committee has recently been formed by the Russian government to plan and direct efforts to remediate or eliminate ecological hazards resulting from items that have been dumped in the seas (e.g., sunken nuclear submarines and chemical munitions). The organizing committee will be chaired by Dr. Borisov, who personally has over ten years of experience in this area and is a corresponding member of the Academy of Technological Sciences of Russia. Formation of the committee will be announced soon in TASS and through formal channels to the international community. The committee will also soon have an exclusive license to let contracts for underwater work in Russian waters.

- The role of the committee includes:
  - Ecological field work
  - Mitigating the effects of potential eco-disasters
  - Monitoring the environment at sites of radioactive and chemical war materials
- The committee has been given responsibility for dealing with sunken nuclear reactors on the seafloor in Russian waters, chemical munitions dumped after World War II in the Baltic Sea, and the *Komsomolets* problem in the Norwegian Sea.
- His committee is also responsible for establishing an International Foundation for Underwater Works, which will include the efforts of sponsoring nations. An organizing committee has been set up and an initial meeting of the foundation is planned for early 1994, with official invitations to be extended to potential attendees. The meeting is intended to be intergovernmental, but interested private organizations may also attend and/or join the foundation. Each member will sit on the Council of Representatives, and a standing group of technical consultants will recommend actions that need to be taken.
- Dr. Borisov stated that the foundation's "success will be due to its international nature with international expert counsel." He also touched on the possibility of investing in other projects (it was not clear if this meant outside of Russian waters).
- The foundation's first step will be to establish risks and priorities, and to decide on methods and unique equipment requirements. The foundation will also take the early step of ecological monitoring, which will begin in the Russian Arctic and at the site of the *Komsomolets*.
- Dr. Borisov said that he is not pushing membership in the foundation, but stressed that "together we can accomplish useful results." In any event, Russia will continue the work but, if it must operate alone, it will do so on a limited basis.
- He also stressed that although there are differences within the Russian government on many things, all are in agreement about the importance of this project. He specifically mentioned agreement between the Government and the Academy of Science.

Mr. Abramov then was introduced to speak for the Committee on Defense and Security. He made the following points:

- o **"This (the foundation) is a good area for cooperation. It is a good field for cooperation between all forces for peace. My committee (of the parliament) will be very cooperative."**
- o **He cited the concern that we are "approaching ecological disaster day-by-day and this effort is the best step to take concrete action against the ecological bomb that has been set with disastrous consequences for future generations."**
- o **He also said that "we have a good opportunity to find joint solutions. With concrete results in this area we can speak on other areas."**

**In the general discussions that followed, Dr. Borisov asked for assurances that his remarks would be in the WTEC panel's report. Dr. Seymour, the panel chairman, then explained that the WTEC charter is to evaluate undersea technologies, and not to report on programs or ecological issues. However, he was told that his remarks might be included as a general site report in the appendices to the report.**

**Dr. Borisov mentioned that numerous technologies were available for the planned work, but when pressed would not be specific. He did allude to technologies for location and encapsulation of radiation sources, and for cutting apart structures using explosives.**



5. **Nonacoustic Ship Signatures Division.** This division is responsible for minimizing electromagnetic noise from ship systems.
6. **Marine Power Plants Division.** This division is responsible for all aspects of power plant design and integration.
7. **Nuclear Power Plant Division.** This division is responsible for all aspects of marine nuclear power plants, including shielding, safety, and control.

Krylov also has a large workshop and model-making capability that supports all of the divisions.

Krylov has 8,000 employees, 2,500 of whom are employed in research. The institute has a very large facility that covers 80 hectares. The institute is considered very similar in facilities and in organization to the David Taylor Naval Research and Development Center's laboratories in the United States.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

### **Tow Tank Test Environment**

Krylov has a wide variety of test environments. There is a linear tow tank 1.4 km long, a circular tank, and a tank for testing simultaneous response to wind, waves, and current in a seafaring test tank. There is a high-speed test tank for testing hydrofoils and other high-speed designs. There is an ice model test tank to evaluate effectiveness of ice breaker designs, and a test environment for testing air/water interaction for ground effect aircraft, and so forth. There is also a propeller design test environment specializing in anticavitation, and air and water interactions such as in a hydrofoil design.

The panel members were able to visit the structural test facility and the pressure test facility. Krylov can test and life-cycle full-size structural components. The institute has a laboratory with a reinforced floor, reinforced walls, and an overhead crane. Krylov has a large hydraulic power source which can drive up to 96 channels with up to a total of 15,000 tons of force or 40 to 600 tons/channel. The institute also has an automated computer control system and a 3,000 point data acquisition system. This facility has the capability of studying crack initiation and propagation using acoustic emissions. It also has the ability to control temperature of the material under test down to -110°C. The panel saw a large structural member that was being life-cycled for certification of the design by Lloyds of London.

This facility is available to subcontract test services at \$1,500 day and fabrication of test structures for about \$0.50/lb.

### **Pressure Test Facility**

Krylov has a large pressure test tank 1.8 m in diameter and 5.5 m deep, capable of testing up to 1,500 atmospheres, and of cycle testing at a rate of 15 cycles/hour.

The panel also saw a larger pressure test tank 3.2 m in diameter and 9.5 m deep and capable of testing to 1,000 atmospheres. These facilities have the capability to test functional equipment such as motors, thrusters, and robotic arms at pressure. When testing pressure hulls, they can measure roundness, thickness, and weld integrity before and during the testing. The panel saw a 2.4 m diameter titanium sphere certified by the Russian Registry to 4,000 m, which would sell for \$1 million.

One of the functions of the institute is to do failure analysis of accidents and marine problems. This helps improve the institute's knowledge of design and testing for future designs.

Krylov is responsible for testing and test methodology. The institute's scientists and engineers test for the shipbuilding industry, set design rules for deep water submersibles, and are currently evolving new rules for the design of icebreakers. They also specify the testing methodology for verification of new concepts in ship design.

Krylov is starting a new area of research in the area of gas and oil production. The institute would like to use its knowledge of structures and testing in marine and land-based deep drilling and in pipelines systems.

Two years ago Krylov designed and built a 6,000 m ROV called *Uran*. It was a tethered vehicle that had small vehicles on 100 m tethers operating from it.

### **SUMMARY**

Krylov is the leading organization in Russia (and, in many areas, in the world) in the academic knowledge of ship building and of testing structural components. For many years, the institute oversaw all of the ship building activity in the former Soviet Union. Krylov is now expanding to include work in all disciplines of ship science. The institute's test facilities and design analysis capabilities are available to the world market at what Krylov believes is a very competitive price. The institute is also contributing to test standards and methodology.

Krylov showed the panel very impressive facilities for structural testing, pressure, and temperature testing. The institute also has a wide range of tow tank facilities, including a 1,400 m long tow tank facility. These are effectively described in Krylov's brochure.



**Krylov is analogous to the David Taylor Naval Research and Development Center in Carderock, Maryland.**

**REFERENCES**

***Krylov Shipbuilding Research Institute. Brochure. 1990.***

***Proceedings of the Last International Ship Structure Congress. Includes two papers on Krylov and its capabilities.***

***The Marine Engineering Review* recently published an article on Krylov.**

**"Russian Shipbuilding Standards." Includes descriptions of Krylov's testing methods.**

**"International Towing Tank Listing of Facilities."**

**Site:** **ERC Kurchatov Institute**  
**Kurchatov Square, 46**  
**Moscow 123182**  
**Russia**

**Date Visited:** **May 19, 1993**

**Report Author:** **D. Walsh**

### **ATTENDEES**

#### **WTEC:**

**B. Mooney**  
**D. Walsh**

#### **HOSTS:**

<b>Dr. George Alekseevitch Gladkov</b>	<b>Chief of Department</b>
<b>Dr. John Jakubovitch Naikov</b>	<b>Chief of Experimental Installation</b>
<b>Dr. Eugene Petrovitch Kaplar</b>	<b>Scientific Advisor of Project "Helena"</b>
<b>Dr. Viatcheslav Petrovitch Kuznetsov</b>	<b>Chief of Laboratory, Executive Secretary of ROSSHELF Company</b>

### **BACKGROUND**

The Kurchatov Institute, located in Moscow, is one of two Russian institutes that design, construct, and operate nuclear power reactors. There are seven reactors currently operating at this site. The institute employs about 10,000 people on a campus-like area consisting of 153 buildings. The WTEC team was at the institute for about three hours.

One of the hosts, Dr. George Gladkov, is a recipient of the Order of Lenin, the USSR's highest personal award. The award, which designates him "A Hero of the Soviet Union," was presented to him for his efforts in designing the icebreaker *Lenin*.

The hosts proposed that two topics be addressed during the visit:

- o **Deep submergence development on the continental shelf**
- o **Thermoelectric installations for undersea energy**

In addition, the panel hoped to get more information about the reactors Kurchatov was developing (or proposed to develop) for the submarines/submersible concepts

proposed by the Lazurit Central Design Bureau. However, only thermoelectric power sources were discussed during the visit.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

Kurchatov's scientists and engineers had developed one small thermoelectric power source and had completed the preliminary design for a larger unit. The general specifications for these units follow.

### **Gamma 6 kWe Power Source**

Development of the Gamma 6 kWe power source began in 1970, and the unit became operational in 1982. The reactor was constructed by Izot in St. Petersburg. Although the design is rated for unattended operations at 6,000 m depth for ten years, this prototype unit has been operating at the institute in a test cell (see Figure Kurch.1). At full power, the life expectancy of the Gamma 6 kWe power source is about ten years. Consequently, this unit will probably be retired in the next two to three years.

This thermoelectric power source produces 6 kWe of electricity and 200 W of heat energy. It has no moving parts, is self-regulating, and uses natural circulation. There are 24 thermionic (heat to electricity conversion) elements in this unit. The radioactive source is  $UO_2$ , with less than 20 percent enrichment (and thus is not weapons grade material).

The primary construction material is titanium. There is no problem with operations at depths greater than 6,000 m if ambient seawater circulation is used for cooling (rather than the present internal freshwater cooling loop). Gamma will fit into a cylindrical space of 2.5 m diameter and 6 m height. The weight would be 10 to 12 tons.

### **Helena 100 kWe Power Source**

This is a proposed power source; none has been built to date. It works on the same principles and basic design as Gamma, but has 300 electrical generating elements. It also has the same 6,000 m depth rating. The price would be from \$6 to 8 million per unit (see Figure Kurch.2).

In addition to the 100 kWe electrical power output, the unit also produces 3,000 kW of thermal energy. For on-land applications, Helena would be made of stainless steel. Its weight would be 200 tons (100 tons of which is cooling water) and it would require a space 4.5 m in diameter and 12 m high. Use of more expensive titanium would reduce the structural weight by about 40 percent (4.5 grams/cm<sup>3</sup>).  $B_2C$  is used as the moderator. The temperatures are as follows: Phase I about 320°C,

Phase II about 100°C, and Phase III about 90°C. However, with stainless steel, there is no single component heavier than 20 tons. Thus the unit could be taken to remote sites by a heavy lift helicopter.

The Kurchatov Institute staff has estimated that this type of unit could support a Russian settlement (village) of 1,050 people, and that there are 15,000 settlements in the country that could use them. These power sources would be particularly useful in colder areas. The design life of Helena is 25 years. It is estimated that Helena could provide energy for a desalinization plant with a capacity of 60 tons per hour. Several operating Helenas at various geographic locations could be monitored at one central monitoring location by having each individual site transmit monitoring data to the central monitor via satellite. Should trouble arise, the central station could shut down any individual reactor.

#### **Disposal of Units at End of Life**

Team members were told that the decay of radiation from high to safe levels would take 1.5 years for titanium and 10 years for stainless steel. Therefore, the preferred disposal method would require leaving the unit in place for this period of time before recovery and scrapping would take place.

#### **SUMMARY**

Clearly these units, and their relatively low power levels, are too large in size and weight for use in submarines or submersibles. The team did ask about Kurchatov's development of reactors for the Lazurit Central Design Bureau (as was suggested to us by Lazurit), but the Kurchatov representatives were not aware of these developments. They did state that Mr. Stanislav Lavkovsky, Chief Designer of Lazurit, was a frequent visitor to Kurchatov, and that he was there the day of the team's visit. Apparently the submarine/submersible reactor work is done by another group at the institute.

Although Dr. Viatcheslav Petrovitch Kuznetsov was present as the Executive Secretary of the Russian Shell Developing (ROSSHELF) Company, there were no discussions of this project during this site visit. Since this project will use several small reactors, both fixed and in a submarine, the WTEC panel members thought it unusual that Dr. Kuznetsov did not offer to answer questions regarding cooperation between Lazurit and Kurchatov.

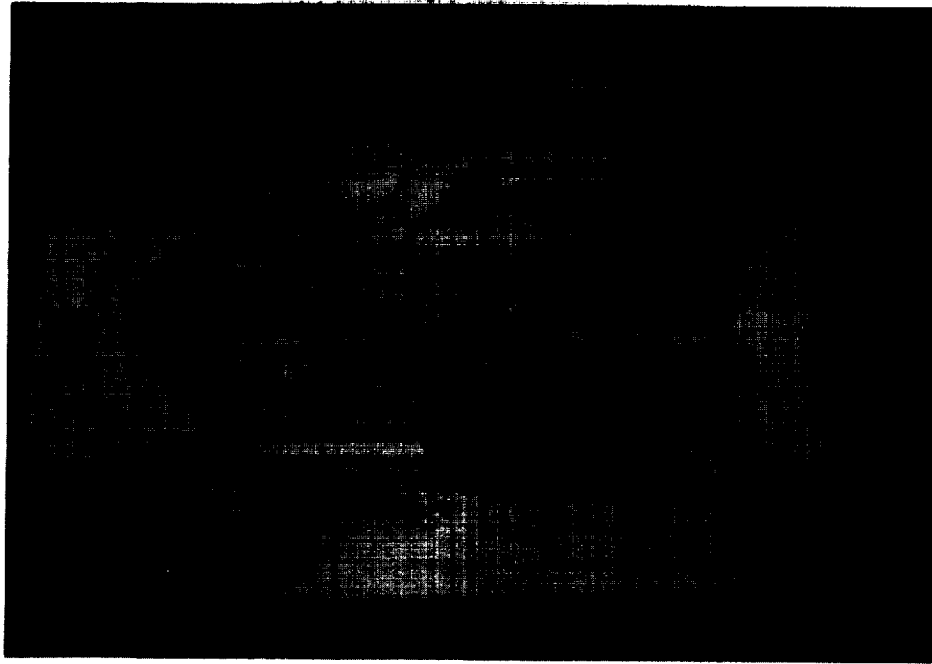


Figure Kurch.2. Helena

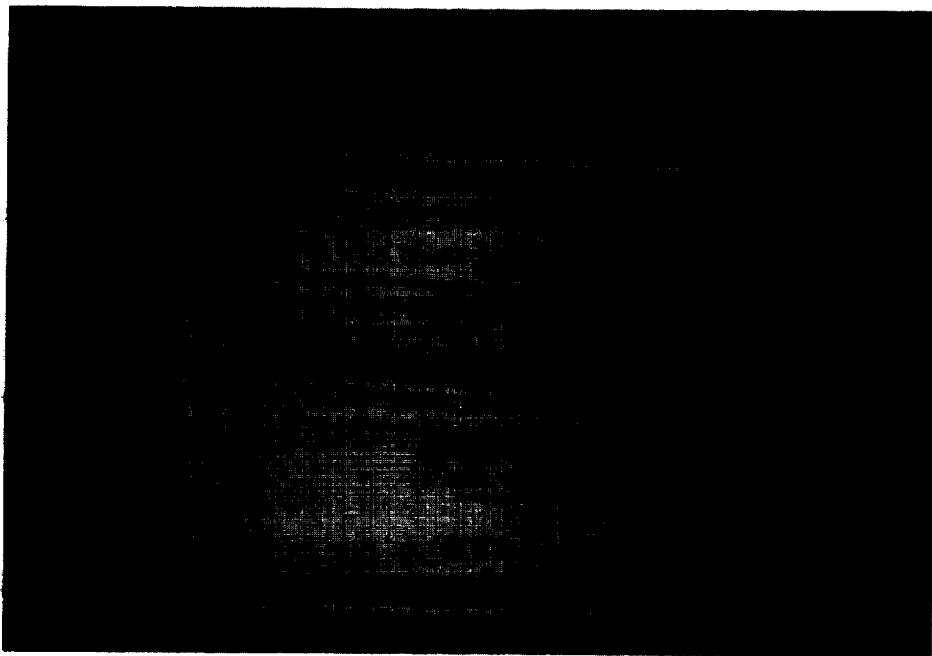


Figure Kurch.1. Gamma

## Site:

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 Moscow 125040  
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## Date Visited:

May 18, 1993

## Report Author:

D. Walsh

**ATTENDEES**

## WTEC:

B. Mooney  
 D. Walsh

## HOSTS:

Nikolai I. Kvasha  
 Stanislav A. Lavkovsky

Designer General; Dir., Central Design Bur.  
 Deputy Director and Designer General for  
 Offshore Technologies

**BACKGROUND**

The WTEC team for this visit was accompanied by Oleg V. Losinsky, the Executive Secretary of the International Integration Association (IIA), who acted as facilitator and translator. The team began by meeting with the top technical and management staff of Lazurit; there were nine professionals and a translator, as well as a person from the bureau's business office present.

The conference room had been set up with displays of Lazurit's capabilities and interests in commercial submarines and deep submersible vehicles. There were eleven models of different submersibles on the table, and diagrams and drawings for another six to eight arrayed along the walls.

The Lazurit Central Design Bureau (CDB) is one of three design bureaus in the former Soviet Union that designed military submarines. The other two are Malachite and Rubin, both in St. Petersburg. Lazurit's work had begun in the 1950s with modern postwar diesel-electric submarines. The bureau's most recent work has been the titanium hull Sierra class nuclear attack submarine. While walking from the parking lot to the headquarters building, Mr. Lavkovsky pointed out the incomplete

pressure hulls of two *Sierra* class submarines that were outside the building hall at an adjacent shipyard. He said that they would not be completed and that the hulls would be dismantled.

The briefing began with remarks by the CDB Director, Mr. Nikolai Kvasha. First, he made it very clear that a four-hour visit to Lazurit was simply not enough time to cover all of the topics listed in the WTEC list of questions. Such an inquiry would require at least a week. Since he felt that the team would receive only a very superficial briefing in the time available, the WTEC questions were not addressed directly during this meeting.

Because government (i.e., Navy) funding has been cut significantly, Lazurit is now busy trying to commercialize its capabilities. But the process is slow and some reductions of personnel have taken place; additional reductions are anticipated. Director Kvasha also said that the bureau has been receiving a lot of foreign visitors, but almost none of these visits have resulted in new business for Lazurit.

Next Director Kvasha reviewed current activities at the bureau. Some of the new directions are:

- o ROSSHELF seafloor-based oil and gas production system for ice-covered oceans.
- o Diving support ship.
- o Fishing vessel (there was a model of this on display).
- o Ocean drilling ship for scientific research.
- o Truck-mounted, portable hyperbaric medical system (there was a model on display).
- o A variety of manned submersible designs, ranging from a 130,000 ton nuclear-powered submarine container ship to a one-person recreational submersible.

Director Kvasha said there were 30 manned submersibles operating in Russian waters and that Lazurit had designed 24 of them. Of the approximately 20 submarines/submersibles shown in the conference room, only one seemed familiar. This was the submarine rescue vehicle, which is similar to the U.S. Navy's DSRVs.

After a four-hour briefing in the conference room, the team had dinner at Lazurit with the director and several members of his staff. The team did not visit any other facilities at this site.

## RESEARCH AND DEVELOPMENT ACTIVITIES

### ROSSHELF

The Russian Shelf-Developing Company proposes to build a complete oil and gas production complex on the seafloor beneath an ice covered ocean in the Arctic. The organization was incorporated as a joint stock company in May 1992. Nineteen different Russian institutes and agencies are partners in the venture. They include the following:

- o Lazurit Central Design Bureau
- o Krylov Research Center (St. Petersburg)
- o Gazprom (state gas concern)
- o SEVMASHPREDPRIYATIE (production association in Severodvinsk, Archangel Region)
- o Kurchatov Institute (Russian nuclear power research)
- o VNIPMORNEFTGAS Institute (offshore oil and gas engineering development)
- o Others

The government has given the rights to the Stockman Field (expected to have primarily gas and gas condensate products) in the Barents Sea to ROSSHELF. The chairman of the ROSSHELF group is Academician E.P. Velikhov, Vice President of the Russian Academy of Sciences and Director of the Kurchatov Institute (nuclear reactors). The Russian group is actively seeking foreign partners to provide investment capital and some technology transfer.

The complex will be built at a depth of 100 to 350 m and will be powered by a nuclear reactor on the seafloor. A nuclear submarine will be constructed for crew transfers and servicing the modules. Several manned submersibles and ROVs will be built to assist with seafloor operations and rescue in case of emergencies. There also has been some discussion about building a nuclear powered tanker for transport.

Lazurit's role will be to design the seafloor modules, as well as the submarines and submersibles, needed to support the complex. Major issues now include the development of optimal engineering solutions to ensure safety and reliability for such underwater complexes and the laying of pipelines to transport the produced gas. It was mentioned that the missile section of a Typhoon class SSBN could be adapted for some of the seafloor modules in the complex.

Clearly, this is a very complex project representing the convergence of several different undersea technologies. Nothing like this has ever been done.

For testing purposes, ROSSHELF plans early creation of an "experimental-and-industrial" (pilot) complex rated at 10% of the planned capacity of the field, to include U.S. and other international participation. Once funding has been secured,



it is estimated that full development of the first industrial seafloor complex will take 10 to 12 years and approximately \$18 to 19 billion. The pilot complex could be completed in 7 or 8 years at a cost of about \$2 billion. Both of these time and cost figures may be optimistic.

### **Ocean Shuttle**

The *Ocean Shuttle* is proposed as a built-for-the-purpose, nuclear-powered oceanographic research submarine. It is to be a 1,300 ton, 600 m capable submarine, carrying a crew of twelve plus eight to twelve scientific staff persons for a maximum mission time of sixty days. One of the models on the conference table was of this submarine.

This originally was a joint USSR-Canadian program. Lazurit planned to design the hull and major operating systems, which would be built in the Soviet Union, and the Canadians would supply the nuclear reactor. Unfortunately, the breakup of the USSR resulted in this program being postponed indefinitely by the Canadians.

However, in the United States (in the Office of Naval Research and at the Woods Hole Oceanographic Institute) there has been some interest in getting a retired Soviet nuclear submarine and converting it for horizontal oceanography. The Lazurit Design Bureau believes that a newly built vessel would be cheaper and more efficient. The estimated cost for the *Ocean Shuttle* would be \$100 to 160 million if the Canadian reactor were used and \$60 million if a Russian reactor were substituted. When asked about the latter, the team was told to obtain this information from the Kurchatov Institute.

The team was shown a brief video tape that showed some artists' sketches of the *Ocean Shuttle*. Of interest was their showing as one of the key program documents an American study on the marine science rationale for this submarine. As the narrator said, it was done by Don Walsh, a member of this WTEC site visit team. He did this work about three years ago for ECS Group, the Canadian company that did the nuclear reactor development.

Although it appears that this proposed project is still in the conceptual stages, it has a lot of powerful friends in the Russian oceanographic community. However, the funding for a project as large as this must come from the West.

### **Submerging Ship Platform**

The submerging ship platform was developed to find a way for submersibles to work under ice or in areas of heavy seas, and to be safely launched and recovered at each end of the mission. It is designed to be a launch and recovery system that would permit manned submersibles to fly off the deck of the ship while submerged.

There is operational experience available in this technique. The Russian Navy has conducted submerged launch and recovery of its submarine rescue submersibles from the deck of specially configured *India* class submarines, also designed by Lazurit.

The submerging ship would be able to conduct these operations down to 180 m, or it could do this while anchored submerged. It would be able to carry two manned submersibles roughly the size of the Russian Navy DSRVs.

### **Tourist Submarines**

Of eleven submersible models on the conference table, six were tourist submarine concepts. The designs ranged from conservative, large (forty to fifty passengers) submarines to a small one-person vehicle. One design was a trimaran cruising yacht with speed of up to 28 kts featuring a side-by-side dual hull configuration, with the third (central) hull being a small submarine capable of detaching and sailing autonomously. Other concepts are self-propelled by diesel-electric power plants.

Of particular interest were two that have transparent hulls. Tourist submarines in the West have used cast and machined massive acrylic pieces for transparent hulls. Lazurit plans to use glass for its hulls. Massive glass has not been used successfully in manned submersibles; its properties are simply too uncertain. Lazurit representatives say that they will use a composite organic and silicon glass. This type of glass, developed by the Krylov Institute, has been successfully used in military helicopters. Lazurit has developed the engineering design of its first all-glass submarine. With a capacity of forty-eight passengers and diesel-electric propulsion, the submarine would require about two years to build once an order is received.

Only one Russian-built tourist submarine is in service. This was designed by Rubin Central Design Bureau; the submarine began operations in 1993 at Antigua in the Caribbean. While the tourist submarine industry has done fairly well in the West, the bureau needs to be careful with its market analysis. The market for large tourist submarines (forty to fifty or more passengers) is mature, and probably no more than ten remain to be sold in the world. Lazurit should concentrate on the smaller (six to twenty passengers) tourist submarines where there is still considerable sales opportunity.

### **Submersible Rescue Vehicles**

Lazurit designed the *Poseidon* class DSRVs now in use by the Russian Navy. Four operational and one experimental models were built. The DSRVs operate in pairs, generally carried onboard an *India* class submarine. They are capable of launch and recovery while the submarine is submerged. The team was shown a video of a simulated rescue mission.

The team was told that normal navy procedure is for the crew of a downed submarine to escape by locking out at depths down to 120 m. Beyond this depth, to a maximum of 500 m, the DSRVs are used. The current vehicles can carry twenty-four passengers and a crew of three.

One of the design models in the conference room was an advanced version of the DSRV, none of which has been built. It probably has a greater depth capability and more passenger capacity than the current models.

In addition to the naval rescue submersibles, the team was shown a design and model of a rescue vehicle to be used for emergency removal of people from offshore oil platforms or from seafloor complexes such as those envisioned in the ROSSHELF project. The submersible lifeboat would be based onboard the platform and transfer operations would be conducted submerged. This requires that the underwater structures be fitted with passageways for emergency exits and hatches compatible with the submersibles. The proposed rescue submersible would have a forty-two person capacity and twelve hours submerged endurance.

#### **Air Independent Propulsion**

Lazurit designed a conversion of a diesel-electric submarine (probably a *Whisky* class) to be powered by an  $H_2-O_2$  fuel cell. The liquefied gases were carried topside in four large cylindrical tanks, two forward and two aft. Some weight compensation was achieved by removing most of the submarine's storage batteries. Lazurit said that submerged endurance was increased five to ten times with this propulsion system. The panel saw a video of this submarine in operation. The most recent operation of this experimental submarine was in 1991.

#### **Other Submersibles**

Because the visit was brief, panel members did not have an opportunity to discuss all the submarine/submersible designs, concepts, and models that were in the conference room. Some of the others that were briefly mentioned were:

**ROSSHELF Mother Submarine.** As noted above, this would be a nuclear-powered submarine designed to support the seafloor operations of the ROSSHELF complex. From its general size and mission requirements, it appears that the submarine design would have much in common with *Ocean Shuttle*.

**9,000 M Depth Submersible.** The panel saw a model of this submersible on the conference table but was not briefed on it due to lack of time. It was generally known that the Soviet Union, through its P.P. Shirshov Institute of Oceanology, was planning to develop a submersible to go to the oceans' deepest depths (about 11,000 m). This model may have represented that design concept.

### **Cargo Submarine**

This concept proposes a 130,000-ton nuclear submarine container ship with a capacity of 1,000 20-ft containers. The vessel's length would be 280 m, its beam 33 m, and its draft 11 m. The maximum operating depth would be 200 m. A transpolar voyage from Japan to Europe would reportedly take about ten days compared to twenty-five days by conventional surface ship routing. While land bridge service by the Trans-Siberian Railway would be about eight days, the railroad was described as "not fully satisfactory for this service."

### **SUMMARY**

Clearly Lazurit has been involved in a wide variety of submarine/submersible programs, and the bureau is very well qualified to undertake any of the projects proposed. Lazurit is able to invoke a wide spectrum of military-developed technologies that are coming to the commercial market for the first time. The question is whether the bureau can develop sustaining programs to avoid damaging reductions in personnel. A major difficulty in making this conversion from military to civil work is being able to effectively market the bureau's capabilities.

The visiting WTEC team agrees with Director Kvasha that four hours was simply insufficient to get into the technical details of the wide variety of deep submersibles and commercial submarines designed/proposed by Lazurit. The scope of projects underway, or proposed, by the bureau was very impressive and educational. However, at best, the visit was only a reconnaissance. Knowledge of technical details would require several more days' work at this site. The director extended an invitation for a more extensive visit.

At the conclusion of the meeting the team requested brochures or papers on the various underwater systems that had been shown. The team was informed that much was not on hand at this time. Some brochures were provided with the promise that a full package would be sent to the team in Moscow before the end of the week. However, this package did not arrive before the WTEC team left Russia.

### **REFERENCES**

*Lazurit Central Design Bureau.* Product description brochure.

Published materials on ROSSHELF.

Brochures for two designs of tourist submarines.

Brochure for the underwater container ship.

**Site:** **Malachite**  
**St. Petersburg Marine Engineering Bureau**  
**ul. Frunze, 18**  
**St. Petersburg 196135**  
**Russia**

**Date Visited:** **May 18, 1993**

**Report Author:** **M. Lee**

### **ATTENDEES**

#### **WTEC:**

**N. Caplan**  
**A. Kalvaitis**  
**M. Lee**

#### **HOSTS:**

**Anatoly V. Kuteinikov**  
**Vladimir I. Barantsev**  
**Vitaliy A. Ostapenko**

**General Designer and Director**  
**Chief Designer**  
**Chief Engineer**

### **BACKGROUND**

Malachite is reputedly one of the leading firms in Russian underwater shipbuilding. Malachite's scientists and engineers built the first Soviet nuclear submarine, the *Leninsky Komsomol*. This was a classified operation until recently. The firm is now participating in the defense conversion program and is interested in making its capabilities available to the world market. A systems design house that partners with other organizations that develop subsystems (acoustics and electronics design subsystems, for example), Malachite has experience in the design and fabrication of several different types of submarines, submersibles, and underwater work mechanisms.

At a conference held in Birmingham, England, in May, Russian military technology conversion was displayed for Western buyers. Malachite was unable to show the WTEC team some of the firm's hardware because it was at this conference.

## RESEARCH AND DEVELOPMENT ACTIVITIES

### Submersibles for Aid of Fishermen

Malachite has designed and built a towed submersible, *Thetis-H* (sometimes translated from the Cyrillic as *Thetis-N*), which is used to assist in improving the effectiveness of fishing trawlers. The vehicle, which is towed behind the net, is steerable up and down and left and right. The man inside of the vehicle can assess the effectiveness of the fishing process and can relay instructions to the surface to steer the net. It is also used to observe fish type and behavior, and to correlate this data to acoustic signatures as heard from the ship.

### Man in the Sea Project

The objective of the man in the sea project is to learn how to allow man to operate down to 800 m while using only a light diving suit. Malachite has a test chamber that is outfitted with video cameras, which allow experimentation with animals to develop mixed gases and decompression techniques. As a result of this program, Malachite's scientists and engineers have been able to send divers to 800 m depth. They have built and operated an underwater habitat that operates to 300 m depth and can hold up to twelve scientists.

### 6,000 M Submersible *Rus*

A new 6,000 m submersible *Rus* is being built by Malachite using a welded titanium sphere, silver zinc batteries, and Russian-manufactured light-weight syntactic foam. The firm estimates that this vehicle could be reproduced for approximately \$12 million. Malachite feels that it brings an expertise in welding thick titanium, an important asset, to the submersible community. The *Rus* is being built for the Ministry of Geology. This vehicle is being delayed by funding problems.

### Test Tank Capabilities

Malachite has test tank capabilities to test a 2.2 m diameter down to 6 km depth and 2.9 m diameter down to 4 km depth.

### Submersible Mounted Drill

Malachite has a submersible mounted drill that can drill and recover the core from a 50 mm x 3 m hole.

### Submersible Oil Tanker

Malachite proposes to design a submersible oil tanker that could carry oil from northern Canada to Japan or Korea via the polar under-ice route. This vessel would be nuclear powered with diesel power as auxiliary for use near populated areas.

## **Tourist Vehicles**

Malachite is interested in designing underwater tourist vehicles of various types.

## **Underwater Vehicles for Sunken Log Recovery**

Malachite has designed and fabricated underwater vehicles for the recovery of sunken logs. These vehicles are lowered to the bottom. They have a manipulator that picks up the logs from the bottom. Some of them have a manipulator and a saw to cut standing lumber, then retrieve it. The vehicles use force feedback on the manipulator through a joystick operator interface.

## **North 2**

The *North 2*, a 2,000 m manned submarine, was designed at Malachite.

## **SUMMARY**

Malachite is a large scale systems designer and integrator with a lot of expertise in submarine, submersible, and underwater work systems design and fabrication. The firm has ties into a network of other organizations that can participate in marine system design and fabrication. The firm's scientists and engineers are not working on ROVs or AUVs because they see no demand.

Until recently, all of Malachite's contact with the outside community for technology has been through a company named Sudoexport. This work is now handled by Defense Export.

Computer-assisted design (CAD) is Malachite's most needed and requested technology. Malachite's scientists currently use personal computers for computing.

## **REFERENCES**

Market literature that describes the specifications for each of the projects included in this report is available from Malachite. Projects included are:

- Rus* (autonomous manned submersible)
- Thetis-H* (underwater towed manned observation vehicle)
- Conself* (underwater autonomous manned observation vehicle)
- Argo-1* (underwater excursion complex)
- Argo-2/4* (underwater excursion complex)
- Argo-3* (underwater excursion complex)
- Triton* (manned submersible)
- Sadko* (underwater passenger complex)

**Investigator** (diesel-electric submarine)

**Pyranja** (small diesel-electric submarine)

**Underwater tanker**

**Underwater transport container carrier**

**Aquarium** (underwater leisure center)

**White Nights** (St. Petersburg international music center on the water --

**Frigate and Archipelago variants)**

**Hyperbaric oxygen complex**

**Mechura-1** (complex for underwater works)

**Akvia** (complex for surface and underwater tours)

**Underwater yacht**

Hudson, Richard L. "Russia Is Displaying Defense Equipment at Show in England."  
*Wall Street Journal*, May 24, 1993:1.



**Site:** Oceanpribor  
Research and Production Company  
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Russia

**Date Visited:** May 20, 1993

**Report Author:** A. Kalvaitis

### **ATTENDEES**

#### **WTEC:**

A. Kalvaitis  
N. Caplan  
M. Lee

#### **HOSTS:**

Juri Koriakn	Engineering Dir., Doctor of Science in Physics and Mathematics
Stanislav A. Smirnov	R&D Director, Doctor of Science in Physics and Mathematics
Arkady A. Soloviev	Head of Foreign Relations Department

### **BACKGROUND**

Oceanpribor combines a research center and two manufacturing plants. It was originally formed 60 years ago as a government controlled enterprise. The primary function was to design and fabricate acoustic systems for Navy ships and submarines. A company was formed in 1973 to market these devices under the trademark KORVET. Oceanpribor considers itself the leading organization in Russia specializing in acoustics, and participates in fundamental and applied research. There are presently a total of 4,000 employees, including 2,000 scientists and engineers working in the Oceanpribor Research Center. Oceanpribor also designs and produces consumer products, including commercial acoustic systems, amplifiers, and record players. Under the defense conversion program now underway, other equipment developed here includes underwater stationary systems for environmental tracking and surveillance; hydroacoustic equipment for research vessels; multi-purpose sonar and positioning systems for manned and unmanned underwater vehicles; resources and equipment for ship-borne prospecting and development; and systems and devices designed to address the problems of marine engineering and geology in continental shelf development, as well as for

hydrographic and oceanological research. Oceanpribor's numerous facilities include a large acoustically isolated tank for conducting in-water acoustic tests and measurements.

## RESEARCH AND DEVELOPMENT ACTIVITIES

In Russia, all projects involving hydroacoustics, or sound transmission in water, are conducted at this center, and the specialists are at this location. They cooperate with 100 other institutions and subcontract work to these groups. Basically, Oceanpribor Research Center is responsible for the design, development, and prototyping of hydroacoustic devices, while production is conducted at other Oceanpribor facilities and outside locations. In the United States there are many companies in this specialty area.

The WTEC team was given a tour of some of Oceanpribor's facilities, which included a museum, a display of underwater acoustics equipment and devices, the large test basin complex, and a demonstration of commercial sound ("HiFi") equipment. The museum depicted a history of hydrophones and the underwater acoustic devices dating to 1933. Displayed were models of large passive sonars installed on their submarines. Also shown was a series of bottom mounted hydrophones that are activated by ship's noise, and a model of a large, rectangular-shaped hydrophone array for long range tracking.

The team was also shown an extensive exhibit of miscellaneous equipment that had been utilized for a defense conversion conference held earlier in the week and attended by representatives from former Soviet and eastern European countries. Side scan transducers, responders, towed arrays, and expendable sound velocimeters, sound reflectors, and other miscellaneous underwater sound-related devices were displayed. Some of the performance specifications were in English and displayed on posters. For example, the specifications stated compressed video transmission capability at 2 to 15 lines/sec, as well as data transmission capability at  $2,000 \pm 500$  bits/sec at ranges of 5 to 15 km.

Next the team was shown the large acoustic test basin complex that is used for measurement and testing of arrays, components, and transducers. Specifications are as follows: dimensions of reservoir 50 x 14 x 10 m; frequency range 0.2 to 600 kHz; absorption factor 0.94; acoustic noise level of not more than 0.05 Pa in one-third octave bands of operating range; and accuracy of reading is 10 mm using linear coordinate devices and 6 minutes using angular coordinate devices.

Oceanpribor has expertise in a broad spectrum of underwater acoustic technologies, equipment, and devices. The research center initiated research on side scan sonar in the early 1980s. The panel was shown a 1984 side scan image of a ship. Presently, work is underway for computer enhancement of the images. Oceanpribor has developed transducers with very uniform directivity patterns and little distortion.

By using complex reflector systems, the side scan antennae exhibit no side lobes and can be packaged in small volumes. Side scan capability can be applied to towed, remote (both ROV and AUV), and manned vehicles. A 255 kHz multibeam Doppler velocity log has been developed that can measure ship velocities in deep water (down to 6,000 m) accurately by bottom tracking instead of tracking on water mass. It is unclear how this capability compares to Western systems (e.g., acoustic Doppler current profilers that can measure current velocities at various depths simultaneously).

In the area of tracking and positioning systems, the center has developed long, short, and ultrashort baseline systems. Oceanpribor's positioning systems work at depths from 50 to 6,000 m at ranges up to 12 km; they are similar to those of Honeywell. Some of these have accuracies of 0.3 m, utilize different frequencies, and can change codes. These can operate several days to years in duration. Their systems are compatible with SIMRAD and other equipment.

We discussed teleoperation, data transmission over large distances, and telemetry capabilities. There is no problem with large amounts of data telemetry over short distances; however, at ranges of 100 to 400 km, the sound channel is used. Oceanpribor is developing algorithms that will work in the multipath environment; this is a major undertaking that may require cooperation with specialists from many countries.

Oceanpribor recognizes the limitations of its computers; to compensate, the center's algorithms are required to be very efficient. Its software designers must understand the physics of the system and implement the real-time software.

Looking into the future, Oceanpribor envisions geology and oil and gas exploration as areas of interest. The firm also anticipates that considerable support of the Russian Navy will continue because Ukraine presently has most of the ships with hydroacoustic capability; therefore this capability will have to be reestablished. (The panel was told that a similar group to Oceanpribor is being formed in Ukraine). Even though Oceanpribor's ocean acoustic technology was previously classified, it can participate in international projects if they are not defense related or if intergovernmental agreements are concluded.

In summary, Oceanpribor claims it is the largest Russian company specializing in the design of underwater acoustic systems for world ocean resource exploration, deep hydrographic surveying, and oceanographic research. Oceanpribor would like to collaborate with foreign companies to design and manufacture new hydroacoustic systems, export existing products, conduct tests and calibrations in its unique test basin complex, and establish cooperative production activities and joint ventures.

**REFERENCES**

**KORVET Oceanpribor Research and Production Company. *Hydroacoustic Devices and Systems*. Short brochure on capabilities.**

**KORVET Oceanpribor. "Hydroacoustic Devices and Systems," KORVET 92. This packet includes performance specifications on approximately thirty underwater acoustic devices, hydrophones, ship positioning systems, and so forth. In English.**

**Site:** P.P. Shirshov Institute of Oceanology  
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23 Krasikova St.  
Moscow 117218  
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Telex: 411968 OKEAN SU  
Fax: 095-124-5987 (or 5983)

**Date Visited:** May 17, 1993

**Report Author:** D. Walsh

### **ATTENDEES**

#### **WTEC:**

L. Gentry  
B. Mooney  
R. Seymour  
D. Walsh

#### **HOSTS:**

L. Savostin	Director
V. Demchenko	Vice Director
Dr. A. Gorlov	(meeting coordinator)
(and about 12 other senior staff members)	

### **BACKGROUND**

The purpose of the meeting was to provide the WTEC team with a general familiarity with the P.P. Shirshov Institute of Oceanology, which is the primary oceanographic research institution in Russia. This took a little over an hour, with the director conducting most of the briefing. A more in-depth visit to Shirshov was made later in the week by a three-person WTEC team. Some of the information that is in the report below was repeated at that time.

Dr. Tengiz Borisov briefed the team on the work of KOPRON, the government's Special Committee for Undersea Work, for which he serves as chairman.

## RESEARCH AND DEVELOPMENT ACTIVITIES

P.P. Shirshov Institute is part of the Russian Academy of Sciences. The institute employs 2,000 people at four locations: St. Petersburg, Kaliningrad (Baltic base), Ghelendzhik (Black Sea base), and Moscow (headquarters). The institute formerly had a branch in Vladivostok and is planning to establish a new branch in Murmansk or Archangelsk. The Moscow headquarters is divided into four branches: biological, marine geology, hydrophysics (which includes acoustics and physical oceanography), and technical (instrumentation, submersibles, etc.).

The institute's technology research and development activities are largely concerned with the production of platform and instrumentation systems needed to support its oceanographic research work. In the time of the Soviet Union it was often extremely difficult to get "standard stock" off-the-shelf oceanographic equipment, due to export restrictions by Western countries and other impediments posed by the Soviet bureaucracy. Thus the institute was forced to do its own design, development, and construction. While this activity was driven by necessity, it also helped to stimulate the development of some unique devices that may now be of interest to the West.

At the time of the WTEC team's visit, much of Shirshov's operational programs and technology development work is shut down or greatly reduced due to severe budget limitations. As of the previous December (1992) all of its vessels were in storage; only minimal standby maintenance was being performed. An illustration of the institute's present difficulties is its newest class (1989) of research ships, which were designed to be super quiet for acoustics work. The two ships are *Vaviloff* and *Ioffe*. Already *Ioffe* has been leased to a German company for use as a passenger vessel. It is feared that *Vaviloff* may also have the same fate.

The institute has ten research ships. Six are specially built for oceanographic science and two are capable of supporting manned submersibles. The institute has six operational submersibles:

- o 2 *Mir* class, 6,000 m depth capability (made in Finland)
- o 2 *Pisces* class, 2,000 m depth (made in Canada)
- o 1 *Osmotr* class, 300 m depth, with diver lockout to 200 m
- o 1 *Argus* class, 500 - 600 m depth

*Osmotr* and *Argus* are at the Black Sea base in Ghelendzhik. The *Mirs* have been quite active until recent budget cutbacks. *Osmotr* is for sale. *Argus* primarily operates in the Black Sea.

There are two new 4,000 m *Mir* class manned submersibles that are about 85 percent complete. Our hosts estimate that about \$1.2 million is required to complete construction. These are of all-titanium construction and have been designed and built in Russia. The institute is actively seeking a Western source of funding to

complete this project. Shirshov has indicated that it would offer one of the two *Rifts* to the investor as payback for the \$2 million funding.

However the news is not all bad. The director said that the institute now has two years work for the *Akademik Kheldish* and its two *Mir* submersibles. This will be a joint mapping expedition in the Kara Sea with Woods Hole Oceanographic Institute. Some U.S. Office of Naval Research funding is involved in this international expedition. The director said that ONR and WHOI representatives would be at the institute the next week to discuss program details. It appears that this work may be connected with surveying the nuclear waste sites in this area (see WTEC site report on KOPRON briefing by Borisov).

After the Kara Sea work, there will be another expedition to the Laptev Sea in cooperation with the German Oceanographic Research Institute at Kiel.

### **SUMMARY OF DISCUSSION**

The director (L. Savostin) is optimistic that he can find funding to keep the majority of the institute's programs and facilities going. He told us that he had met with both the Prime Minister and the President, and was assured that support funding would be available.

In subsequent correspondence with the panel, Mr. Savostin noted that the institute is active in developing new robotics technology for a global ocean observing system and for long-term underwater ecological monitoring, and welcomes international partnerships in these fields.

**Site:**

**P.P. Shirshov Institute of Oceanology  
Academy of Sciences of Russia  
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**Russia**

**Telephone: 095-124-5998**

**Fax: 095-124-5987**

**Date Visited:**

**May 20, 1993**

**Report Author:**

**D. Walsh**

**ATTENDEES****WTEC:**

**C. Brancart  
B. Mooney  
D. Walsh**

**HOSTS:**

**L. Savostin  
V. Demchenko  
Dr. Vyacheslav S. Yastrebov**

**Dr. Lev L. Utiakov**

**Dr. A.N. Paramonov**

**Dr. Alexander B. Kostin**

**Yuri S. Russak**

**Dr. Alexandre B. Zaretsky**

**Dr. Lev Merkin**

**Dr. Alexandr A. Gorlov**

**Director**

**Vice Director**

**President, Near-Bottom Research Institute**

**Head, Department of Underwater  
Vehicles (former Director of P.P. Shirshov  
Institute)**

**Laboratory Chief, Long-Term Bottom  
Stations, Sensors, and Electronics**

**[Vice Director for Technology as of 12/93]**

**Underwater Robotics and Instrumentation  
Development**

**Principal Scientist, Deep Tow Systems, Side-  
Scan Sonars, Signal Processing, and  
Transducer Developments**

**Principal Scientist, Signal Processing, Side-  
Scan Sonars, and Transducer Developments**

**Senior Research Scientist, Design of AUV  
Systems and Control Program Software  
Development**

**Senior Scientist, Geophysics Signal  
Processing, High Resolution Array Design,  
and Signal Processing**

**Principal Scientist, Deep Submersibles  
Engineering, *Pisces* Pilot (mtg. coordinator)**



## BACKGROUND

After an initial briefing period in the auditorium, the team spent about four hours at the institute. Most of the time was used to visit various offices and laboratories to view, demonstrate, and discuss equipment.

This site visit was very well organized. Upon arrival the team was taken to a conference room where each staff member to be visited gave a briefing on his research work and recent developments. This took less than an hour and was very useful in giving an overview of activities related to team member's interests.

There were four briefers whose laboratories or bureaus the team did not visit this morning:

- o Mr. Victor Brovko, who was with the institute from 1965 to 1975, when he was responsible for the design and construction of seafloor habitats for divers (e.g., *Chernamor*), AUVs (in Academician Vyacheslav Yastrebov's laboratory) and manned submersibles (e.g., *Argus*). Since 1970, Mr. Brovko has been with the Experimental Design Bureau of Oceanological Engineering, which was then part of the Shirshov Institute. He is presently Science and Technology Director of the bureau, which is now independent. The team visited his bureau later this day.
- o Mr. Eugene Pavljutchenko is the Chief Engineer of the Experimental Design Bureau. He has worked on the submersibles *Argus* (1975), *Osmotr* (1985), and *Rift* (two are currently under construction).
- o Mr. Sergei Surkachin works in diving, diving methods, and underwater habitats. He is doing a joint project with the University of Maryland for scientific diving operations in the Black Sea, in Lake Baikal, and in the Chesapeake Bay (in the United States). He said that the Russian State Committee on Science and Technology and the U.S. National Oceanic and Atmospheric Administration (NOAA) have an agreement for scientific diving cooperation. His group hopes to get a mission in NOAA's seafloor habitat *Aquarius*.
- o Vladimir Kuzin is chief pilot of the 2,000 m *Pisces* (there are two of them) submersibles. He said that they have successfully tested a hydrazine energy source to depths of 5,000 m. (This is probably the system that is now being offered commercially by Rauma Repola in Finland). During the conversation, our hosts mentioned possible work underway elsewhere in Russia on materials such as acrylics and glass for manned submersible pressure hulls.

With respect to the general state of the P.P. Shirshov Institute of Oceanology, please see the preceding report, which describes the team's first visit there on May 17,

1993. At the time the team was briefed by the director, however, he was unable to join us for this site visit. As with most of the site visits, there was far more information available than there was time to evaluate it in any detail. This was especially true at Shirshov, where there was a genuine eagerness to tell the team about projects, hardware developments, and ideas for new research directions.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

This section is organized in the order of the offices and laboratories visited.

### **Department of Underwater Vehicles and the Near-Bottom Research Institute**

Academician Yastrebov met the team in his office to provide a more detailed briefing on his work. He mentioned that he had been at the Shirshov for twenty-five years, but in the past two years the institute had received no new funding. So the institute is working on accumulated hydroacoustics data instead of making additional oceanographic voyages at sea.

With a private company, the Near-Bottom Research Institute is developing "intelligent robots," that is, autonomous underwater vehicles. The applications of these submersibles will be for biological monitoring and measurements of the general oceanographic environment.

An important first step is programming the vehicle. One approach is to provide the AUV's onboard memory with "genetic information" about the general/generic nature of the mission. As with other AUVs, the specific mission information will also be programmed. In this way, a sort of pseudo-artificial intelligence is provided to the submersible. Also the actual "experience" of the vehicle will be collected from each mission and programmed back into it to increase its "learning curve" and collective intelligence.

The institute's scientists and engineers are presently doing laboratory modeling and simulation to test these ideas. The team was taken to the laboratory and shown several test runs on a computer screen. They have developed nine training programs of varying complexity. The simulated AUV is fitted with forward-looking and vertical sonars for terrain/obstacle avoidance and maintaining the programmed altitude above the seafloor. In practice they will be able to maintain navigation accuracy to within 7 m at the seafloor.

The team was also shown two geological sampling devices that had been constructed for use onboard the *Mir* (6,000 m) manned submersibles. These hydraulically operated units are a rock coring device and a rock breaker. The coring device has successfully drilled 28 cm cores in basalt from a *Mir* operating near the Azores.

Mr. Yastrebov also mentioned a 6,000 m towed sled developed by Shirshov that carries side scan sonar as well as TV and a still camera. He indicated that the team would see more details on this system during visits to the other laboratories and offices.

### **Sonar Information Processing**

In addition to the data processing of signals, Mr. Yuri Russak's group is involved with development of the transducer elements for the side scan sonar and the imaging systems for the 6,000 m towed fish (with a 10,000 m umbilical).

The onboard low light level, black and white TV camera has a threshold of 0.005 lux using a supervidicon tube. With the lighting available on the fish, the maximum visible range is about 20 m. The institute does not have color TV since the line loss (over 10 km umbilical length) would be too great.

The photography is done with a two-camera, color stereo, 35 mm system. The film magazines hold 3,000 exposures/frames. A strobe flash provides lighting for the cameras.

This fish was used to investigate the wreckage of the *Mike* class submarine *Komsomolets*, which is lying on its side in 1,400 m of water. A photograph of the fish is enclosed with this report (see Figure Shirshov.1).

### **Sensors and Devices for Long-Term Bottom Stations**

Dr. Lev Utykov showed a variety of electronic devices developed and made by his group. Of particular interest is a family of electronic chips that can be used at ambient pressure to great depths. These chips have also been successfully tested by boiling in oil and freezing with liquid nitrogen. He believes that ambient-pressure electronics (either exposed to direct depth pressure or in pressure-compensated containers) will be the way to put much greater computer capacity into vehicles with minimal weight penalties.

Another equipment development that Dr. Utykov's group has worked on is a hydroacoustic transponder/beacon system for attaching to divers and marine mammals. In both cases it could send physiological and location data back to the control facility. It could also be used to warn a diver about unsafe conditions (exceeding dive time at depth, onset of nitrogen narcosis, etc.). Presumably a marine mammal that has had conditioning training could be controlled via long distance acoustic transmissions.

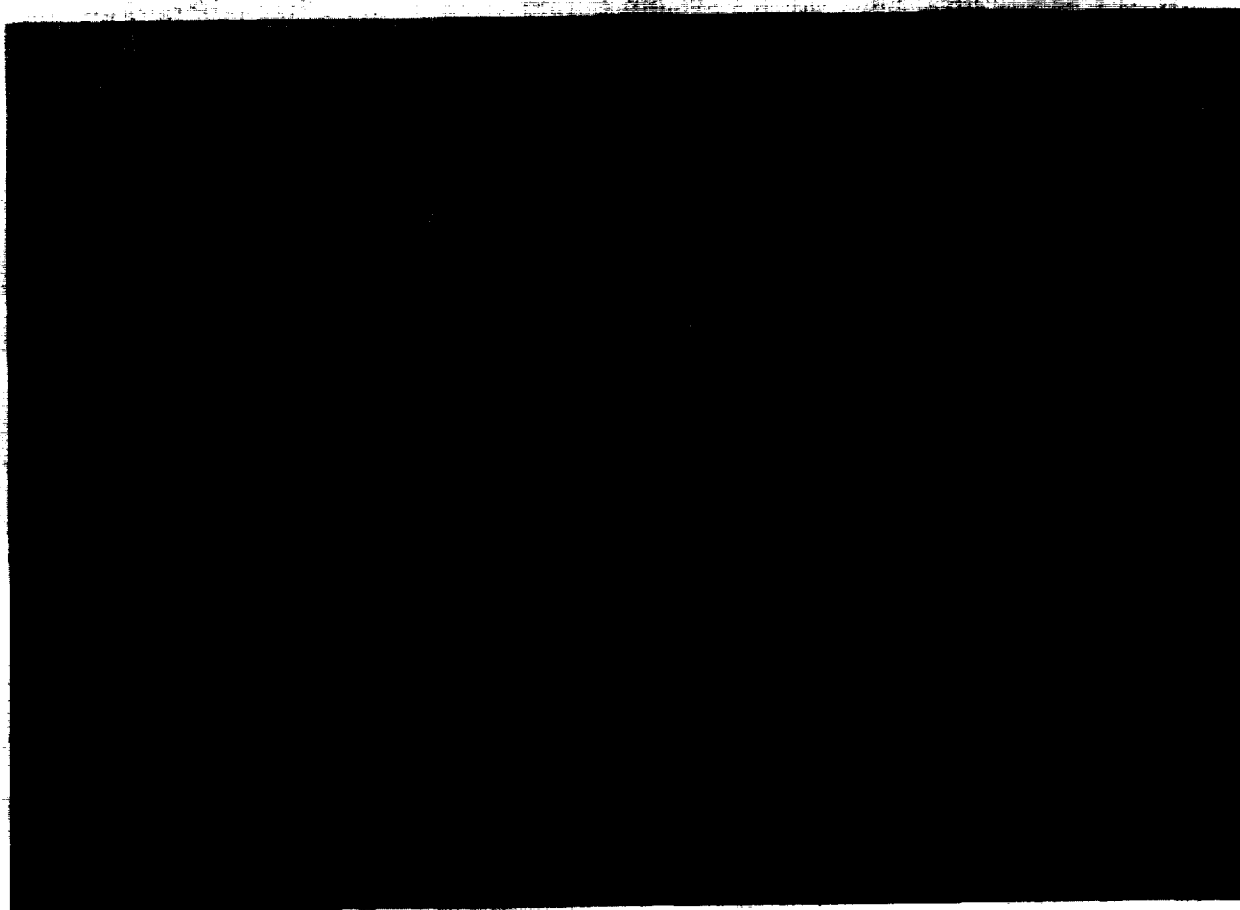


Figure Shinkov.1. Photograph of Fish

### **Geophysical Towed Arrays**

Mr. Lev Merdin discussed his development of lower-cost, smaller geophysical seismic systems. Since the existing 3-D systems are large and expensive, his goal is to achieve similar results with much less complexity. He hopes to develop a 5 km long towed array using sensors that are only 20 to 25 mm in diameter. A microjet transmitter would transmit a broad-band, complex signal. However, cable self-noise is a problem when the operator uses a very thin cable with built-in multichannel hydrophones.

## **SUMMARY**

Since the WTEC team's visit to the institute was really a series of visits to several offices and laboratories, this summary is a synthesis of these activities. There was no single summary meeting before the team left.

The entire institute suffers from a greatly reduced level of investment from the government agencies that had been the principal source of support. This is forcing the various components of Shirshov to review what they know how to do, what they can make, and what can be sold outside Russia. In addition, a vigorous effort to seek cooperative research programs with foreign scientific agencies and institutions is evident. Since the P.P. Shirshov Institute of Oceanology is well known and respected throughout the world, this path of cooperative arrangements may be the most promising direction in the near term.

The team saw quite a few innovative technology developments during this brief visit. With a proper marketing approach, there could be success along this path. The director of the institute seems to be aware of these opportunities and plans to develop an organized catalog of their capabilities to be used as a marketing tool. Hopefully, professionals selected from the institute will be able to attend some of the major ocean trade shows in the world to make the larger community aware of what is available from this source.

Unfortunately, economic conditions in Russia may get worse faster than such organizations are able to develop means of self support. Considerable institutional downsizing will be an almost certainty. Hopefully this can be done without significant loss of the intellectual and physical assets that have made this a major oceanographic institution in the world.

## **REFERENCES**

*Rock Coring Device That Can be Mounted on Submersibles. Brochure.*

*Underwater Hydraulic Breaking Device That Can be Mounted on Submersibles. Brochure.*

6,000 m depth towed sled for ocean floor. Photograph.

Site: **Central Design Bureau  
for Marine Engineering (RUBIN)  
Ulitsa Marata 80  
St. Petersburg 191126  
Russia**

Date Visited: **May 19, 1993**

Report Author: **A. Kalvaitis**

### **ATTENDEES**

#### **WTEC:**

**N. Caplan  
A. Kalvaitis  
M. Lee**

#### **HOSTS:**

**Dr. Alexander Zavalishin  
Nickolay A. Nossov**

**First Deputy Head, Chief Engineer  
Deputy Chief Designer**

### **BACKGROUND**

The Central Design Bureau for Marine Engineering (RUBIN) specializes in submarines and other underwater technologies. Several years ago, RUBIN was a secret institute that could not be mentioned openly. The *Typhoon*, *Oscar*, and *Komsomolets* submarines were designed here. Because of recent conversion efforts, approximately 40 percent of the work is presently defense related, with major thrusts in the past several years concentrating on high-speed train development, nonmilitary submarines, and tourist submersibles. RUBIN designed the only Russian tourist submersible now in service, which began operations in 1993 at the island of Antigua in the Caribbean. Other defense conversion activities have focused on areas in which RUBIN has expertise: coal and nuclear power stations; floating power stations for the northern parts of Russia; gas and oil exploration and production; and participation with ROSSHELF, which has U.S. company partners. The team was told that about 2,000 employees work at this location.

A salient feature is that RUBIN has strong connections to former Soviet Union countries. RUBIN has created a broad spectrum of organizational expertise that is incorporated in books and on a computer database. In addition, RUBIN has had extensive at-sea experience with sunken submarine investigations.

## RESEARCH AND DEVELOPMENT ACTIVITIES

The team was given a briefing on RUBIN that focused on the bureau's responsibilities regarding the *Komsomolets* nuclear submarine that sank in 1,700 m water off Norway in 1989. Mr. Nikolay Nossov, the submarine's designer, informed the team that RUBIN is heading a team of forty Russian institutes, organizations, and companies that are studying the submarine. Concern was expressed that radiation could leak from missiles and contaminate a large area because of the aperiodically high (up to 1.5 m/sec) currents in the area. RUBIN planned to attend the Radioactivity and Environmental Security in the Oceans Conference at Woods Hole Oceanographic Institution on June 7-9, 1993 to describe the environmental monitoring program on the *Komsomolets* submarine.

Two videos (including an ABC newscast) and numerous pictures of the submarine that were taken by the *Mir* 6,000 m submersibles were shown to the team. Also present at this meeting was one of the *Mir* pilots. Two remotely operated vehicles designed for operation from the *Mir* submersibles while inspecting the submarine externally and internally were described. Specifications on these ROVs were provided by Intershelf. See M. Lee's site report on Intershelf for more information.

The WTEC team's hosts from RUBIN described two versions of gamma counters that were specifically designed for radioactivity measurements at the submarine site. These designs use sodium iodide (NaI) gamma detector. One version is attached to the *Mir* submersible and measurements are made directly; the other instrument is configured so that it can be inserted into the submarine hull and record data for a one-week deployment.

RUBIN was responsible for leading the development of selective absorbants of radioactive nuclides, including cesium, uranium, and plutonium. These absorbants were developed by the Nizhny Khlopin Radiation Institute of St. Petersburg and the Arzamas 16 Russia Nuclear Center near Nizhny Novgorod. These absorbants are used in conjunction with the NaI gamma counters to provide a complete measurement of the radioactivity.

There have been three expeditions to the *Komsomolets* site. Two expeditions were organized by RUBIN. However, the first one was conducted by another institute that may have used an autonomous undersea vehicle called the *MT-88*. This 6,000 m capable AUV was developed at the Institute for Marine Technical Problems in Vladivostok. RUBIN recognizes the high cost of conducting operations with large ships and the need for automated systems.

RUBIN has created a working group of many firms and institutes capable of investigating radioactive objects on the ocean bottom. Having been responsible for many of the designs, the institute's scientists are very knowledgeable of the object, can conduct the necessary sampling and experimentation, and can predict the effects.

## Site:

Scientific Research Institute  
of Computer Complexes (NIIVK)  
108 Profsoyuznaya St.  
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Russia  
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Fax: 095 494-0086

## Date Visited:

May 11, 1993

## Report Author:

D. Blidberg

**ATTENDEES**

## WTEC:

D. Blidberg

## HOSTS:

Alexander Krupsky  
Juri Mordovski

Director for Research and Development  
Director, Sigma Technologies  
Telephone: 095 924-1654, 921-6396  
Fax: 095 924-1654

**BACKGROUND**

The meeting at the Scientific Research Institute of Computer Complexes (Nauchno-Issledovatesky Institute Vychislitelnyh Kompleksov or NIIVK) was held with representatives of NIIVK and other companies that were using the software that had been developed at the institute. An overview of the institute and its activities was presented and then various applications were described by members of the companies that had developed or were developing those applications. The institute was represented as the organization in Russia that was responsible for designing all computer hardware and software. It did not build many of the subsystems, but participated in the design, development, and system integration. It seemed that the institute was guided by the needs of radar and sonar processing as well as the missile warning system. Recently some of those applications (such as the missile warning system) were unclassified, but many of the sonar and radar processing applications remain classified.

NIIVK was founded in the 1960s to develop computer hardware and software systems. In 1976 the institute moved to its current location. NIIVK has developed



four to five generations of large computers (supercomputers). Originally the institute focused on developing computers for classified applications, but recently it has focused on some unclassified applications. NIIVK's scientists developed the early warning system for missile attack that is now unclassified, but continues to develop some systems for radar and sonar applications that remain classified. The following summary will give some idea of the focus of the institute.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

### **Scientific Research Institute of Computer Complexes**

The Scientific Research Institute of Computer Complexes, situated in Moscow, is a member of the Scientific Industrial Association for Computers (NPO SVT), the largest such association in Russia.

The staff of NIIVK was formed in the early 1950s. After creating the M-2 and M-4 computers (two of the first Soviet computers), the serial semiconductor computer M-4-2M was designed in 1964 and was serially produced until the end of the 1980s. The computer M-10, designed by the NIIVK in 1975, contained parallel architecture. Novel technical ideas were realized in this computer that allowed noted scientist and computer architect M.A. Kartsev, the first director of NIIVK, to achieve a high performance. American researchers P. Wolcott and S. Goodman wrote: "The N-10 is distinguished by its ability to conveniently parallel-process data of different formats, dynamically changing the clustering of processors to match the format of the data at hand."

The newspaper *ComputerWorld USSR* gave the following estimation of the computer M-10: "Apotheosis of heroic period of the Soviet informatics was a creation of the powerful 64-bits vector-pipeline supercomputer M-10...."

The original trends of the NIIVK supercomputer are characterized by usage of so-called "type M" architecture, the first representative of which was computer M-10. This architecture is notable for using a wide-format memory that exchanges vector operands with several identical processors, executing the same instruction stream. A later stage in the development of the type M computer architecture was the creation of the new vector multiprocessor supercomputer M-13, which was produced serially beginning in 1985.

The peculiarities and architectural principles of computers developed by NIIVK provide high performance for real time data flow processing with large amounts of information (real time radar and sonar signal processing, image recognition, etc.). These peculiarities and principles are as follows:

- o SIMD-type architecture
- o Architecture with wide command word and adjacent operations parallelism
- o Vector processing on the base of the wide format memory buses (up to 512 information bits per machine cycle)
- o Variable vector components' format (1,2,4 or 8 bytes per component)
- o Vectors components masking
- o Nontraditional vector processing operations (vector component sums' summing, scalar product of vector operands, etc.)
- o Virtual memory (segment-page organization), capability-base addressing, segment protection on lock/keys base (without tagging)
- o Special processors, working with the computer common memory, including FAT processor (performance up to 2.4 billion operations/s) etc.
- o I/O channels processors and connection processors with programmable interfaces (connecting practically arbitrary devices without need of special equipment)
- o High capacity for external information exchange (up to 400 byte/s)

Architectural principles developed and realized by NIIVK in the M-10 system were used in the Burroughs BSP Computer. Some technical decisions in vector processing coincide with those in Cray and CONVEX computers. Also, some memory organization features are similar to capability-based systems (like Plessey System 250 and Intel IAPX 432).

NIIVK has designed software products for its computers, including the following:

- o Operating systems (time sharing, real time), programming languages of various levels together with correspondent compilers
- o Programming systems for these languages (including vector processing oriented languages)
- o Application packages for mathematical calculation methods' support (linear algebra, integration, differential equation solving, etc.)

The different models of computers designed by NIIVK have been produced serially for nearly thirty years and work with high reliability, providing all requirements of the most crucial networks and systems up to the present.

Because of the need to model sound propagation fields, a new computer design has been undertaken. The new machine is referred to as a database machine. The system design was completed and construction had begun; however, construction has been stopped due to lack of funding. The machine deals with numeric data, textual (or symbolic) data, and other information. This new computer was felt to be the system on which artificial intelligence (AI) systems might be implemented as well as other software. AI may be used for identification and classification applications in the future.

When asked about the data to be included in the database machine, the team was told that the institute focuses only on the design of hardware and software systems. However, the institute's scientists have collected various oceanographic data from the Atlantic Ocean that has been included in the new computer design efforts.

### **Applications Discussions**

Mr. Juri Mordovski, Director of Sigma Technologies, discussed work underway at the company. Sigma Technologies was started two years ago to focus on the development of AI and the transfer of that technology to the United States and other markets. The company undertook several applications, including two that were suggested by the Director of NIIVK, Mr. Alexeev. Some of the applications suggested were the development of a system for monitoring large mechanical systems, and development of AI systems for automatic monitoring of other complex systems, and automatic surveying. When Mr. Mordovski was asked if he knew of any AI efforts being undertaken in Russia related to undersea systems, he stated that as far as he knew, "there is no work in Russia where AI is being applied to undersea systems." His company had recently undertaken a summary of AI work underway in Russia and found only work in expert systems.

The company has developed some automatic translation tools that are now available. One discussed was a translator to translate legal documents from Russian to English in real time over electronic mail (E-mail). The company has been working on this with Lockheed and several other U.S. companies.

Mr. Anekyn is the head of a small group in Volna that is focusing on the development of sonar systems utilizing some of the work produced at NIIVK.

### **Acoustic Fields Investigations**

Algorithms with super resolution have been developed in the institute. This high resolution is possible because the institute's scientists have been able to eliminate all surface and bottom reverberations, greatly suppressing unwanted returns.

NIIVK has databases of oceanographic data; physical and geological data; bottom and surface data; and hydrological water parameters, such as CTD information.

### **Near Area View Sonar**

Bottom and surface reverberation is understood and mapped in this system.

### **Medical Imaging**

Development of medical imaging systems is underway at the Cardiological Center of the Russian Academy of Sciences. The center has a 5 MHz sonar that develops

2-D images. Scientists can combine those 2-D slices to develop 3-D images now, but hope to develop a system that will produce 3-D images in real time.

### **SUMMARY**

As a result of visits to the United States, specifically NASA, NIIVK representatives assess their capability as being up to date in the area of software development but not in terms of hardware development. Their computers seem to be less capable than comparable U.S. hardware, but the Russians make up for that disadvantage by increased sophistication of microprogramming and more complex control devices within the computer hardware. There seems to be a concerted effort to bring some of the developed algorithms into commercial products. These, when developed, will be very capable systems.

The NIIVK representatives with whom the WTBC team met were very helpful and encouraged further cooperation in all of the areas discussed. They want to find methods by which to disseminate information about their work, such as professional publications to which they might submit their results. There seems to be much good work to better understand. Time limitations constrained in-depth discussions of their various activities.

**Site:** **St. Petersburg State  
Marine Technical University  
of Ocean Technology  
3 Lotmanskaya St.  
St. Petersburg 190008  
Russia**

**Date Visited:** **May 21, 1993**

**Report Author:** **A. Kalvaitis**

### **ATTENDEES**

#### **WTEC:**

**A. Kalvaitis  
N. Caplan  
M. Lee**

#### **HOSTS:**

**Dr. Dimitriy M. Rostovtsev  
Dr. Aleksey M. Markov  
Dr. Tatiana Peregudova  
Professor V.I. Nikolaev**

**Rector, Dr. of Sc., Professor  
Head of Patent Department  
Vice Director, Research Dept.  
Director, Research Lab of Automation of  
Designing Ship's Power Installations  
Dean, Dept. of Electronics & Control Systems**

**Dr. Juri I. Zhukov**

### **BACKGROUND**

This university was founded in 1902 as a department of St. Petersburg Polytechnic. It later gave birth to the Leningrad Shipbuilding Institute, which became a leading educational institute for ocean technology and marine engineering in the former Soviet Union (FSU). Subsequently, it evolved into the State Marine Technical University (MTU). At present, MTU provides a wide range of programs, both undergraduate and postgraduate, leading to B.Sc., Engineer and M.Sc. Doctoral degrees (equivalent to Ph.D. and D.Sc.). A major department within MTU is the Department of Naval Architecture and Ocean Technology. MTU's 8,000 students are involved in all aspects of marine and ocean technology, with approximately 30 percent specializing in electronics and control systems. Until last year, most of the foreign students were from Eastern Europe, Vietnam, North Korea, and Cuba. However, now MTU is soliciting students from other countries (e.g., India, Nepal, Jordan, and China). The university has 600 faculty members, 1,500 auxiliary

personnel, and 300 professional researchers. Over 1,000 patents have been awarded to faculty members. The university is interested in sending its professors abroad on two-year teaching assignments to broaden their knowledge.

## RESEARCH AND DEVELOPMENT ACTIVITIES

Since nearly all undersea technology in the FSU had been associated with the defense sector, concern was expressed about the future and the defense conversion process. Nevertheless, MTU seems to have redirected its programs toward the civilian sector. For example, new educational programs have been offered on underwater capabilities for the exploration of ocean resources. The goals are to provide engineers of the 21st century with the capability to develop underwater robots with elements of artificial intelligence. Other study areas include: design of unmanned submersibles; power systems for submersibles (generally unmanned); design of control instrumentation, automation and computers for unmanned submersibles; information systems, hydroacoustics, navigation, and underwater communication; autonomous control of submersibles; and automation of technical processes, robotics, and underwater manipulators.

Professor V.I. Nikolaev gave the panel a computer capabilities demonstration. The computer laboratory consists of four personal computers; these were the only computers this travelling party of WTEC team members saw in Russia. Prof. Nikolaev showed us a model that measures the effectiveness of such underwater vehicles as submersibles, ROVs, and towed systems for locating underwater objects. The model incorporates a 25-year data base. It also tracks reliability and maintenance.

The university is interested in foreign partnerships and cooperation in various fields: design and construction of ships, underwater platforms and apparatus; ecology (pipeline safety); miscellaneous underwater tasks (salvage techniques); ship and vehicle propulsion, including drag reduction; power plants (Sterling engines); new technologies (laser treatment of materials); strength and structural mechanics (dynamics of the interactions with platforms); instrumentation, measurement, and information systems; and other underwater programs.

The university has established a company, PAKS Ltd., for joint ventures and marketing various innovations. PAKS has a staff of 28 people, including three who received "USSR Inventor" titles. The company provides designs for unconventional propulsion for ships and submarines, constructs models, and conducts scientific and experimental studies in the university's test facilities.

WTEC team members were given a brochure describing a Complex for Lifting Large Sunken Objects (CLSO). The *Kamsomelets* nuclear submarine was obviously the genesis of this capability. A 100:1 scale working model of the lifting apparatus and

a video tape have been produced. Software has been developed for simulating the lift dynamics; design of various holding devices for salvaging large objects of different types and sizes; robotics systems; and burying techniques if the object is not salvaged. The university seeks foreign partners for the detailed design, development, and use of this CLSO capability.

Other ideas of interest that the university has developed include an ultra-short baseline underwater tracking system with a range of 1,000 m. It is unclear if this is a prototype or a production model. Another development is a low noise thruster (noise is reduced by 12 dB) called "double counter jets" that operates in laminar flow. The university is seeking an industry partner to continue this research since the military no longer supports these activities.

In summary, the State Marine Technical University of Petersburg is a unique educational facility that offers a broad spectrum of training in nearly all disciplines related to undersea systems. The university has initiated several enterprises and companies, and is interested in establishing joint ventures. The WTEC team was told that this university trained most of the engineers and researchers working at the design institutes we had visited in St. Petersburg.

## REFERENCES

*Complex for Lifting Sunken Objects (CLSO). Brochure.*

*International Cooperation in the Field of Science and Higher Education. Proposals. 1992.*

*Direction Finder Sonar Transponder DF 1000-04. Performance specifications (brochure).*

*Paks Ltd. Brochure. 1991.*

*Paks Ltd. Rotor-Rudders for Seagoing and River Vessels. 1991.*

*Educational materials on the Marine Technical University. In Russian and English. 1993.*

*Reliability of Ship Structures Research Laboratory. Brochure.*

**APPENDIX C. SITE REPORTS - UKRAINE****Site:**

**E.O. Paton Electric Welding Institute  
Ukrainian Academy of Sciences  
11, Bohanenko St.  
Kiev 266650  
Ukraine  
Telephone: 227-61-16  
Fax: 227-12-88**

**Date Visited:****May 1, 1993****Report Author:****R. Seymour****ATTENDEES****WTEC:**

L. Gentry  
R. Seymour

**HOSTS:**

Professor Konstantin A. Yushchenko Deputy Director  
Dr. Yuri Ya. Gretsхий Department Chief

**BACKGROUND**

Paton, founded in 1934, has become one of the largest research institutes in the world with about 8,000 employees (3,000 at the headquarters in Kiev). The institute undertakes research in all phases of electric welding and certain specialized related processes such as brazing, explosive forming, electrometallurgy, and friction welding. The institute's work covers welding of virtually all metals and alloys as well as ceramics in thicknesses varying from submicron to tens of centimeters. In addition to research in the welding processes, the institute also develops welding equipment, manufactures pilot plants, and develops welding consumables. These efforts are carried out in special centers at other locations.

The institute's scientists and engineers work cooperatively with many institutions internationally, the National Aeronautics and Space Administration (NASA), ABS, and the American Welding Society. Their experience includes military, space, and civil structures such as bridges and offshore structures, as well as temperature extremes



and high radiation applications. The institute maintains a close relationship with industry, assisting in the development of new materials and surface treatments.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The Paton Electric Welding Institute is involved in several research and development projects, including:

1. Research in electric (arc, resistance, electron beam, magnetic pulse, etc.) welding of metals, metal-based composites (principally aluminum matrix), and ceramics.
2. Large scale explosive forming.
3. Vacuum brazing of dissimilar materials, such as titanium to steel.
4. Plasma coating processes to improve corrosion and erosion resistance of metals and ceramics, with special processes to control thicknesses to a micron or less.
5. Advanced nondestructive testing techniques. The team was shown some color contour maps of components containing welds that were described as being produced through holography.
6. A special titanium department where engineers weld thicknesses that are 400 mm and thicker. There were many applications in the chemical industries, but the institute is now seeing increased use in offshore platforms and piping. Paton achieves yield strengths up to 800 MPa. The team had heard elsewhere that Paton was involved with welding processes for submarine hulls, but the institute's representatives did not discuss this beyond stating that their work in aviation and space had been applied to underwater projects.
7. Electroslag casting operations for manufacturing difficult-to-fabricate alloys and metals of great purity.
8. Use of both field and shop techniques in welding and manufacturing joints for offshore platforms, for thicknesses from 1 mm to 50 mm.

Information on the previous activities was obtained through discussions with Professor Konstantin Yushchenko and a 30-minute promotional film in English. Dr. Yuri Gretsikii led the team in demonstrations and detailed discussion of the underwater welding and cutting research. A diver demonstrated manual arc welding in a water tank at shallow depths and automatic welding in a pressure chamber at

a simulated depth of 200 m (this was gas-free welding using flux cored wire). Paton claims that this welding meets Class A standards under the U.S. D3.6 standard. American divers typically produce only Class B welds. There were many 180° bend samples in the lab; those that the team inspected showed good ductility and no visible inclusions. The team also examined a feed device to weld wire during wet welding; the institute commented that it was working on reducing its weight.

Dr. Gretsik discussed the problem of J-laying pipelines in deep water, and indicated that although they were working on a flash butt weld process for this application, there were many problems to be solved.

### **SUMMARY**

The underwater welding was the only area that the team explored in detail. The team would have preferred more data on welding titanium, but did not have time to pursue this (Paton was the last stop on the Ukrainian tour). The Paton Institute appears to have developed excellent techniques for mild steel and low alloys for manual and automatic underwater welds (ship, platform, and pipeline repair).

### **REFERENCES**

*E.O. Paton Electric Welding Institute. General brochure; illustrated. 1990.*

**Site:** **Institute of Geological Sciences**  
**Ukrainian Academy of Sciences**  
**55-B Chklova St.**  
**Kiev 252054**  
**Ukraine**  
**Telephone: 216-94-48**

**Date Visited:** **May 18, 1993**

**Report Author:** **R. Seymour**

### **ATTENDEES**

#### **WTEC:**

L. Gentry  
R. Seymour

#### **HOSTS:**

Professor Peter F. Shpak  
Dr. George N. Ladyzhensky  
Dr. Rudolph Kh. Greku  
Vladimir C. Gevorkian

Director

Chief Researcher  
Chief of Subdivision of Underwater  
Investigations

### **BACKGROUND**

The Institute of Geological Sciences is responsible for exploration and assessment of all mineral resources in the Ukraine, whether terrestrial or undersea. These include both oil and gas as well as metals and rare elements.

The institute's scientists study the structure and evolution of geological features in order to make predictions on resource availability. Their work on underwater resources had previously been worldwide in scope, but their present emphasis is on national waters. Their present experimental program involves studying the underwater geology of the Black Sea and recent sedimentation patterns. The Black Sea appears to have significant gas reserves but no known oil reserves in Ukrainian territorial waters. The institute's scientists have found traditional methods of investigation inadequate, and have developed new technology. In particular, they believe that direct observations by scientists are essential, and have developed a fleet of manned submersibles to meet these needs.

## RESEARCH AND DEVELOPMENT ACTIVITIES

One area of research involves understanding the interactions between biological and geological processes. In the study of the distribution of minerals in the deep ocean, the institute's scientists study ecological effects in high production areas.

They report detection (by mixed gas, lock-out diving) of gas hydrates -- a frozen mixture of natural gas and water -- at depths of only 200 m and only 50 cm or so below the surface of the sediments. In the present plan for gas recovery, they propose using conventional techniques to recover the gas in reservoirs below the hydrates and, subsequently, to mine sediments for the gas contained in the hydrates (see Figure Geo.1). One of their concerns is to find an environmentally acceptable means to accomplish this.

The institute's scientists also report finding polymetallic crusts in the Black Sea that contain significant amounts of iron. The Kiev group consists of users, not developers, of the submarines, towed vessels, and support ships used in their research. The development activity is carried out at Mariecoprom in Sevastapol (see that site visit report).

## SUMMARY OF DISCUSSIONS

The institute's charter limits the organization to the Ukrainian territorial waters in the Black Sea, which places large emphasis on the natural gas resource. These waters extend to depths of greater than 2,000 m. The institute's scientists and engineers will be responsible for developing gas extraction and hydrate mining equipment for this application.

## REFERENCES

- Greku, R. and V.C. Gevorkian. "Gas Hydrates of the Black Sea." Technical proposal of the Institute of Geological Sciences, Ukrainian Academy of Sciences. Kiev. 1993.

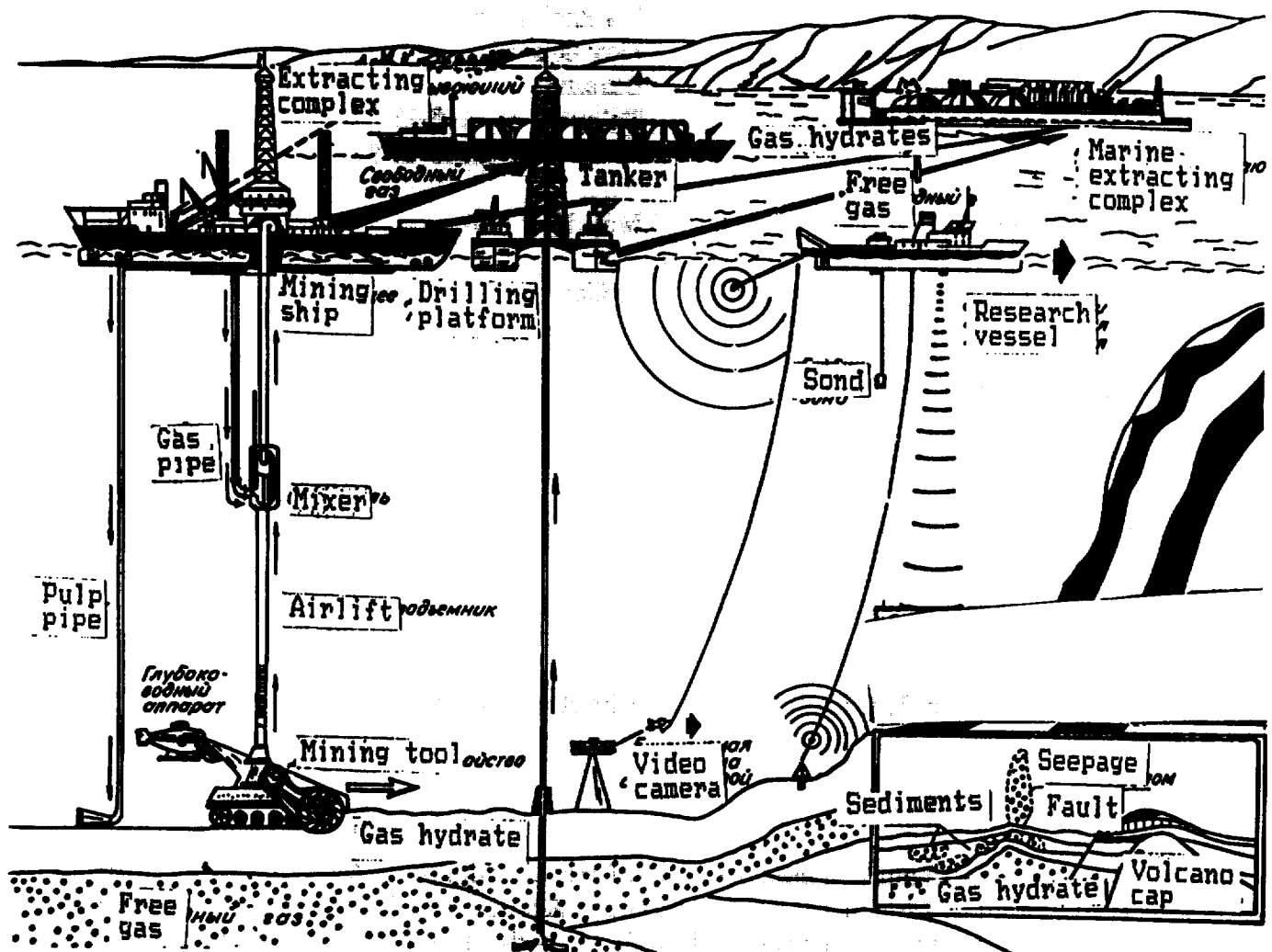


Figure Geo.1. Scheme for Mining Seabed Gas Hydrates

## Site:

Institute of Hydromechanics  
Ukrainian Academy of Sciences  
8/4 Zhaiabova Str.  
Kiev 262067  
Ukraine  
Telephone: 440-43-13  
Fax: 440-42-20

## Date Visited:

May 18, 1993

## Report Author:

L. Gentry

**ATTENDEES**

## WTEC:

L. Gentry  
R. Seymour

## HOSTS:

Professor Victor T. Grinchenko      Director, Institute of Hydromechanics

**BACKGROUND**

The Hydromechanics Institute is one of three institutes in Kiev that belong to the Department of Mechanics of the Ukrainian Academy of Sciences. The center that the team visited is concerned with a wide range of hydrodynamics and hydroacoustics. The other mechanics institutes study solid body mechanics and the strength of various materials in harsh environments. The Hydromechanics Institute employs 160 researchers and has a total staff of over 300 persons.

The twelve departments at the Hydromechanics Institute are listed below:

- o Hydrodynamic Acoustics
- o Vortex Motions
- o Hydrobionics and Boundary Layer Control
- o Free Boundary Flows
- o Hydrothermal Processes Modelling
- o Hydrodynamic Processes Control
- o Technical Hydromechanics
- o Applied Hydrodynamics
- o Hydrodynamics of Wave Processes

- o Hydrodynamics of Hydraulic-Engineering Structures
- o Dynamics of Elastic Systems
- o Stratified Flows

Some areas of investigation that interested the WTEC panel include the following:

- o Boundary layer control (i.e., compliant surfaces, polymer injection, Coanda effect ducts, etc.)
- o Propulsive efficiency (small ROVs)
- o Resistance coefficients in unsteady flows
- o Wave/structure interactions
- o Hydrodynamic acoustics
- o Vibration control and other methods for drag reduction

The institute has extensive and very capable test facilities, and conducts a variety of physical experiments along with parallel investigations in numerical modelling. The team saw no computing equipment, but was told that a few 486 personal computers are used for modelling, data processing, and design.

Due to the present unsettled political situation, the institute has funding difficulties and is very interested in joint studies with other institutes in the West.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The team observed a wide array of test facilities and research projects at the institute during the three-hour visit, including a high-speed tow tank with a tow carriage capable of speeds to 25 m/sec. It is equipped with a special control system to allow smooth and rapid deceleration. The facility has been used for control and drag experimentation of surface and submersible vehicles. The model basin is 140 m long by 3 m wide by 1.8 m deep.

A second tow tank was also observed that was 30 m x 5 m x 3 m deep and equipped with a more conventional tow carriage. This second basin was fitted with wave making and local wind generation equipment. A towed acoustic array was observed at the tank. The institute's scientists explained that they conduct hydroacoustic studies and elastic motion studies in waves using this facility. The team saw examples of miniaturized pressure and acoustic transducers at this facility. They mentioned that they develop and test active acoustic devices using piezoceramic transducers for low frequency applications.

The panel observed a high velocity hydrodynamics laboratory where experimentation in very high speed underwater projectiles and propelled bodies is conducted. The specifications sheet distributed during the visit mentions velocities up to 1,000 m/sec. The institute also claimed to have data on velocities near the

speed of sound and theoretical work to velocities of Mach 2. These projectiles are launched at speeds that create a surrounding cavitation field that exhibits very low drag. The drag is essentially limited to the area of the tip of the projectile and is actually less than the drag in air at the same speed. No information was provided relative to the distance travelled or stability in flight; however, the team did observe a few crumpled projectiles that tumbled during flight.

The Hydromechanics Institute has other hydrodynamic test facilities that the team did not have time to inspect. These include a closed water tunnel and hydrodynamic test stand for flow and low-intensity turbulence testing to flow velocities of 8 m/sec.

The institute also has equipment for open-ocean testing. The team did not see this equipment, but it is believed to be located at a remote site along with support ships used by the institute for at-sea hydromechanical investigations. The equipment includes a towed test sled and two small ROVs named *Polus* and *Adeline*. These are very small (60 kg) and shallow water (300 m) units used in support of shallow testing.

## SUMMARY

The institute demonstrated the high speed (25 m/sec) towing of a submerged sphere in the large tow basin. The institute's scientists and engineers also are doing work on oscillating wing propulsion systems (see Figures Hydro.1 and Hydro.2), including clusters of these control/propulsion devices for submerged vehicle maneuvering.

The Hydromechanics Institute appears to be capable of advanced laboratory experiments in many areas related to underwater vehicles, although the team was not shown numerical results because of insufficient time. Institute representatives said that they had recently obtained a few 486 personal computers. However, the team was not able to assess the institute's numerical computation capabilities.

The institute has a strong program in ocean wave studies, and its work on high speed projectiles appears to be unique and exciting. The projectiles, about 1 inch in diameter, and tapering to a point over 10 inches in length, are explosively launched to speeds approaching or exceeding Mach 1. As the vapor cavity forms, resistance/drag drops to less than that experienced in air. The actual test velocity achieved is uncertain, but was claimed to be above Mach 1. The team saw high speed photography of the institute's tests; institute representatives claim to be able to numerically model cavity shape and formation at even higher speeds.

The team was given a package of project description sheets for a development group known as "NIPIOceanmash" at Dniepropetrovsk, located about 300 km southeast of Kiev. Although there is no formal connection of the Hydromechanics Institute with NIPIOceanmash, papers were offered to the team on behalf of the



director of NIPIOceanmash. The papers described projects involving a wide range of ocean engineering activities and equipment for deep ocean mining, deep offshore drilling, marine salvaging, and dredging. The data describes what appears to be available systems not unlike the Glomar Explorer with heavy lift and deep drilling capabilities to depths of 6,000 m. While little time was available to explore this capability, it is very interesting and worthy of future follow-up to determine if technologies appropriate to underwater vehicles are involved. The team was told that the director of NIPIOceanmash would be interested in further contact.

## REFERENCES

*High speed tow basin and water tunnels. Specifications sheet.*

*High velocity hydrodynamics facility. Specifications sheet.*

*At-sea tow complex. Specifications sheet.*

*Small ROVs Polus and Adeline. Data sheets.*

*Various underwater projects conducted at NIPIOceanmash in Dnipropetrovsk, Ukraine. Data sheets.*

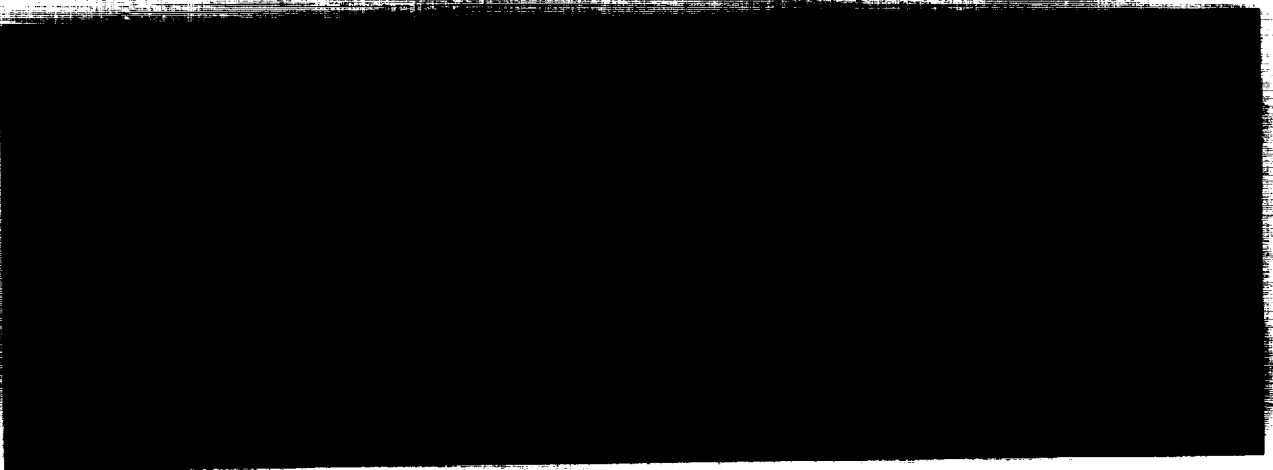
*Large model for testing oscillating wing propulsion for submersibles. Two photographs.*

*Flow visualization using bubbles. Photograph.*

*Model testing of U.S.S. Lafayette class submarine hull. Photograph.*



**Figure Hydro.1. Large Model Testing of Oscillating Wing Propulsion for Submersibles**



**Figure Hydro.2. Test Model for Oscillating Wing Propulsion (side view)**

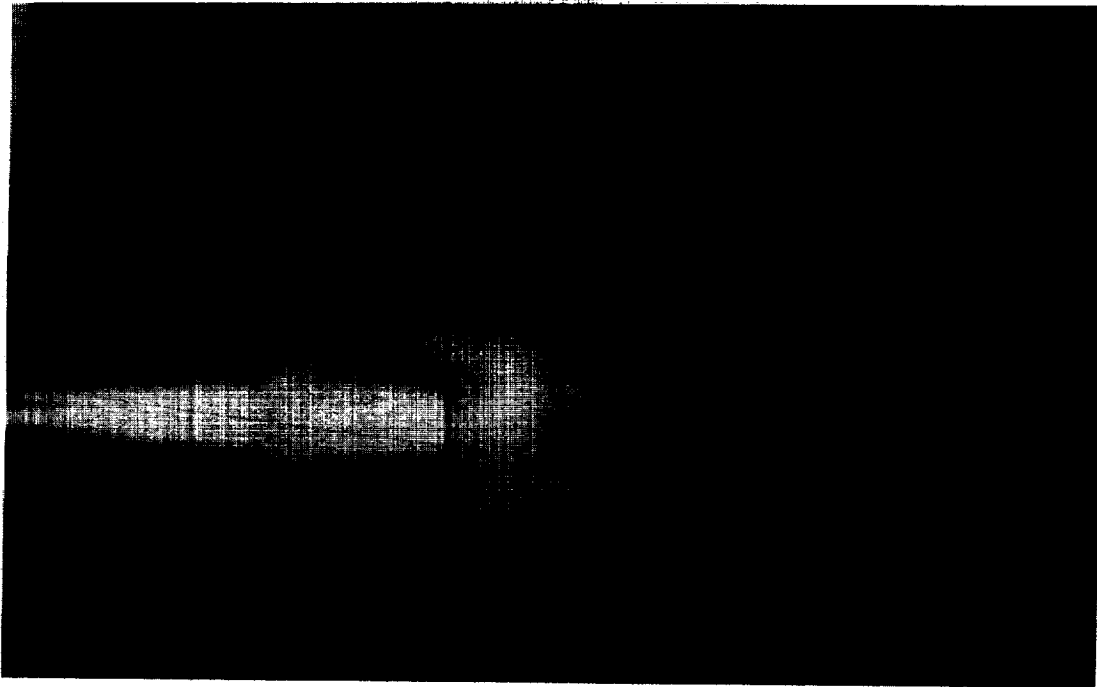


Figure Hydro.3. Flow Visualization Using Bubbles

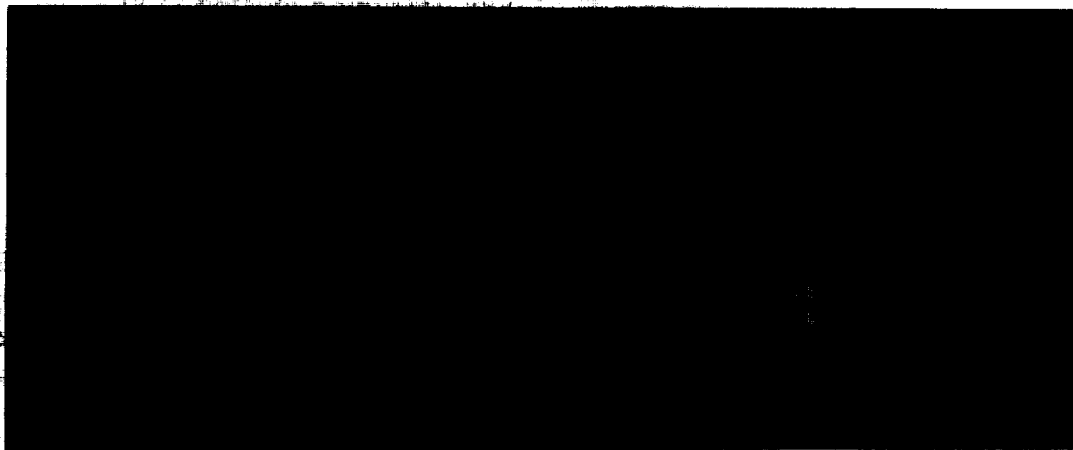


Figure Hydro.4. Model Testing of U.S.S. Lafayette Class Submarine Hull

## Site:

Mariocoprom  
 Scientific Research Association (IRA)  
 Sevastopol 335100  
 Ukraine  
 Telephone: 552074  
 Fax: 552454

## Date Visited:

May 19-20, 1993

## Report Author:

L. Gentry

**ATTENDEES**

## WTBC:

L. Gentry  
 R. Seymour

## HOSTS:

Igor M. Nestorenko  
 Vladimir G. Usenko  
 Victor A. Horoshev  
 Marat V. Sarvanidi  
 Vladimir C. Gevorkian

General Director  
 Chief, Department for Operations  
 Chief Engineer  
 Chief, Electronics Department  
 Chief, Underwater Subdivision of Underwater  
 Investigations Institute of Geological  
 Science (although located in Kiev, he  
 accompanied the team to Sevastopol to  
 coordinate our visit)

**BACKGROUND**

Mariocoprom is the operating arm of the Ukrainian Academy of Sciences, and is located at Sevastopol on the Black Sea. The association operates a fleet of research vessels and manned submersibles for various institutions of the academy to carry out oceanographic and geological studies (see separate site reports on the institutes of hydromechanics, hydrophysics, and marine geology). Mariocoprom has in the past operated its fleet in many areas of the world. In fact, the association still has ships operating in Peru (*Odyssey*, with its submersible, the *Sever-2 Bis*) and in the Far East (*Gidronavt* and its submersible, the *Tinro-2*), but most of its interests are now in the Black Sea, where much of the Ukraine's plans for exploitation of resources are focused. Oil, subsea minerals, and gas hydrates are among the riches available in the Ukrainian portions of the Black Sea. Funding also limits the international

operations of the Black Sea research fleet; only those on contract work venture out of this local inland sea.

The nine vessels (most are converted fishing vessels) range in size from 1,200 to nearly 4,000 tons. Each vessel supports one or more of ten manned submersibles in scientific investigations of the water column and seafloor. Mariecoprom does not operate unmanned vehicles since the association feels strongly that the best science is accomplished in situ by knowledgeable and trained academics. The submersibles at Mariecoprom range in size and capability from the very large, twelve-person *Benthos-300* to the small, towed, three-person *Tetis-H*. Mariecoprom is able to provide well qualified operating crews for its vessels and submersibles, and is willing to share research of mutual interest in the Black Sea or lease its assets for worldwide operations at very low daily rates. The estimated rate in the Black Sea for a fully crewed *Sever-2* submersible and support vessel *Ichtiander* is about \$500 per day, excluding fuel and oil. This is purely an estimate; actual costs will depend on the area of operation and many other factors.

## RESEARCH AND DEVELOPMENT ACTIVITIES

Mariecoprom does not conduct research and development directly. The association operates and maintains the platforms for the Ukraine government and the Academy of Sciences institutes, and works with other institutes to conduct field investigations and studies.

## SUMMARY OF DISCUSSION

The team met with Mr. Igor Nestorenko and his staff at the Mariecoprom offices for general discussions, then toured the Sevastopol harbor facilities where the ships and submersibles are serviced and maintained. Only three submersibles were available for inspection at the time.

The team visited the *Omar* (built in 1989), which was in the shop being prepared for operations in the summer. It is equipped with two seven-function manipulators and can accommodate scientific payloads of 250 kg. *Omar* is a hydraulically powered vehicle with twin main propulsors and three maneuvering forward thrusters for pitch and yaw control. The vehicle, which has no computer systems onboard, is essentially manually controlled. Both *Omar* and its sister boat the *Langust* (1990) are very simple, rudimentary vehicles and are far behind the sophistication of similar submersibles in the West. However, they are proven, reliable, have outstanding safety records, and are cost-effective alternatives to their high-tech counterparts in the West. The depth rating of *Omar* (540 m) is marginal for many scientific missions.

The team then toured the *Sever-2* (1972) submersible onboard her support ship, the *Ichtiander*. The *Sever-2* and *Sever-2 Bis* (1976) are older than the *Omar*, but they are larger and more capable boats. They support a crew of five for a submerged duration of about six hours at depths to 2,000 m, with a payload of 800 kg. The design and level of sophistication of *Sever-2* is similar to *Omar* (e.g., both have simple manual controls and a magnetic compass for navigation). Geodetic navigation and position are tracked from the surface using acoustic long baseline transponders. View ports and external lights are used instead of video systems for all operations, including the use of manipulators. *Sever-2* is better outfitted for science than the smaller *Omar*. It has a roomy forward observation sphere for three people, with the two pilots seated at side-by-side consoles aft of the observation sphere. Piloting at the maximum forward speed of three knots is aided by a forward looking sonar, but all controls are manual, with no indication of closed loop computer controls and no remote video systems.

The team also toured the *Benthos-300* Submersible Laboratory. Two *Benthos-300s* were built in 1976 and 1981. Both are still operational in the Black Sea. They are very large research submersibles capable of supporting a twelve-man crew for seven days of submergence at up to 320 m. At over 50 m in length and more than 800 tons displacement, the vessels are too large to launch from a support vessel. Thus, they are towed to the work site on the surface or submerged in bad weather. The boats are diesel powered while on the surface and battery powered when submerged. Their submerged speed is up to 5 kts. The crew is composed of a mix of operators, divers (hydronauts), and scientists, depending upon the mission. Shallow diving operations to 60 m are done on compressed air. Deeper diving is done on mixed gas. A large diver support area aft contains a four-man diver lockout chamber, a two-man recompression chamber, diving gas storage, and a dive locker. Six berths, a small galley, and a mess area were observed; also, a large area for scientific equipment is located forward. The *Benthos-300s* are old and, like the other submersibles toured, not equipped with many modern features. Although they are cramped and could be uncomfortable for continuous seven-day submergence, the *Benthos-300* seems to be reliable, safe, and well crewed. It is certainly adequate for the purpose of seafloor work and science.

Maricoprom has developed an over-the-side launch and recovery technique for the fishing trawlers used as support ships. Large davits, booms, and side doors have been fitted to the ships, and the submersibles are handled off the lee side with heavy tackle. Divers or small boats are needed to make connections and disconnections in the water, but they claim to have made safe recoveries in sea conditions to Beaufort 7.

Vladimir C. Gerverkian, the father of *Benthos-300*, and the other submersible engineers and crew members were very helpful in answering questions. The team was especially honored by the ceremony where Mr. Seymour and Mr. Gentry were named as "hydronauts of the *Benthos-300*."

**REFERENCES**

*Support Ships and Submersibles.* Book of specification sheets and photographs.

*Benthos-300.* A history of the *Benthos-300* in Russian. Moscow: 1992.

*Submersibles Available at Mariecoprom.* Booklet in Russian. Sevastopol, Kiev: 1991.

## Site:

Marine Hydrophysical Institute,  
Ukrainian Academy of Sciences  
2, Kapitanskaya St.

Sevastopol 339000

Ukraine

Telephone: (0990) 525046

Fax: (0990) 523055, 520165

Omnet: MHLSevastopol

Date Visited:

May 20, 1993

Report Author:

R. Seymour

**ATTENDEES****WTEC:**

L. Gentry  
R. Seymour

**HOSTS:**

Professor Vladimir V. Efimov  
Michael E. Rabinovich

Deputy Director  
Director of Special Design-Technology  
Bureau and Head of Marine Instruments  
Department

**BACKGROUND**

The Marine Hydrophysical Institute (MHI) is one of the largest research institutions in the world devoted principally to the study of physical oceanography. In addition to the headquarters facility in Sevastopol, the institute has an Experimental Division in Katsiveli (Crimea) and an Acoustics Division in Odessa.

The institute operates five ships, two of which are major ocean-going vessels that have been active in the world oceans on programs such as WOCE, TOGA, and JGOFS. Because of present budget constraints, work outside of the Black Sea is restricted to contract investigations. The institute was founded in 1929 and the base in Sevastopol was established in 1963. In addition to deep water physical oceanography, MHI has had a continuing interest in coastal and shelf processes, and operates a shelf mounted observational platform at a depth of 35 m in the Black Sea.



The research interests of MHI include: turbulence, hydrophysics, optics and biophysics, ocean-atmosphere interactions, wave theory, and dynamic and stochastic modelling. The institute has a substantial design, development, and manufacturing capability for the specialized instruments employed in its investigations. Because of time constraints, the WTEC team was unable to visit the acoustics facility at Odessa, and concentrated on the instrumentation developed at Sevastopol.

## RESEARCH AND DEVELOPMENT ACTIVITIES

This report will focus on the instrumentation developed by MHI for its physical oceanographic investigations, and will not discuss those research activities.

MHI has developed a family of towed and lowered CTDs. Of the towable systems, Model *MGI-1201* (see Figure Marine.1) can operate to a depth of 1.5 km and at speeds to 15 kts. It utilizes a 6,000 m single conductor cable. Measurements include temperature (resistance thermometry with a 50 m/sec time constant), conductivity (induction), and a strain gauge type pressure sensor. An interface unit, a digital display and output to an external personal computer, is supplied to provide power. This appears to be an improved model of the Model *MGI-4204*, which has a depth limitation of 1,000 m and a 1.5 sec measurement interval. The Model *MHI-9201* towed body (see Figure Marine.2) has control surfaces and can be maneuvered in three dimensions. In addition to the CTD measurements, this unit also measures light attenuation spectrally and the intensity of chlorophyll "A" radiation. Its maximum depth is 200 m and the maximum towing speed is 12 kts.

MHI has developed a series of profiling systems that are lowered on a cable (see Figure Marine.3). They can be equipped with internal battery power and onboard data recording for use on the shelf with unsophisticated support vessels, or can be powered from the ship for operations to depths of 2.5 km. In general, they profile pressure, temperature, conductivity, dissolved oxygen, pH, and distance to the bottom. They can be supplied with a 10 bottle water sampling module with about 1 liter samples. The *Shick-3*, the most advanced of these models, also contains an electromagnetic current meter, and can be outfitted with sensors for turbidity and chlorophyll fluorescence. The WTEC team was provided with information on a more recent sounder (*Probe OLT*; see Figure Marine.4), which measures current velocities with a multiaxis acoustical meter as well as the standard CTD capabilities. It has a 2 km depth limit.

MHI has developed vane, propeller, electromagnetic, and acoustic current meters. Most of these systems can be supplied with an internal microprocessor for autonomous operation for periods up to one year, or with data output to a personal computer. They cover a range of applications from the *Shist-1*, an acoustic shelf system that has a depth range of 50 m to the 3-D acoustic current meter *Dit-1*, which operates to 6 km and includes a CTD measurement capability. This unit stores data

onboard for up to a year, and operates on twelve standard batteries. The team received a photograph of the institute's latest acoustic meter (see Figure Marine.5), but without specifications. All of the acoustic meters appear to be time-of-travel type instruments, rather than the Doppler type that is common in the United States. MHI has developed, and apparently will supply, individual sensors for temperature, conductivity, and a variety of chemical parameters such as dissolved oxygen. These units are designed for plug-in to standardized connectors. The institute also provides a family of position sensors (pitch, roll, and heading) for application to towed vehicles and ROVs.

### **SUMMARY OF DISCUSSIONS**

The institute has developed a full suite of instruments for sampling hydrographic conditions from shallow to deep water. These instruments were described by Mr. Vladimir Rabinovich as being equivalent to those of "Neal Brown" (an American oceanographic instrument company). The institute's scientists have concentrated on acoustic current meters that measure velocity components at a point rather than utilizing the range-gated Doppler system. The worldwide charter of MHI has been severely reduced by present economic conditions; it would appear that instrument development efforts will be curtailed, as well.

### **REFERENCES**

- Sensors and Devices for Oceanographic Survey.* Catalog of specification sheets of MHI instruments. 1993.
- Marine Hydrophysical Institute.* General brochure on MHI; in English and Russian, with some illustrations. 1992.
- Marine Hydrophysical Institute.* General description of MHI, ships, and towed systems. 1992.



Figure Marine.1. Towed CTD Instrument, Model MGI-1201

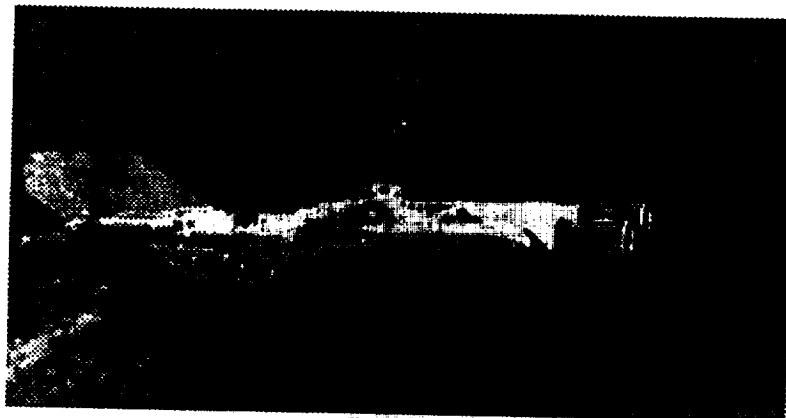


Figure Marine.2. Controllable Towed CTD Instrument With Optical Measurement Capability

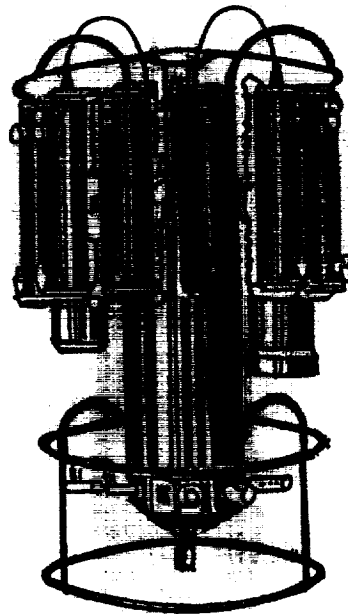
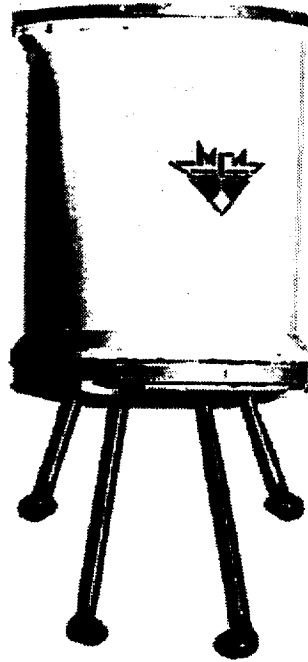


Figure Marine.3. Lowered CTD Complex With Water Sampling Capability



Figure Marine.4. Probe CLT with CTD Measurement and Multi-axis Acoustic Current Meter



**Figure Marine.8. New Acoustic Current Meter Device**

**APPENDIX D. SITE REPORTS - FRANCE**

**Site:** **IFREMER**  
**Center de Toulon-La Seyne**  
**Zone Portuaire de Dragageon**  
**B.P. 330-83507 La Seyne-sur-mer**  
**Cedex**  
**France**

**Date Visited:** **May 14, 1993**

**Report Author:** **A. Kalvaitis**

**ATTENDEES****WTEC:**

**A. Kalvaitis**  
**M. Lee**

**HOSTS:**

<b>Jean-Louis Michel</b>	<b>Program Manager, Undersea Intervention Dept.</b>
<b>Jean-Francois Drogou</b>	<b>Undersea Engineering and Technology Dept., Project Manager 6,000 m ROV</b>
<b>Jean-Francois Cadiou</b>	<b>Head of Underwater Computers Group</b>
<b>Dr. Vincent Rigaud</b>	<b>Head, Robotics and Artificial Intelligence</b>

**BACKGROUND**

The French Research Institute for the Exploitation of the Sea, or IFREMER, is a government agency with scientific, industrial, and commercial roles, and acts on behalf of the French government to direct, fund, and promote ocean research and development. It has a budget of approximately \$160 million (1992), with 1,200 personnel at five centers (Boulogne-sur-Mer, Brest, Nantes, Toulon, and Tahiti). IFREMER has responsibilities that are evenly split between applied research projects and operations.

Underwater intervention and instrumentation are recognized as major themes in IFREMER's strategic plan. The institute's successful program in manned underwater vehicles, such as the *Cyana* and *Nautilie*, has allowed France the capability of

carrying out research and projects at water depths to 6,000 m. Other undersea capabilities include the Sar, a 6,000 m deep towed side scan system, which provides high resolution data for bottom acoustic imagery and subbottom profiling. In addition, IFREMER has created two research laboratories for robotics and underwater acoustics that have been associated with outside laboratories to stimulate progress in applied research in key areas of underwater intervention.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

In addition to manned submersibles, IFREMER has been developing remotely operated vehicle capabilities. To maintain European leadership in deep ocean activities, a feasibility study has been underway since 1991 for the development of a 6,000 m science-dedicated ROV. Total costs are estimated at \$7 million, not including manpower resources. The present schedule includes completion of conceptual studies (1993), subsystem design (1994), and system integration and sea trials in mid 1996. Although several 6,000 m ROVs are available commercially, IFREMER feels that better control is exercised by conducting the project internally. Also, since it is a science ROV, the institute has direct communication with the research community. Specific features include a 20 mm fiber optic cable, 20 kw, 400 Hz, and a 300 m tether with two different down weights. The ROV motors will be oil compensated, and the electronics will be in pressure housings. Three different tool sleds will be progressively developed for biology, geology, and sensor packages. The ROV will have two manipulators and six thrusters at 5 hp each. It will utilize two VME computers running VXworks real-time operating system, one on the ship and the other on the ROV. Vehicle tracking will be conducted using a combination of an ultra-short baseline system in conjunction with a long baseline system.

IFREMER is also a major partner in a MAST II (Marine Science and Technology) cooperative European project for the development of key technologies for a 6,000 m *Abyssal Survey Vehicle (ASV)*. This is an autonomous, self-powered vehicle for the surveying and mapping of deep ocean regions. The program is headed by the United Kingdom's Institute of Oceanographic Sciences (IOS), and includes partners from France (ECA and INRIA), the United Kingdom (DRA), Greece (University of Athens), and Portugal (Hydrographic Institute). The project's feasibility study is scheduled for completion in 1995, and includes a succinct preliminary design. Total funding is approximately \$2.5 million. The vehicle will use carbon fiber pressure housings instead of syntactic foam. The projected range is 200 km at 2 m/sec, and it will be able to survey a 5,400 m wide swath. The overall program objective is to develop a cost-effective autonomous vehicle to survey the deep ocean regions. Specific performance objectives include: independence from support ship during survey; submergence time in excess of 20 hours; 200 km survey range per dive; and deployment from existing vessels. Monitoring of the data quality could be done using a French acoustic transmission system, TIVA, at up to 20 kbits. The ASV will

be designed to provide bathymetry and imagery concurrently. IFREMER's scientists believe that key technologies include guidance (automation and mission planning), energy sources, navigation, and pressure housings.

Also described in detail was the IFREMER program in software and control of future undersea vehicles, such as the 8,000 m ROV, which is presently under study. A test bed vehicle called VORTEX (Versatile Open Subsea Robot for Technical Experiments) has been constructed, and allows the demonstration and verification of ROV controls. VORTEX has six thrusters, sonar, and a video camera, and is in transition to AUV sensor based control of stationary and moving objects. The team was given a demonstration that verified three modes of operation: (1) manual; (2) PERAT (control software developed by IFREMER); or (3) by directly entering PILI (standard interface language). There exists a capability to pilot the VORTEX vehicle remotely from Brest or Sophia using Internet.

Other subsea research and development activities include: acoustic data transmission, acoustic determination of seabed characteristics, array processing (tomography), very low frequency transducers, autonomous piloting, man-machine interface, teleprogramming, materials, and hydrodynamics. The last two activities are being conducted at the Brest Center.

In conclusion, IFREMER provides France with the capability to conduct undersea research and intervention activities up to 6,000 m. IFREMER has maintained a level of excellence in technology development and research that serves the science community, equipment manufacturers, and facilities companies.

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Date Visited: May 13, 1993

Report Author: M. Lee

### ATTENDEES

#### WTEC:

A. Kalvaitis  
M. Lee

#### HOSTS:

Bernard Espiau  
Claude Samson

Directeur de l'Institut Supérieur d'Informatique  
Directeur de Recherche Responsable de  
Project ICARE  
Charge de Recherche  
Charge de Recherche

Daniel Simon  
Patrick Rives

### BACKGROUND

Institut National de Recherche en Informatique et en Automatique (INRIA) is a coordinating center for scientific cooperation with scientists of the former Soviet Union in the area of underwater vehicle technology. INRIA performs basic research in system design and in control architecture. The institute works closely with IFREMER, which does applied research in underwater vehicles. The concepts that are developed under the ICARE project and that relate to underwater vehicles will be demonstrated on the *VORTEX* test bed vehicle at IFREMER.

The underwater vehicle and sensor-based control research at INRIA is in the project ICARE (Instrumentation, Control, and Architectures in Robotics), headed by Mr. Claude Samson. This project has fourteen full time people, including six graduate students. The program has three principal investigators: Mr. Bernard Espiau, Mr. Daniel Simon, and Mr. Patrick Rives. Mr. Espiau, who hosted the WTEC team, was scheduled to transfer from INRIA to Grenoble later in 1993.

The focus of this group is basic research in automatic control, and research into programming environments. The objective is the development of a methodology of design, integration, and assembly of many components of a control system (which is able to deal with unknown environments and has real-time programming capability) for complex mechanical systems. These activities are organized into three major projects.

## RESEARCH AND DEVELOPMENT ACTIVITIES

Mr. Simon presented his group's work on sensor-based control. The group is currently using vision as its primary sensor for local control. The scientists are interested in integrating sonar and vision. They would like to use the fusion of this data for local terrain sensing and for a reference for their control system.

The team saw the fixed base robot that INRIA has been using to date for its research platform. A mobile robot platform was demonstrated that will be the institute's future technology test bed. Underwater applications of the technology are done jointly with Mr. Vincent Rigaud at IFREMER.

INRIA is interested in tradeoffs of high speed/low speed control for underwater vehicles. The institute is also interested in characteristics and impact/integration into the control system design for other types of actuators, such as variable ballast systems. The institute's scientists are working on control schemes using time varying control for nonholonomic systems.

Although video servoing is being done at Sophia, the work on video servoing using optical flow is being done at Brest.

One research topic that is being addressed is identifying when the vehicle has enough information to complete a requested task. INRIA is also working on developing an estimation of the errors that evolve when navigating the vehicle from local sensors. INRIA's scientists would like to determine when the sensor drift errors will make completion of the task impossible. This can then be fed into a planning system to define how the vehicle must proceed to get the additional information necessary to complete the task. INRIA is not working on building a large scale world model of its environment. Rather than work from a world model, the institute is focusing on the portion of the world that can be sensed from the vehicle.

The institute's scientists are working on parallel algorithms for planning systems. Their approach is to focus on deterministic algorithms rather than artificial intelligence techniques.

Their first project in control from local sensors started two years ago. The goal of this project was to do bottom following. This application would be used to do a sonar survey and to make maps from the data. Now INRIA is doing work on defining

sensors, actuators, and control tradeoffs for the MAST project ARSUAUV (Advanced Research System for Unmanned Autonomous Underwater Vehicles).

The institute is interested in research in underwater intelligent operation. This includes sensor-based control, programming tools, and man/machine interface. The team saw demonstrations of automatic program generation. The inputs to this program are the tasks, the communication links, and the modules that define the servo algorithm to be used. The geometry of the robotic system can be input through a computer assisted design environment. The output is C code that can run in a VXworks environment. INRIA scientists also demonstrated a code simulation system which allows the user to simulate sensor inputs and line-by-line code execution.

## **SUMMARY**

INRIA is a basic research organization that is creating technology in software architectures, sensor-based control, and control systems. INRIA is a leader in this area of research. This research is creating enabling technology that will have a significant impact on underwater vehicles. Software architectures that allow easy integration on local sensor-based control will open up the field of underwater experimentation and new methodologies for scientific research using underwater vehicles. It can lower the cost of doing science underwater by reducing the dependency of the vehicles on large scale positioning capabilities.

INRIA has only recently entered the field of underwater robotics and is interested in expanding its role in this area of research.

## **REFERENCES**

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Espiau, B., F. Chaumette, and P. Rives. "A New Approach to Visual Servoing in Robotics." *IEEE Transactions: Robotics and Automation*, Vol. 8, No. 3. June 1992.

Martinet, P., P. Rives, P. Fickinger, and J. Borrelly. "Parallel Architecture for Visual Servoing Applications." *Workshop on Computer Architecture for Machine Perception*. Paris: 1991.

Rives, P. and R. Pissard-Gibollet. "Reactive Mobile Robots Based on Visual Servoing Approach." *AIS 92*. Perth: July 1992.

*INRIA* Brochure. 1992.

**Site:** Laboratoire d'Informatique Fondamentale et  
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**Date Visited:** May 10, 1993

**Report Author:** M. Lee

### **ATTENDEES**

**WTEC:**

**M. Lee**

**HOSTS:**

**James Crowley, Ph.D.**

Professor, Institut National Polytechnique de  
Grenoble

**Patrick Reignier**

Ph.D. Candidate, Active Vision and Mobile  
Robotic Group

### **BACKGROUND**

Laboratoire d'Informatique Fondamentale et d'Intelligence Artificielle, or LIFIA, is one of seven research laboratories that make up IMAG. Other labs include INRIA, INPG, UJF, CNRS, LGI, and LDS. LIFIA is divided into two divisions. One division contains the formalists. The second division is made up of four groups: robotics, vision, artificial intelligence, and active vision. Professor James Crowley heads up the group PRIMA - Mobile Robotics and Active Perception. There are thirteen Ph.D.s and Ph.D. candidates in this program, which has a budget of 1.4 million francs plus salaries.

This group is researching the basic technologies that will enable sensor-based control of remote vehicles. The scientists' focus is on using data from a video camera and from a sonar as input to a vehicle control system. They are also involved in 3-D model construction of observed objects. They develop and demonstrate their research on land robots, although the technology is equally applicable to underwater vehicles. The laboratory's scientists are interested in collaborative efforts that will demonstrate their research on underwater vehicles.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The laboratory has a program in navigation and control from local sensors. The WTEC team first saw a description and then a demonstration of LIFIA's system on its simulator. It is comprised of a series of sonar sensors that are mounted to look out horizontally around the periphery of a mobile robot. By processing the data from these sensors, the distance to a barrier or wall is determined. Points that are continuous and in line are linked and defined as being part of a wall segment. Wall segments are matched against a world model for fit. If a match is achieved, the vehicle uses its estimated position in this world model as an input to its global navigation system. It is able to be commanded relative to its global position as determined from the sonar or it can be commanded to respond directly with respect to the sensed barrier, as in obstacle avoidance or tracking. The data from these disparate types of sources are brought together and fused in an extended Kalman filter.

## **SUMMARY**

The technologies that we saw (including the research vehicle, software, video sensor subsystems, sonar subsystems, navigation, control, and sensor fusion) all seem to be applicable to underwater vehicle systems. Overall, LIFIA's work seems to be competitive with work in the United States and in other countries. The laboratory seems to be funded at a level that allows it to have a reasonable computer and hardware environment for its research. The laboratory's scientists are converting their software operating environment to VXworks, which will make them compatible with many research organizations in the United States and will make interchange of software more feasible. They are interested in joint projects with IFREMER and other French underwater vehicle research organizations to demonstrate their technology underwater. Active vision and control, using sensing of local terrain data, are potentially important technologies in the future of remote underwater vehicles.

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- Vision as Process*. Esprit Basic Research Action. BR 3038/BR 7108.

**APPENDIX E. SITE REPORTS - UNITED KINGDOM**

Site: **Institute of Oceanographic Sciences  
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Date Visited: May 11, 1993

Report Author: B. Mooney

**ATTENDEES****WTEC:**

D. Blidberg  
C. Brancart  
L. Gentry  
B. Mooney

**HOSTS:**

Dr. Peter G. Collar  
Dr. Keith H. Scrimshaw

**BACKGROUND**

Deacon Laboratory is a major United Kingdom deep water laboratory. It is the international headquarters for WOCE. Recent past efforts have included a multilayered numerical model of the Southern Ocean, which will eventually extend to global oceans. The forte of the Deacon Laboratory is interdisciplinary deep ocean science, including both modelling and observations, closely supported by innovative technology. The current thrusts of the laboratory involve marine physics, chemistry, biology, geophysics, and geology. Ocean tools developed there include GLORIA and TOBI.

Deacon Laboratory is funded at a level of about £9 million a year by the National Environment Research Council. There are plans for Deacon Laboratory to move in

the next year or two to Southampton and co-locate with the University of Southampton. Deacon Laboratory employs about 200 people, 120 of whom are scientists or engineers. The technology group is composed of 45 people.

Deacon Laboratory is one of four marine science laboratories in the United Kingdom. The others are: Oban in northwest Scotland, and Plymouth and Proudman in Liverpool. Facilities at the Deacon Laboratory include a tow tank and pressure testing facilities. Deacon Laboratory has close ties with the laboratories of the Defense Research Establishment, with academia and with industry.

### RESEARCH AND DEVELOPMENT ACTIVITIES

Deacon Laboratory is involved in a Marine Science and Technology collaborative project supported by the European Commission. The other participants are IFREMER (France), INRIA (France), the Defense Research Agency (U.K.), the National Technical University of Athens (Greece), and the Instituto Hidrográfico (Portugal).

A major project at Deacon is the Autosub project, which may involve as many as three autonomous undersea vehicles. The present thrust of the project is the development of a demonstrator test vehicle, which will have full ocean depth capability (6,000 m). Two follow-on vehicles are envisioned: *Dolphin*, also a 6,000 m AUV, will follow a vertically undulating path taking oceanographic measurements in the water column. Whenever it surfaces it will receive navigation data from GPS and any desired reprogramming down to the module level. While on the surface, through the second of two antennae, it will transmit oceanographic data gathered and its geographical position. The task is to cross the Atlantic gathering data as it proceeds. The third AUV, tentatively dubbed *DOGGIE*, is being designed for sea floor exploration with missions of three to five days at about 5 knots.

The Autosub project commenced in 1988. Several workshops that are part of the Autosub project asked scientists for requirements that such AUVs might satisfy. This resulted in the commissioning of 20 studies. The Autosub project receives about £780,000 in funding per year. These project funds have enabled the development of a dynamometer capable of working submerged and under pressure to determine speed, torque, and efficiency of the brushless motor that drives contra-rotating propellers via seawater lubricated ceramic bearings. This community research program led by Deacon Laboratory involves industry, the Defense Research Agency, and academia.

The Autosub project has three phases:

Phase I: Focusing on pressure hull (carbon fiber), buoyancy control at depth, propulsion, hydrodynamic coefficients (from 3/4 scale model), GPS



navigation. The critical path includes pressure hull and variable buoyancy control.

**Phase II:** Subsystem technology development will determine the design. Batteries have been selected as the energy source.

**Phase III:** The main thrust of this phase is to produce the demonstrator test vehicle. The goal for this is 1997.

**Phase IV:** Evolution to *Dolphin* and *DOGGIE*.

The Autosub project at this time is examining the use of correlation sonar, subsea navigation, and low drag research. The project intends to use off the shelf electronic hardware.

### **SUMMARY**

The Autosub project dominated the team's conversations at Deacon Laboratory.

### **REFERENCES**

*1991-1992 Report of the Institute of Oceanographic Sciences. Deacon Laboratory.*

*Scientific Autonomy in the Deep Ocean - Autosub. Brochure.*

*Nautilus. Newsletter of the Autosub CRP. Issues 1-5.*

Site:

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Date Visited:

May 11, 1993

Report Author:

D. Blidberg

**ATTENDEES****WTEC:**

D. Blidberg  
 C. Brancart  
 L. Gentry  
 B. Mooney

**HOSTS:**

A.N. Williams  
 Keith A.R. Knight  
 A.M. Tonge  
 Ron D. Short

Divisional Director  
 Regional Marketing Manager  
 AUV Projects Leader  
 Business Development Executive

**BACKGROUND**

Marconi Underwater Systems Ltd. is an operating company within GEC-Marconi, one of the major divisions of GEC. The company employs 5,500 people at twelve sites, including four design and development units, production and test facilities, and an applied research lab. The company's headquarters is in Waterlooville, and its former subsidiary, UDI (now Fugro UDI -- see UDI site report) is in Aberdeen.

The team's host briefly touched on several technologies, but focused on Marconi's *Ocean Data Acquisition System (ODAS)* vehicle. *ODAS* is the company's attempt to develop an AUV system for the ocean science market and other similar markets. It builds on the technology the company developed for torpedo projects, although the company states that most of the vehicle is of a totally new design. The company does suggest, however, that much of the development infrastructure at Marconi (tools and techniques, project management, testing, and fabrication) has helped the company's scientists and engineers during the development of *ODAS*.

The system design philosophy is to focus on a specific market, develop a low cost solution, get the vehicle in the water, and let it evolve. Marconi suggests that the *ODAS* system should be priced in the \$100,000 to \$200,000 range.

The *ODAS* vehicle was launched eighteen months prior to the WTEC panel's visit. It is being jointly undertaken by Marconi, Moog Controls, Chelsea Instruments, and Alupower. Its primary mission is the collection of oceanographic data through the use of instruments developed by Chelsea. The vehicle is 21" in diameter and approximately 20 ft long. It has an endurance of 36 hrs (24 nominal) and reaches a speed of 5 kts. It currently has 37 kWhrs of energy that is divided between propulsion (65 percent) and payload (35 percent). A future aluminum-air system under development by Alupower will be used to increase the energy density of the onboard battery in order to reduce the size of the vehicle. The vehicle will turn in 200 m of water with its current configuration and will reach depths of 300 m. The hull is of aluminum alloy. The computer system is based on the Intel 386, with software written in ADA. Structured programming techniques are used within the ADA software development environment. The payload weight is 45 kg within a 20" long section of the body.

The vehicle has no obstacle avoidance sonar, but does have a minimal communications capability that currently allows an abort command to be sent to the system. More complete communications are planned with the eventual capability of transmitting data back to the remote user. The system is positively buoyant and also includes a droppable keel for emergency recovery.

Trial runs have been conducted in Portland Harbor with success. The vehicle transited along a predefined path at a depth of 10 m. A simple yet effective launch and recovery system has been developed for recovery of *ODAS*. The recovery system is towed behind the mother ship and a line is fed through the device and attached to the *ODAS* system during recovery. The vehicle is then winched (pulled) into the cradle and locked in place. The entire system is then recovered.

A small, fiber-optic cable controlled system was briefly discussed. It was felt by Marconi representatives to be a unique system that might have many applications.

## CONCLUSIONS

There is no question that this company has many capabilities in the design of undersea vehicles. Marconi's scientists and engineers are looking hard at commercial applications of this technology and have a number of thoughts on what those applications might be. Marconi is continuing to explore the potential market, and believes that low cost systems have a role in that marketplace. The launch and recovery system for the *ODAS* vehicle is a good example of the company's efforts to develop innovative, low cost solutions.

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**Date Visited:** May 14, 1993

**Report Author:** C. Brancart

### **ATTENDEES**

#### **WTEC:**

C. Brancart

#### **HOSTS:**

Douglas Brand

### **BACKGROUND**

Reson is a Danish-based acoustic research and manufacturing company founded in 1976 by three brothers. Their product line includes transducers, hydrophones, arrays, and complete sonar systems. The presentation to the WTEC team was limited to the company's sonar systems.

### **RESEARCH AND DEVELOPMENT ACTIVITIES**

Reson Systems discussed in detail its Seabat sonar systems.

#### **Seabat 6012**

The Seabat 6012 was developed in 1990/1991 as a real-time imaging sonar for mine counter measure from ROVs. The operating frequency is 455 kHz, and the acoustic window is 90° horizontal and 15° vertical. The system's range is from 25 to 200 m, and its resolution is 5 cm. The system is small enough so that it can readily be handled from inflatables, ROVs, and patrol crafts. The system's capability is equal to a land-based CCTV security system. In October 1991, Reson announced that "The Seabat 6012 is the world's first real-time electronically scanning mini sonar."

**Seabat 9001**

The Seabat 9001 multibeam bathymetric sonar is a high resolution sea bed mapping and profiling system for use from ROVs or surface crafts. The operating frequency is 455 kHz and the acoustic window is 90° by 1.5° cross-section footprint. There is a real-time color display of the sonar image with the ZX coordinate superimposed in profile. The system is capable of inputting the data into high grade survey software packages for integration with position and attitude sensor data, therefore providing a means to conduct accurate surveys in greatly reduced time scales. If a roll, heave, and pitch sensor package and a Doppler Velocity Log are incorporated with the sonar, position accuracy better than  $\pm 1$  m can be maintained with a datum check at 1 km intervals. The Seabat sonar system's characteristics are given in Table Reson.1.

**Table Reson.1**  
**Seabat Sonar System Characteristics**

	MODEL	
	6012	9001
Frequency	455 kHz	455 kHz
Ranges	2.5, 5, 10, 25 m	2.5, 5, 10, 25 m
Resolution	5 cm	5 cm
# Beams	60	60
Horizontal	1.5° Recvr. 165° Transm.	1.5° Recvr. 100° Transm.
Vertical	15° Recvr. 15° Transm.	15° Recvr. 1.5° Transm.
Power	24 VDC (Subsurface) 2 amps (unit)	24 VDC (Subsurface) 2 amps (unit)
Tow Speed	10 kts	10 kts

**SUMMARY**

Depending on the cost of these systems, their general characteristics may justify taking a hard look at them.

**REFERENCES**

**Reson. General brochure.**

**Underwater Intervention, Detection and Protection. Brochure.**

**The Seabat Range of Multibeam Sonar Systems. Brochure.**

**Seabat 6012 Imaging Sonar. Brochure.**

**Seabat 9001 Bathymetric Sonar. Brochure.**

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Date Visited: May 12, 1993

Report Author: C. Brancart

### **ATTENDEES**

#### **WTEC:**

D. Blidberg  
C. Brancart  
L. Gentry  
J. Mooney

#### **OTHER:**

J. Sampson (ONR London)

#### **HOSTS:**

David Hartley, B.Sc.  
A.G. Coulter, B.Sc., Ph.D.  
Brian Forbes, O.B.E., M.N.I.

John Digman

Technical Manager  
Deputy Technical Manager  
Consultant, Submarine, Marine, and  
Underwater Systems  
Slingsby Aviation Ltd., Marketing Director

### **BACKGROUND**

Slingsby started business by being part of BUE, a holding company owned jointly by the British government and commercial entities. In 1986, ML Holdings was founded, and Slingsby Engineering became part of a multidivision corporation.

The firm is located in the Kirkbymoorside countryside near Thirsk, halfway between Manchester and Newcastle. At this location, there are two separate Slingsby companies: Slingsby Engineering, which is involved with underwater hardware and systems, and Slingsby Aviation, where the *T67 Firefly*, military basic training aircraft, is fabricated.

Slingsby Engineering has a staff of about 80 people. The corporate thrust is the offshore oil marketplace and telecommunications (underwater cables). Specific areas of involvement are:

Underwater systems:	ROVs ROV tooling Manipulators
Underwater equipment:	Underwater communications equipment (UQC type) Underwater connectors
Engineering services:	Design studies SubSea engineering Training and service personnel
Test facilities:	Pressure Bottom Wet

Slingsby has respectable test facilities, especially for pressure. It has numerous small pressure tanks, and a large test tank, 8.5 m long x 2.8 m diameter (27 ft long x 10 ft diameter), rated for 7,500 ft of sea water (3,350 psi). SEL uses water as the test medium and has numerous throughput wires for testing, but no temperature controls. The wet tank is 30 ft x 10 ft x 12 ft deep, and the mud/bottom basin is 7 m x 24 m.

Slingsby Engineering has designed and built numerous manned systems in the past, but current market demand is such that the company is only involved with unmanned systems. In 1978, Slingsby built the last of five submarine escape and rescue vehicles, the *LRS Rescue Submarine*. The *LRS* has a maximum operating depth of 1,500 ft and is capable of carrying nine rescues on each trip. Number 5 boat is presently on stand-by duty for the Royal Navy. In 1986, Slingsby designed and built the *JIM* suits, a one-atmosphere carbon-fiber-skin diving suit rated for 1,500 ft operating depth. This market was short lived because of the trend toward unmanned systems, the ROVs. Other previous projects have been the *Scarab III* water jet system for cable burial, bottom crawlers with trenching capabilities, and a system to place a very large cover plate over the tension-leg cables of a surface platform. SEL also performed the *Dolphin 10K* study, which has ended up being the 10,000 m ROV for Japan.

Presently, Slingsby is concentrating on large working ROVs. The company started with the *TROJAN* series, and is now building the *MRV* series. Associated support equipment ranging from power packs and manipulators to handling systems are also being developed.



## RESEARCH AND DEVELOPMENT ACTIVITIES

Slingsby's major product line consists of the large ROVs and associated support components and systems. The *Trojan* ROV, which is approximately 7 ft x 5 ft x 5 ft, 4,000 lbs, and rated for 3,300 ft, was the first of a series. The company's scientists and engineers built thirteen units and sold twelve. They made the mistake of showing their customers the next generation unit, the *MRV* ROV, and the thirteenth *Trojan* unit is still for sale. Typical of the Slingsby philosophy, the system is modularized with optional power packs, variable ballast option, and seven function master/slave to five function manipulators, or both. Each vehicle comes with a topside control van, rated for offshore platform use, handling systems, both the surface winch and A-frame, and the underwater garage. Additional options are available based on customers' needs.

The *multirole vehicle (MRV)* is designed to be flexible. There are many possible variations available (see Table Sling.1).

**Table Sling.1**  
**Design Variations of the MRV**

Length (m)	1.9	to	2.3
Width (m)	1.5	to	1.5
Height (m)	1.6	to	1.6
Depth Rating (m)	600	to	2,000
Air Weight (kg)	1,500	to	1,930
Power (kw)	28	to	45

The options are as varied as the customers' needs. Vehicle options include power, tools, cameras, lights, and navigation equipment. Systems options are umbilical (soft or armored), topside handling systems, control cabin and consoles, tether management system (TMS), and specialty work skids. Special work packages have been added on to the *MRV* that are larger than the vehicle itself. The complete *MRV* system (with all ancillary support equipment along with customer training) sells for \$ 2 million. *MRV* number 5 is presently in acceptance testing.

In addition to fabricating *MRVs*, Slingsby also continually augments and upgrades subsystem capabilities, especially vehicle thrusters, power units, manipulators, and tools. Examples of what is available are listed in the references. The *MRV* units are completely modularized in design, and component variations are easily incorporated into the vehicle.

**SUMMARY**

Slingsby has focused all of its efforts on standardizing high cost ROV systems. The company's philosophy implies that even with a one-of-a-kind ROV, it is possible to modularize the system design to meet specific functional capabilities. The hardware has achieved a high level of maturity. It is difficult to determine the level of software compatibility. The company's representatives state that they are trying to follow ISO 9001 open system architecture.

Slingsby intends to continue pursuing the MRV system design by value engineering the vehicle design to reduce cost, and designing special tools for their customers. The new generation ROV are being designed as part of the subsea completion systems, and not as independent external repair/maintenance capability.

There does not appear to be any major effort in autonomous underwater vehicles, AUVs. The customers, the oil companies and the support service companies, are suspicious of autonomy.

In summary, Slingsby has the capability of support the existing offshore oil market. It is a cost-driven organization that expends very little funds on the design of the next generation systems. The company's growth evolves like the oil patch: slowly and deliberately.

**REFERENCES**

*Slingsby. General brochure.*

*LR5, Rescue Submarine. Brochure.*

*Gerald O'Brien. Submarine Escape and Rescue.*

*Trojan: Quietly Getting On With The Job.*

*Trojan MRV. Technical Specifications.*

*MRV: Multirole Vehicle. Brochure*

**Specialty Tools:**

20 lb-ft torque tool; 6,000 lb-ft torque tool; tool deployment system (TDS); lift depressor system (L/DS); fluid injection stab unit; docking latch.

**Site:** **The Marine Technology Directorate Ltd.**  
**(MTD)**  
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**Exploration Drive**  
**Offshore Technology Park**  
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**Date Visited:** May 14, 1993

**Report Author:** C. Brancart

### **ATTENDEES**

#### **WTEC:**

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C. Brancart  
L. Gentry  
J. Mooney

#### **OTHER:**

J. Sampson (ONR London)

#### **HOSTS:**

Dick Winchester

Office Manager

### **BACKGROUND**

The Marine Technology Directorate (MTD) is a United Kingdom-based association with an international membership. The membership comes from industry, government, research establishments, academic institutions, the U.K.'s Science and Engineering Research Council (SERC), and the Royal Academy of Science. The members have significant interest and capabilities in ocean-related technology, and their membership level entitles them to certain privileges. MTD advances research and development through its funding of marine technology studies via academia, research institutions, and industry. Many of the ongoing programs are managed by

the eight marine technology centers. Presently, MTD operates programs with a total value of \$9.6 million in three broad areas:

- o Research and development
- o Education and training
- o Publication and information services

The marine technologies that are presently under contract are:

- o Marine resources
- o Ocean structures and materials
- o Underwater working
- o Ship and floating structures
- o Physical ocean environment

North Sea oil and the commercial market interests motivated the creation of MTD. Nevertheless, the technology developed is of interest to commercial, environmental, and military concerns.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

### **Marine Resources**

The major thrust has been directed toward the needs of oil and gas endeavors, with the balance (10 percent) directed to mineral resources, energy, and bioresources. The 1990 budget was \$1.6 million.

### **Ocean Structures and Materials**

During 1990, there were forty-five projects and six managed programs budgeted for a total of \$3.7 million. Major topics under evaluation are: structural integrity monitoring, defect assessment, fatigue, stress, buckling, grouts and grouting, corrosion and fouling, foundations and piles, welding and materials, concrete, other ocean structures' (e.g., pipelines) designs, and decommissioning of structures.

### **Working Underwater**

This area involves diving, viewing, measurement, survey, communications, subsea automation, automation technology, and underwater working. The annual budget in 1990 was \$880,000.

### **Ship and Floating Structures**

Programs in this area involve compliant systems, wire rope and cables, shipping semisubmersible technology, and floating structures. In 1990, the budget was \$1.1 million. Areas of high interest have been fire safety and offshore reliability.

### **Physical Ocean Environment**

Studies pursued are fluid loading, ocean environment, and coastal engineering. In 1990, the budget was \$600,000.

The advancement of unmanned underwater vehicle (UUV) technology has proven to be of value to both the civil (commercial and scientific) and military sectors of marine operations. The needs of the civil sectors (namely the offshore oil and gas industry, the search and recovery industry, and the scientific community) and those of the defense industry cannot be met with existing available technology. Consequently, MTD has undertaken the Technology for Unmanned Underwater Vehicles (TUUV) program. This is a two-year, \$2.4 million program that was started in October 1992. The problems to be studied under TUUV include work that is fundamental to the development of truly advanced UUVs. TUUV has identified six major missions:

- Pipeline surveying (inspection and routing)
- Offshore platform IRM (inspection, repair, and maintenance)
- Wellhead and satellite wellhead IRM
- Seabed object detection and classification
- Subsea construction
- Wet salvage

Based on the review of fifty-three proposals received, twelve were selected to form the TUUV Program Portfolio (see Table MTD.1).

### **SUMMARY**

MTD appears to be a cohesive force to tie together the offshore and ocean industry needs and available knowledge. Its major operating area is the North Sea/European sector, but it is forging closer links with North America and the increasingly important countries of the Pacific rim.

MTD is a relatively new multifaceted spin-off from the SERC organizational structure. Apart from its research efforts, activities include marine technology student ships, training and master of science courses, society for underwater technology, and international collaboration. Several European Community maritime efforts are given in Table MTD.2.

### Table MTD.1 Program Portfolio

<b>Sensing</b>	
TU1	Techniques for the processing of sidescan sonar from large data sets. Heriot-Watt University (Automatic processing using fractal and statistical techniques)
TU2	Probabilistic sensor fusion for reliable workspace sensing. Heriot-Watt University (Optical and acoustical sensor fusion, to interface closely with TU5)
TU3	A new underwater vision system. Strathclyde University (Fusing stereo pair optical imagery with 2-D matrix ultrasonic array)
<b>Control</b>	
TU4	Network architecture for self tuning, adaptive control of UUVs. Liverpool University
TU5	Advance control of manipulators. Heriot-Watt University (Adaptive force and position control, task planning, coordination and collaboration of two arms)
<b>Communications</b>	
TU6	High data rate subsea communications for UUVs. Newcastle University (Shallow acoustic link for 10-20 kbps, <3 km range)
<b>Navigation</b>	
TU7	A self-contained navigation for UUVs operating around subsea installations. Strathclyde University (Integration of sonar signatures of structures and engineering drawings)
TU8	A study of multi-spectrum data association for the precision navigation of UUVs. Glasgow University (Extension of GPS to subsea via acoustics)
TU9	Navigation of a UUV within structures using fusion of sensor data and world modeling techniques. Liverpool University
<b>Propulsion</b>	
TU10	Design studies of power electronic drive systems for thrusters of UUVs. Southampton University (Optimising electronic drives)
<b>Analysis</b>	
TU11	Snag loading of cables during launch and recovery of tethered subsea units. Strathclyde University
TU12	Hydrodynamics of UUVs near the air/sea interface. Strathclyde University (Determining hydrodynamic characteristics and coefficients)

**Table MTD.2**  
**EC Maritime Activities**

<b>MAST</b>	<b>Marine Science and Technology program under Directorate XIII of the EC Brussels</b>
<b>WEGEMENT</b>	<b>West European Graduate Education in Marine Technology</b>
<b>IFREMER</b>	<b>Institut Francais de Recherche pour l' Exploitation de Mer</b>
<b>UETP</b>	<b>University Enterprise Training Partnership</b>

**Note:** The MTD office in Aberdeen was opened in 1992 to service North Sea interests. The major point-of-contact for MTD is:

The Marine Technology Directorate, Ltd.  
15 Buckingham Street  
London, WC2N 6EF  
United Kingdom

Telephone: 44-71-321-0674  
Fax: 44-71-930-4323

#### **REFERENCES**

*Technology for Unmanned Underwater Vehicles (TUUV). Prospectus.*

*MTD, A Focus of International Activity in Ocean Technology. Brochure.*

## Site:

Camera Alive Ltd.  
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C. Brancart

**ATTENDEES**

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## OTHER:

J. Sampson (ONR London)

## HOSTS:

John Turner

B.Sc., F.Inst.D., M.B.I.M., Managing Director

**BACKGROUND**

Camera Alive was established in 1978 to provide specialized noncontact measurement systems and underwater equipment to the offshore oil and gas industry.

**RESEARCH AND DEVELOPMENT ACTIVITIES**

Camera Alive has developed a basic stereo video system that has been augmented for noncontact measurement capability.



**DC2: Underwater High Resolution Digital Array Camera**

The DC2 is a high resolution digital array camera designed for underwater use to 1,000 m. The system has the following features:

- o Operates under the PC environment (MS-Windows based software control)
- o 1242 x 1182 x 8 bit digital data output
- o Does not require specialist frame acquisition hardware
- o Extremely accurate calibration is enabled through full pixel for pixel correlation
- o Supplied as a fully operational system including camera and RS 422 card, rated to 1 Mbits/second), software, surface cabling, ready to work with standard 386 personal computer

**NCS2: Noncontact Video Measurement System**

The NCS2 is a noncontact measurement system with video input. The system is a fusion of software and hardware to:

- o Capture video from video cameras VD1 and VD2
- o View real-time stereo video in color
- o Take dimensional measurements from the captured stereo video
- o Output these measurements to a CAD

The system operates with MS-Windows, allowing nonspecialized users to operate the system with minimum training and experience.

**SUMMARY**

Camera Alive has operational equipment that has proven to be successful in the underwater environment.

**REFERENCES**

*Camera Alive. General write-up.*

*DC1: High Resolution Digital Array Camera. Brochure.*

*DC2: Underwater High Resolution Digital Array Camera. Brochure.*

*NCS2: Noncontact Video Measurement System. Brochure.*

*Stereo Viewing and Noncontact 3-D Measurement. General brochure with useful information.*

## Site:

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 B. Mooney

## OTHER:

CDR John Sampson (ONR Europe)

## HOSTS:

Professor George T. Russell  
 Dr. Robin M. Dunbar

Head of Department  
 Sr. Lecturer and Head of the Ocean Systems  
 Laboratory  
 Senior Lecturer  
 Lecturer  
 Lecturer  
 Lecturer  
 Research Fellow and Head of Sonar Image  
 Interpretation Group

Robin T. Holmes  
 Dr. David M. Lane  
 Ron McHugh  
 Michael J. Chantler  
 Dr. Laurie Linnett

**BACKGROUND**

Heriot-Watt University (HWU) has been involved with unmanned underwater vehicles since the early 1970s. Dr. Robin Dunbar and Dr. Robin Holmes were key to the development of the *Angus* class of remotely operated vehicles. *Angus-1*, the first

deep diving ROV in Europe (>1,000 FSW) is a general purpose ROV used as an early test bed for a variety of underwater tasks and equipment under development at HWU. It was followed by *Angus-2* and *Angus-3*, which were similar but improved ROVs also used in the HWU projects. HWU also built *Rover*, a small autonomous underwater vehicle that operated in coordinated tasks with *Angus-3* and divers. *Angus-4* was designed in the early 1980s, but was never built due to funding constraints that have continued to hinder further development of UUVs at HWU. Operation of *Angus-3* has also been halted by funding constraints. Due to the lack of funding for development of UUVs, HWU has changed the development emphasis from vehicles to key UUV subsystems for ROV and AUV applications (e.g., acoustic and optic sensors, signal processing software, robotic systems, and knowledge-based systems). In line with this approach, the university has evolved a very capable set of laboratories to accomplish this objective.

Supporting the department's work are five laboratory complexes:

- o Computing Laboratory
- o Electronic and Electrical Laboratory
- o Telecommunications Laboratory
- o Human-Computer Systems Laboratory
- o Ocean Systems Laboratory

The WTEC team was most interested in research activities that were being conducted in the Ocean Systems Laboratory group headed by Dr. Dunbar; however, the team noted the good collaboration and synergy between laboratories for various projects. Dr. Russell's department also provides a full range of standard university curricula for computing and electrical engineering.

HWU's UUV-related work is fully funded for the next two years through the European Economic Community MAST program and the United Kingdom's Marine Technology Directorate research and development programs coordinated by the MTD office in Aberdeen (see separate site report on MTD).

Over the years, the type of funding available has been a problem for HWU. Most of the university's funding is earmarked for research. Thus when programs and projects reach a certain point in maturity, HWU is expected to seek alternate funding, generally from industry, to complete the work. It is difficult for the universities to obtain funding from industry. In the case of most projects, the universities' inability to acquire transition funding stops the work before the systems and components reach commercial usefulness. Nonetheless, HWU's accomplishments -- both in scope and depth -- are impressive.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The work in the Ocean Systems Laboratory was described in some detail. Then the team visited the labs to observe demonstrations of a variety of projects.

### **Subsea Robotics and Multisensor Fusion**

The team witnessed a demonstration of two combined projects involving autonomous robotics and multisensor fusion. The robotics project led by Dr. David Lane is to develop autonomous interactive controls for two seven-function manipulators. The two arms are mounted on a wet test tank, and cooperative operation and mutual avoidance of the arms was demonstrated in water. In this demonstration, the two arms were programmed to operate in the same workspace without collision or interference. Mr. Michael Chantier's sensor fusion project has been coupled to the robotics development and will eventually include video and very high resolution sonar and laser triangulation sensors to provide reliable sensing in the manipulator's workspace. The sensor data alleviates the sensory deprivation typically experienced by operators of ROV manipulators. In the future there is the prospect of intelligent robotics able to autonomously visualize, plan and control manipulative tasks with a minimum of operator involvement. The work is at an early stage yet but is making good progress, and the demonstration was successful.

### **Advanced Manipulator for Deep Underwater Systems (AMADEUS) Project**

The AMADEUS project is a joint project with the University of Genoa and the Italian Naval Automation Institute, and is funded by the European Economic Community as one of the MAST II initiatives. It is a five-year program to develop a highly dexterous, multifingered, hydraulic gripper. This gripper is to have position and force control and be suitable for attachment to a number of existing manipulators. The project will develop hardware and methodologies for grasping, simulation tools, and hardware and software for man-machine architectures. The result is to demonstrate a range of underwater grasping tasks using the robot arm that is being developed in the robotics project.

### **European Experimentally Validated Models for Acoustic Channels (EEVMAC) Project**

The EEVMAC project is another cooperative EC-funded effort. The object is to gather acoustic data from a number of sources including the Firth of Forth, Loch Ness, and the Mediterranean Sea. The data will be used to validate acoustic propagation models and support design of high data rate acoustic communication systems for AUVs.

### **Forth Base Project**

In conjunction with EEVMAC, HWU is developing the Firth of Forth as a communications test range. Acoustic instruments in the Forth will transmit and receive signals that are then carried by subsea cables to a new base at Leith Harbor. The signals are microwaved directly to the laboratory at HWU, allowing the range to be used in real-time testing and interaction between the scientist in the lab and the sensors in the field. This permits a real-time evaluation of communication signal propagation and system effectiveness. The range will be ready late this summer.

### **Other Projects**

The team also visited Dr. Laurie Linnett's Image Processing Laboratory, where research projects related to interpretation and classification of sonar images are in progress. The lab is largely funded under the Technology for Unmanned Underwater Vehicles program managed by the Marine Technology Directorate (see separate MTD site visit report). One project is developing algorithms for rapid processing of entire side scan seabed surveys, using fractal techniques to characterize the seabed sediment textures and then employ probability statistics to identify abnormalities in the textures. In this way rapid processing of very large data sets can be achieved. Another project is developing real-time processing of side scan sonar data to locate unsupported sections of pipeline for the oil industry. A third group has been working on object detection algorithms for sonars for some time. The group has achieved excellent detection rates and is now focusing on improving detection of objects against different backgrounds and clutter. Other work in the lab is directed toward compression of sonar data to achieve manageable sized data sets from high-output, modern sonars. The results will allow more efficient storage, manipulation, and transmission of data for real-time operations. Yet another group is working on mathematical and graphical techniques for simulation of side scan sonars to better understand the sonar process and aid in the projects involved with acoustic detection and classification. Linnett's laboratory continues to do outstanding work that is well funded and recognized. The demonstrations were well organized and impressive, and it was obvious that the team of researchers are highly motivated and productive.

### **SUMMARY**

HWU has done outstanding work in many areas related to underwater vehicles and intelligent subsystems relating to robotics, acoustic imaging and communications. The university's program has the objective of integration of all these intelligent subsystems to accomplish useful demonstrations with ROVs and AUVs in the ocean environment. HWU has been one of the pioneering forces in the area of UUV systems for over two decades, and has a well deserved reputation for excellence.

**REFERENCES**

- Research Review and Postgraduate Prospectus*. Heriot-Watt University. Department of Computing and Electrical Engineering. Brochure.
- Oceans Systems Laboratory*. Overview brochure.
- Advanced Manipulator for Deep Underwater Systems (AMADEUS)*. Brochure.
- Heriot-Watt University Sonar Processing Research Group*. Brochure.
- Heriot-Watt University Department of Computing and Electrical Engineering*. Brochure reviewing programs and laboratories.
- Paul, J.G., R. McHugh, and S. Shaw. "The effect of DSP on the point spread function of a sonar beamformer." Heriot-Watt University.
- McHugh, R., J.G. Paul, and S. Shaw. "A digital focused beamformer for sonar." Heriot-Watt University.
- Dunbar, R., et al. "European Experimentally Validated Models for Acoustic Channels (EEVMAC)." Heriot-Watt University.
- HWU; Department of Computing and Electrical Engineering: The Firth of Forth Estuary Research Programme*. Brochure.
- European Conference on Underwater Acoustics*, edited by M. Weydert. Commission of the European Communities. Brussels, Belgium.
- Dunbar, R.M., et al. "The Transmission of Fractally Coded Sonar Images by a Frequency-Hopped Acoustic Signal." Heriot-Watt University.
- Sampson, J.A., CDR, U.S. Navy. "Technology for Unmanned Underwater Vehicles." Office of Naval Research, European Office; April 1993.

**Site:** Mobil North Sea Ltd.  
Gramplan House, Union Row  
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**Date Visited:** May 14, 1993

**Report Author:** C. Brancart

### **ATTENDEES**

#### **WTEC:**

D. Blidberg  
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L. Gentry  
J. Mooney

#### **OTHER:**

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#### **HOSTS:**

Donald G. Langrock Development Engineering

### **BACKGROUND**

Mobil is one of the users of the technology and hardware developed by firms with ocean-oriented products. In its position, Mobil can direct the technology to places where it is needed. The *Mobil-FSSL* Diverless Intervention System is a prime example of this operating mode.

### **RESEARCH AND DEVELOPMENT ACTIVITIES**

The object of the Mobil Intervention program is to maintain a subsea "tree" (completion system) by an ROV in water depths to 1,000 m. The justification for this program is cost savings. For example, two cases were presented that review operating costs (see Table Mobil.1).

The capabilities of the *Mobil-FSSL Diverless Intervention System* are:

- o Component replacement
- o Valve operation
- o Valve maintenance and pressure testing
- o Control umbilical and flow lines installation

**Table Mobil.1**  
**Two-Case Scenario for Operating Costs**  
 (Monetary figures given in U.S. dollars)

	Diver	ROV
Planned Maintenance, 20 Working Days on Location	\$1,680,000	\$592,000
Savings	\$1,088,000	
Unplanned Intervention, 2 Working Days on Location	\$528,000	\$160,000
Savings	\$368,000	

The benefits derived from this capability are:

- o Reduced installation and maintenance costs
- o Increased safety
- o Reduced weather-related downtime
- o Delivery by an ROV of opportunity
- o Working depths to 1,000 m

### SUMMARY

The *Mobil-FSSL Diverless Intervention System* is presently being tested and evaluated. The basic ROV is the Slingsby MRV, with add-on modules that triple its size. Results to date have been very encouraging.

Mobil identified the following technology areas that should be developed for future subsea completion system needs:



- o **Autonomous navigation**
- o **Better ROV trusters (more vehicle control)**
- o **Better and faster data communications (7 to 10 km is present limit)**
- o **New manipulators**
- o **Supervisory control**
- o **Lock-on capability**
- o **Tactile sensor systems**
- o **3-D video to operate manipulator without operator intervention**

## **REFERENCES**

*Mobil-FSSL Intervention, New Frontiers, New Technology. Brochure.*

Site: **Tritech International Ltd.**  
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#### OTHER:

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#### HOSTS:

Richard J. Marsh, C. Eng.  
Kevin A. Parker

Managing Director  
Sales Manager

### BACKGROUND

Tritech Ltd. appears to be a very small company. Company representatives introduced Tritech by stating the following:

- o Seabat is the best electronics scan sonar
- o UDI is the best mechanical scan sonar
- o Tritech is the best cost-effective sonar

### RESEARCH AND DEVELOPMENT ACTIVITIES

All Tritech systems have PC-compatible hardware (PC 486-50 with two to three proprietary boards). Their display used MS-Windows, where on a single monitor it

is possible to bring up the scan display, the video display, and the sonar display, or whatever combination of displays the operator wants. All of the data is logged and is recallable.

Tritech has produced many types of small sonar. The company even hard-canned one of its units for subsea display by frogmen.

### **SUMMARY**

Tritech did not have brochures to pass out to the participants. However, indications are that their products are very inexpensive and could be of interest to others.

**Site:**

**Marconi UDI (UDI)<sup>1</sup>**  
**Dunrobin Road**  
**Bridge on Don**  
**Aberdeen AB23 8JW, Scotland**  
**United Kingdom**  
**Telephone: 0224 733 811**  
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**OTHER:**

J. Sampson (ONR London)

**HOSTS:**

Guthrie Robertson

Product Sales Manager

**BACKGROUND**

Marconi UDI (UDI), a GEC-Marconi company at the time of the WTEC team's visit, may have technical and manufacturing depth gained from its parent company.

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<sup>1</sup> Marconi UDI was sold in August 1993, and is now known as Fugro-UDI Limited. Fugro-UDI indicated in November 1993 that the change in ownership has not affected activities described below.

## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The Sonavision 4000 high definition sonar system incorporates a new composite transducer array and digital processing that has closed considerably the gap between underwater television pictures and previous sonar systems. The interpretive qualities of the unit are defined by the target's shape, size, color or shade variation, and shadows. This permits the operator to more effectively identify targets. Some of the system's unique features including the following:

- o Real time acoustic zoom
- o Audio output representing range and bearing
- o Built-in joystick for range and bearing cursor
- o Infinitely variable sector and position overlay
- o Selection of display modes in recordable S-VHS standard
- o HPIB/RS 232 interfaces for acoustic and cursor data
- o Choice of telemetry link to suit umbilical
- o Wideband composite array technology
- o 120 colors, either 352 x 256 pixels (recordable), or 640 x 480 pixels for high resolution monitor or printer

The composite array is the result of UDI's newly developed technology. The results are wider bandwidth and much greater efficiency in the conversion of electrical energy into mechanical energy.

## **REFERENCES**

Marconi UDI. *Profiles*. Brochure describing key people and projects.

"1-3 Connectivity Composite Piezoelectric Materials for High Frequency (> 100 kHz) Transducer Arrays."

*UDI Sonavision 4000. High Definition Sonar. Brochure.*



## **RESEARCH AND DEVELOPMENT ACTIVITIES**

The WTEC team was given presentations on the company's capabilities by Mr. Seppo Seppala, president, and Mr. Jari Lind, product manager.

Rauma has broad expertise in various undersea and high pressure areas from design through construction. The company has manufactured two deep submersibles (6,000 m) and a 300 m diver lock-out submersible. Rauma has also developed buoyancy materials, ballast pumps, a seawater hydraulic pump, and battery packages. Other specialty designs have included a hyperbaric welding spread, a deep ocean corer, decompression chambers, and hyperbaric simulators.

Rauma Oceanics has broad expertise in maraging type ultra-high strength steels that were used as pressure hull materials for the *Mir* research submersibles. Maraging steels offer superior strength/weight ratios compared to titanium, and since collars for viewports are integrally cast with the pressure hull, large diameter viewports are possible. The company could readily build full ocean depth systems if there was a market demand.

Rauma's design capabilities are based on computer aided engineering. This includes a 3-D layout design of complete systems and assemblies, geometry from a 3-D model database, dimension drawings for manufacture, finite element analysis, and the documentation processes. The design software codes (CATIA, VERTEX, IGBS, CAEDS, ANSYS) were also described. Other undersea developments include a 7,000 ft, 22 pound/ft<sup>3</sup> syntactic foam using special microballoons and a 6,000 m rescue device for submersibles. The team was also given a short tour that focused on the company's *DLO-300* diver lock-out submersible.

An interesting innovation has been an air independent power system (AIP) that is pressure compensated and can be used in depths to 6,000 m. Rauma's RDP-100 power pack, an autonomous Rankine engine, has been successfully used in an autonomous vehicle. The normal power is up to 50 kW with virtually unlimited operating time. The Rankine engine is very reliable because there are few moving components. Rauma designed the special bearings for the turbine. The system weight is 950 kg without fuel. Efficiencies of 30 percent have been achieved. AIP could have broad applications in special ROVs, deep-sea research stations, and submersibles.

Rauma also has test capabilities that include a 2.5 m diameter, 6.0 m high, and 7,500 m equivalent pressure tank, and a 4 m diameter, 12 m high, and 1,000 m pressure tank. Det Norske Veritas (DNV) has provided Rauma Oceanics with an umbrella certification.

In summary, Rauma Oceanics is a leader in managing steel construction and has capabilities in other undersea technologies. The *Mir* submersibles are well-designed deep ocean vehicles and represent 40 percent of the world's manned diving capability to 6,000 m.

#### **REFERENCES**

*DLO - 300 Diver Lock-Out Submersible. Brochure.*

*Air Independent Power Pack. Brochure.*

*Computer-Aided Engineering. Brochure.*

*Rauma Oceanics. Brochure.*

*Hyperbaric Training Semester. Brochure.*

*HBO Medical Treatment Chamber. Brochure.*

*Rauma 1992 Annual Report.*

*Drass - A Rauma Subsidiary. Brochure.*

*Galeazzi. Brochure.*



## APPENDIX G. GLOSSARY

ABS	American Bureau of Shipping (technical and certification society)
ADCP	Acoustic Doppler current profilers for ocean current measurement at various depths (remote sensing system)
AI	Artificial intelligence
AIP	Air-independent propulsion (energy sources)
<i>Akademik</i>	A proposed 6,000 m Soviet Academy of Sciences research submersible to be built for the P.P. Shirshov Institute of Oceanology. Eventually the two <i>Mirs</i> evolved out of this earlier project concept.
<i>Alvin</i>	4,500 m DSV operated by Woods Hole Oceanographic Institute
<i>Angara</i>	Russian tourist submarine design, 6 passengers to 600 m
<i>Angus-1</i>	First deep operating (300+ m) ROV in Europe
<i>Angus-2 &amp; -3</i>	Improved versions of the original Angus-1 design
<i>Argus</i>	Russian-designed and -built 600 m depth capable manned submersible which operates primarily in the Black Sea
ASV	Abyssal survey vehicle
ASW	Antisubmarine warfare
AUV	Autonomous underwater vehicles -- self powered systems that operate without a physical connection to the surface
Batfish	Towed underwater platform for oceanographic measurements
Bathymetric	Topography of ocean floor; depth measurements of large bodies of water
Boomer	Ballistic missile submarine
CAT	A center for underwater tourism (a concept being pursued by Kharax)
CIS	Commonwealth of Independent States
CLSO	Complex for Lifting Large Sunken Objects
cpu	Control and power unit (of a computer)
CTD	Conductivity, temperature, and depth (Oceanographic parameters)
<i>Cyana</i>	IFREMER's manned submersible with 3,000 m depth capability, based at the Toulon laboratory
<i>Delphine</i>	French submersible
DEM	Electronic module
DNV	Det Norske Veritas, the Norwegian classification society
DO	Dissolved oxygen (in water)
DOGGIE	Deep Ocean Geological and Geophysical Instrumented Explorer: AUV that will be used for geological survey

	using acoustic imaging sensors of the seabed. Part of the future plan for the Autosub project of the U.K. government.
<b>DOLPHIN</b>	<i>Deep Ocean Long Path Hydrographic Instrument</i> , a 6,000 m depth capable AUV. Another vehicle planned for future implementation in the Autosub project.
Doppler (System)	Acoustic sensor used to measure velocity over the seafloor
DSP (Chips)	Digital signal processing
DSRV	Deep submergence rescue vehicle
DSV	Deep submersible vehicles, e.g., <i>Alvin</i> , <i>Mir-I</i> & <i>-II</i> , etc.
DTI	British government's Department of Trade and Industry
DTVS	Diving TV Systems (Intersheff)
EEC	European Economic Community
EEVMAC	European Community supported project to develop underwater communication technology
<i>Fish 102</i>	A compact 100 m depth capable ROV from Intersheff
Foton (Photon)	A hydrogen-oxygen (H <sub>2</sub> -O <sub>2</sub> ) fuel cell developed by Energia in Russia
FSU	Former Soviet Union
Gamma	An operating prototype of a 30-ton nuclear-powered thermoelectric power source (proposed by Intersheff)
GCOS	Global Climate Observing System
<i>Gidronavt</i>	Support vessel for submersibles <i>Omar</i> and <i>Langust</i> . "Gidronavt" (pronounced "heedronaut") translates as "hydronaut."
GOOS	Global Ocean Observing Systems -- international program
GPS	Global Positioning System
Helena	A Kurchatov Institute design concept for a larger nuclear power unit of 100 kW <sub>e</sub> that employs the same basic fuel elements and design approach as Gamma
HOBU	Hydrogen-oxygen electrical battery
Hydrostat	Common usage term for hydrostatic test (i.e., pressure test)
IFREMER	French Research Institute for the Exploration of the Sea -- government agency with scientific, industrial and commercial roles for French programs in ocean R&D
<i>Ichtiandr</i>	Support vessel for submersibles <i>Sever-2</i> and <i>Sever-2 Bis</i> , operated by Marieloprom in Ukraine.

<b>IOS</b>	<b>Institute of Oceanographic Sciences (Deacon Laboratory; U.K.)</b>
<b><i>Kaiko</i></b>	<b>ROV being tested by Japan. Fell 4 m short of reaching 11,000 m world's record depth in March-April 1994.</b>
<b><i>Komsomolets</i></b>	<b>Nuclear submarine (<i>Mike Class</i>) -- Soviet submarine that sank April 7, 1989 in Norwegian Sea in 1,400 meter water. Several expeditions have been conducted to study environmental effects.</b>
<b>LAS</b>	<b>Leisure submersible apparatus (<i>Kharax</i>) tourist submarine designed to carry six persons and a crew of two</b>
<b>Lidar</b>	<b>Laser imaging detection and ranging system</b>
<b>Mariecoprom</b>	<b>Agency responsible for operation of Ukrainian submersibles</b>
<b><i>MARIUS</i></b>	<b>Marine utility vehicle proposed funded under MAST-II (EC cooperative project) -- for coastal seabed and environmental surveys</b>
<b>MHD</b>	<b>Magneto-hydrodynamic propulsion system</b>
<b><i>Mir-I &amp; -II</i></b>	<b>Russian 6,000 m manned submersibles, built by Rauma Oceanics in Finland for P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences</b>
<b><i>MRV</i></b>	<b><i>Multirole Vehicle</i> -- 5,000 m research submersible owned and operated by IFREMER</b>
<b><i>Nautile</i></b>	<b>French submersible with a 6,000 m depth capability; operated by IFREMER, based at its Toulon laboratory</b>
<b><i>Neptun</i></b>	<b>Tourist submarine designed and built by RUBIN (St. Petersburg); currently operating in Antigua</b>
<b>NERC</b>	<b>United Kingdom's National Environment Research Council</b>
<b>Ocean Shuttle</b>	<b>Nonmilitary nuclear-powered submarine project that has been proposed by Lazurit; a small submarine (about 1,000 tons) that is designed for oceanographic and commercial ocean work tasks</b>
<b>ODAS</b>	<b><i>Oceanographic Data Acquisition System</i> -- U.K.-based AUV project jointly undertaken by Marconi, Moog Controls, Chelsea Instruments, and Alupower</b>
<b><i>Odissey</i></b>	<b>Support vessel for submersibles <i>Sever-2</i> and <i>Sever-2 Bis</i></b>
<b><i>Osmotr</i></b>	<b>Russian 300 m depth, diver lockout submersible</b>

pH	Measure of acidity or alkalinity of a solution
<i>Pisces</i>	Canadian built class of submersibles with 2,000 m depth capability. Two <i>Pisces</i> vehicles are operated by the P.P. Shirshov Institute of Oceanology
<i>Poseidon</i>	Russian deep submergence rescue vehicle
Profiler	Acoustic instrument for subbottom characterization
Project FAMOUS	1970s French-American Mid-Ocean Study on the Mid-Atlantic Ridge
PSK	Phased shift key
PTT	Press-to-talk switch
<i>Keldysh</i>	Large oceanographic Russian research ship which is equipped to support deep submersibles. It has been the principal support ship for <i>MIR-I</i> and <i>-II</i> .
ROSSHELF	Russian company proposing seafloor-based oil and gas production complex
ROV	Remotely operated vehicle, an unmanned vehicle cable-connected and -controlled from a support platform
RRC	Russian Research Centers (e.g., Kurchatov Institute)
<i>Rus</i>	A 6,000 m submersible designed by Malachite
<i>Saga</i>	Submarine built by COMEX in France, powered submerged by two Swedish Sterling cycle engines
SE&I	Systems engineering and integration -- the discipline that brings together technologies and hardware/software into an efficient product
<i>Sever-2</i>	2,000 m submarine designed by Malachite (tourist submarine) (also know as <i>North-2</i> )
SIMD	Single instruction multiple data -- type of computer architecture
SIMRAD	Norwegian company engaged in acoustic systems development such as sonar, tracking as well as camera systems
SSBN	A class of U.S. nuclear powered strategic missile-carrying submarines -- term often used to describe any submarines of this general type
<i>Sub Tour 10/100</i>	Ten-person tourist submarine (Intershelf)
Subbottom	Refers to sediments or rock making up the seafloor
Submersible OPS	Submersible operations
Tass	Soviet (now Russian) News Agency
TEUs	20-foot equivalent units. This refers to 20 foot cargo containers for carrying cargo onboard container ships

<b>Thermocline</b>	Temperature inversion layers found in all oceans; water on the surface overlying colder water
<b><i>Thetis-H</i></b>	Towed manned submersible designed by Malachite in Russia; operated currently by Mariecoprom in Ukraine
<b>TMS</b>	Tether management system -- control system for ROV tether
<b>TOGA</b>	Tropic Ocean Global Atmospheric (international program)
<b><i>Trojan</i></b>	ROV built by Slingsby Engineering in U.K.
<b><i>TS 20/100</i></b>	Russian tourist submarine design for 20 passengers; designed to operate at a depth of 100 m
<b>TUUV</b>	Technology for Unmanned Underwater Vehicles program (U.K.)
<b><i>Uran</i></b>	Deep ROV developed by Krylov Institute of Russia
<b>USB</b>	Ultra Short Baseline (tracking system) -- technique for underwater locating and tracking
<b><i>VORTEX</i></b>	Versatile Ocean Subsea Robot for Technical Experiments -- IFREMER's testbed ROV for validating hardware and concepts
<b>WOCE</b>	World Ocean Circulation Experiment (international program)
<b><i>Yamato</i></b>	Japanese experimental vessel with the most advanced MHD operational system in the world

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