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Denmark

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Science

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DENMARK

CONTENTS

This chapter supersedes the scientific coverage in the General Survey dated March 1968.

FIGURES

Science

A. General (S)

Denmark has a moderate capability for scientific and technical research. The overall effort is restricted by limited financial resources, but there are many competent scientists, and the quality of research is good. The volume of research is less than in such neighboring countries as Sweden and the Netherlands, but greater than in Norway. Prior to about 1940 the Danish research effort was slanted toward agriculture, but especially since World War II, with the rapid expansion of the industrial sector, industrial scientific research has increased. Denmark is considerably stronger in basic research than in applied research, however. By concentrating on fundamental research and by emphasizing those aspects of science that do not require large investments in expensive equipment, Denmark is able to make important contributions to scientific knowledge in several fields, including physics, chemistry, and medicine.

The nature of Danish scientific research precludes a great contribution toward industrial or military capabilities. During recent years several institutes for industrial research have been established with government and private funds. Most industrial organizations are too little to support extensive research and development facilities. Because the population is small, there are few problems of communication between scientific and engineering counterparts. Scientific effort is seldom duplicated, because specialists in most research fields work together in groups, or they consult with one another when they pursue research independently at different laboratories.

Denmark does not have a science policy as do more scientifically advanced countries, but both government and private industry are aware of the need for encouraging scientific education and research. Since Denmark has few natural resources and must import large amounts of fuel and raw materials, the government realizes the importance of providing industry with the technology necessary to compete successfully in world markets. Most of the technology is acquired from other countries. Scientific progress has been favored by the high level of literacy and by the strong scientific tradition in universities. The Danes take pride in their past scientific accomplishments, such as the contributions by Hans Oersted, who discovered electromagnetism, and Niels Bohr, a nuclear physicist and the recipient of a Nobel prize in 1922.

Denmark participates actively in international scientific affairs and is a member of numerous international scientific organizations, including the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the World Health Organization (WHO), the Food and Agriculture Organization, the International Atomic Energy Agency (IAEA), and other U.N. specialized agencies. Denmark takes part in the scientific activities of the Organization for Economic Cooperation and Development (OECD), European Space Research Organization (ESRO), European Atomic Energy Community (EURATOM), and the European Organization for Nuclear Research. Denmark is active in the Nordic Council for Applied Research, which was established in 1947 to facilitate Scandinavian cooperation in scientific and technical research and in the utilization of research results. Another inter-Scandinavian organization, the Nordic Institute for Theoretical Atomic Physics (NORDITA), is located in Copenhagen.

Denmark has followed a relatively uniform policy in dealing with Communist nations. For the past 10 years good relations have existed, as noted by exchanges of scientists and students at various research laboratories and universities. Small numbers of students and research scientists from the People's Republic of China, the Soviet Union, Poland, Hungary, Romania, and Czechoslovakia have visited Denmark for periods of up to 1 and 2 years. At the same time Danish students and researchers have spent some time in the Soviet Union, pursuing their studies and conducting research.

B. Organization, planning, and financing of research (S)

Responsibility for scientific and technical research is about equally divided between private and government organizations, i.e., universities, governmental research institutes, and institutes operated by foundations or under the Academy of Technical Sciences (ATV), Copenhagen. Figure 1 shows the government ministries responsible for research. The Ministry of Education is the most important with respect to research and development through its administration of the higher educational institutions, the Atomic Energy Commission (AEK), and the Council for Scientific and Industrial Research. The ministry also has members in the Science Advisory Council. It does not become involved directly in the supervision of university research, but exerts influence through budgetary control. Funds for research at Copenhagen University, Copenhagen; Arhus University, Arhus;[1] and the Technical University of Denmark, Lyngby, a suburb of Copenhagen, are distributed through the general scientific fund of the ministry.

A major governmental organization concerned with research is the Danish Council for Scientific and Industrial Research (DTVF), which was established in 1960 to promote and coordinate research for the benefit of industry and commerce. Its 13 members are

[1]For diacritics on place names see the list of names on the apron of the Summary Map and the map itself in the Country Profile chapter.

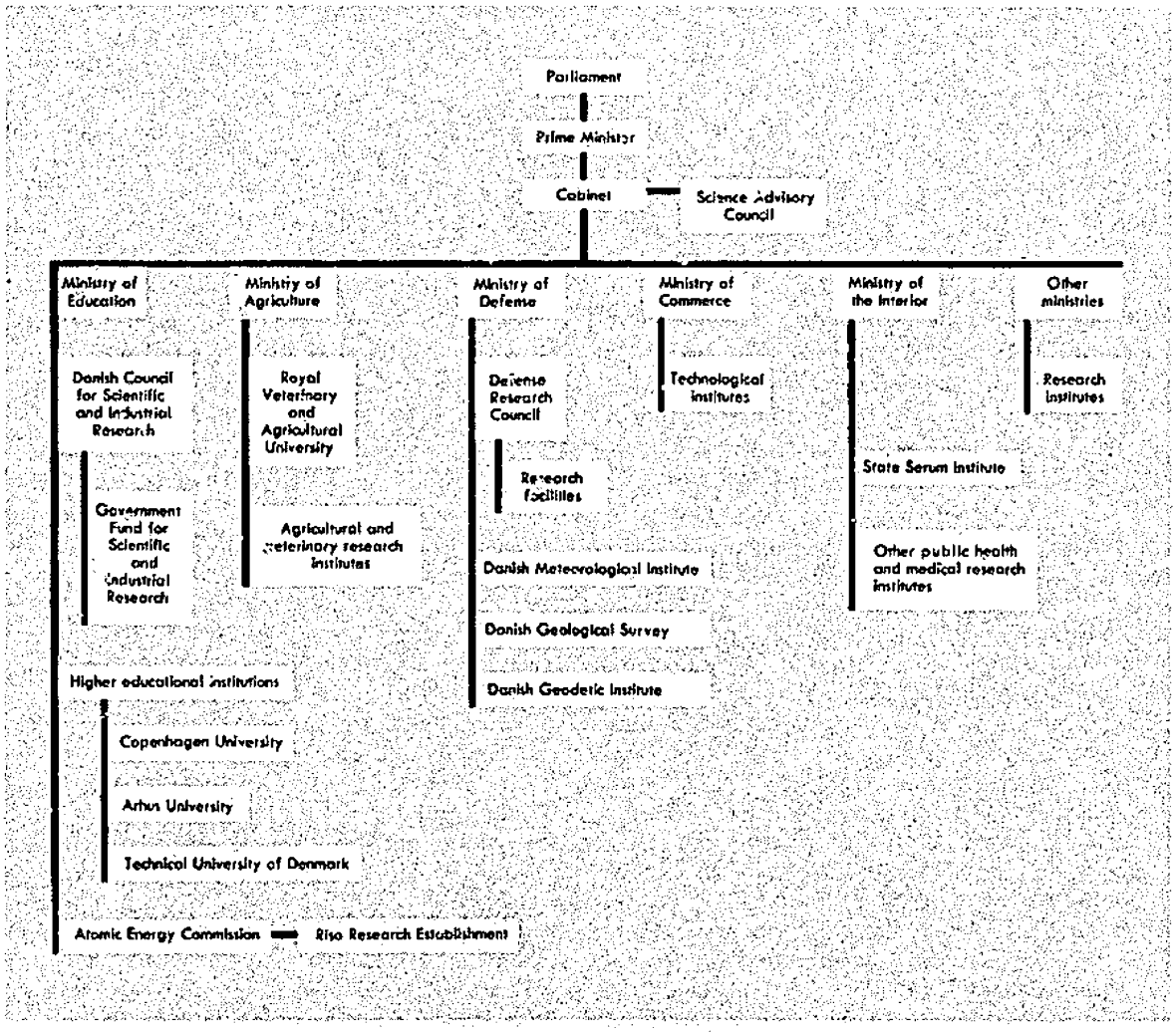

FIGURE 1. Organizations for scientific and technical research (U/OU)

appointed by the Minister of Education. The DTVF advises the government on industrial research and promotes recruitment and education of scientific personnel. It allocates funds to support non-governmental research institutes through its affiliated Government Fund for Scientific and Industrial Research (STVF). The DTVF maintains the Technical Information Service.

In 1965 the government established the Science Advisory Council; its main task is to advise the Cabinet ministers and parliament on research policy in all fields. The council comes closest to being a policymaking group. It advises the ministers on the allocation of research funds and assists the Minister of Finance in setting up research budgets. The council has 16 members, who are appointed by the Minister of Education and represent government ministries and agencies, industry, and the universities. The council secretariat, numbering seven full-time professionals, is drawn, however, from the disciplinary research councils that function as granting agencies for academic science. Through the influence of the council, five research councils were set up for the humanities, and the natural, social, medical, and agricultural sciences to replace the single organization that previously had dispensed funds for academic research.

The new councils were given authority to initiate research. Furthermore, their chairmen meet together as a central commission and are charged with promoting interdisciplinary activities. Each council has about 11 members, with active research workers comprising the majority. The councils handle a small proportion of research expenditures, probably about 10% of the funds going into academic science. Even though this is a small amount, it is believed that the approach involves a means for asserting some influence over the scope and direction of academic sciences. The next step planned is to transfer the responsibility of administering research fellowships from the university faculties to the councils.

The AEK, located in Copenhagen, is concerned with all matters relating to the peaceful uses of nuclear energy. It is composed of about 27 members, six of whom form the executive committee. Its most important research facility is the Riso Research Establishment, in Roskilde, on the Riso peninsula. In addition, the AEK has the following responsibilities: 1) coordination of nuclear research at the Institute of Physics of Arhus University, at the Technical University of Denmark, and at the Niels Bohr Institute of Copenhagen University; 2) collaboration with companies interested in nuclear energy applications; and 3) cooperation with foreign and international organizations in the field of nuclear energy.

The Academy of Technical Sciences, an important private organization for scientific research, was founded in 1937 to further scientific research and the application of results to industry and trade. The ATV has about 20 affiliated research institutes and centers, establishes new independent institutes, and functions through numerous committees concerned with specific technological areas. It has about 550 members, of which approximately one-half represent science and one-half represent industry and agriculture. The ATV plays an important role in formulating and implementing science policy. Research and development activities are supported primarily from contract work and scientific services for industry, but also from a special fund established in 1938 and from annual and special contributions from 150 larger Danish companies and banks. The ATV receives approximately one-fifth of its support from the government.

Other private organizations which support and encourage scientific activities are the Royal Danish Academy of Sciences and Letters, Copenhagen, with a membership of about 130, and several foundations. The Carlsberg Foundation in Copenhagen has a significant influence in fundamental research; independent financial resources enable it to support research in fields not undertaken by the government. It maintains the Carlsberg Laboratory for scientific work in chemistry and physiology and the Biological Institute, both in Copenhagen. The five directors of the foundation are elected by the Royal Danish Academy of Sciences and Letters. The Rask-Oersted Foundation, established in 1919 under the direction of the Ministry of Education, promotes international scientific cooperation by providing grants to scientists for studies abroad and by establishing and maintaining contacts between Danish and international scientific organizations.

In 1966 the Danish Government established a standing committee to advise parliament on scientific research and to strengthen contacts between legislators and members of the scientific community. This committee has aided in educating members of parliament on the importance of scientific support.

A few industrial organizations maintain their own research facilities; the most important are in the chemical, pharmaceutical, ship propulsion, power development, and food preservation industries. The electronic industry is newly developed and has a number of relatively small industrial units employing a large number of highly qualified technical personnel and performing considerable research and develop-

ment. Since only about 20 industrial companies in Denmark have more than 1,000 employees, most of them are unable to conduct extensive research. Therefore, much of the industrial research is conducted through cooperative associations working with the ATV or with the Technical University of Denmark.

Research and development are supported by the government, private industry, and foundations. The government finances most of the research in universities and in laboratories operated by the ministries, the AEK, and other government agencies. In addition to direct appropriations, two government research foundations provide funds. The State Research Foundation supports research in natural sciences, social sciences, medicine, agriculture, and veterinary science. The STVF works closely with the DTVF and supports applied research and development. In the fiscal year 1969/70, the DTVF had total expenditures of about US$2.43 million. Also, shortly before, the Danish Loan Fund for Industrial Research was established by parliament to provide loans of about US$700,000 annually for research and development projects in industrial organizations. Little information is available concerning the overall expenditures for scientific research and development. It is estimated that Denmark spends about $150 million annually, or less than 1% of its gross national product, for scientific research and development activities. Several private foundations (Carlsberg, Thrige, Moensted, and Andersen) contribute a total of about $2 million annually to scientific research and education.

The government has been aware that research expenditures have been inadequate and has substantially increased expenditures in recent years. The higher educational institutions have received the largest government research appropriation, followed by the nuclear research facilities. Total investment at the Riso Research Establishment is US$22.4 million, and the AEK operating budget is $6.5 million. The Danish Research Center for Applied Electronics operates on a budget of $470,000 per year. The Danish Central Welding Institute has grown steadily since World War II, and its expenditures are about $1.4 million. It has built new facilities at a rapid rate, bringing its total investment to $2 million.

C. Scientific education, manpower, and facilities (S)

Scientific and technical education at higher educational institutions is of high quality. The most important institutions involved in scientific education are Copenhagen University, Arhus University, and the Technical University of Denmark, which is concerned primarily with the applied sciences and engineering. Affiliated with the Technical University of Denmark, which has about 3,000 students, is the Engineering Academy of Denmark, with 1,500 students. The academy, established in 1957, provides shorter courses of study than the university, with less emphasis on research training. A major goal of the university is the education of engineers to about the equivalent of the U.S. master's level. About half of its effort is devoted to scientific research, both basic and applied. All universities are operated and financed by the government. Copenhagen University in 1967 had about 60 professors and 3,000 students in the Faculty of Sciences. In 1969 Arhus University had about 24 professors and 1,200 students majoring in science in the Natural Sciences Faculty.

Students entering higher educational institutions in Denmark are well prepared and more advanced than high school graduates in the United States. Science and engineering courses in Danish universities are highly specialized. Upon completion of the program of studies, the successful student is usually awarded the *candidatus scientiarum* degree, which is roughly equivalent to a U.S. master's degree. The *magister scientiarum* degree is awarded by universities to students who have concentrated in a single field of science and who have shown a particular aptitude for independent research. Advanced degrees include the *licentiatus* (which ranks between a master's and doctor's degree in the United States), the *licentiatus technicae*, and the doctoral degree.

Few recent statistics are available on scientific and technical manpower. There appears to be an adequate supply of scientists and engineers to meet important requirements. A 1963 estimate indicated that Denmark had between 3,000 and 4,000 research scientists, not including technicians. In 1962 industrial companies employed about 1,200 full-time equivalents of scientists and engineers with academic degrees in research and development. In 1967 Denmark employed a total of 8,378 workers in research and development. Of the total, 3,919 were considered qualified engineers and scientists, with competency for high-caliber research and development. In this respect Denmark is far ahead of Norway and Finland; however, Sweden employs three times as many in its research and development community and has twice as many qualified research engineers and scientists. Thus, it appears that Denmark has a shortage of research assistants and technicians.

The programs of research conducted in the many small laboratories require few but well qualified personnel. A typical example is the internationally known Niels Bohr Institute for Theoretical Physics, which has a staff of 70. The ATV employs slightly more than 700 persons, of which 190 have academic qualifications. The Danish Central Welding Institute, which recently has become associated closely with the growing shipbuilding industry, has a total staff of 138. The technical institutes of Copenhagen and Arhus, which carry out research, developmental work, and testing for individual firms, employ about 650 persons, including about 250 engineers. About 750 persons were employed at the Riso Research Establishment in 1967, of whom 190 held academic degrees.

Research and development facilities are generally adequate in the higher educational institutions and research institutes, but some very expensive pieces of equipment found in some more advanced countries are lacking. Research programs are structured so that the equipment available can be used. The Riso Research Establishment is well equipped with facilities, including three reactors. It has departments for physics, electronics, reactor chemistry, health physics, metallurgy, and agricultural research. Formerly the equipment at the Niels Bohr Institute was modest compared with the facilities of the larger countries; however, during the past 10 years the addition of a 12 MeV tandem Van de Graaff accelerator improved the situation. The institute recently acquired an 18 MeV accelerator, a new isotope separator, and several particle spectrometers for study of short-lived isotopes. With the addition of a computer, the institute has been able to work closely with Swedish institutions in scanning data obtained from photographic emulsions used in bubble chambers of these institutions.

The Danish public regards scientists favorably and with considerable respect. Persons holding the position of professor are socially prominent and surpassed only by royalty and Cabinet ministers. Physicians and graduates of the Technical University of Denmark also enjoy high public esteem. Outstanding scientific achievements are recognized by professional societies, universities, private enterprises, and the Academy of Sciences and Letters.

D. Major research fields

1. Air, ground, and naval weapons (S)

Denmark has a limited capability for the development of air, ground, and naval weapons. Although the Danes maintain a modern air force as part of their commitment to the North Atlantic Treaty Organization (NATO), the government has continually pursued a policy of procuring aircraft and related equipment from abroad. No change in this policy can be foreseen in the 1970's, especially in view of recent deliveries of Swedish-built supersonic fighter aircraft to the Danish Air Force. Because of lack of funds for the military there is little possibility for Denmark to improve its capability in weapon research and development. The munitions industry has degraded to one government-owned shell-loading plant and two privately owned munitions companies. Denmark depends upon imports of explosives, propellants, and mechanical components.

In the missile field Denmark is one of six countries involved in the development of the NATO Sea Sparrow, a short-range, ship-to-air missile. Denmark is committed to the development and production of the radar and ground equipment components. Its other missile systems are the air-to-air Sidewinder, the surface-to-surface Honest John, and the surface-to-air Hawk and Nike systems. The Sidewinder missiles are used to arm the two squadrons of F-104G fighters, and the Hawk and Nike systems are deployed in a ring around Copenhagen for the defense of that area alone.

In the space field the Danes rely on foreign rockets, satellites, and launch facilities to carry out their scientific experiments, while they supply the payloads. Since 1961 Danish scientists have developed sounding rocket payloads to measure electron density and collision frequency, very low frequency (VLF) profile, radiofrequency (RF) impedence and conductivity, high-energy particle density, and the monitoring of Lymanalpha radiation. They have developed a rocket payload which uses three orthogonal magnetometers and two electric field sensors to measure the electromagnetic wave field from 0.5 to 81 kHz. Balloon instrument packages have been used to determine the charge and mass of galactic high-energy cosmic particles. The Danes have provided the equipment needed on ESRO I and ESRO II in the performance of high-energy proton research. Scientists have also developed the digital readout system used in a low-energy electron-proton experiment and another experiment concerning the measure of angular distribution of total particle flux. The equipment on HEAOS-A2 and HEAOS-B needed in measuring solar radiation noise at very low frequencies and the isotropic composition of various elements in the magnetosphere have also been provided by the Danes.

From September 1971 to May 1972 the Soviets negotiated the purchase of Danish equipment for their space research program, and at the same time Danish businessmen were in the U.S.S.R. discussing the

possibility of entering into a joint space research effort. Reportedly the Danes would provide the test stations, telecommand systems, and biomedical equipment, while the Soviets would provide the launch systems and conduct the actual experiments. No information is available indicating the outcome of these negotiations.

Denmark is not engaged in significant research on ground weapons; most of such materiel is purchased abroad. Although research on small arms has been underway for the past two decades, the army has adopted only one locally developed weapon, a submachine gun. Research has ceased in this field, as well as on engineering, transportation, and quartermaster equipment. Although Denmark has a potential capability to develop small naval vessels and marine engines, it has not chosen to do so.

2. Biological and chemical warfare (S)

Denmark has no offensive biological warfare (BW) research and development program, although some research related to defensive BW is conducted. Laboratories engaged in defense-related research, through the development of vaccines and biologicals for public health needs, are located at the State Serum Institute, Copenhagen, and the National Veterinary Institute for Virus Research on the island of Lindholm. Research applicable to BW agent detection also has been carried on, e.g., development of interference filters for improved immunofluorescence microscopy.

The chemical warfare research and development program is directed primarily toward the improvement of defensive materiel. Research on the offensive aspect is conducted on a limited scale. The Royal Danish School of Pharmacy and the Royal Veterinary and Agricultural College, both in Copenhagen, may produce small quantities of G-type nerve agents developed during World War II; this work is in support of the chemical agent detection and antidote program. Toxicological studies have been conducted on organophosphorous-related compounds. These compounds seem to be more potent when oxygen is substituted for sulphur in the thiocholine moiety of the V-type molecule.

Research has been conducted to develop a rapid colorimetric process for field detection of nerve agents. Work also is underway toward the development of a chemical agent identification set that utilizes silica gel impregnated sampling tubes. The Danes also plan to improve U.S. kits, including the M18, by expanding the nerve agent detection capability to include V-agents through the use of an enzyme ticket. The Danes consider the disposable protective clothing designed to meet NATO requirements too expensive to produce. As an alternate approach, a project is underway to test the resistance of many commercial materials to penetration by mustard and lewisite in an effort to develop an inexpensive, disposable chemical-biological-radiological cape. Numerous toxicity studies, which could lead to a better antidote for nerve agent poisoning and improved prophylactic methods have been undertaken. Other research on nerve agent antidotes for field use includes studies on the effectiveness of a variety of oxime compounds in conjunction with atropine, the standard antidote.

3. Nuclear energy (S)

Denmark has a small nuclear energy program consisting primarily of research activities with nuclear power development as the ultimate objective. It has no military potential in nuclear weapons and has no plans for efforts in this field.

The Atomic Energy Commission was established in 1956 to promote the peaceful uses of nuclear energy. The AEK is composed of representatives of scientific and technical research organizations, as well as others interested in the exploitation of nuclear energy. The Riso Research Establishment was begun in 1958 and is equipped with three research reactors and a number of laboratories. The DR-1 (Danish reactor-1) is a 2-kilowatt thermal (kWt) aqueous homogeneous reactor which went into operation in 1957; the DR-2, a 5-megawatt thermal (MWt) high flux, tank-type reactor, which went into operation in 1958; and the DR-3, a 10-MWt high flux, materials-testing reactor that went into operation in 1960.

Research at the Riso Research Establishment is divided into fundamental research, research concerning reactor technology, and other technological research, such as physics, chemistry, medicine, biology, geology, metallurgy, and agriculture. The fuel elements program includes testing of design variables, process development, irradiation conditions and postirradiation examination. In addition to using their own test facilities, the Riso Research Establishment utilizes the Halden reactor in Norway and the Kahl reactor in West Germany. Test elements and full-size fuel elements are manufactured by the Riso laboratories in collaboration with the Elsinor Shipbuilding and Engineering Company of Denmark.

Although Denmark has no immediate plans to construct nuclear power reactors, there have been discussions regarding the construction of 500-megawatt electric (MWe) nuclear power stations in the late 1970's, and five sites in the Jutland and Fyn areas have been studied for this purpose.

Denmark has no domestic uranium deposits; however, the Danes have been actively exploring for uranium in Greenland. Tentatively deposits there are estimated to contain 5,000 to 6,000 tons of uranium and 15,000 tons of thorium, but the low grade of the ore and the remoteness of the deposits do not make them economically exploitable at the current market prices. No commercial mining is taking place.

Denmark is active in international atomic energy affairs and has agreements for peaceful uses of atomic energy with the U.K. and the U.S.S.R. (The U.S.-Danish bilateral atomic energy agreement expired on 24 July 1973.) It is also a member of the International Atomic Energy Agency (IAEA), the European Center for Nuclear Research (CERN), EURATOM, and numerous other international organizations.

4. Electronics (S)

Danish research in communications and electronics deals primarily with lasers and computers, with relatively little research in other electronic fields. The H.D. Oersted Institute at Copenhagen, the most important of four facilities, is concerned primarily with gas lasers and have built operational CO_2 helium-neon, argon, and cadmium vapor devices. Also, some basic research has been conducted in the areas of diffraction and the parameters of laser cavity design. A few students have done theses work on lasers, e.g., Raman spectroscopy with helium-neon and second harmonic studies using potassium-diphosphate (KDP) crystals. Some of the optical components also are made there, principally laser mirrors and other optical components; some are made for a German company. The laser research apparently is for spectroscopy studies and is supported by the Danish State Science Federation, which is similar to the U.S. National Science Foundation. There appears to be little interest in the optical communications aspect of electro-optics. Two organizations involved in the Danish optical and electro-optical work are the Copenhagen University and the Technical University of Denmark.

The Institute of Physics of Arhus University is heavily engaged in basic research on semiconductors. The institute appears to be extremely well funded, and the caliber of its personnel and quality of its equipment are high. The Laboratory of Electromagnetic Theory of the Technical University of Denmark does some theoretical work on antenna arrays and solid-state microwave devices. The Academy of Technical Sciences constructed the first Danish computer, the DASK; in 1957 and in 1960 produced the GEIR for the Danish Geodetic Institute, Copenhagen. The GIER is the first computer of purely Danish origin and is a fully transistorized, medium-sized, general-purpose machine.

Regnecentralen, a company located in Copenhagen, produced the RC4000, a general-purpose digital computer until 1973, when production of central processors ceased. The company now intends to import NOVA minicomputers from the Massachusetts-based Data General, Inc. *Regnecentralen* purchases the necessary software and peripheral equipment from U.S. and European manufacturers and assembles and sells complete computers systems in Europe and the U.S.S.R.; the latter receives the bulk of the company business. The quality of computer research in Danish universities has improved considerably since 1968. Computer activities are centralized under the direction of *Datacentralen*, Copenhagen, which was founded by the government in cooperation with local governmental authorities throughout Denmark. The center is equipped with large computers of U.S. manufacture and provides economical data processing facilities.

The Danish telecommunications and electronics industry, which includes radar, is fully capable of producing required quantities for the armed forces as well as considerable amounts for worldwide export. Military radio communications equipment produced includes fixed, mobile, vehicular, and portable types and is based primarily on U.S.-supplied grant aid furnished in the early 1960's. Other electronic equipment produced includes artillery ranging radar a uniquely constructed navigational radar, a manpack infantry patrol radar that was developed under contract of the Ministry of Defense, a long-range acquisition radar, and a surveillance and fire control radar. Electronic training devices have been produced, such as a simulator of communications satellites, used by ESRO for checking ground equipment.

Denmark produces no optical or photographic materiel of military value, and army requirements are satisfied entirely through imports. Native sources of army materiel are not known but probably correspond with those for the civilian market, in which the United States, West Germany, Japan, and the United Kingdom are the main suppliers. No infrared materiel is produced in Denmark. Substantial investments have been made in Swiss detection devices, as well as sighting, observation, and night-driving devices manufactured by various NATO countries.

5. Medical sciences (S)

Danish biomedical research is equal in quality to that of the most advanced western nations. Volume of

production is relatively small, however, because of limited resources, finances, and manpower. Support is derived from the government, private sources, and elsewhere, including WHO and the United States. Medical training is excellent, and teaching personnel are selected for research potential as well as for teaching ability.

Denmark has considerable strength in biochemistry and molecular biology, and these disciplines are employed in other areas of biomedical research. Nutritional biochemistry receives special attention. Current basic work includes study of the molecular properties of isoenzymes to determine specific functions and the biochemical nature of their reactive sites, the sequence of steps in the activity of enzymes, the metabolism of fatty acids and vitamins, including induced deficiency, microdetermination of enzyme inhibitors, chemical modifications of various groups in enzymes, and immunophoretic studies of vegetable protein. Important centers for this research include the Chemical Section of the Carlsberg Laboratory, the Department of Biochemistry and Nutrition of the Technical University of Denmark, the Institutes of Molecular Biology in Arhus and Odense, and the A, B, and C units of the Biochemical Institute of Copenhagen University.

The Institute for Biotechnical Research and Development, Copenhagen, an independent organization associated with the Academy of Technical Sciences, is an important center for studies on food hygiene and nutritional assay and on the chemical analysis of food proteins, fats, and carbohydrates.

Microbiological research is excellent. Scientists at the Institute of Medical Microbiology of Copenhagen University are doing impressive work on the epidemiology of various staphylococci and on chemical classification and phage typing of microorganisms. Other contributions include high-caliber virus research, development of microscopic techniques for fine study of antibodies, use of electrophoretic mobility characteristics to identify bacterial strains which cause intestinal infections, and a culture bank collection that ranks among the foremost in the world.

The State Serum Institute in Copenhagen has enjoyed international prestige. It has a staff of 100 scientists and 1,100 assistants to support its voluminous fundamental and applied work in bacteriology, mycology, protozoology, virology, immunology, vaccine production, blood fractionation, hormones, biological standardization, biochemistry, biophysics, biostatistics, and epidemiology. The high reputation of Danish microbiological competence is attested by the fact that the country has an International Escherichia Center, an International Laboratory for Biological Standards, an International Reference Center for BCG, a WHO Reference Regional Laboratory for Enteroviruses, a WHO National Influenza Center, a WHO Serological Reference Center, a WHO Neisseria Center, and a WHO Virus Collaborating Laboratory for Trachoma.

Fundamental and clinical work in radiobiology includes the chemical and pharmaceutical aspects of radioisotope therapy, the use of hydrogen and deuterium to investigate the secondary and tertiary structures of protein, and the influence of X-rays, prenatal, and perinatal factors on infant development. Pharmacologists are investigating the use of psychotropic agents in drug rehabilitation studies, development of antibiotics from plants, and trials of a caries prevention agent. The Royal Danish School of Pharmacy in Copenhagen provides strong research orientation in education and appears to be the leader in pharmaceutical education throughout Scandinavia.

Biomedical engineering is advancing, especially in the production of an apparatus for renal dialysis, food quality control, and air pollution control. Very precise instruments are being developed to support research in molecular biology. The Danish Institute of Protein Chemistry has developed instrumentation for solid-phase research on protein synthesis. It is contributing basic studies on automatic sequence determination of amino acids in proteins. Physiologists have contributed authoritative studies of the climates of closed environments and exhibit a good understanding of the nature of the heart beat and its relation to the stresses of deep sea diving. A pulsating ultrasound device has been developed for diagnosis of cardiovascular disease.

6. Other sciences

a. Chemistry and metallurgy (C)

Denmark is moderately active in chemical research, and the work is of good quality. The level of capability in chemistry is somewhat lower than that of Sweden, but is higher than that of Norway. Most of the research effort is carried out in universities and is much stronger in fundamental than in applied chemical research. The greatest strength is in physical organic chemistry, synthetic organic chemistry, and biochemistry. Industrial organic and inorganic research is of little significance, and the chemical technology used by chemical plants is almost entirely imported.

Copenhagen University is outstanding in physical organic chemistry. Professor Bak has for many years

been involved in research on determining the molecular structure of organic compounds through the use of infrared, microwave, rotation, and proton magnetic resonance spectra, and through the study of isotopically labeled compounds. Others at Copenhagen University are doing research in hydrogen bonding, organic photochemical reactions, and the mechanism of organic reactions involving rearrangements. Mass spectroscopy and nuclear magnetic resonance studies are conducted by capable staffs at this university and at Arhus University. The work at the latter institution has stressed organic phosphorus and sulfur compounds.

Organic chemical research, including synthetic work, is strong. Particular attention has been given to organic sulfur compounds. Alexander Senning, at Arhus University, has worked extensively on the synthesis of sulfides, sulfenylation reactions, thiocarbonyl compounds, and trichloromethylthio compounds, some of which are of interest as fungicides. Dr. Kai A. Jensen, Copenhagen University, has long been recognized for his outstanding work on organic sulfur and selenium compounds, including thio- and seleno-acids and heterocyclic 5-membered ring compounds containing sulfur or selenium and nitrogen. Another prominent investigator in the field of organic sulfur compounds is Professor Anders Kjaer, formerly at the Royal Veterinary and Agricultural University but presently at the Technical University of Denmark. He has worked for many years on isothiocyanates and other naturally occurring products, such as glucosinolates. Considerable work has been done on esters and other derivatives at the Technical University of Denmark. The Royal Danish School of Pharmacy does work on natural products and on the synthesis of pharmacologically active compounds.

There is considerable interest in electrochemistry. The work at Copenhagen University by Vernon D. Parker and associates deals with anode processes and anodic oxidation of organic compounds. Electrochemical research at the Technical University of Denmark includes work on solid-state and liquid-state, ion-selective electrodes. Interest in general physical chemistry, as differentiated from physical organic chemistry, is rather limited. There is some research on the physical chemistry of high polymers at the Technical University of Denmark. In inorganic chemistry, work is in progress on metal complexes and on soil chemistry.

Biochemistry is an important field of research activity. At Copenhagen University, the biochemical research is very diversified, including recent studies on enzymes, insulin, lipid synthesis, ethanol metabolism in the liver, and urinary pigments. Varied studies at Arhus University include work on binding of bilirubin to human serum albumin, kidney function, and insulin. The Carlsberg Laboratory does research on proteins and enzymes.

Very little is done in metallurgical research. Lacking such resources as iron and nonferrous metal ores and coal, and, although the quality of its work is good, the scope and depth of the effort is far below that of Sweden, the Netherlands, and Norway. Limited research is done in narrow specialized fields, such as handling and fabricating nuclear fuel elements and the general area of corrosion and electrochemistry. The Danes are investigating fracture mechanics, fuel elements cladding, dimensional changes in fuels and cladding during irradiation, and the development of improved cladding alloys at the Riso Research Establishment under the direction of Niels Hansen.

Dr. E. Knuth-Winterfeldt, an authority on corrosion and electrochemistry, directs research at the Technical University of Denmark. Research includes corrosion studies on various metals and alloys, including stainless steels, and on welding processes. The Danish Corrosion Center and the Danish Central Welding Institute conduct research for industry on a nonprofit contractual basis. The only industrial concern undertaking metallurgical research is the Northern Cable Wire Works; work includes the patination of copper and studies of the toughness and machinability of leaded brasses.

b. Physics and mathematics (S)

Approximately 70% of the physics research in Denmark is divided equally between solid-state and the nuclear sciences. In the latter, research includes studies in high energy, low energy and experimental work, nuclear-radiation effects on materials, and the applications of nuclear energy for peaceful purposes. The remaining efforts are devoted to subbranches of optics, plasma, acoustics, and spectroscopy.

The majority of solid-state physics research is done at the Technical University of Denmark, Copenhagen University, the Riso Research Establishment, and Arhus University. The research laboratories of the Technical University of Denmark are staffed with about 30 highly competent solid-state physicists. Some outstanding experimental work is being done by N. E. Christensen, who has developed a reputation on gathering data concerned with the photoemission spectra of gold, silver, and rhodium, and their relations to band structures. M. R. Samuelsen and his associates have been pursuing interesting research on

methods of microwave-aided tunneling which leads to production of superconducting tunnel diodes. Other advanced projects at the university involve germanium and silicon semiconductors, studies of characteristics pertaining to cadmium-selenium laser crystals, and parameters of antiferromagnetic materials.

About 40 highly qualified solid-state researchers at Copenhagen University do work of a basic nature. The concentrated effort at the university appears to be in theories and fundamentals associated with magnetic structures. Magnetic studies are spread over the areas of magnetoelastic interactions, magnetic properties of semiconductor compounds, spin lifetimes of magnetic alloys, energy spectra, geometric effects, photomultipliers, particle detectors, and Josephson junctions. The facilities at the Riso Research Establishment involve radiation effects on the structures of alloys, radiation detection, and neutron diffraction associated with the various alloys used in reactor design. The solid-state physics laboratory at Arhus University conducts research in semiconductor materials, radiation detector devices, and sputtering processes of pure metals.

H. B. Nielsen and P. Olesen, who are associated with Copenhagen University, are internationally known for their research in high-energy physics. They have emphasized hadron interactions and are highly regarded for their work dealing with the scaling of distributions in high-energy hadron collisions. Z. Koba, at Copenhagen University, has been quite active also in high-energy nuclear physics research and has recently contributed results from an advanced study of hadronic production. High-energy physicists at Arhus University direct their efforts to studies dealing with pion-pion interactions and pion-nucleon scattering. Recent activities at the *Nordita* research facility involve studies of dynamical models for meson and baryon resonances, and single-pion photoproductions, as they relate to higher baryon couplings. The low-energy aspect of nuclear physics research is pursued by many Danish universities and research laboratories.

Most of the research in optics is pursued at the Laboratory for Technical Optics of the ATV. The activities involve the design of imaging systems of all types. The technical personnel have been adept in using computer programs for the design of optical systems, thus enabling them to develop highly accurate telescope and microphoto systems. Danish optic specialists have been well known for their involvement in the large telescope for the European Southern Observatory in Chile, where the optical system was modified to use ultraviolet glasses instead of quartz for its corrective elements.

Denmark has several expert acousticians and well equipped facilities for sonic research at the Acoustical Laboratory of the ATV. The laboratory carries out research and testing of acoustical materials, construction, and equipment. It participates extensively in international standardization within the acoustical field. Industry is involved also in acoustical research. The excellent instrument firm of Bruel & Kjaer has been connected with industrial research on studies of acoustic intensity generated by sonic impulses and has made an analog analysis of acoustic shocks.

The Danes are well advanced in most types of spectroscopy, as evidenced by their use of spectroscopic systems as a research tool. Research is pursued in molecular and neutron spectroscopy, and high-quality work is done in visible and near-infrared spectroscopy. By using their knowledge of nuclear spectroscopy, physicists at Copenhagen University have furthered their studies of excited states in isotopic reactions.

Denmark has a long-standing reputation for good mathematical research, dating to the first half of this century with the work of Niels and Harold Bohr. Recent emphasis has dealt primarily with analysis, numerical methods, probability and statistics, and algebra. Important mathematical centers in Denmark are at Arhus University, Copenhagen University, and the Technical University of Denmark. Arhus is strong in fields such as algebra and analysis, especially function analysis. Copenhagen in statistics, and the Technical University of Denmark in numerical methods. These universities frequently have visiting mathematicians from the United States, and mathematicians from Denmark often make extended professional visits to American universities. About one-fifth of the mathematical publications by Danish authors appeared in U.S. journals during the past 2 years. West Germany, France, the United Kingdom, and occasionally an East European country published Danish-authored papers also.

c. Astrogeophysical sciences (C)

Research in astronomy is very limited in Denmark. Copenhagen University has two astronomical facilities. One, its original observatory in Copenhagen, has engaged in astrophysical research and in cometary and planetary astronomy, and the second, a more modern observatory at Brorfelde, Tollose, has emphasized photometry and photoelectric spectroscopy. The Ole Romer Observatory at Ole Romers,

Greenland (associated with Arhus University), does research in meteors, theoretical astrophysics, and variable stars. There are also a few private astronomical observatories in Denmark.

Research is conducted by the Danish Space Research Institute and by the Ionospheric Laboratory of the Danish Meteorological Institute. Both the institute and the laboratory are located at Lyngby and are associated with the Technical University of Denmark. Denmark is a member of ESRO and expects to become a member of the incipient European Space Agency (ESA). Ionospheric and magnetospheric experiments have been conducted aboard ESRO satellites and sounding rockets. Denmark also is a member of the Scandinavian Space Research Organization, and since the early 1960's has cooperated, principally with Norway and the U.S. National Aeronautics and Space Administration, in sounding rocket ionospheric research.

Before early 1970 Denmark established a rocket-launching range at Sondre Stromfjord, Greenland. The Danish Space Research Institute has also made cosmic ray studies aboard balloons flown from Narsarssuaq, near the southern tip of Greenland. In addition, Denmark has had a space tracking and telemetry monitoring station at Rude Skov, near Copenhagen. The Ionospheric Laboratory has geophysical observatories at three locations in Greenland where polar cap ionospheric research is conducted, and all-sky camera auroral observations have been made at the Godhavn and Narsarssuaq observatories.

Seismological research is conducted by the Danish Geodetic Institute. It maintains a seismological station in Copenhagen and three stations in Greenland. All are participating stations in the World-Wide Network of Standard Seismographs of the U.S. Coast and Survey. The Danish Geological Survey, Copenhagen, is reportedly primarily academically oriented. However, in 1970 it was engaged in studying the economic aspects of large uranium ore deposits in Greenland. The work was in conjunction with the physical exploration of these and associated deposits of other minerals being conducted by the Riso Research Establishment.

The Danish Meteorological Institute, in Charlottenlund, is headed by Dr. Karl O. Andersen and is responsible for providing all weather services except civil aviation forecasting. By late 1972 the large network of meteorological stations had grown to nearly 600 in Denmark, 5 in the Faeroe Islands, and 60 in Greenland. Eight of the 600 are participating in the International Hydrological Decade (IHD), which ends in 1977, another 20 operate nearly all year as lightning counters, and the others operate as climatic and synoptic stations. The purchase of equipment for use with American meteorological satellites and the establishment of a computer division in 1971 within the institute should greatly enhance Danish capabilities in such activities as storm warnings, extended period forecasting, ship routing, and weather research.

The Danish Meteorological Institute is engaged in the meteorology-related fields of sounding rocket experimentation and ionospheric research in Greenland. The geographic position of Greenland offers a favorable platform for investigation into the polar cap ionosphere, and the institute considers such investigations necessary. Geomagnetic surveys and auroral studies are conducted by the Danish Meteorological Institute. Several geomagnetic surveys for the west coast of Greenland and also one for Denmark itself are contributions to the World Magnetic Survey Project.

Geodetic research and development have been directed toward the improvement and expansion of triangulation and leveling and increasing the number of gravimetric stations. Denmark participates in geodetic satellite programs within the Western European Sub-Commission for Artificial Satellites and has cooperated with the United States on similar programs. The Danish Geodetic Institute is the center for all geodetic and gravimetric research and has a relatively free hand in determining policy. Instruction in geodesy is available at the Copenhagen University and the Technical University of Denmark. Danish scientists are using modern instruments and techniques to solve their geodetic problems. Most of the instruments are of foreign design.

Research in triangulation and leveling has primarily been routine and is devoid of any significant developments. Horizontal surveys have led to new connection networks with Sweden and West Germany. A revised and densified network has been established on the Faeroe Islands, and several networks have been established in Greenland for geodetic and geological purposes. Considerable time and effort have been devoted to data processing problems dealing with geometric geodesy and investigations concerning the method of least squares. As a member of the Nordic Geodetic Commission, Denmark has participated in projects concerning stellar triangulation, distance measurement, land uplift, geoid investigation, and treatment of geodetic observations with electronic computers. Leveling activity has resulted in contributions to the United European Leveling

Network and the Northwest European Lowland Leveling. International work has also included contributions to recent crustal movements and investigations of mean sea level and of secular movements between sea and land.

Activity in gravimetry has included inland surveys to extend the existing gravity net and to investigate the correlation between gravity anomalies and station heights. Gravity measurements at sea were established in interior Danish waters as the first part of a detailed survey of the Danish continental shelf. Extensive theoretical research has been carried out in dynamic geodesy.

Denmark has an active interest in hydrologic and hydraulic research, and although the programs are small, they are diverse. Most of the research is performed at the Hydraulic Laboratory of the Technical University of Denmark and at the Institute of Applied Hydraulics of the Academy of Technical Sciences. The Hydraulic Laboratory has modern facilities, including computers, and specializes in the study of density currents, hydrodynamics, sediment transportation, groundwater flow, hydrology, and glaciology. Research involves theoretical studies, hydraulic model investigations, and field investigations.

The Institute of Applied Hydraulics specializes primarily on coastal and estuary problems and works closely with the academic and research staff of the Coastal Engineering Laboratory of the Technical University of Denmark. The Geological Institute, also of the university, is small and is mostly interested in the geology of Denmark and Greenland, particularly as it relates to water supply and natural resource utilization.

Danish hydrologists and hydraulic engineers are active in international scientific organizations and conferences, and they participate in technical committees on flow through porous media, fluvial hydraulics, hydraulic machinery and equipment, cavitation, maritime hydraulics, and water resources systems.

Coastal engineering research compares favorably with that of other small European countries. The Coastal Engineering Laboratory of the Technical University of Denmark performs most of the coastal research and has wave tanks, oscillating water flow tunnels, and scale models for requiring simulated shore and sea conditions. Studies have been undertaken on the stability of underwater drilling platforms, wave forces on lighthouses, and harbor construction. Other major projects have dealt with littoral sand drift, tide effects on sediments, forces on breakwaters, and groin protection of shorelines. Experiments using radioactive isotopes for investigating littoral drift have been conducted.

Denmark has a long tradition of research in fisheries and oceanography, and until approximately two decades ago it was one of the most prominent European countries undertaking work in these sciences. However, because of a lack of funding and resources to support the present highly complex and sophisticated surveys, the status of Denmark has declined. Nevertheless, it is very active in promoting international cooperation with other countries in oceanographic research, fisheries research, hydrographic expeditions, and in the exchange of oceanographic information. The permanent secretariat of the International Council for the Exploration of the Sea (ICES) is located at Charlottenlund. Denmark is a member of the Intergovernmental Oceanographic Commission of UNESCO, the Northeast Atlantic Fisheries Commission, and the International Commission for the Northwest Atlantic Fisheries.

The most important Danish oceanographic facility is the Fishery and Marine Research Institute of the Ministry of Fisheries at Charlottenlund. Other organizations conducting marine scientific research are the Institute of Physical Oceanography of Copenhagen University and the Coastal Engineering Laboratory of the Technical University of Denmark. The National Council for Oceanography coordinates the oceanographic activities of these organizations.

Glossary (u/ou)

ABBREVIATION	DANISH	ENGLISH
AEK.....	*Atomenergikommissionen*..	Atomic Energy Commission
ATV.....	*Akademiet for de Tekniski Videnskaber*.	Academy of Technical Sciences
DTVF.....	*Danmarks. teknisk-videnskapelige Forskningsrad*	Danish Council for Scientific and Industrial Research
STVF...	*Statens teknisk-videnskapelige Fond*....	Government Fund for Scientific and Industrial Research