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Abstract: The Risø National Laboratory of Denmark started as a nuclear research centre, under the Atomic Energy Commission in 1955, with research reactors, an accelerator and related facilities. The research component, aimed at the introduction of nuclear power plants in Denmark, was wound up in 1985 with the country deciding to forego nuclear power in its energy planning. From 1993 the centre is under the jurisdiction of the Ministry of Research with three main areas of work: i) research on high international level; ii) train researchers; and iii) provide service to industry. The centre is funded up to 53% by the Danish Government and 47% by contract earnings. Some areas of current research include: i) materials science; ii) optics and sensor systems; iii) plant production and ecology; and iv) systems analysis. The nuclear component of the research centre is related to the operation of the nuclear facilities and for maintaining national expertise in nuclear safety and radiation protection.

Risø's history in brief

The Danish Atomic Energy Commission was created in December 1955 with Niels Bohr as its first chairman. The peninsula Risø at Roskilde Fjord, 40 km from Copenhagen, was chosen as site for the commission's research centre. Construction works were started in 1956 and the official inauguration of the centre took place in June 1958. The first small reactor DR1 went critical already in August 1957, followed by the larger research reactors DR2 in December 1958 and DR3 in January 1960. DR2 was closed in 1975, while DR1 and DR3 are still in operation. In addition to the reactors, Risø has had an electron accelerator, a hot-cell facility, and a treatment plant for radioactive waste in operation for many years. The hot-cell facility was closed in the mid 1990s.

During the first two decades nuclear research in a broad sense dominated the work at Risø, partly preparing for the introduction of nuclear power plants in Denmark. However, more generally oriented research in natural sciences and engineering also played an important role. In 1976, when nuclear power was heavily debated in Denmark, it was politically decided to postpone the decision of introducing nuclear power plants until further studies of reactor safety and disposal of radioactive waste had been carried out. At the same time the Atomic Energy Commission was abolished and in a new law the purpose of Risø was defined more broadly to be energy research in general but still including nuclear energy. In 1985, The Danish Parliament decided that nuclear power should no longer be included in Danish energy planning, and the purpose of Risø was restated to being scientific and technological research centred around energy. Nuclear research should still be included to the extent needed as a basis for operating Risø's nuclear facilities and for maintaining a national expertise in nuclear safety and radiation protection.

In 1990 a major reorganisation took place at Risø. Some departments and areas of research were discontinued while others were initiated. It was defined that Risø's research should mainly be concerned with energy, environment and materials. In 1993, Risø came under the jurisdiction of the newly established Ministry of Research, and from January 1994, Risø entered into its first four-year contract with the ministry. From January 1998, a new four-year contract went into force, which stipulates that Risø shall continue to carry out research on a

high international level and will also be evaluated on its ability to service industry and to train new researchers.

The number of employees at Risø reached a maximum in the late 1980s of about 1000. During the 1990s the personnel has amounted to between 899 and 974 man-years per year until 1998 where it was reduced to 863. There has been a steady shift from technical and administrative staff to academic staff during the years, so that now more than half of the staff is academic staff including post docs and Ph.D.-students. In 1998 the annual turnover was about 500 million DKK, of which 53% was government appropriations and 47% was contracts earnings.

The present situation

Risø's transformation from a nuclear research centre to a national laboratory beginning in 1976 has been successful, and Risø has been commended for carrying out this transformation in a timely and efficient manner. Nevertheless, there have been many discussions about Risø's role during the last decade. Today Risø's role is to carry out research within science and technology, providing Danish society with new opportunities for technological development. The research aims at strengthening Danish industry and reducing the adverse impact on the environment of the industrial, energy and agricultural sectors. In addition, Risø maintains the scientific and technical knowledge needed for advising the authorities and the public on nuclear matters. Risø's research is now organised in seven programme areas that can be shortly summarised as follows:

Industrial materials: Development and studies of materials technologies to find economically feasible and safe applications for advanced materials. The activities cover long-range research, design and testing, and are particularly directed towards the energy and industrial sectors both in Denmark and internationally. The key areas of expertise are materials physics, solid state mechanics, electro-chemistry, materials technology, and mechanical design and testing, as well as interdisciplinary combinations of these areas.

New functional materials: The research focuses on the synthesis and structural characterisation of materials, including new polymers, at the atomic, molecular and supramolecular levels. A significant part of the research utilises neutron radiation from the DR3 reactor and X-radiation from the synchrotron facilities in Hamburg and Grenoble. In this connection work is carried out on developing advanced methods, as well as theory and computer simulations. The key areas of expertise are condensed matter physics, structural chemistry, chemical synthesis, and interdisciplinary combinations of these areas.

Optics and sensor systems: The research aims at the understanding of nonlinear processes in optical and fluid dynamic systems as well as the development of diagnostics methodology and information processing that can be applied in research and industry. The foundation is laid for new types of miniaturised optical systems, including systems for image and pattern generation. A new area of research is biomedical optics. Key areas of expertise are physical optics, continuum dynamics, mathematical-numerical methods, and information processing.

Plant production and ecology: The research is primarily directed towards the need for cost-effective plant production with minimal adverse impact on the environment. Besides this, the research helps to alleviate and restrict adverse impact on the environment resulting from energy consumption and industrial production. Key areas of expertise include genetics and genetic engineering, chemistry, ultra-sensitive analyses of trace elements, as well as

controlled multi-parameter experiments in the RERAF greenhouse facility. RERAF is Risø's Environmental Risk Assessment Facility, where experiments are carried out in areas such as the interaction between plants and micro-organisms, the development of new plant properties by means of transformation, as well as assessment of risks from spreading genes.

Systems analysis: The objective of the research is to develop and apply methods and models to provide Danish society and international organisations with an improved basis for decision-making concerning technological priorities in society. Key areas of expertise are systems reliability, organisation, informatics, simulation methods, work studies, economics, experimental psychology and technological foresight. The UNEP Collaborating Centre on Energy and the Environment, financed by the UN, Danida and Risø, provides technological-scientific support to the United Nations Environmental Programme through energy and environmental projects in a number of developing countries.

Wind energy and atmospheric processes: The research is concerned with the development of methods for designing, testing and siting wind turbines, determining wind loads and wind resources, as well as methods for determining dispersion of air pollution. The key areas of expertise are boundary layer meteorology, aerodynamics, aero-acoustics, and machine and construction technology, exploiting full-scale field tests and advanced numerical simulation. Risø operates test stations for wind turbines at Risø and in Jutland with the purpose of promoting the use of wind energy in Denmark and abroad through the testing, approval and certification of wind turbines.

Nuclear safety: The research addresses the needs of governmental authorities and others for consultancy on nuclear and radiation matters and the operation of Risø's own nuclear facilities. The research areas include nuclear safety, radiation protection, radioecology, and the development and application of nuclear methods for tracer studies and other applications. Key areas of expertise are reactor physics, radiation protection, radioecology, radiation measurements, dosimetry, dispersion and dose calculations, and contamination physics.

Risø's interaction with the Danish society

In 1997 an international evaluation of Risø was carried out. Among the conclusions were that the overall quality of the science at Risø is very good, but it is an important challenge to Danish society to find more effective ways of utilizing Risø for the benefit of Danish industry and the educational system. Risø's interaction with the Danish society has been extended during recent years and can be viewed as taking place within four areas.

Research: The collaboration with universities and government research institutes entails obligations for both parties and involves the development of more operational and integrated forms of collaboration. For example, Risø and the Technical University of Denmark (DTU) have entered into three agreements under the national strategy on materials research. This implies that a new joint centre for polymer research and two joint programmes, one for materials research on the nanometre and micrometre scales, the other for biomedical optics, have been set up. The agreements cover an exchange of staff, whereby Risø becomes involved in teaching at DTU and DTU becomes involved in Risø's research. As another example, Risø has entered into an agreement with the National Environmental Research Institute (DMU) implying that the activities of the DMU Systems Analysis Department and Risø's research programme Energy Systems Analysis are being integrated into a new Centre

for Analysis of the Environment, Economy and Society, whereby the two institutions will co-ordinate their efforts in this area, sharing tasks, finance and management.

Education: Risø has been engaged in education of researchers for many years offering Ph.D.-projects at Risø in co-operation with the universities. This has been intensified during the 1990s where also an increasing number of post docs, many of them from other countries, have received training at Risø. Since 1996, the number of Ph.D.-students and post docs at Risø has exceeded 100 man-years per year. A number of Risø employees have also contributed to the teaching at the universities for many years on an ad hoc basis. It is expected that more Risø staff will be involved in teaching at the universities during the coming years in connection with the extended research co-operation between Risø and the universities. Risø has also been involved in a few Ph.D. and post doc projects in direct co-operation with industrial companies. More projects of this type are expected in the future in connection with an extended interaction between Risø and industry.

Industry: As one of the means of meeting the challenge of increasing the interaction between Risø and the industry, Risø has entered into new projects with industrial companies implying an integrated type of collaboration, similar to that mentioned above for universities and governmental research institutes. A co-operation with Danfoss A/S concerns the development of artificial muscles, while another co-operation with DLF-Trifolium concerns the development of knowledge to make it possible to control the formation of stems and flowers in grasses. Both co-operations receive support from the Danish Research Councils. The joint work with DLF is located in Risø's Plant Biology and Biogeochemistry Department as an independent programme, DLF-Risø Biotechnology, and is managed by a researcher employed at DLF-Trifolium. In 1998 Risø, on its own or jointly with collaboration partners, has applied for eight patents and entered into seven new licensing agreements on the use of patents and know-how.

Governmental authorities: In the nuclear field Risø has a special role as scientific-technical back-up and as adviser for governmental authorities with an interest in nuclear matters. This is particularly the case for the Emergency Management Agency under the Ministry of the Interior and for the National Institute of radiation Hygiene under the Ministry of Health. There is a formal co-operation agreement between Risø and the Emergency Management Agency. In addition, Risø also acts as adviser in other areas, e.g. for the Ministry of Energy and Environment.

International collaboration

Risø has always been strongly involved in international collaboration. The research is carried out in a world-wide co-operation with other research institutes and other partners. The research reactor DR3 is appointed as a European Large-Scale Facility and the neutron beam instruments are intensively utilized by researchers from Risø and from other EU-countries. Risø also participates in the EURATOM research programmes on fusion, fission safety and radiological sciences, and to a larger extent in the EU non-nuclear energy and other programmes. There has been a close co-operation on nuclear safety research (the NKS programme) among the Nordic countries for many years, and in the 1990s the collaboration with East European countries has been extended. Risø collaborates with a number of international organisations, in the nuclear field notably with the EU, IAEA, ICRP and OECD/NEA. Risø operates the UNEP Collaborating Centre on Energy and the Environment, supporting the United Nations Environmental Programme.

Future challenges

In 2000, Risø will work out a new strategy which will form the basis for new contract negotiations with the Ministry of Research in 2001. It may be expected that Risø shall further develop the interaction with industry, the universities and other research institutes, the governmental authorities, and the society in general.

In the nuclear field the main challenges will presumably be to prepare for the eventual decommissioning of Risø's nuclear facilities, and to maintain a national expertise in nuclear matters through transfer of knowledge and skills to the young generation.

The future operation of DR3 will be influenced by the continued need for neutron sources in Europe and how this need can be met. However, in a 10–20 years perspective it is to be foreseen that, with the exception of the Waste Treatment Plant, the nuclear facilities at Risø will all be in some stage of decommissioning. For DR2 and possibly DR1 the decommissioning could even be completed already during the next decade.

As part of the work on a new strategy, the possibilities of new large research facilities at Risø will be discussed. In addition, Risø will take part in international efforts, such as the preparations for a large European Spallation Source.