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1. INTRODUCTION

Danish Decommissioning (DD) [1] and DTU [2] are the Danish representatives in EAES.

DD is responsible for the decommissioning of the nuclear research facilities at Risø. These facilities are the only nuclear facilities in Denmark.

DTU is the Technical University of Denmark. DTU undertakes education, research, public sector consultancy and innovation within the natural and technical sciences, including nuclear technologies.

2. ENERGY SOURCES AND PRODUCTION

Denmark has been net self-sufficient in energy from 1997 to 2012. Self-sufficiency is measured in terms of energy production and consumption, calculated on the basis of energy statistics. Around 2005 the degree of self-sufficiency was more than 150%. This is now declining, because the decrease in oil and gas production from the North Sea is not outweighed by the increase in domestic renewable energy sources.

![Figure 1. Degree of self-sufficiency, total (histogram) and oil (blue line), Source: www.ens.dk energystatics/slides2017.pptx.](image)

Much of the information given in this report concerning energy sources and production has been taken from the web site of the Danish Energy Agency [3], where further details can be found.

2.1 Production of oil and gas

The oil and gas production is from fields in the North Sea. Maersk Oil and Gas AS has been the operator of most of these fields, until spring 2018, when it was taken over by French Total. Other operators are DONG E&P AS (from 2017 INEOS Oil & Gas Denmark) and Hess Denmark ApS.

The operators report to the Danish Energy Agency on the production of oil, gas and water from each field. Gas and oil reserves in Denmark have been decreasing since 2000.
2.2 Production of electricity

Electricity generation in Denmark can be divided into three main types of units:

- central power stations with heat extraction to six urban regions
- decentral CHP plants (combined heat and power) with district heating supply for towns and villages
- wind turbines

Central power stations are located on sites near large district heating networks and primarily use coal and biomass. Decentral CHP plants encompass around 600 generators, industrial and local plants. They typically use natural gas, waste, biogas and biomass. The total generation from wind turbines was nearly constant from 2002 to 2010, but increased significantly from 2011, mainly by the commissioning of off-shore wind farms. By 2015 wind power's share of domestic electricity supply was 55% in Denmark West (synchronised with the European Continental grid) and 23% in Denmark East (synchronised with the Nordic grid). With the planned deployment of new off-shore wind turbines the share will increase to more than 50% by 2020 in the country as a whole, compared to 42% in 2015. It means that hourly electricity from wind will vary from zero to far more than the domestic consumption. Thus, the key issue for electricity generation in Denmark will be balancing these variations by a wide range of measures: demand response, heat pumps, electric boilers and heat storages in district heating networks supplied by CHP, individual heat pumps, electric storages, e.g. electric vehicles, and - last but not least - international electricity trade. Electricity generation from thermal units has decreased significantly.

Figure 3 shows the yearly development in the production of electricity. The very significant variation in power-only generation is mainly due to variation in hydro production in Norway and Sweden. The years 1996, 2004, 2006, 2010 and 2013 were particular ‘dry’ years, while 2012 and 2015 were 'wet' years.
2.3 The electricity market

Since 2005, the state-owned company Energinet.dk has been in charge of maintaining the overall short-term and long-term security of electricity and gas supply and developing the main Danish electricity and gas transmission infrastructure.

Energinet.dk owns the natural gas transmission system and the 400 kV electricity transmission system, part of the transmission grid, and the 600 MW Great Belt HVDC link, which connects the two Danish systems, and is co-owner of the electrical interconnections to Norway, Sweden and Germany. New connections to neighbouring countries will be developed together with large off-shore wind farms; the COBRA cable (700 MW) to the Netherlands is under construction to be commissioned in 2019, and the Viking Cable (1400 MW) to England was agreed upon in 2016 and expected to come in operation in 2023. In addition, the NORD-LINK and NSN link (both 1400 MW) between Norway and UK and Germany are under construction – expected to be in operation from 2020 and 2021.

**Wholesale electricity market prices**

Electricity in Denmark is divided into two small markets, each with strong connections to the neighbouring countries, but with no direct connection between each other until 2010. Cross-border trade is significant, but varies with the hydro power production in Scandinavia. Since 1999 and 2000 the two parts of Denmark (east and west of the Great Belt) have been bidding areas with separate area prices of the Norwegian based Nordic Power Exchange, Nord Pool, covering Denmark, Norway, Sweden and Finland and parts of Germany. The hourly variation in wind power range from practically zero to far more than the national electricity consumption. Thus the prediction of wind supply is very significant for the wholesale electricity price.

Nord Pool operates a day-ahead spot market with regional hourly prices (Elspot), an intraday market with continuous power trading up to one hour prior to delivery (Elbas), and a financial market for the following days, weeks, months and annual contracts up to five years. The partici-
pants in the markets are power producers, distributors, industries and brokers. On the day-ahead market a ‘system price’ is calculated covering the whole area of Nord Pool assuming no network constraints. In hours when congestion occurs on interconnections between bidding areas Finland, Sweden, Norway, and Denmark calculate separate hourly area prices.

**Consumer electricity prices**
The total price paid by consumers consists of the following elements:

- market electricity price
- grid tariffs, i.e. payments to the grid owner and transmission system operator for transmission
- PSO (public service obligation), which is now being phased out
- subscription to grid owner and electricity dealer
- state levies and VAT

The total price depends on:

- the consumer category
- grid owner
- location
- market prices etc.

### 2.4 Heat Supply in Denmark

More than 50% of the market for space heating is covered by district heating (DH), which is expanded in areas with sufficient heat densities. Areas with less heat density are typically supplied by natural gas for individual boilers. Oil boilers and direct electric heating are used mostly in areas with low densities. DH is produced by incineration of urban waste, combined heat and power plants (CHP), mainly from large plants. District heating system networks is continuously being expanded. Heat storages are important in district heating systems to allow electricity generation in CHP plants to respond to variations in wind power. Surplus electricity from wind power will increasingly produce heat using large electrical driven heat pumps and electric boilers. Small heat pumps are supported to replace direct electric heating and oil boilers in single-family houses. This will add to the flexibility in electricity generation.

### 2.5 Nuclear power

For many years nuclear power has not been an issue in Denmark. Deploying large size nuclear units and operating these for base load power generation is becoming increasingly incompatible with the Danish electricity system, because of the key issue of balancing large variations in wind power on a few-days or weekly basis.

Nuclear R&D has for many years been limited to the level required to maintain an expertise allowing the government to make independent national assessments, to support the operation and decommissioning of the nuclear facilities at Risø, and to ensure a scientific and technical backup for the authorities. Nuclear related research at DTU is mainly concerned with radiation protection and the application of nuclear technologies in science, industry and the health sector, and includes radiation physics, dosimetry, radioecology and the production of medical isotopes.
In 2015, however, two small start-ups were formed, aimed at developing and supporting new nuclear reactor design. One of these, Seaborg Technologies, received substantial public and private funding in 2017, to carry out development projects on Molten Salt Reactors.

DTU and other Danish institutions participate in the Nuclear Fission Safety Research Programme of the European Commission, particularly in the radiation protection part of the programme, and also in the Nordic Nuclear Safety Research Programme. DTU also participates in the EUROfusion Consortium of the EU Horizon2020 Research Programme.

Danish Decommissioning participates in a number of activities under the IAEA related to decommissioning. A DD staff member is involved in work under the ICRP.

3. POLICY AND R&D IN NON-NUCLEAR ENERGY FIELDS

The Danish energy policy has three focal points: security of supply, climate impact and cost effectiveness. Both previous and the current Danish government have in their government platforms the vision of Denmark to be a green and sustainable society with a visionary climate and energy policy. To meet these political goals, various funding schemes offer public grants to R&D in new energy technologies. The primary goal is that Denmark shall be independent of fossil fuels from 2050. [4]

A key issue of Danish energy policy – both in the short-term and the long term is to support the development towards more flexible power systems through cost-efficient and CO2 emission reducing measures, and different sources of flexibility, including transmission grid and thermal power plant flexibility. [5]

_EUDP or Programme for Energy Technology Development and Demonstration_ supports the development and demonstration of new energy technologies. The program is headed by an independent Board, appointed by the Minister for Climate and Energy, which decides on EUDP priorities. Administration of EUDP will be carried out by a secretariat in the Danish Energy Agency.

_Energinet.dk_ (the electricity and gas system operator) provides funding for energy RD&D projects concerning environmentally friendly production of power. Further information can be found at [www.energinet.dk](http://www.energinet.dk).

_Dansk Energi – (The Danish Energy Association)_ is a commercial and professional organisation for Danish energy companies. It provides funding for energy RD&D projects concerning efficient use of electricity. The programme focus areas are buildings, LED (Light Emitting Diode) lighting and cooling technology. Further information is available on [www.danskenergi.dk](http://www.danskenergi.dk).

_Innovation Fund Denmark_ invests in new knowledge and technology creating growth and employment in Denmark. Further information is available on [http://innovationsfonden.dk/en](http://innovationsfonden.dk/en).

Denmark takes part in the studies by the International Energy Agency (IEA) Nordic Energy Research on Nordic Energy Technology Perspectives [6]. The first studies were published in 2014 and 2016. The latest study focuses on the integration of variable renewables and trade infrastructure among the Nordic countries and other countries in Northern Europe.
4. DECOMMISSIONING OF THE NUCLEAR FACILITIES AT THE RISØ SITE

4.1. Introduction

At the Risø peninsula in Denmark there were six nuclear facilities to be decommissioned in 2003 including three research reactors (Figure 4).

- **DR 1 (2 kW, homogeneous core)**
  - Fully decommissioned
  - The reactor building and land was released for unrestricted use in 2006

- **DR 2 (5 MW, pool type)**
  - Fully decommissioned in 2008
  - The reactor building is still in use for other nuclear purposes

- **DR 3 (10 MW, heavy water cooled and moderated)**
  - Removal of the internal parts are completed
  - Decommissioning is planned to be completed in 2022

- **Hot Cells (six cohesive concrete cells)**
  - Cleaning by remote grid blasting has been completed
  - Decommissioning is planned to be completed in 2022

- **Fuel Fabrication Facility (produced fuel for DR 2 and DR 3)**
  - Ground floor and first floor were fully decommissioned in February 2015
  - Basement level: More contamination found in 2016 and a layer of the basement floor needs to be removed. It has been decided to wait until DTU has vacated the building (planned to take place in 2020). This work is planned to be completed in 2021

- **Waste Treatment Plant (still in operation)**
  - The project description was completed in 2018 and approved in May 2019.
  - Decommissioning is planned to be completed by 2023 subject to the new upgraded storage facility

*Figure 4: The six nuclear facilities in Denmark at the Risø peninsula.*
4.2. Progress in decommissioning

Research reactor DR 3

DR 3 (Danish Reactor 3) was a 10 MW_\text{th} heavy water cooled and moderated research reactor of the PLUTO type. It was in operation in 1960-2000, and was predominantly used for material testing, production of isotopes and silicon doping.

The peripheral systems inside as well as outside the reactor building along with the primary cooling system situated below the reactor block have been removed previously. Figure 5 shows the internal parts of the reactor block which have been removed.

The following internal parts have been removed from the reactor block: The Top Shield Plug (TSP) and Top Shield Ring (TSR) as well as the Reactor Aluminium Tank (RAT), the graphite reflector, which consisted of 685 blocks and the cast layer of lead behind.

Figure 5: Current (May 2019) decommissioning status of DR 3: The red marked areas have been removed.
Dismantling of the graphite reflector
Removal of the 685 graphite bricks in 13 layers took place in 2018. It turned out to be necessary to break the first block in each layer to make it possible to lift out the rest of the blocks. During this work, four different tools were developed for the job: a pneumatic chisel, a pneumatic drill, a handsaw and a pneumatic vacuum lifter. With the drill, we were able to perforate the first graphite block in each layer.

Our hydraulic cutter was used to remove parts of the first block, where one of the experimental tubes had passed through the block. Following this, each block in the layer was then lifted out with the vacuum lifter as shown in Figure 7. In total, six containers were filled with the graphite reflector.

Removal of the cast lead
The lead that had been cast between the graphite and the boral layer did not bond to the boral layer or to the nuts used to fix the boral sheets to the steel tank. The different pouring’s of the lead over time were visible and had not fused the pours together, so it was possible to pull them off as sheets. These were placed in containers after being folded to take up as little space as possible (figure 8).

Figure 6: A hydraulic cutter breaks the first part of the block after drilling the holes

Figure 7: Vacuum lifter in use.

Figure 8: Lead sheets in the DD type 2 container.

Figure 9: Removal of the Packing Hut and Manipulator Box on the reactor top.
The Hot Cell facility
The Hot Cell facility was commissioned in 1964 and operated until 1989. Following a partial decommissioning from 1990 to 1994, only a row of six concrete cells remains as a sarcophagus inside the building. The remaining part of the building has been released and is now being used for other purposes.

Blast cleaning
By the end of 2018, the initial blast cleaning of all the cells was finished, except for a few hot spots. To minimize airborne dust development, the surfaces of cell no. 2 were primed with a dust binder. This worked well and proved to be an effective method and clearly had a positive effect on the visibility while working in the cell. Due to the positive results, priming with dust binder was also applied in cell no. 1.

Cell no. 1 was one of the most contaminated cells. The cleaning was effective, but a few hot spots proved to be hard to cleanse. In early 2019, one hotspot was successfully removed and the preliminary cleaning is now considered finished.

Figure 9: Blast cleaning on the table in cell 1

The Fuel Fabrication Plant
The Fuel Fabrication Plant was used for the production of uranium fuel elements for DR 2 and DR 3 from the 1960s until 2002. In February 2015 decommissioning of the Fuel Fabrication Plant was completed.

However, by the end of 2015 clearance measurements of the gutters below the drainpipes in the basement revealed that these could not be released. Planned milling of 6 cm of the basement floor needs to be carried out. This task will likely be difficult, both technically and with regard to work-environment safety, if the building is still in use. Therefore it was decided to postpone the work until DTU has vacated the building, planned to take place early 202.

The Waste Treatment Plant
The last of the six decommissioning projects, the waste treatment plant, has been initiated. In March 2018 a project description was reviewed by DD’s international expert panel in November 2018, submitted to the authorities in December 2018, and approved in Maj 2019.
4.3. **Long term solution for the Danish radioactive waste**

On 15 May 2018, Resolution B90 outlining Denmark’s national policy and programme for radioactive waste and spent fuel management was adopted unanimously by the Danish Parliament.

The resolution includes the following:

- Continued intermediate storage of the radioactive waste at the Risø area for up to 30-50 years. For this purpose a new upgraded storage facility will be build. The facility will be placed at a higher elevation than the present storage facilities in order to counter possible flooding events.
- Further investigation of the possibility of exporting the special waste (233 kg irradiated research fuel from our Hot Cells facility).
- New investigations to find suitable locations for a deep geological disposal (in previous studies, only surface and intermediate depth solutions have been investigated).
- Preparations for the waste to be disposed of in a deep geological disposal.
- A political process including stakeholder involvement is to be organized.

Subsequently, Danish Decommissioning has started planning the design of the new upgraded storage facility and work on the application for the facility license has commenced.

The Geological Survey of Denmark and Greenland is planning a new programme of geological investigations with the purpose of identifying suitable areas to potentially host the disposal.

**References**

1. Danish Decommissioning [http://www.dekom.dk/english.aspx](http://www.dekom.dk/english.aspx)
2. DTU, Center for Nuclear Technologies, [http://www.nutech.dtu.dk/](http://www.nutech.dtu.dk/)