Digital Systems
From Sensor to Decision

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National and international nuclear fission with respect to Norway

Research for a better future

29 Jan 2023

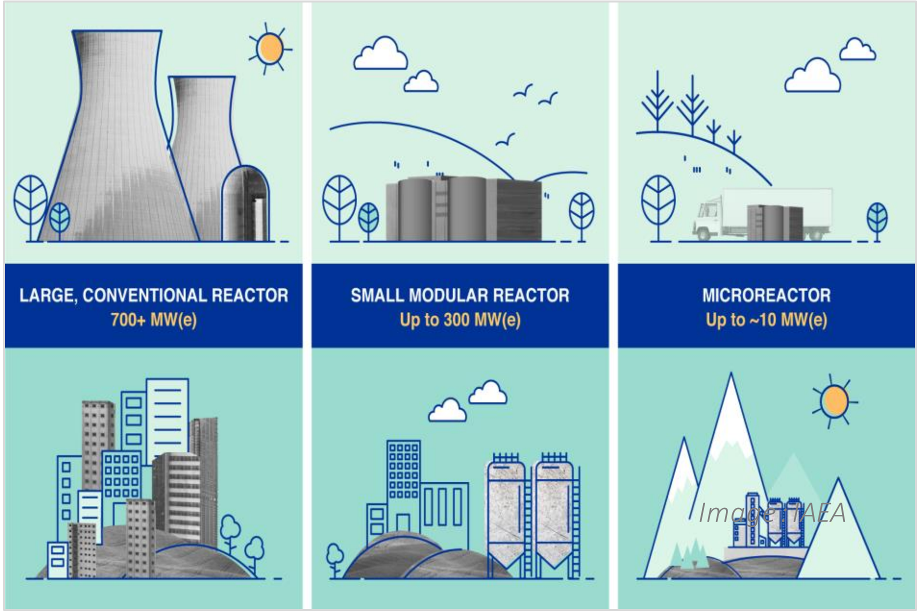
NUCLEAR HISTORY

Short History

- The science of atomic radiation, atomic change and nuclear fission was developed from 1895 to 1945, much of it in the last six of those years.
- Over 1939-45, most development was focused on the atomic bomb.
- 1941 MAUD committee two summary reports
- From 1945 attention was given to harnessing this energy in a controlled fashion for naval propulsion and for making electricity.
- Since 1956 the prime focus has been on the technological evolution of reliable nuclear power plants.
- 1953 first naval reactor (US)
- 1954 first nuclear reactor with main aim to produce electricity for the grid (Russia)
- 1954 first nuclar submarine
- 1957 first US reactor for the grid

Nuclear power plants, a size comparison

- Large Conventional Nuclear Power Plant
  - Power output of 700-1400 MWe
  - Site footprint for 1000 MWe = ~2.5 km^2
  - 70-80% constructed on site
  - Active safety systems requiring electrical power
  - Used primarily for baseload electricity production and some hydrogen production
- Small Modular Reactor
  - Power output of 10-300 MWe
  - Site footprint for 195 MWe = ~0.06 km^2
  - Factory built with final 10% constructed on site
  - Passive safety systems, inherent negative reactivity feedback
  - Can be used for electricity generation, district heating, sea water desalination, hydrogen production, etc.
- Micro Reactor
  - Power output of < 10 MWe
  - Typically used for space rocket propulsion, space craft power supply, power supply for remote towns, and provision of emergency power after natural disasters



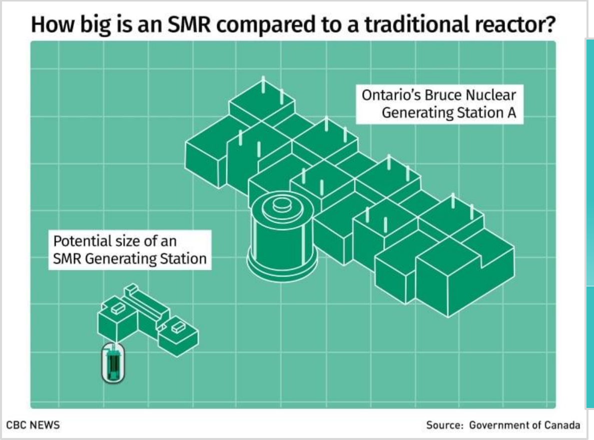
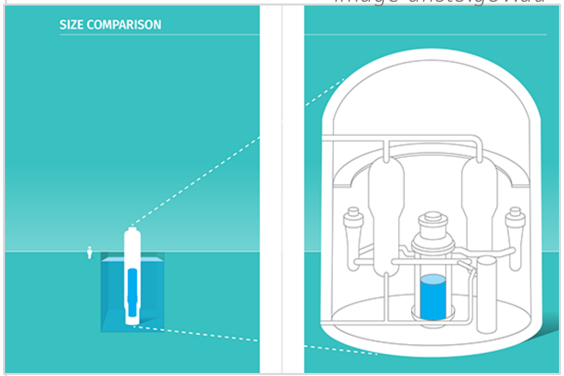


Image ansto.gov.au



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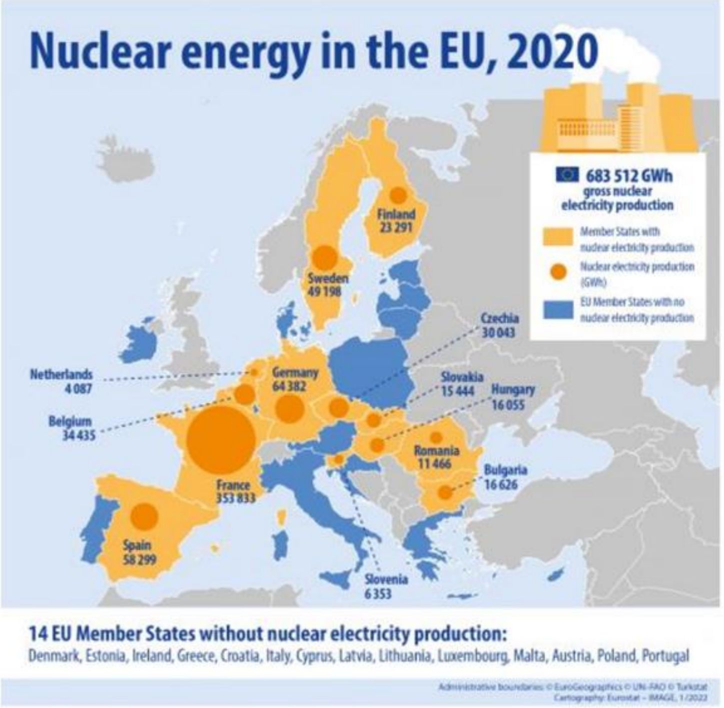
International, what is happening around nuclear fission power?

Nuclear power recognised as part of the Green Shift

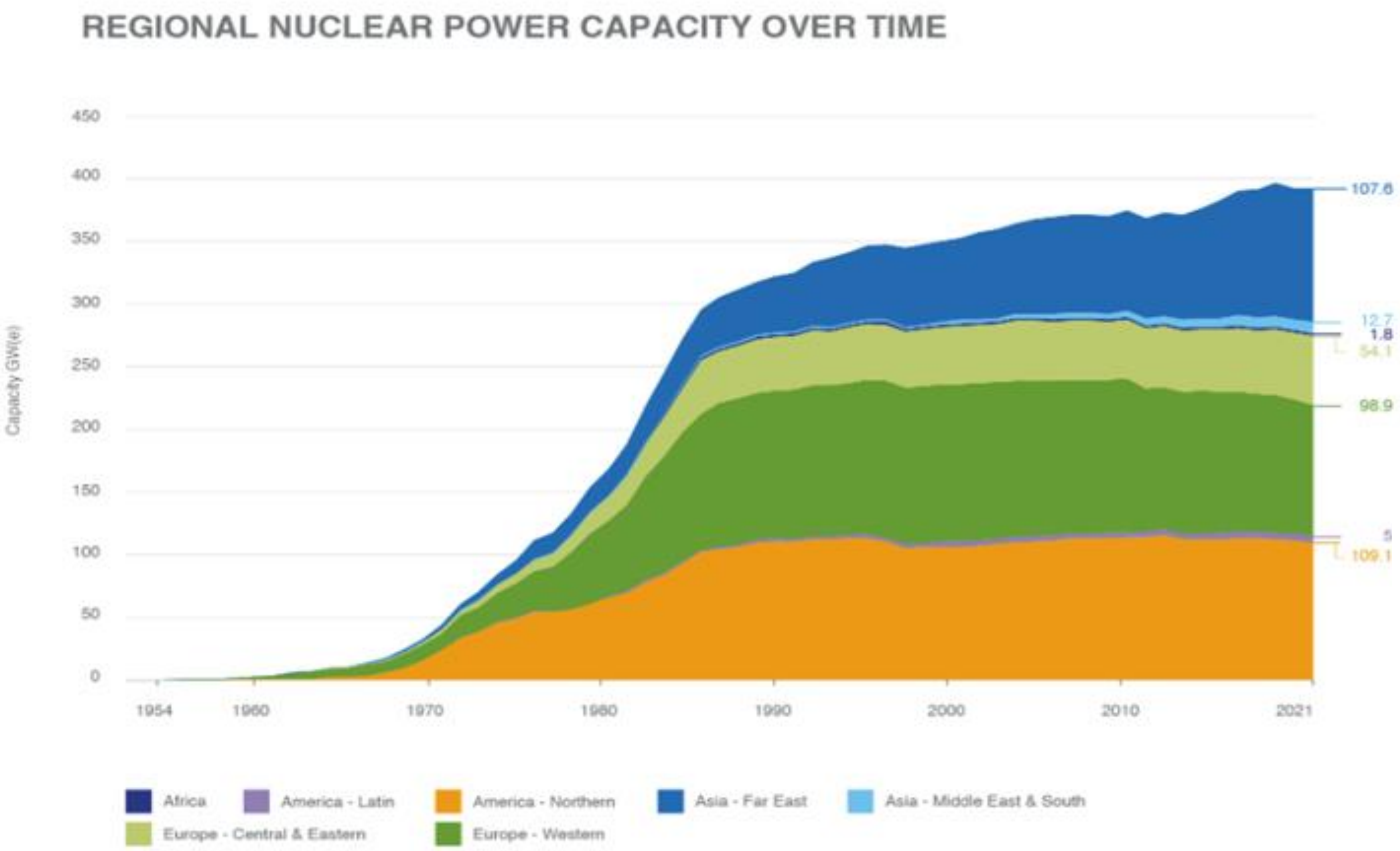
- An important contributor to the EU goal to be climate-neutral by 2050
- Nuclear part of the **sustainable finance taxonomy for green investment** (EU Taxonomy) – setting a new standard for safety (Generation 3+, sustainable waste management solutions), paving the way for social acceptability?
- Continued concerns for costs – cost of nuclear is not going down, despite increased operational experience and technological standardising (f. ex. fuel)

European Commission

Image: carnegieendowment.org

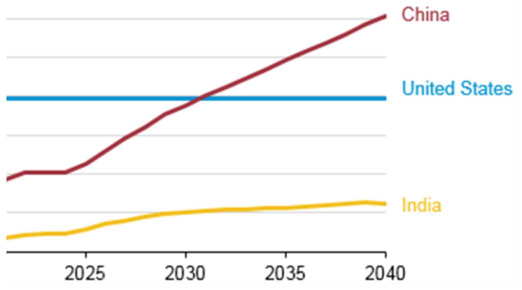


Large regional differences in perspectives on nuclear power

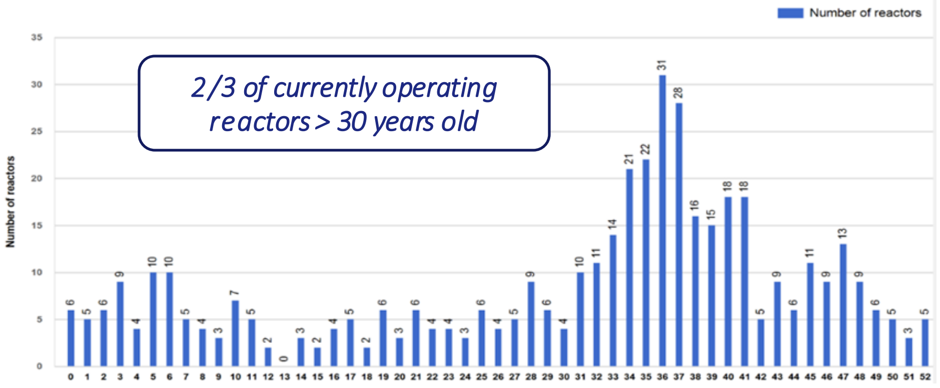


Nuclear Power Plants *[Source: IAEA PRIS database September 2022]*

Growth in China, India and Russia



Aging fleet in particular in Europe and the US



OPERATING NUCLEAR REACTORS, BY AGE

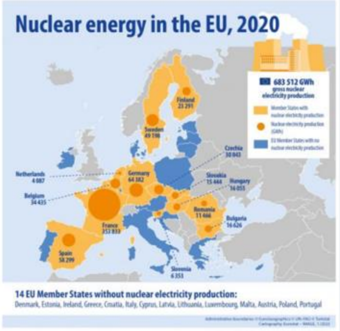
Trends in innovation and developments in the global nuclear industry and development

Europe

Decommissioning important in Europe (€250 billion spent on decommissioning and waste disposal out to 2050)

Lifetime extensions in Europe (€50 billion will need to be invested in lifetime extensions and another, for nuclear to play its part in the energy mix). **A substantial nuclear new-build programme** worth €350-500 billion to maintain 95-105 GW of nuclear in Europe in the long-term. In addition, SMR under development in many countries. However, industrial base deteriorating due to lack of new-builds.

Europe lacks coordination mechanisms for regulatory agencies, making effective innovation and implementation more difficult.



North-America

Capacity in **the US** retirements and derating of some reactors will result in **less total nuclear electricity generation capacity in 2050 than in 2022**

Fusion is promoted (through defence-spending), the US strive to start construction of the pilot by early 30-ties

A large program on **SMR development** is being carried out, supports research, development, and deployment activities to accelerate the availability of U.S.-based SMR technologies into domestic and international markets (supported by licensing activities)

Canada: large effort on nuclear/ SMR-development, potentially in operation early 30-ties.

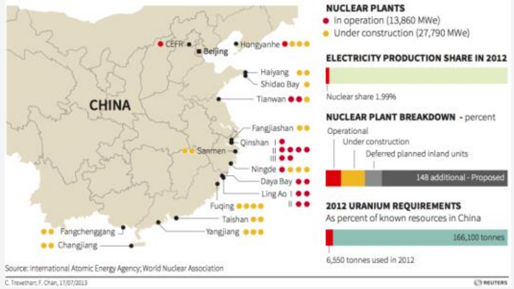
Asia

Russia continuing an aggressive large-scale export program on commercial nuclear power

The impetus for nuclear power in **China** is increasingly due to **air pollution** from coal-fired plants. China **has pledged over the next 15 years to build more than 150 nuclear power stations.** China's policy is to have a closed nuclear fuel cycle.

Broad-based energy research programs also involving fusion is being implemented (defence-related), also including SMR development.

South-Korea: continuing ramping up nuclear/ SMR/ closed fuel cycle.



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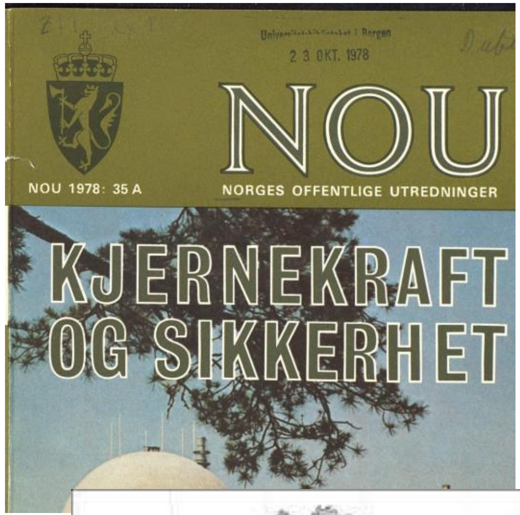
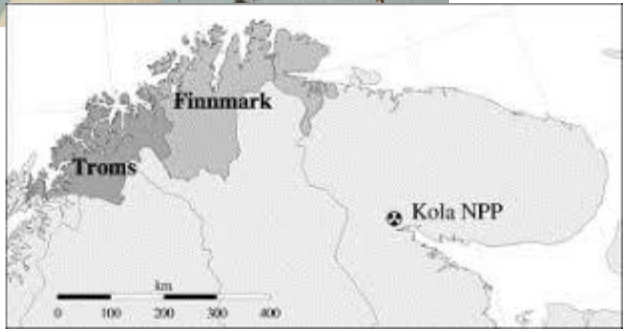
National, what is happening around nuclear power

Norway and nuclear power – from “no-go” to nuclear pragmatism





- From early 90-ties, Norway has had an active role in nuclear safety for decades, with continued ambitions (Europe, Russia, Ukraine)
- The many faces of nuclear science – contributing to fundamental science (ESS in Sweden, PSI), the quest for renewables and nuclear medicine – have slowly expanded the perspectives of the research council
- The role of nuclear power in the Nordic electricity market is not controversial (source, ownership), and the global role in combatting climate change is gaining recognition (ex. fusion investments)
- Rapid changes in the principal attitude towards nuclear power as electricity prices increases – political action groups, youth parties and local groups are actively pursuing more knowledge on nuclear power

ess EUROPEAN SPALLATION SOURCE

Commonwealth Fusion Systems

NORSK KJERNEKRAFT

Klimavenner vil ha atomkraftverk i Norge

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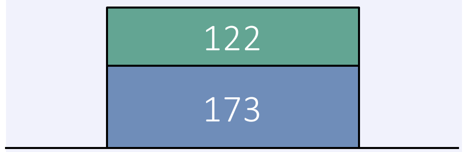
IFE – Norway’s nuclear experts

IFE and our nuclear research history

The Large Halden Projects with a legacy from 1957

2018 – 2020

mNOK budget



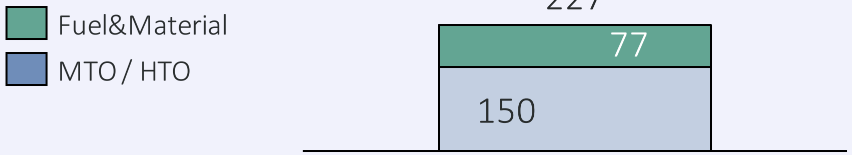
2018-2020

Halden reactor project (HRP)

- Largest project in Halden Project was the Fuel and Material Project to understand how to extend fuel utilization and degradation of core mat.
- The Man-Technology-Organization (MTO) project had 76 Halden Work Reports and 61 papers within 7 topics

2021 - 2023[2]

mNOK budget



2021-2023

HTO set up as separate project

HRP winding down

HTO Project

Improving the safety of nuclear power plants

- Human Performance
- Dig. Instrumentation & Controls- Safety
- Control room design and evaluation
- Digital systems for maintenance and operations
- Digital transformation of nuclear decom.
- Human automation collaboration
- Cyber Security for main control rooms

2024 – 2026

Best guess budget in application

Continuation of HTO

Changes:

- Additional theme (simulator based training)

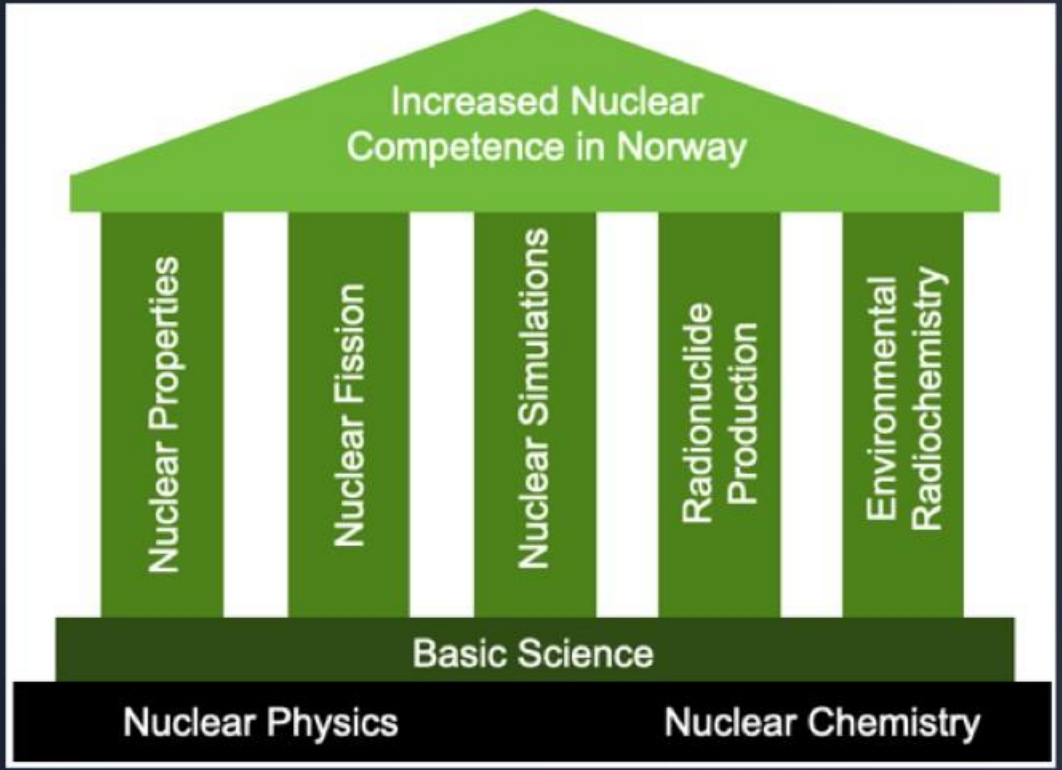
OECD — OECD-driven project membership — IFE Host

Norway	Canada	China	France	Germany	Japan	Korea	Netherlands	Sweden	UAE	UK (new)	USA
Høgskolen i Østfold, IFE, equinor, NTNU, NND	Canadian Nuclear Laboratories, CANDU Owners Group Inc. (COG)	上海核工程研究设计院有限公司	IRSN	GRS, framatome	CRIEPI	KAERI	NRG	Strålsäkerhetsmyndigheten	FANR	National Nuclear Laboratory	U.S. Department of Energy, U.S.NRC, EPRI

NNRC Norwegian Nuclear Research Centre

Academia

Research & Application Sector



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Decommissioning

Dozens of international decom projects over decades (Japan, Italy, Russia, Ukraine, Sweden, and Norway, etc.)

IAEA Collaborating Centre the first IAEA collaborating centre with a focus on decommissioning.

Our HADRON lab (Hazard Aware Digitalisation & Robotics in Nuclear and other domains)

Norway's Decom cluster

DigiDecom 2022 – AI, data and robotics powered transformation for sustainable decommissioning in nuclear and other industries.

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A closer look at SMRs

What is an SMR?

- A Small Modular Reactor is a nuclear fission reactor with a power output of between 10-300 MWe [*OECD Nuclear Energy Agency*].
- SMRs are often integral and modular, typically designed for factory fabrication, taking advantage of the benefits of the economies of series, and to be transported and assembled on-site, resulting in shorter construction times.
- SMRs can be broadly divided into 5 categories:
  - Water cooled reactors
  - High temperature gas cooled reactors
  - Fast neutron spectrum reactors
  - Molten salt reactors
  - Microreactors

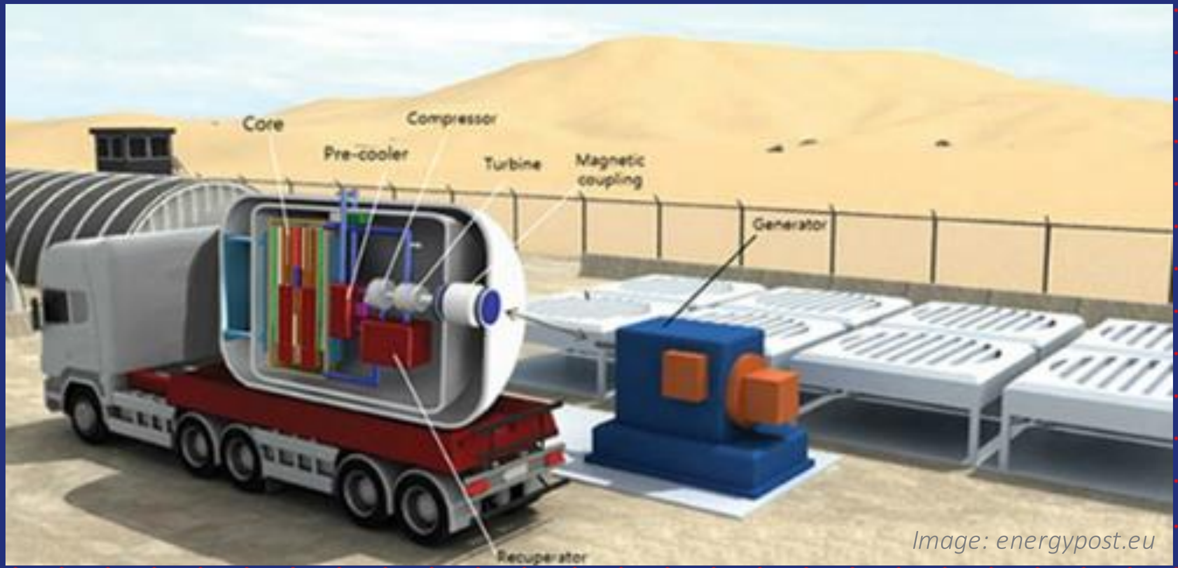


Image: energypost.eu

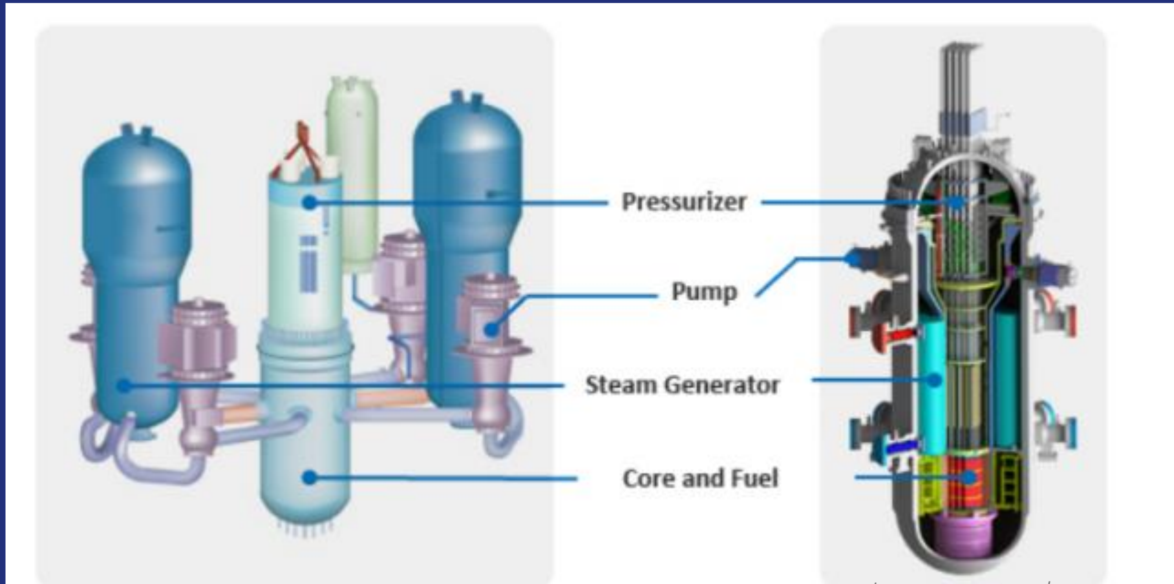


Image: neutronbytes.com

SMR design status & near-term construction

- There are currently more than 80 SMR designs in development worldwide [Source: IAEA]
- Westinghouse eVinci (2027)
  - Heat Pipe technology
  - Up to 5MWe plus 8MWth residual heat
- Seaborg CMSR (2028)
  - Molten Salt technology
  - 200-800 MWe floating system
- GE Hitachi BWRX-300 (2028)
  - Boiling Water Reactor
  - 300 MWe
- NuScale Voygr (2029)
  - Pressurized Water Reactor
  - 77 MWe per unit, scalable from 4 to 12 units.
- Rolls-Royce SMR (2030)
  - 3-loop Pressurized Water Reactor
  - 470 MWe, Gen 3+ 60-year life cycle

Four properties that will makes SMRs a game changer

Image from Oregon State University

1. Load balancing the existing (& future) power grid

- SMRs can supplement the existing green power grid through load following.
- During periods of low wind / solar / hydro power, SMR output can be increased to meet energy demands.
- In times of high renewable energy output, SMRs output can be reduced or redirected for other uses.

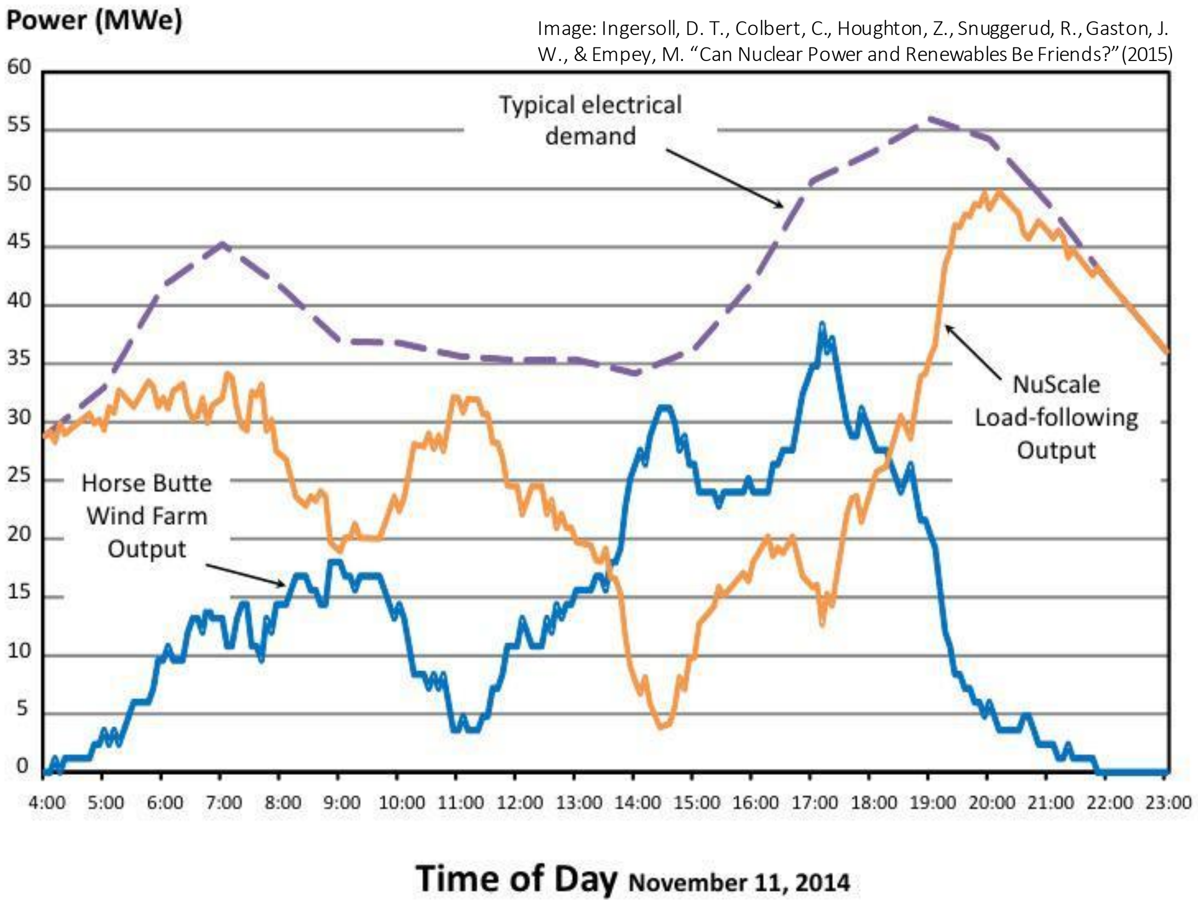
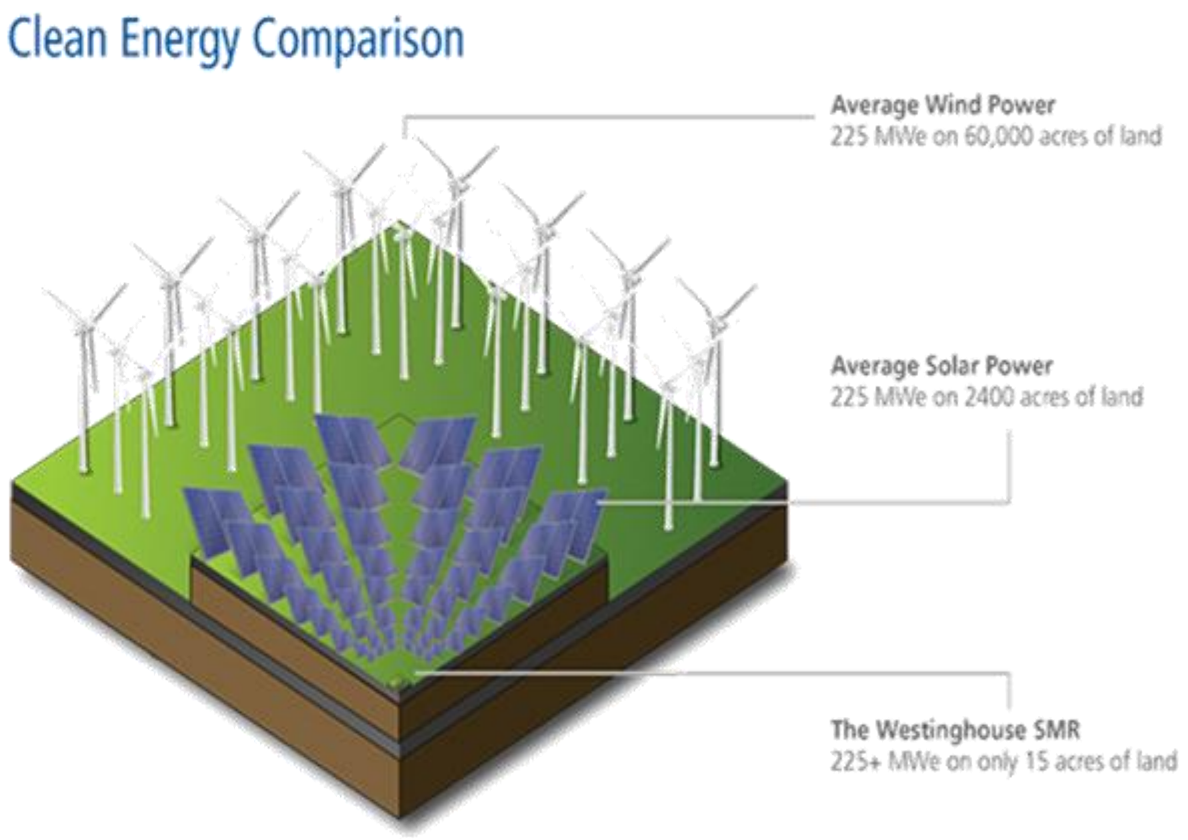


Image: Ingersoll, D. T., Colbert, C., Houghton, Z., Snuggerud, R., Gaston, J. W., & Empey, M. "Can Nuclear Power and Renewables Be Friends?" (2015)

Image from forbes.com

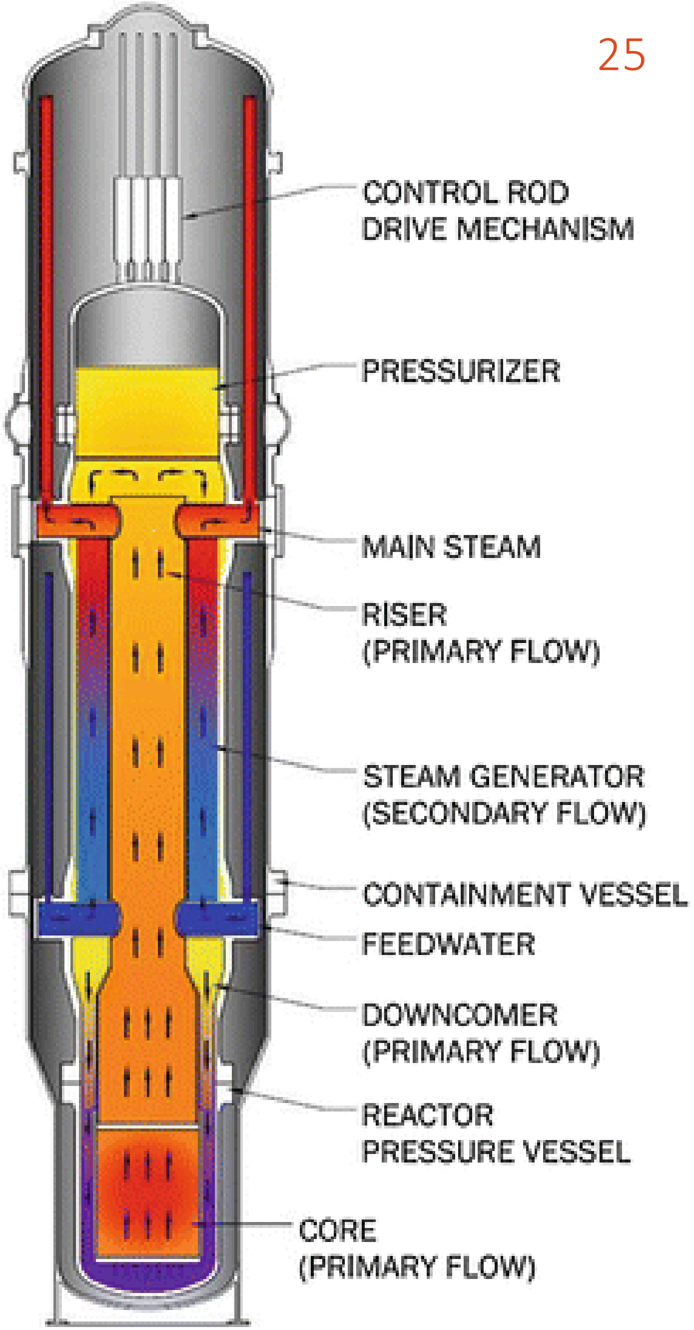
2. Less space, more power

- SMRs take up significantly less land space than conventional nuclear power plants
- SMRs can provide significantly more power per acre of land than many renewable energy sources
- For example, to generate 225+ MWe:
  - A wind farm needs approx. 60.000 acres (~242km^2)
  - A solar farm needs approx. 2.400 acres (~10km^2)
  - An SMR needs only approx. 15 acres (<1km^2)
- Significantly smaller footprint means that SMRs can be built in areas where it would not have been possible to construct a conventional nuclear plant.



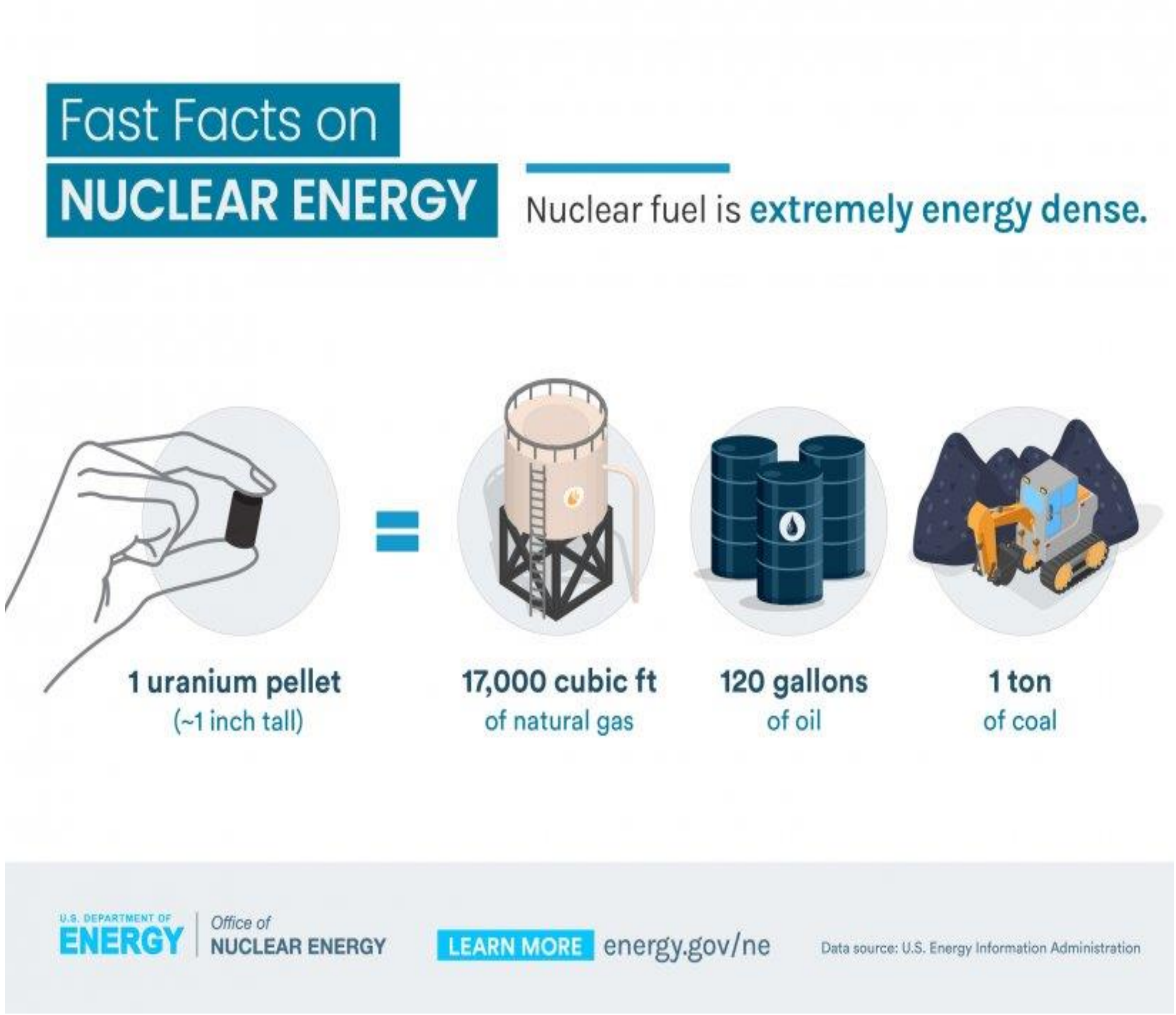
3. Inherently safer design

- SMRs use passive safety systems, which rely on the natural laws of physics to shut down and cool the reactor in abnormal conditions
  - Examples: gravity, differential pressure, natural heat convection
- Passive safety systems require no power source, and no human actions in order to initiate, so they are not affected if there is a loss of power, and the risk of human error is significantly reduced



4. Less nuclear waste

- The smaller core of the SMR means that it uses less nuclear fuel than a conventional plant, thus producing less waste
- SMRs require less frequent refueling (every 3-7 years vs. every 1-2 years for conventional plants)
- Some SMRs (e.g., molten salt) can recycle spent fuel from conventional plants.
- The smaller, inherent design of SMRs means less contaminated parts so overall the amount of nuclear waste generated by the SMR is significantly reduced.
- Load balancing reduces waste in comparison to standard nuclear powerplant



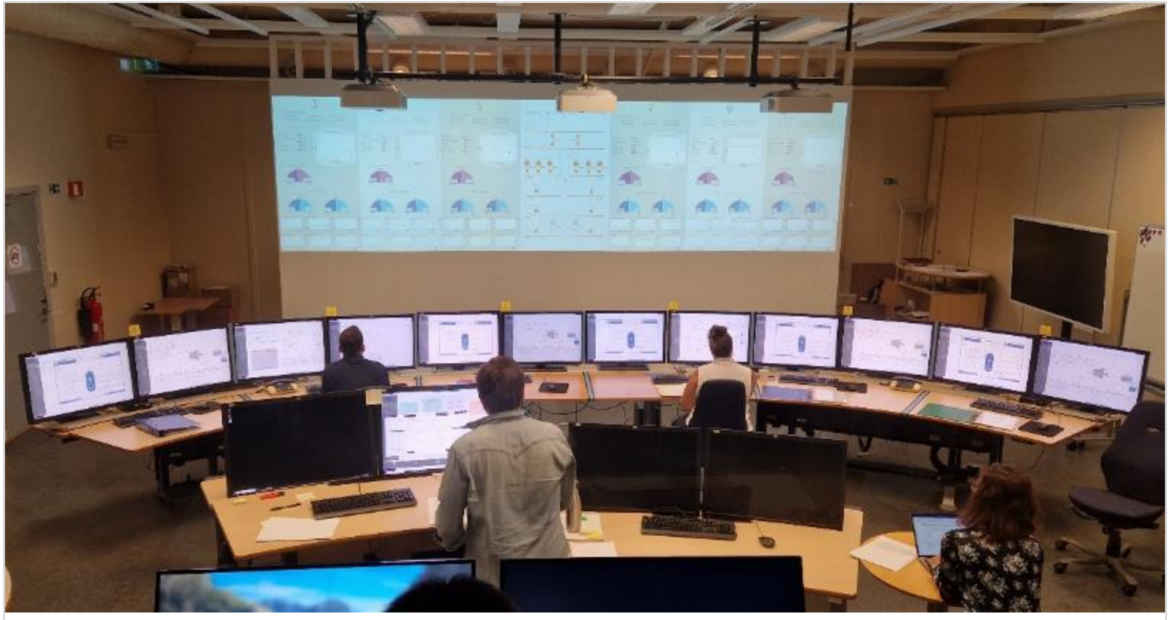
SMR at IFE

The Halden Human Technology Organisation project

- IFE initiated a research activity on SMRs as part of the Halden Reactor Project in 2018, titled "*Operation of Multiple Small Modular Reactors*"
- Research focus:
  - How will SMRs be operated, and how does this differ from conventional large nuclear plants?
  - What are the human error risks, and could the design and operational changes result in new types of human errors?
  - What effects could design and operational changes such as multi-unit operation, use of passive safety systems, higher levels of automation, etc. have on human performance and safety?
- The research activity continues through the 2021-2023 Halden HTO program and is proposed for the next 3-year program.
- The full scope Halden iPWR SMR simulator was installed in HAMMLAB in 2022, and is the first research simulator of this kind in the world.
- Performance studies have been conducted using a basic principle simulator in 2019 and the full scope simulator in 2022 (US crew) and 2023 (Swedish crew).

Halden Reactor Project

HALDEN PROJECT HTO



REGULATION

Extensive and complex requirements for nuclear activities in Norway

Reg. legal basis for nuclear power – complete and coordinated revision is needed for implementation of nuclear power in Norway:

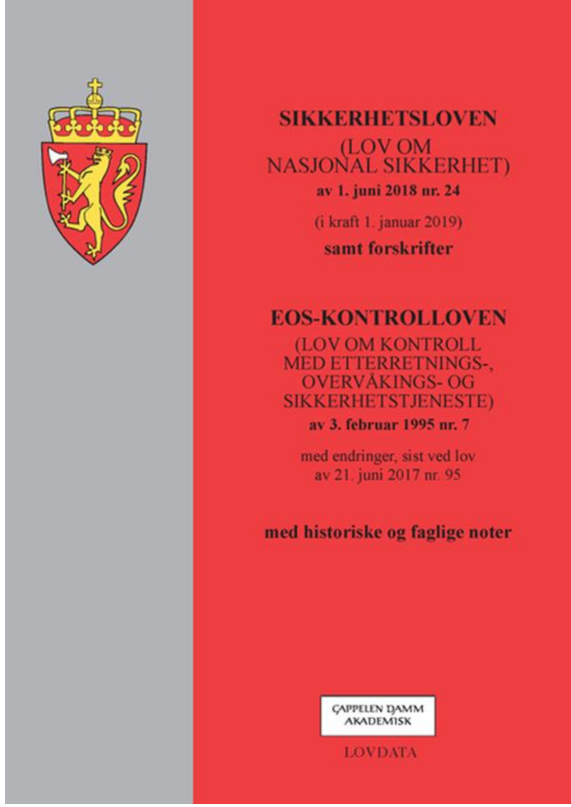
- Nuclear energy act (f. ex. from 1972), IFE has been regulated through single decisions
- Radiation protection act, Pollution act, Export Control act, Personal Information act, Act relating to mediation and procedure in civil disputes, Planning av building act, transport acts (land-based, sea-based), insurance regime (national legislation and international conventions) etc.
- IAEA recommendations
- Etc.

Key government actors:

- DSA
- PST
- NSM
- Politiet
- SKM (Sivil Klareringsmyndighet)
- NFD
- HOD
- KLD
- UD
- Kommuner

Key stakeholders:

- Neighbours and companies located next to nuclear facilities
- Civil society
- Environmental organizations



Example: Security measures

- New Security Act of 2019
- Nuclear facilities are defined as "fundamental national function" in accordance with the Security Act
- Requires enhanced security control, guards and emergency preparedness
- Security clearance, access clearance and authorisation of employees and external parties reduce access to expertise among Norwegians and abroad
- IFE has invested more than NOK 200 million NOK since 2019 in security measures (and still implementing additional measures)

Main Challenges for Nuclear Power in Norway


Q&A