Issues in SMR Spent Fuel and Waste Management from (mainly) Finnish Perspectives

Ville Koskinen (STUK), Tim Schatz (VTT), Paula Keto (VTT), Pauli Juutilainen (VTT), Sami Naumer (VTT), Silja Häkkinen (VTT), Artur Hashymov (Energorisk), Oleksandr Sevbo (Energorisk)

SÄTEILYTURVAKESKUS
STRÅLSÄKERHETSCENTRALEN
RADIATION AND NUCLEAR SAFETY AUTHORITY

Current situation in Finland

- Olkiluoto: 2 BWR reactors operating and 1 PWR under commissioning. Site has wet type spent fuel interim storage
- Loviisa: 2 PWR reactors operating. Site has wet type spent fuel interim storage.
- Posiva (private company owned by the NPP operators) applied for an operating license for the spent fuel disposal facility at the end of 2021.
  – The spent fuel disposal facility is designed only for SF from Olkiluoto and Loviisa NPPs
- There is no national nuclear waste management company; according to the nuclear energy act and decree operators are responsible for nuclear waste management
- A reform of the Finnish nuclear energy legislation has been started. The reform process will last for several years. One aim of the reform is to take SMRs into account in licensing process.

Current situation in Finland

Olkiluoto NPP - TVO
- 2 operating units - ABB BWRs
- OL3 (EPR) under commission
- Interim Spent Fuel Storage
- L/ILLW repository

Olkiluoto - Posiva
- SF repository

Espoo - VTT
- FiR 1– Research reactor

Loviisa NPP - Fortum
- 2 operating units– VVERs
- Interim Spent Fuel Storage
- L/ILLW repository

Current situation

- There are no SMR-projects going on.
- The current NPP operators as well as some major utility companies have indicated that they may be interested to build SMRs.
- Utility companies are specifically interested to generate CHP (Combined Heat and Power) with SMRs replacing fossil fuels.

- Regulatory work has focused on LWR-type reactors, since those are the most mature concepts.
- It is assumed that the fuel usage concept is once-through, and there would be no reprocessing.

Interim spent fuel storage- safety aspects

- The LWR SMR spent fuel is similar to the large NPPs so wet or dry interim spent fuel storage would be suitable. There is no need to develop SMR specific safety requirements regarding ISFS.
- However, since the SMRs might be located in urban areas or at least closer to urban areas to be able to provide district heating, there may be economic reasons for companies to investigate off-site/centralized ISFS solutions.

Spent fuel transport

- Assuming that there will be licenced transport casks for the SMR spent fuel, there are no special safety issues related to the transport.

Spent fuel disposal

- The disposal facility is designed and being licenced only for the Olkiluoto and Loviisa NPP spent fuel from existing reactors.
  - Even if the licensing would be changed, the disposal facility has limited capacity.
- In the case of a new SMR operator, they will need to make commercial agreement with Posiva and it’s owners or start the process to construct a new disposal facility.
- No SMR specific safety issues have been recognised in the KBS-3 concept, as long as the fuel will be disposed without reprocessing and the enrichment is in a similar range as in the current reactors.
- However there are needs for technical optimization for SMR fuel assemblies, to make it more economical.

Other issues

- The safeguards measures would be similar to the large NPPs.
- Since it is likely that there might be some new NPP operators there is likely to be need for greater support in the safeguards measures for the different phases.

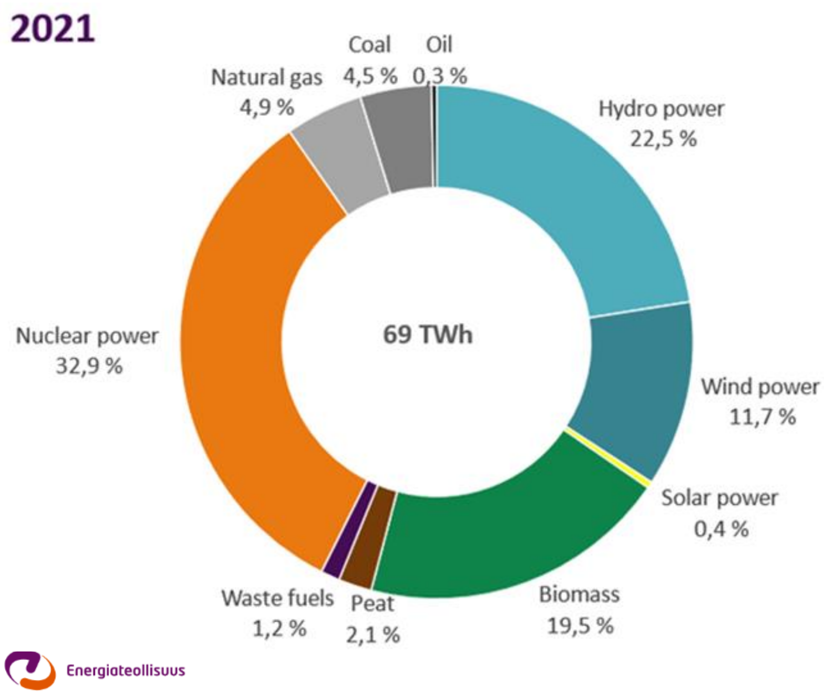
SAFER2028 (National Nuclear Safety and Waste Management Research Programme 2023-2028)

- SAFER 2028 research program is starting at the beginning of 2023.
- The annual funding of the program is around 10 M€.
- SMRs have been recognized as a focus point for the next 6 years, so research projects in the area are expected. However, the first call for proposals is ongoing so it is too early to say anything about the funded research projects.

Issues in SMR Spent Fuel and Waste Management: Finnish Perspective

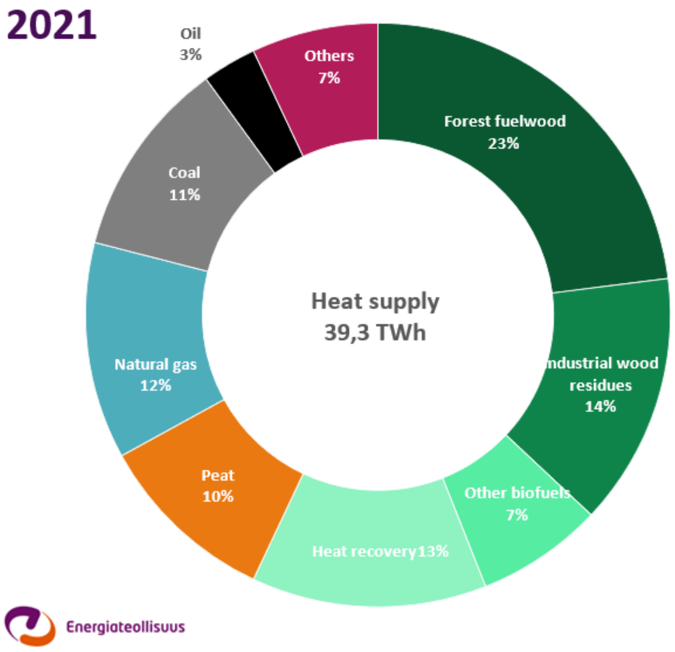
- Heat and electricity production in Finland
  - opportunities for SMRs
- Cases for preliminary studies of spent fuel, waste management and disposal plans
  - electric power LWR-type SMR
  - district heating LWR-type SMR
- Initial Outcomes
  - spent fuel characteristics
  - compatibility with current disposal routes in Finland
  - SMR deployment schemes and waste management strategies
  - adjustments to regulatory framework

Electricity Production in Finland



- Nearly 70% of electricity produced in Finland is carbon-free.
- OL3 reactor to soon be fully operational.
- Domestic wind power production is increasing.
- Finland is expected to become fully self-sufficient in electricity production by 2023.
- Nationwide distribution network.

District Heat Production in Finland



- Produced almost entirely through combustion.
- Fossil fuels still used to a significant extent (36%).
- District heating supplies over 50% of demand in Finland.
- Decentralised networks covering local end-user needs (<30 km).

➢ SMRs?

Opportunities for SMRs in Finland

VTT

Political Support

The Nuclear Energy Act is being reformed with special attention to SMRs.

Industrial Support

TVO’s strategic planning includes detailed review of 10 SMR technologies/designs (all LWR type).

Commercial Interest

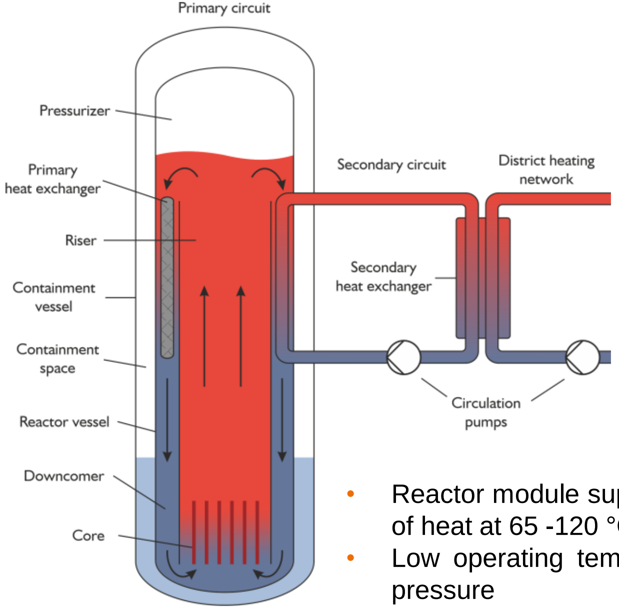
Rolls-Royce SMR Ltd has recently opened an office in Finland.

District heating production units in Finland 2018.

Energiateollisuus

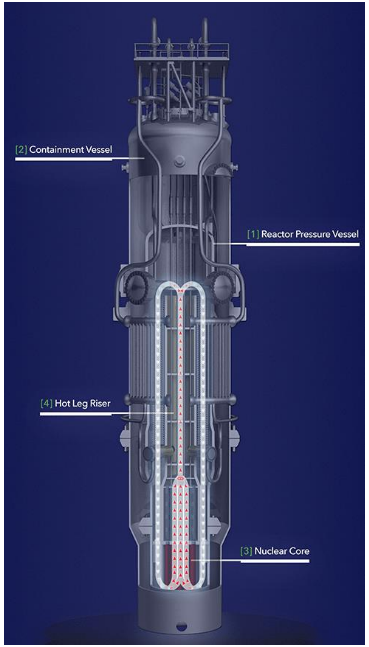
Cases for preliminary studies of spent fuel, waste management and disposal plans

LDR-50



- Reactor module supplies 50 MW of heat at 65 -120 °C
- Low operating temperature and pressure
- No turbine cycle

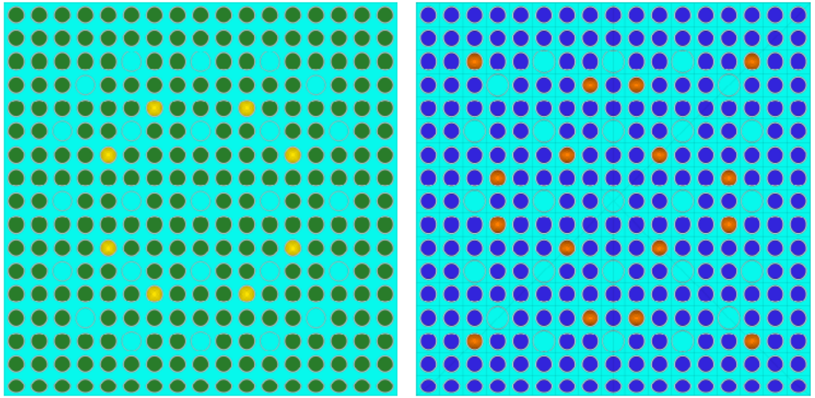
NuScale Power Module™



https://www.nuscalepower.com/technology/design-innovations

- Generates 77 MW of electricity
- Possible cogeneration
- Relatively mature design

Spent fuel calculations



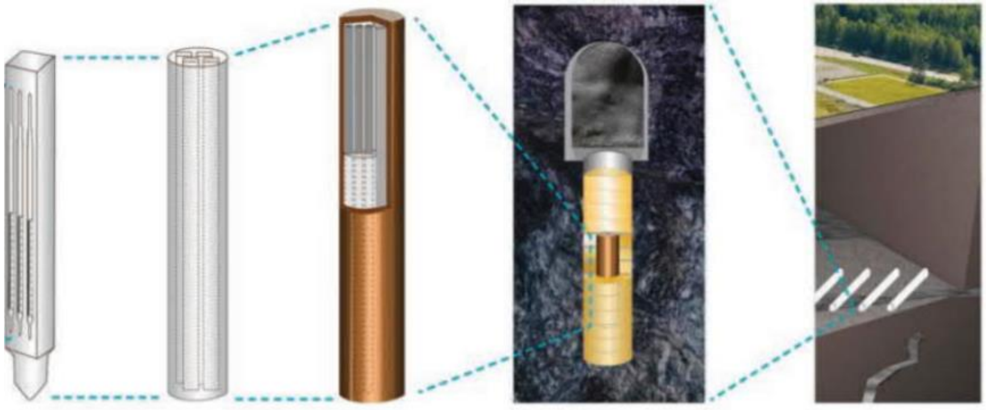
LDR-50 (left) and NuScale (right) model fuel assembly geometries used in Serpent calculations.

- Burnup calculations were performed with various uranium enrichment and burnable absorber contents in infinite 2D geometries for fuel assemblies resembling the NuScale power module and LDR-50 designs.
- Results are compared to those of an EPR due to the highly similar configurations of fuel assemblies for all three:
  - 17 x 17 arrays of fuel rods, control rods and instrument tubes
  - The burnup for multi-cycle assemblies was assumed to be 45 GWd/MTU for the EPR, 40 GWd/MTU for NuScale and 20 GWd/MTU for LDR-50.

Spent fuel characteristics

- The lower discharge burnups in the SMRs lead to lower decay heat and ionizing radiation at the assembly level.
- Concentrations of mobile nuclides in the SMR spent fuels are lower.
- The lower average burnups in combination with high enrichment variations will contribute to higher post-irradiation reactivities.
    - Impact on how criticality safety criteria for transportation, storage and disposal are met.
- Some studies suggest that SMR use may lead to more spent fuel and LILW being generated per GWe-year (Krall et al. 2022, Brown et al. 2015, Glaser et al. 2013) than in large NPPs.

Spent fuel disposal



- The fuel assemblies used in the LW-SMRs are based on 17×17 HTP type fuel designs and are quite similar to the fuel assemblies used in OL3, with the exception of height.
- No overriding factors prohibiting the use of the KBS-3V concept for disposal of LW-type SMR spent fuel.
- Differences in fuel assembly dimensions, fuel configuration, fission product inventory, decay heat generation, physical and chemical form and fissionable material content would need to be taken into account in repository design (spent fuel mass per canister, canister spacing, etc.)

Waste Management Strategy

- Centralised waste management strategy where spent fuel and other nuclear waste is transported from different SMR sites from across Finland to a centralised site in the country that features resources for spent fuel and waste handling, treatment, processing, packaging, interim storage, encapsulation and final disposal facilities. These facilities could include a near surface repository for VLLW, an intermediate depth geologic repository for LILW (including decommissioning waste) and a deep geologic repository for HLW (spent fuel).

  - Individual SMR plants produce limited waste volumes. Some waste management systems would be required at plant sites (sorting, etc).

  - Ownership of centralised facilities?

  - The use of a centralised repository would greatly increase the need for cross-country transport of SNF (and other nuclear waste), given the potential for SMRs to be deployed at multiple locations around the country (district heating application).

Alternatives

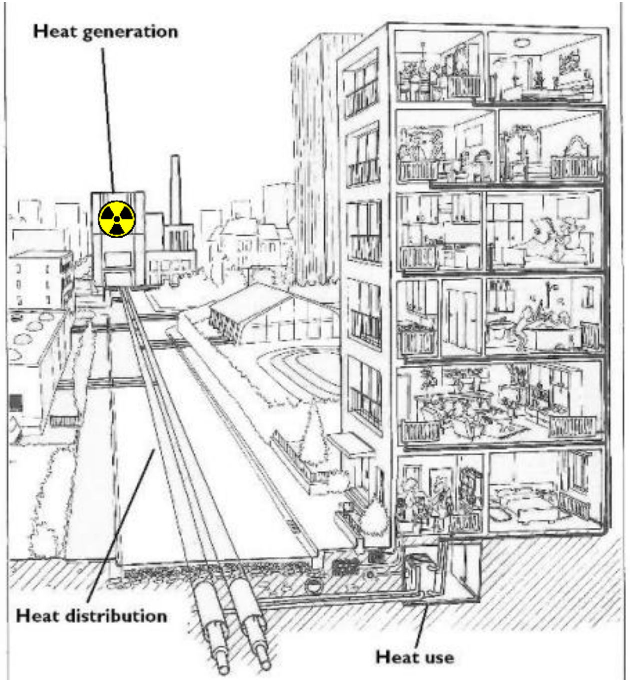
- Decentralised waste management
  - Not technically, economically or socially feasible over the entirety of the SMR nuclear waste management cycle.
  - Deep borehole disposal is often discussed as an option for decentralized deposition of SMR spent fuel and some LILWs. However, DBD is still relatively unproven technology at least in this application.

- Hybrid Waste Management
  - Some part of the management could be handled in a centralised manner and some locally. E.g., one centralised facility for SF packaging and disposal another for LILW waste streams (also from decommissioning) and possible VLLW disposal on site. Or some combination thereof.

Restricted Options

- Sending spent fuel (and other radioactive waste) to another country for final disposal, e.g., to a European Multinational Repository.
- Decommissioning of SMR units outside Finland (even considering that the final disposal would still take place in Finland).
  - The dismantling and recycling of components of a decommissioned SMR at a centralised factory might be more efficient and less expensive compared to performing the activity on-site.
- Leasing of the SMR itself with agreements that upon reaching the end of its service lifetime the entire plant facility is decommissioned and returned to its point of origin along with any accumulated wastes (take-back option).
- Service model where the responsibility is contracted to a third party for handling, storage and/or for final disposal of the spent nuclear fuel and/or other waste streams. Is carrying the financial responsibility enough to fulfill requirements?
- Reprocessing of the spent fuel outside Finland.

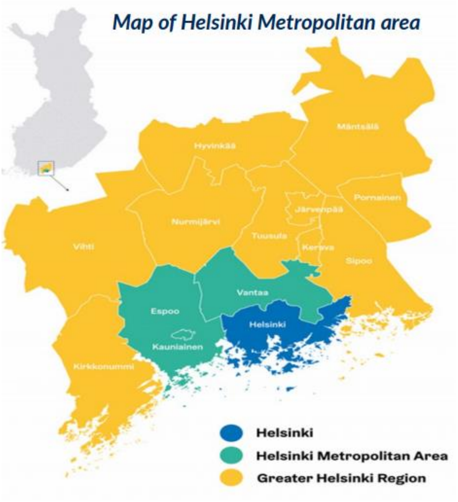
Are we ready for nuclear reactors and waste management in more urban settings?

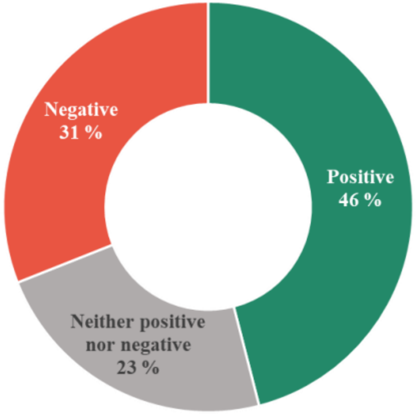


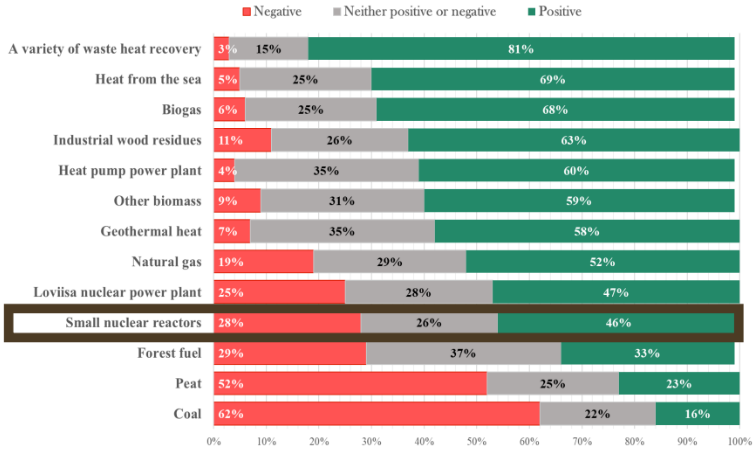
https://e3p.jrc.ec.europa.eu/sites/default/files/9_eulf2_ispra_urban_persson.pdf

Social Acceptance

- What would be your stand on SMRs if one would be located in your residential area (Kojo et al. 2022)?







- The Eurajoki Municipality, where the Olkiluoto SF repository is situated, has already stated some concerns regarding the disposal of additional SNF there in the future.

WP 2: Development of safety analysis methodology for LW-SMRs

Task 2.7 Safety methodology for Refueling, spent fuel management, transport and disposal as well as decommissioning assessment

ELSMOR
Towards European Licensing of Small Modular Reactors

The ELSMOR project has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553

http://www.elsmor.eu

- Geological repositories for the final disposal of spent fuel are not expected to be in operation globally for several decades.
- Interim storage may be the primary spent fuel management solution in many countries for the foreseeable future.
- More spent fuel storage capacity will be required if (/when) additional nuclear capacity is brought online (plant lifetime extension, plant upgrading, new builds, SMRs) and geological repositories are not available.
- Dry storage can be regarded as an established industrial technology
- With longer storage periods, dry storage becomes increasingly important.

ENERGORISK

WP 2: Development of safety analysis methodology for LW-SMRs

Task 2.7 Safety methodology for Refueling, spent fuel management, transport and disposal as well as decommissioning assessment

ELSMOR
Towards European Licensing of Small Modular Reactors

The ELSMOR project has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553

http://www.elsmor.eu

- Long-term Storage Issues:
  - behaviour of spent fuel, fuel assemblies and packages (addressing uncertainties and relative to possibly more strict criteria due to SMR locations near urban areas)
  - behaviour of wet storage facilities
  - behaviour of dry storage systems
  - regulatory concerns related to long-term spent fuel storage

ENERGORISK

Thank you!