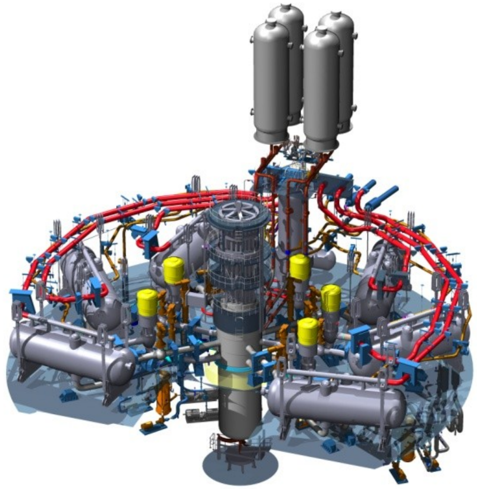

Nuclear Design Practices and the Case of Loviisa 3

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Third Nuclear Power School,
20-22 October 2010, Gdańsk, Poland

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Objectives

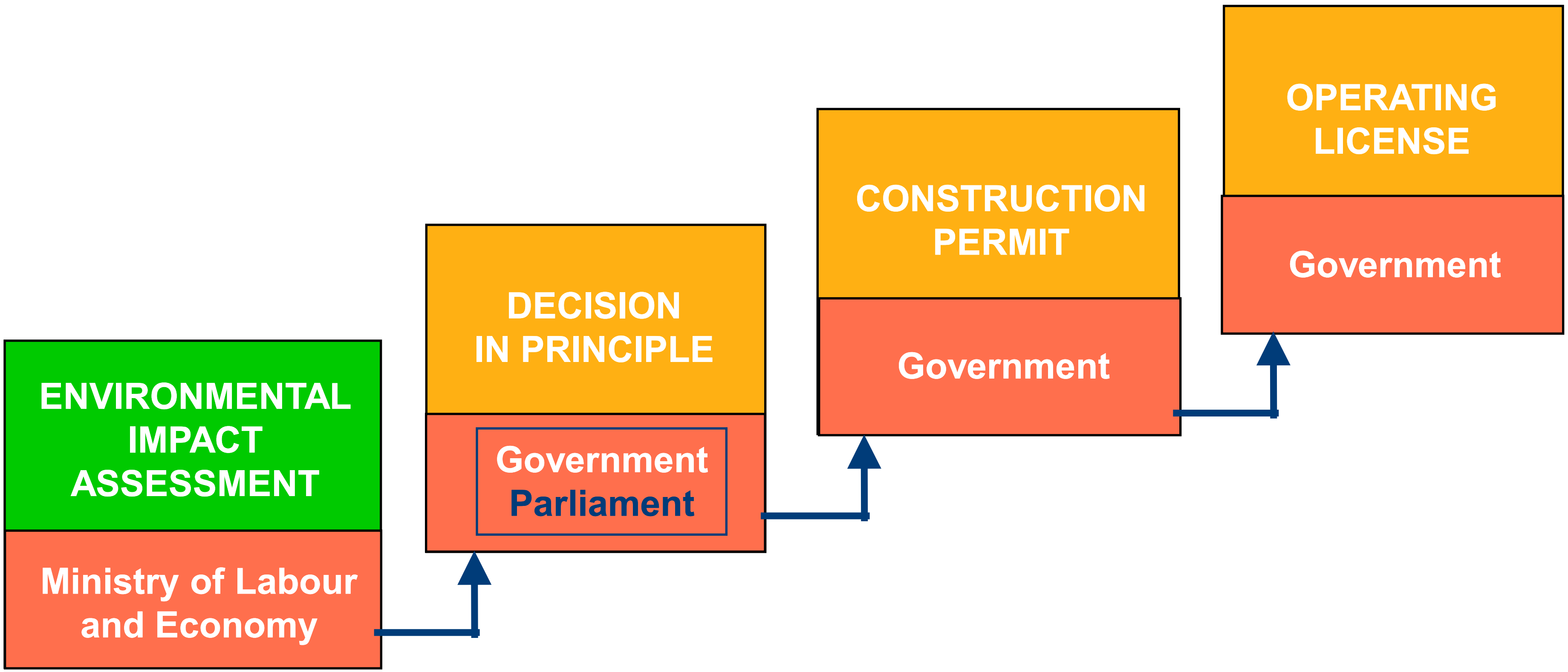
The objective of this presentation is to

- introduce current situation of nuclear power utilization in Finland
- discuss design principles and practices of a nuclear power plant, with a special emphasis on the safety,
- demonstrate the use of design practices with a practical case of combined heat and power CHP option for Loviisa Unit 3,

Design and construction practices

CONTENTS

Licensing process of New Builds in Finland



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Nuclear power facilities in Finland

Hannu Huovila/TVO©

Loviisa (Fortum)

- **Units 1, 2 - VVER 2x500 MW, start of operation in 1977 and 1980**
- Unit 3: DiP not granted

Olkiluoto (TVO)

- **Units 1, 2 - ABB BWR 2x850 MW, start of operation in 1978 and 1980**
- Unit 3: EPR under construction
- Unit 4: DiP granted in 2010 *

Posiva (TVO 60%, Fortum 40%)

- disposal of the spent fuel at Olkiluoto site
- start operation in 2020

Fennovoima

- DiP granted for 1 new unit on two new candidate sites *

* Decisions-in-Principle granted by the Finnish Government in May 2010, ratified by the Finnish Parliament in July 2010

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Performance of the current fleet

	Net power MWe	Commercial operation	Licensed until	Cumulative production TWh	Cumulative load factor %
Loviisa 1	**488**	**1977**	**2027**	**120**	**86**
Loviisa 2	**488**	**1981**	**2030**	**110**	**89**
Olkiluoto 1	**860**	**1979**	**2039**	**191**	**92**
Olkiluoto 2	**860**	**1982**	**2040**	**175**	**93**

- *Loviisa reactors are of VVER-440 type, initial power 440 MWe*
- *Olkiluoto reactors are of BWR type, initial power 660 MWe*

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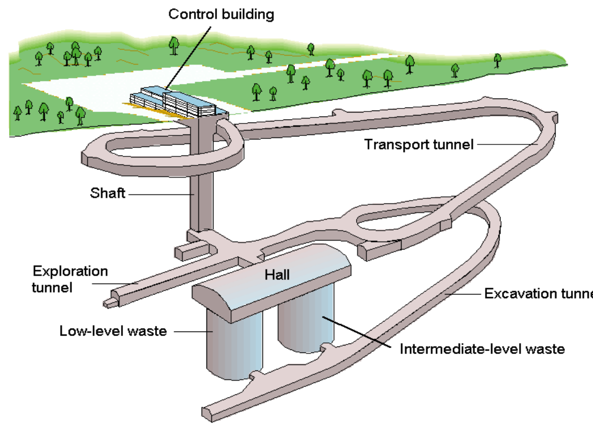
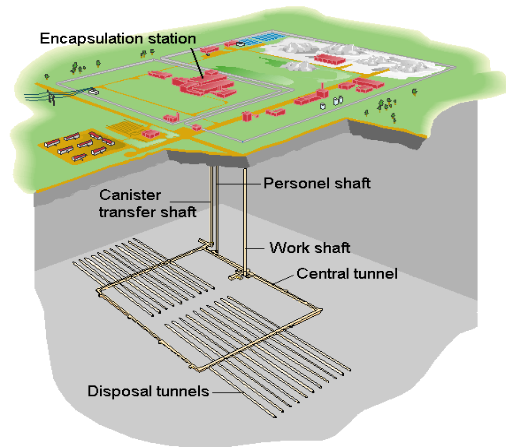
Nuclear Waste Management in Finland
- the full responsibility of the licensee -

- Interim storage of spent fuel
  - Loviisa 1983, Olkiluoto 1987
- Final repository for low and intermediate level waste
  - Loviisa 1997, Olkiluoto 1992
  - Deep repositories in crystal bed rock, 100 m below ground level
- Final repository of spent fuel
  - Posiva selected Olkiluoto site in 1999
  - Deep repository, crystal bed rock, 500 m below ground level
  - Government Decision in Principle ratified by the Parliament in 2001
  - New DiP granted for the capacity extension





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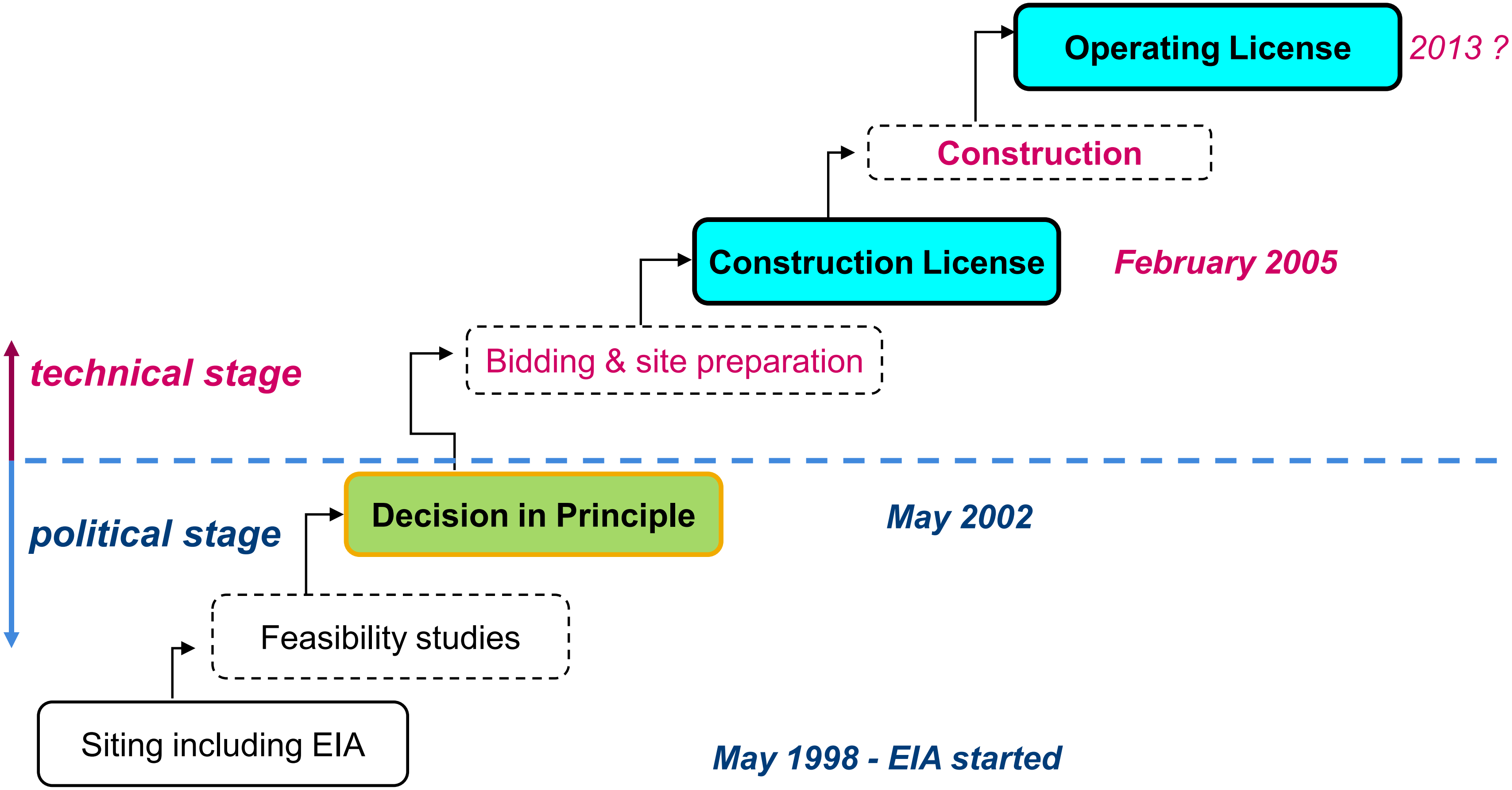
Licensing Stages - Schedule of Olkiluoto 3



Features of the nuclear power companies in Finland

- **TVO** (Olkiluoto Units 1 and 2 operating, Unit 3 under construction, DiP granted for Unit 4)
  - TVO is owned by the Finnish industry, municipal companies and Fortum (25%)
  - TVO produces electricity to its owners (non-profit company)
- **Fortum** (Loviisa Units 1 and 2 operating, owns minority assets in TVO and in Sweden)
  - Fortum is a Nordic energy company listed in the Helsinki exchange, owned 51% by the Finnish state
  - Fortum sells the electricity through Nord Pool (the Nordic power exchange)
- **Fennovoima**
  - Fennovoima is owned by E.ON (33%), Finnish industrial, trade and municipal companies
  - Fennovoima plans to produce electricity to its owners (non-profit company)

Nuclear design principles and practices

- General design principles
- Safety functions
- Safety classification
- Defense in Depth
- Design practices

General design basis

- **General Design Basis** is to cope with the range of operational states and DBAs within defined radiological consequences
- To be achieved with **conservative** design measures and sound engineering practices

- In addition to the design basis the performance of the plant beyond the design basis – including severe accidents and large airplane crash – has to be accounted for, but it can be done on the best-estimate basis. It is now customary to call them Design Extension Conditions or DEC (as launched in the EUR documentation).

Design principles: Safety functions

SAFETY FUNCTIONS

Fundamental safety functions have to be performed in operational states and DBA conditions – and in the BDBA to the extent practicable. Three fundamental safety functions are:

1. **Reactivity control**
2. **Core heat removal**
3. **Confinement of radioactive material**

Altogether **19 detailed safety functions** have been derived from the three fundamental safety functions.

A given SSC can perform one or more safety functions: this provides a basis for safety gradation or **classification** of the SSC.

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Design principles: Safety classification

Principle:
All SSC of safety importance – including I&C – have to be classified.

The classification is to be based on deterministic methods and complemented with probabilistic methods and engineering judgment that can account for

1. the safety functions to be performed by a SSC
2. the consequences of failure to perform its function
3. the probability of calling upon performing the safety function
4. the time or the period of its operation

SSC: system, structure and component

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Design principles: Defence in depth

Defence in depth consists in the hierarchy of different levels of equipment and procedures to maintain the effectiveness of physical barriers placed between radioactive materials and workers, the public and the environment.

Defence in depth is implemented through design and operation to provide a graded protection against a wide variety of transients, incidents and accidents.

Defence in depth is applied at three various levels and contexts

1. Functional level
2. Physical barriers
3. Failure tolerance

Defence in depth: Functional levels

Level 1	Prevention of abnormal operation and failures
Level 2	Control of abnormal operation and detection of failures
Level 3	Control of accidents within the design basis
Level 4	Management of severe accidents
Level 5	Mitigation of radiological consequences

Defence in depth: Physical barriers

Fuel structure

- Ceramic material that retains radioactivities
- Fuel cladding

Reactor cooling circuit

Containment

- Pressure resistant and leaktight building

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Defence in depth: tolerance to failures

Three different principles are applied in the design of SSC important to safety to improve the tolerance to failures

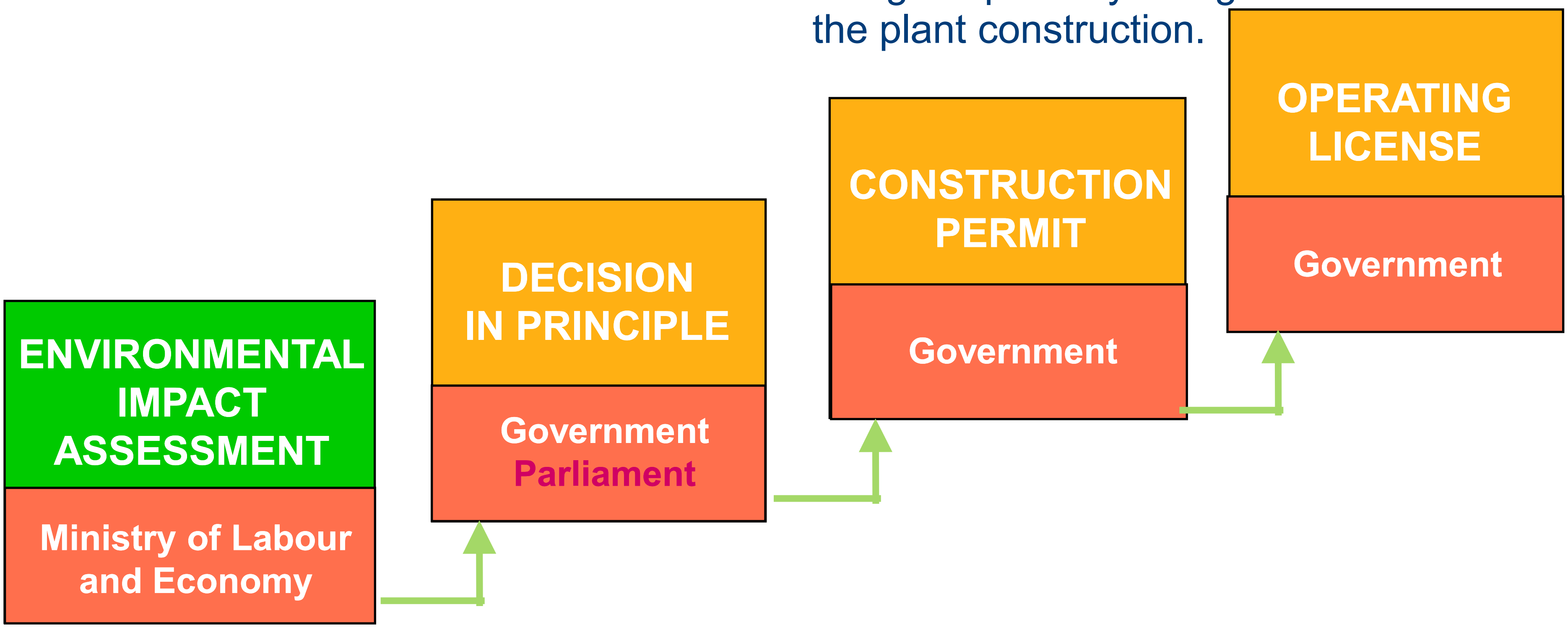
- **Redundancy**
  - several similar and parallel subsystems (or components)
  - against single failures
  - vulnerable to common cause failures
- **Diversity**
  - parallel components and subsystems that function on mutually different principles
  - against common cause failures failures
  - maintenance requires more effort
- **Independence (separation)**
  - parallel subsystems are physically separated from each other
  - against external (fire, flood etc) common cause failures and consequential failures (pipe whips, jets etc)

Design in the licensing process in Finland

Not design specific

Principal designs of candidate plants

Approval of the design of the plant to be constructed.
Approval of the detailed design separately along the plant construction.

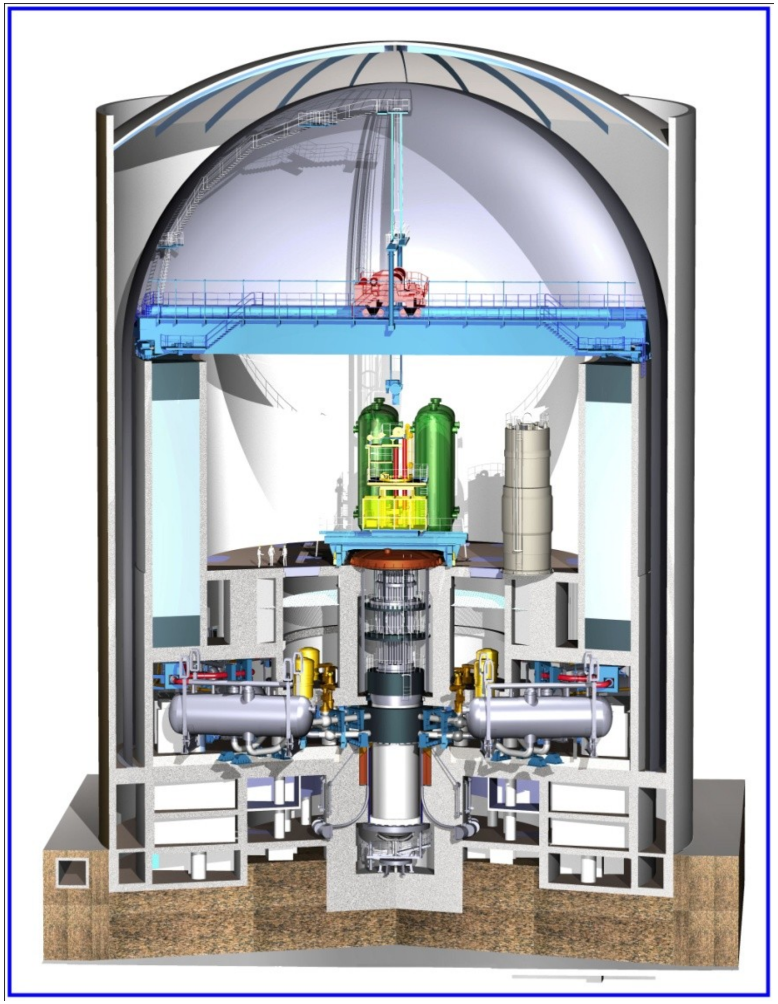


Design practices

Importance of the 3D-modelling

- 3D CAD models should be availble as soon as possible in the design phase
- detailed and advanced models will be an essential support for the justification of design and for planning the construction and erection works
- 3D models can be utilized for generation of models into safety analysis codes and for the structural calculations
- coupled analysis methods will benefit of the compatible 3D models

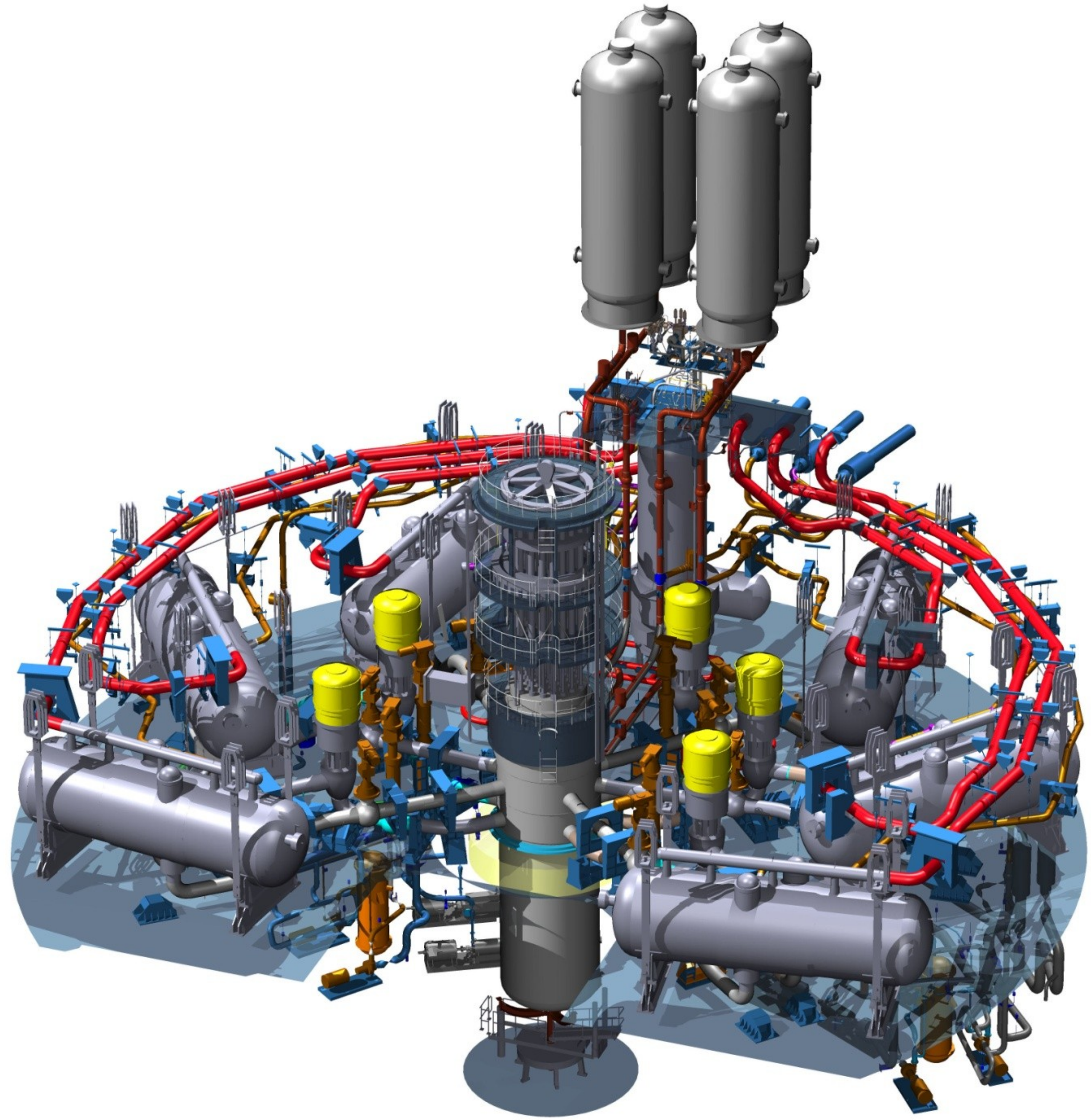
3D Models



- Loviisa VVER-440
- Overall containment model

3D Models

- Loviisa VVER-440
- Overall reactor circuit model



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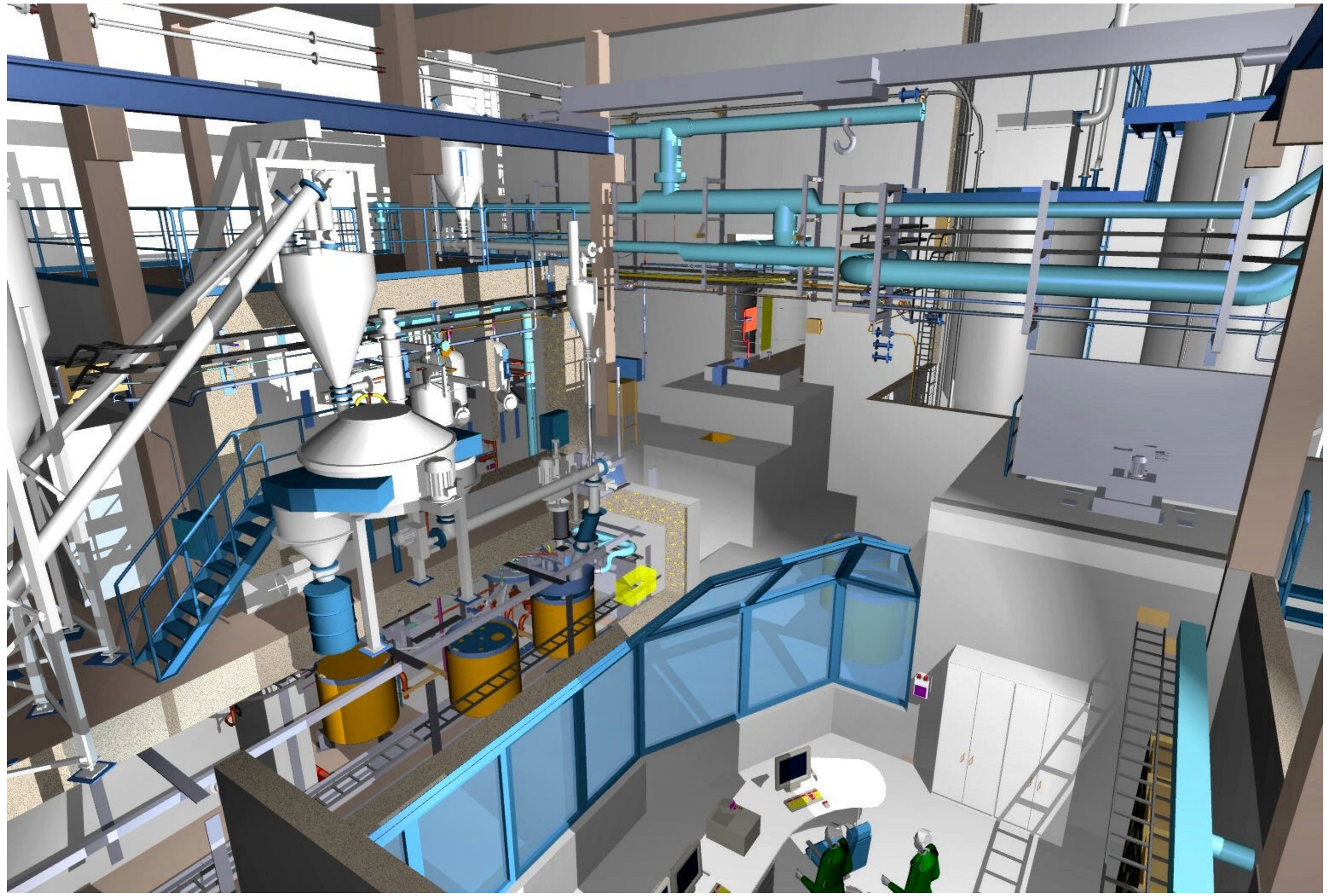
3D Models

- Loviisa liquid waste solidification plant
- Constructed in 2003-2006 by Fortum
- Extensive utilization of 3D modelling



Loviisa 3 CHP

Next slides introduce some findings from the studies carried out by Fortum

Option of combined heat and power production (CHP) from the Loviisa Unit 3

Heat would be transported to the Helsinki metropolitan area:
- distance from Loviisa NPP is about 80 km
- heat capacity up to 1000 MW

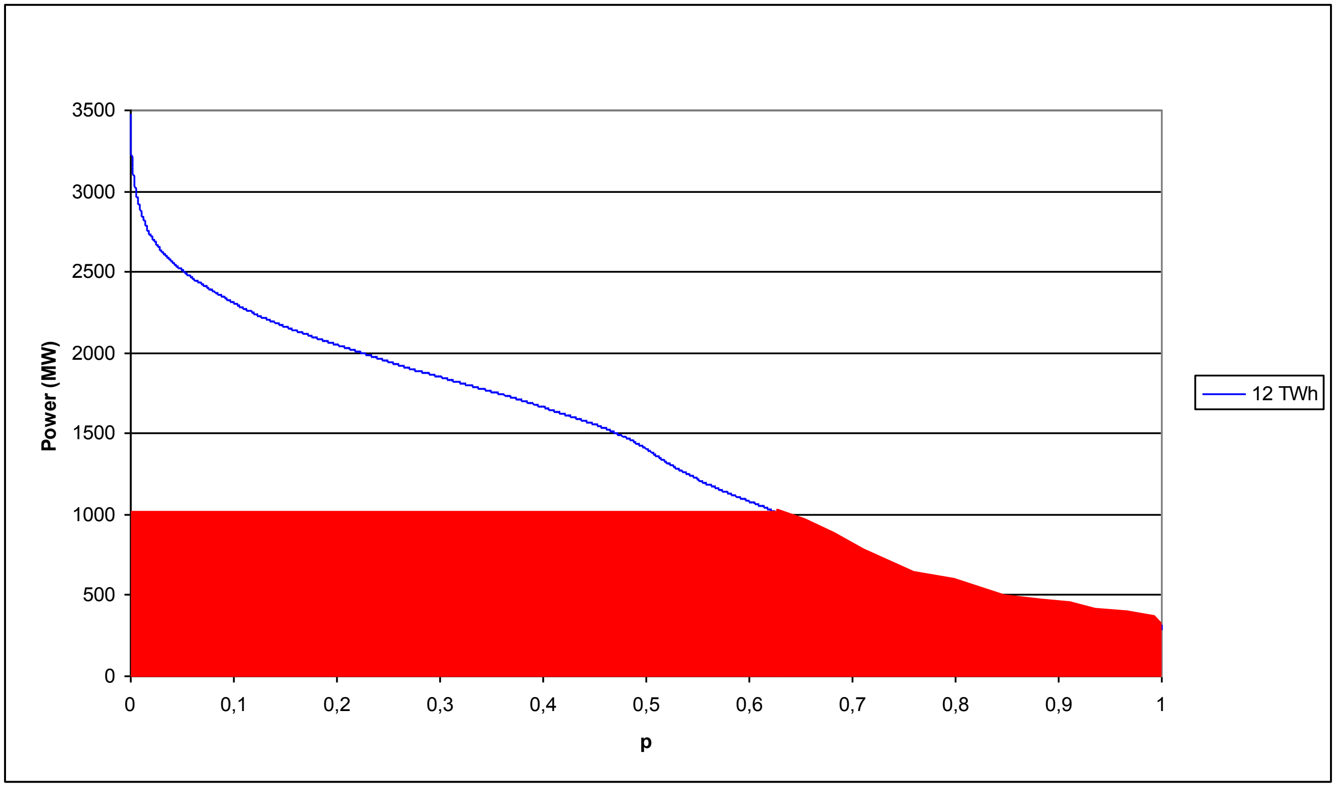
Loviisa 3 CHP

Basis of the Loviisa 3 CHP option

- Replacement of heat generated with fossil fuels
  - thermal energy consumption (**district heat**) 11 - 12 TWh per year
- Large reduction of carbon dioxide emissions
  - up to 4 million tons annually (6 % of the entire CO_2 emissions in Finland)
- Higher plant efficiency
  - reduction of heat discharge to the Gulf of Finland
  - net electrical power loss approx. 1/6 of the thermal power generated
- Steam extraction from the turbine
  - Before low-pressure turbines or several extractions from lp turbine
  - optimisation, and redesign vs. design of new turbine

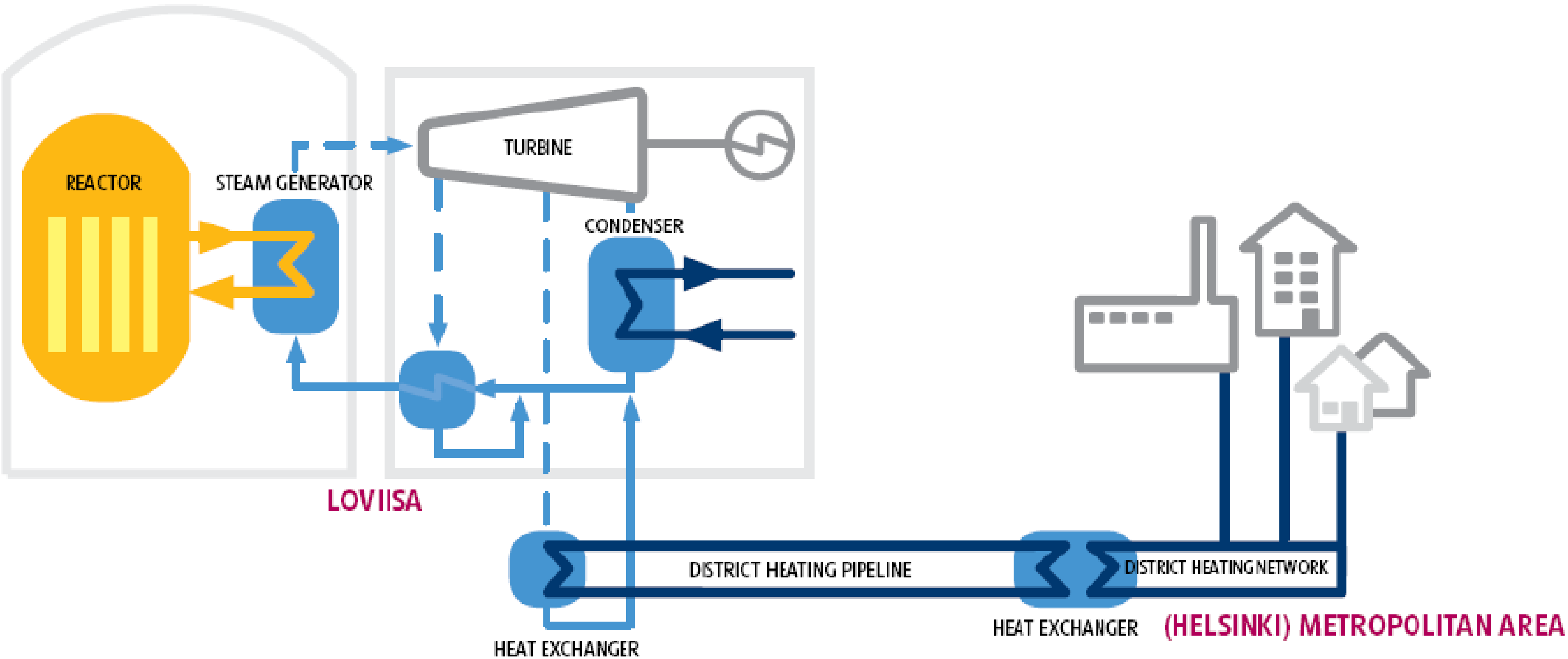
Loviisa 3 CHP

Cumulative probability distribution of heat generation power in Helsinki metropolitan area for 12 TWh annual generation



PWR connection

Heat extraction from a Pressurized Water Reactor



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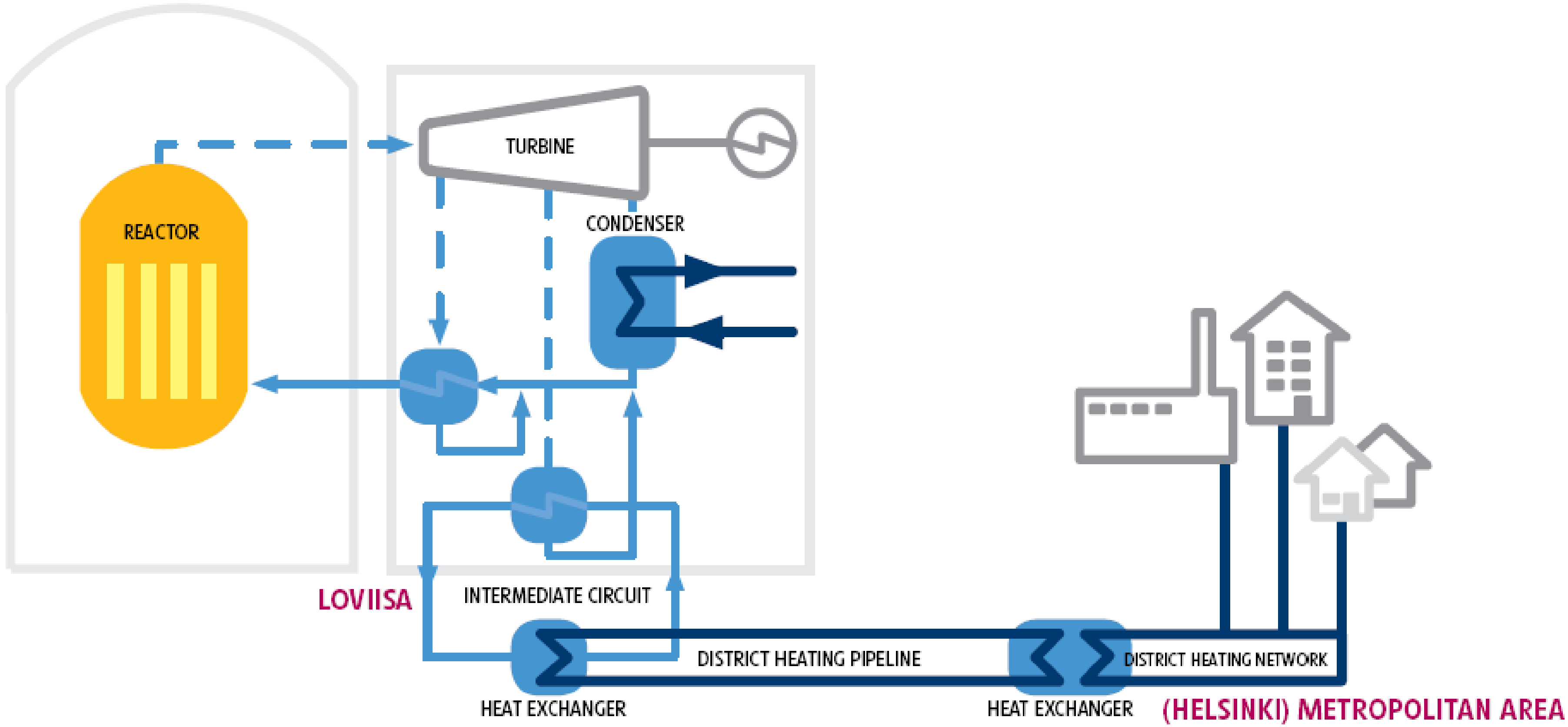
BWR connection

Heat extraction from a Boiling Water Reactor



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Loviisa 3 CHP – technical data

District heat transport system

- Distance over 75 km (Loviisa – eastern Helsinki)
  - 2 x Ø 1200 mm pipes, PN25 bar, Q = 4 - 5 m^3/s
  - 4 - 7 pumping stations
    - total pumping power needed tens of MWs
    - compensates for heat losses
  - Control scheme
    - district heat water temperature or flow rate
  - Heat accumulator needed, heat distribution to the local district heat network via heat exchangers

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Loviisa 3 CHP – heat transport on a long distance

Heat transport in pipes

- Mounting in a rock tunnel, cross section 30 m^2
  - stable conditions
  - positive maintenance aspects
- Near surface installation
  - lower costs
  - environmentally more challenging

Further options: Heat transport by sea

- with boats or pusher barges
- requires a lot of new infrastructure

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Application of nuclear design principles for CHP (1)

General design requirement

"The cogeneration plant shall be designed to prevent transport of any radioactive material from the nuclear plant to district heating units under any condition of normal operation, anticipated operational occurrences, design basis accidents and selected severe accidents."

Additional safety requirements

- The heat generation design solutions have to be such that they will not increase safety risks of the NPP
- The heat transport system should not pose unacceptable safety hazards to the population and environment

Application of nuclear design principles for CHP (2)

Design of a NPP for the combined heat and power production:

Coping with the design requirements:

General design requirement

- The heat ectraction takes place via heat exchangers and intermediate circuits
- The PWR case: heat exchangers at the NPP site and at the connection to city district heating network
- The BWR case: additionally an on-site intermediate circuit is foreseen

Additional safety requirements

- Application of advanced accident analysis method (APROS, integrated model of the whole plant and the heat transport system) to show that there are no consequences from the heat transport system transients to the plant safety
- Implementation of the heat transport piping in the tunnel. Analysis of the consequences of the heat transport pipe leakages (with the APROS)

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Summary

- Finland has a good experience of deploying nuclear power for more than 30 years
- Commitment to using fission nuclear power with light water reactor continues at least for the next 60-70 years
- Nuclear waste facilities exist for low and intermediate level waste, spent fuel disposal planned to start in 2020
- One new NPP unit is under construction (Olkiluoto 3 EPR)
- Two granted Decisions in Principle for two more units
- Loviisa 3 application made provisions to deploy nuclear also for district heat production