Harri Tuomisto, Fortum, Finland

Leveraging Research and Operational Experience for Plant Upgrades and LTO at Loviisa NPP

SNETP Forum, 2-4 February 2021

Technical Session 1 on 3 February 2021

Join the change

fortum

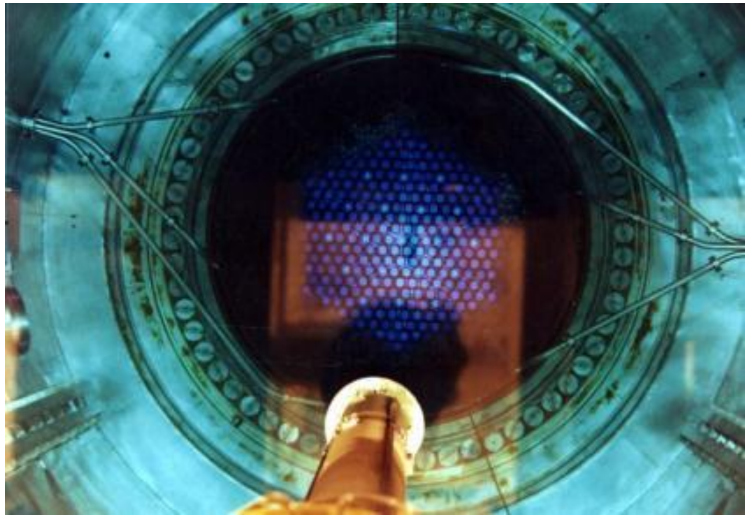
Contents

- Loviisa NPP and its specific features
- Long-term operation
  - Plant performance and lifetime profile
  - Plant modifications
- Operating experience and plant modifications
  - Internal hazards
  - Severe Accident Management program
  - Role of experimental and analytical research

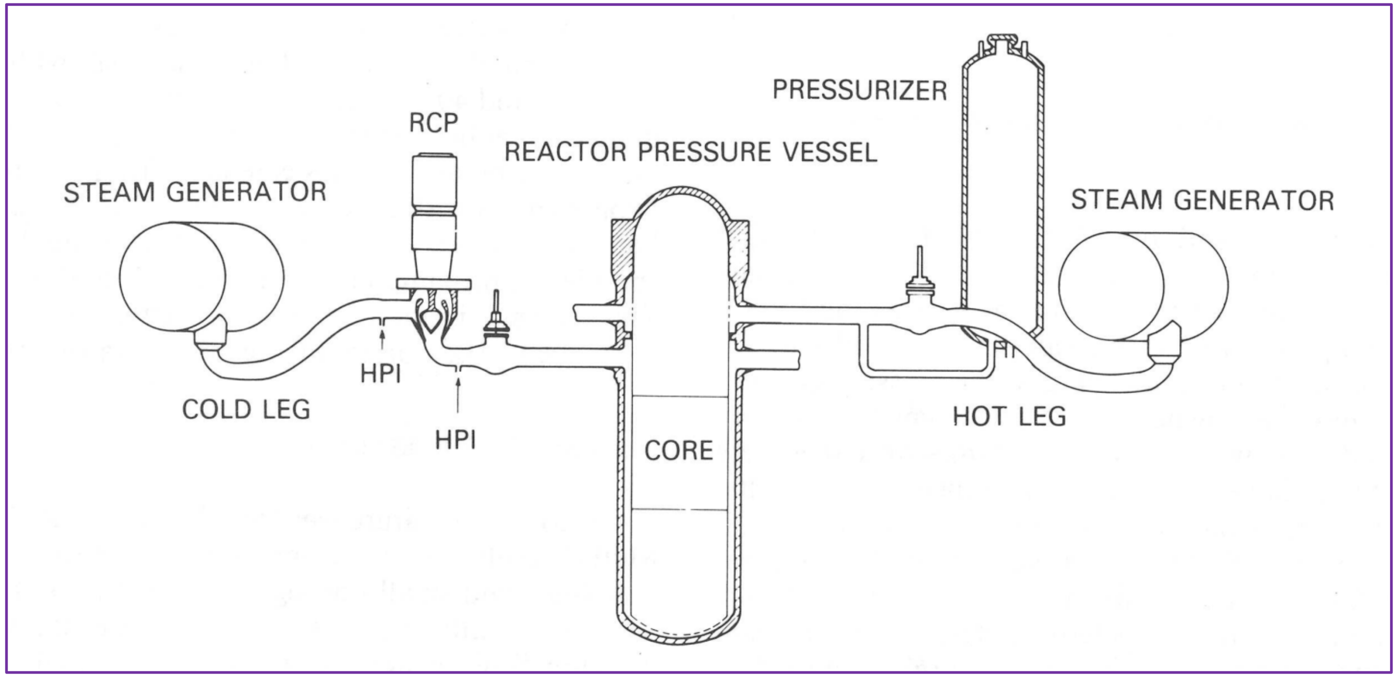
Loviisa Power Plant

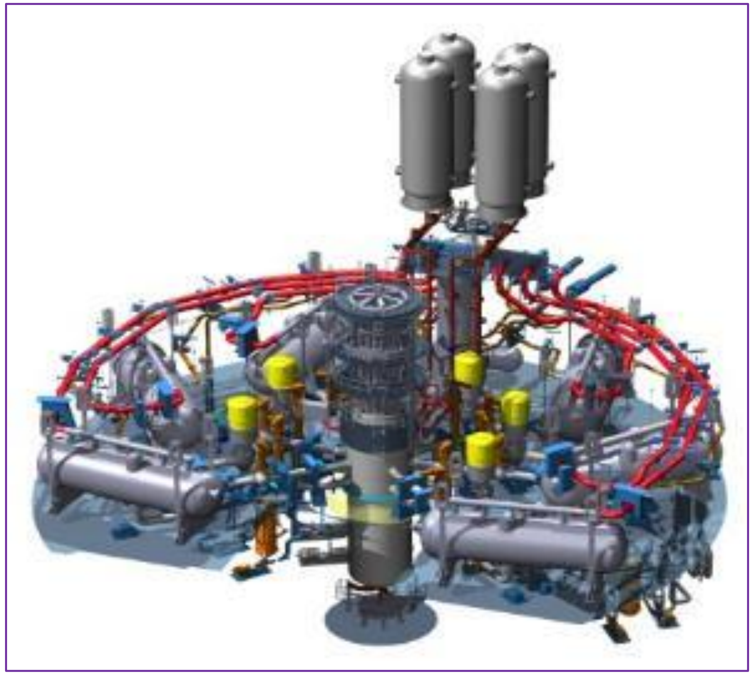
- Two VVER-440 units, 1004 MW (2 x 502 MW).
- Loviisa 1 started operation in 1977 and Loviisa 2 in 1980.
- Current operating licenses are valid until 2027 and 2030, respectively.
- Safety and performance reliability indicators have been good throughout the operational history.
- The annual load factors exceed 90%.
- In 2020 Loviisa produced 7.8 TWh of electricity, and the load factor was 87.7 %

Loviisa VVER-440: primary circuit



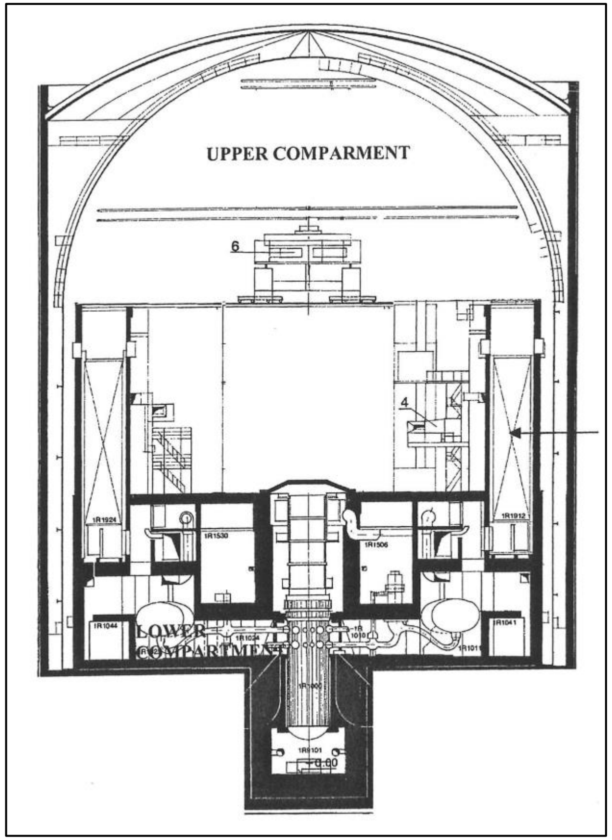
- Six loops with horizontal steam generators
- Loop seals both in the hot and cold legs
- Gate valves both in the hot and cold legs
- Diagonal type reactor coolant pump

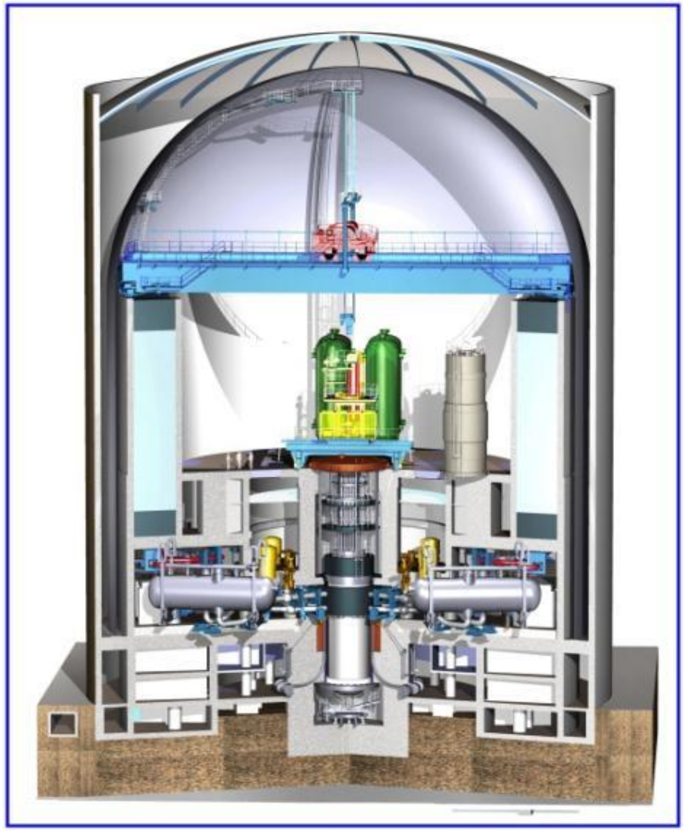


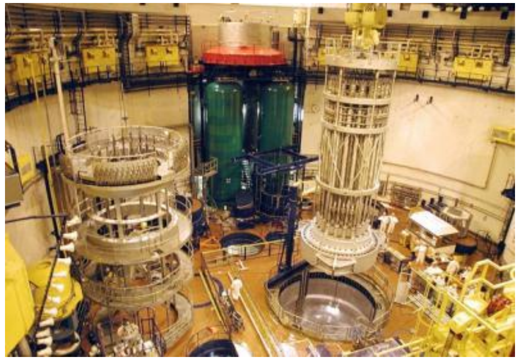


Loviisa ice condenser containment

- V = 58 000 m^3,
- design pressure = 1.7 bar(abs)







Life span of the Loviisa power plant

1969-1981 Planning, construction and commissioning phase

- Main contracts signed and construction permit in 1970
- Construction started 1971, commissioning in 1977 and 1980

1981-2004 Period of major safety modifications and upgrades

- TMI-modifications, reactor pressure vessel upgrades, emergency feedwater, primary-to-secondary leakage management etc.
- Modernization and power upgrading 1997
- Modifications brought out by PRA since 1989
- Severe Accident Management implementations

2004-2030… Plant life management phase

- I&C renewal
- Fukushima modifications
- Current operating licenses up to 2027 and 2030 (50 yrs), beyond that under consideration

fortum

Overview of Plant Modifications/Design Changes Implemented at Loviisa NPP

• **Pre-construction** design changes during construction	1970s
• **Operational experience**: TMI, Chernobyl, Barsebäck, Fukushima	
• Improving protection against **internal and external hazards**	1980-
• **SAM Programme** including hardware modifications	1986-2004
• **Modernization and power upgrading** with 9%	1996-1997
• Plant life management: **I&C renovation**	2000s
• **Fukushima modifications**	2011-

- **Radioactive waste management:**
  - Interim storage for spent nuclear fuel
  - Deep repository for low and intermediate level waste
  - Liquid waste solidification plant

Plant modifications resulting from Operating Experience

Operating experience	Resulting plant modifications
Loviisa RPV surveillance results, 1979-80	• Dummy assemblies to reduce neutron fluence, • Safety injection capacity and temperature, • Steam line isolation I&C, etc
Three Mile Island-2 accident, 1979	Hydrogen igniters, emergency gas removal, loop seal issue, etc
Chernobyl accident, 1986	Development and implementation of comprehensive SAM Programme
Rovno PRISE accident, 1982	PRISE management: PZR spray, increased coolant pool capacity, SG primary collector cover
Barsebäck suppression pool strainer clogging, 1992	New sump strainer designs
Fukushima accident 2011	• UHS with air cooling • Protection against high sea level • Battery and diesel fuel capacity increased , etc

fortum

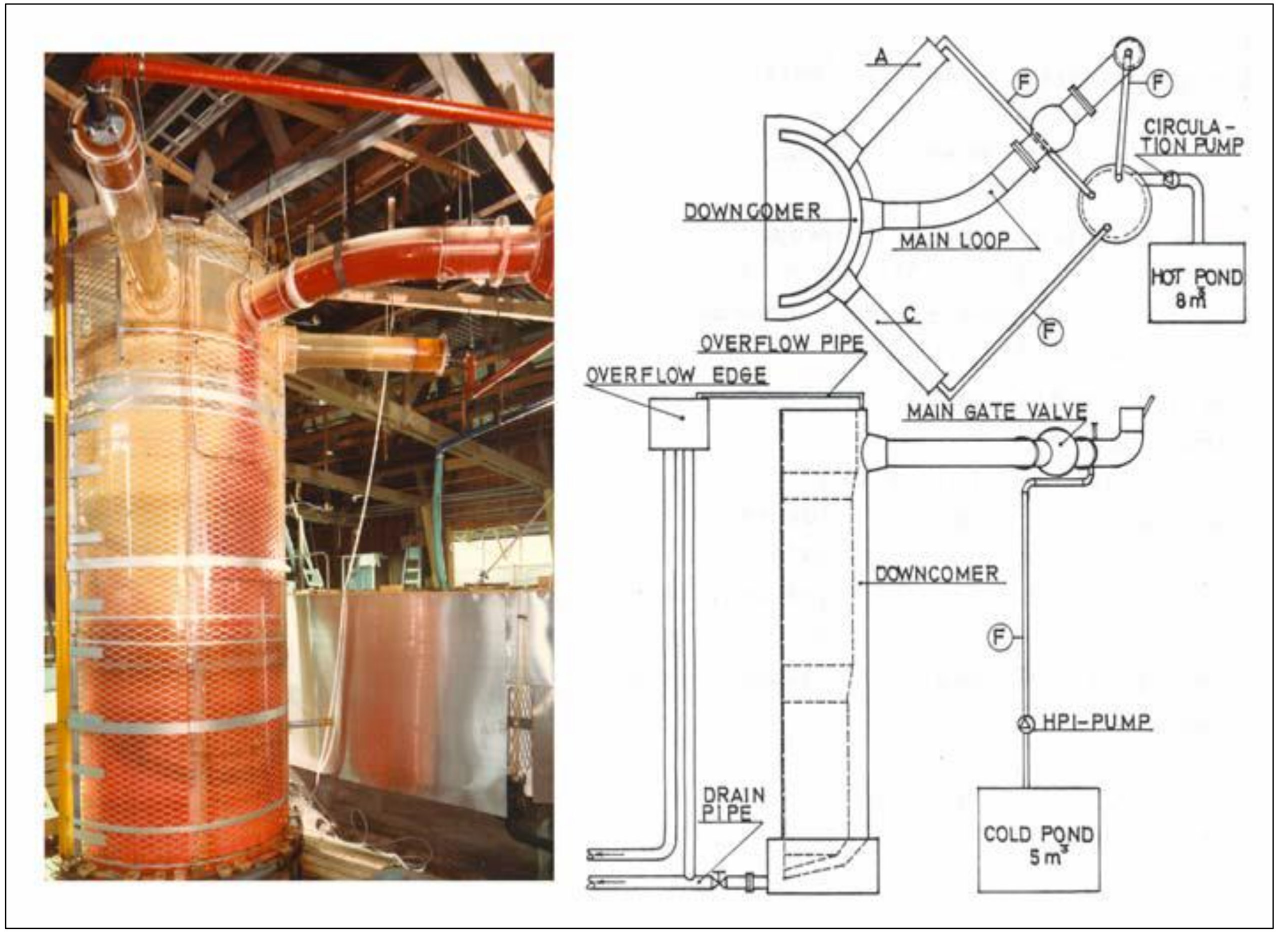
Internal hazards and contributed experiments

Internal hazard*	Features studied	Experimental facilities
PTS: pressurized thermal shock to reactor pressure vessel	• Thermal mixing of ECCS • Flow stagnation properties	• IVO Thermal mixing facility • REWET-III
Loop seal issue (during LOCAs)	Static pressure drop over the loop seal	IVO Loop seal facility
Limited ECCS water penetration to the reactor core (LBLOCAs)	Counter-current flow limitation (CCFL)	IVO CCFL facility
Boron crystallization (during LOCAs)	Boron concentration buildup in the reactor vessel and in the reactor core	REWET-II at LUT VEERA at LUT
Sump clogging by insulation debris (during LOCAs)	• Insulation debris formation • Sump screen clogging • Sump strainer design • Fuel assemblies blocking	Various experimental rigs at IVO Since 2004 at LUT
Ice condenser penetration leading to containment overpressure	Steam flow penetration in case of non-uniform ice loading	IVO Ice condenser facility

* Internal hazard used here to mean initiating event or consequential hazard that can challenge Defence in Depth by penetrating of multiple layers of physical barriers or functional levels

IVO Thermal Mixing Experiments

Facility modelling Loviisa reactor pressure vessel and cold legs in scale 2:5

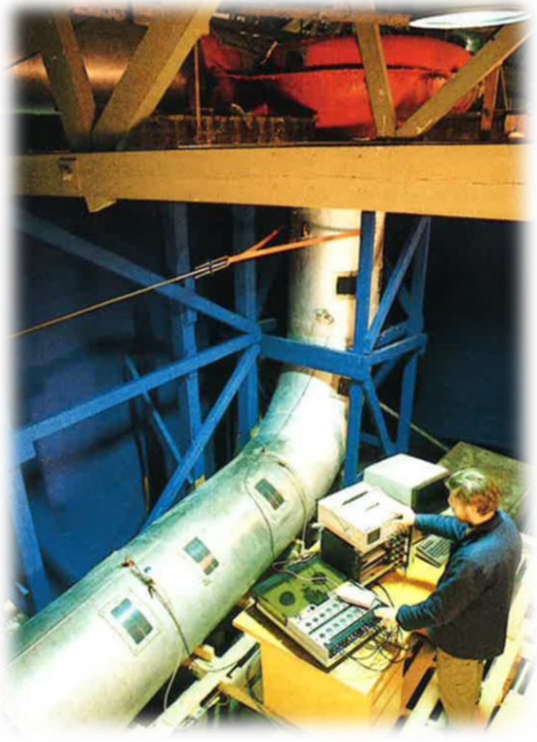


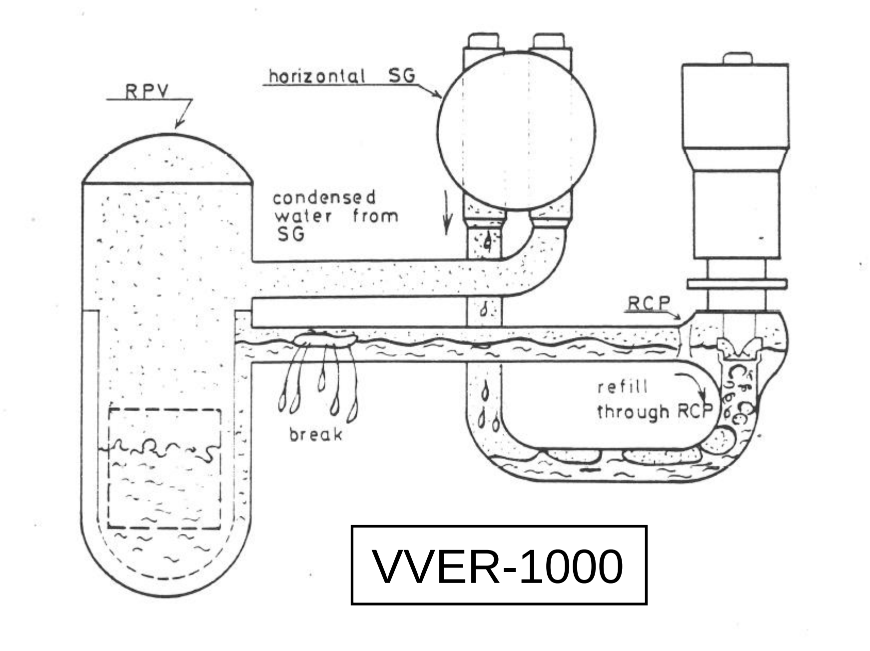
Loop seal experiments

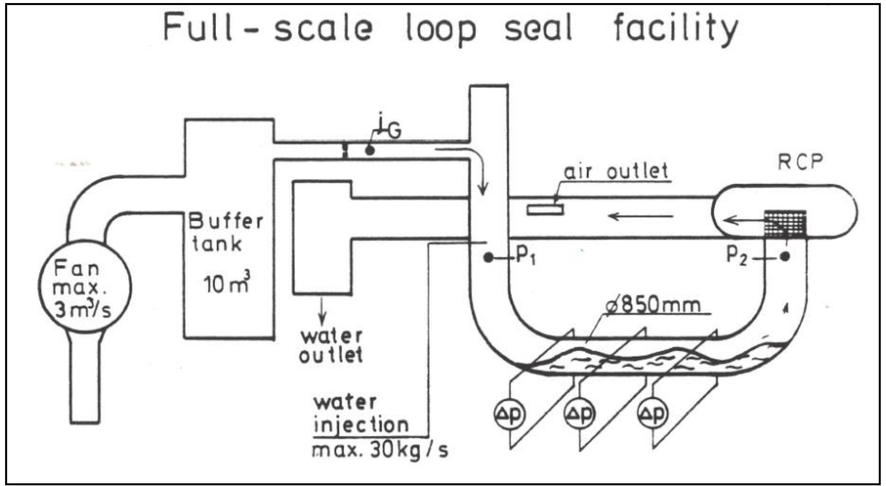
- Done both for Loviisa VVER-440 and VVER-1000 geometries
- The attached drawings demonstrate the conditions and geometry

- The results were used for validation of used system codes such as RELAP5 and APROS

- The results also allowed to define the flow regime map for the loop seal

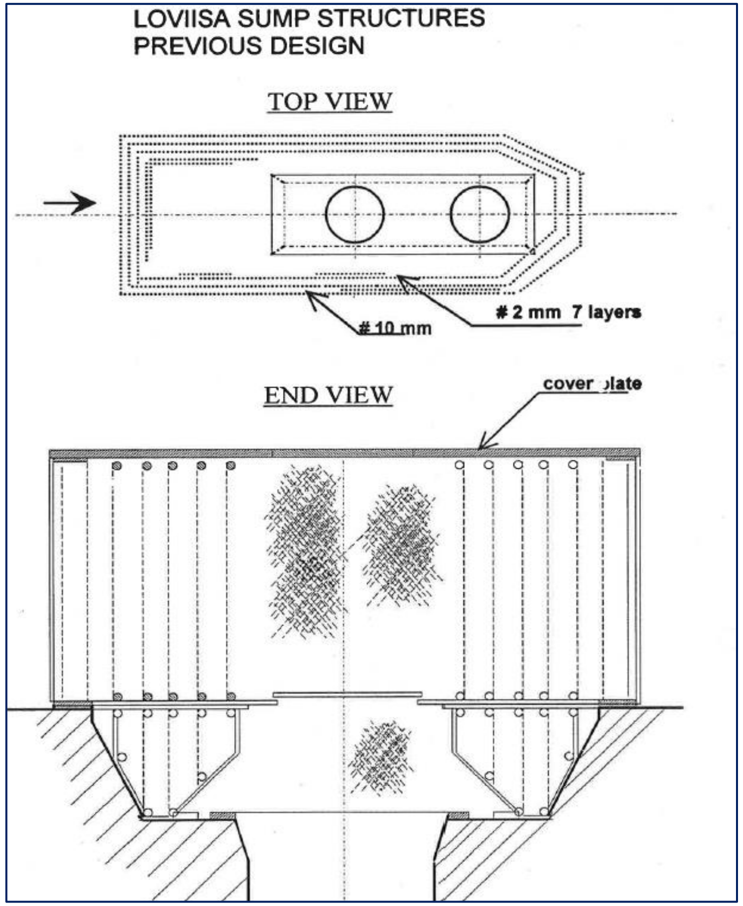




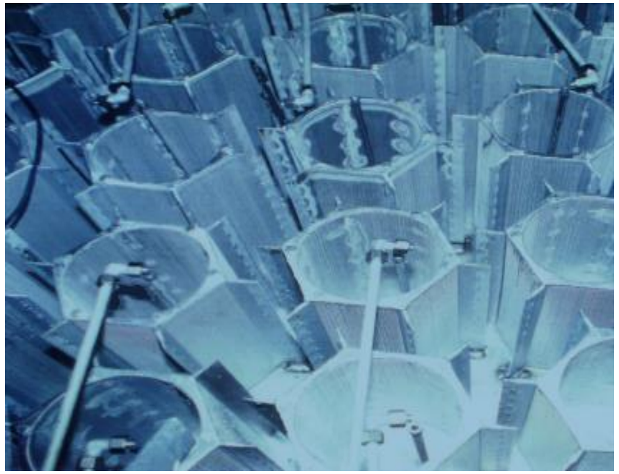


Evolution of sump strainers

Initial design 1978:
sumps protected by screening nets



Modification after Barsebäck event (early 90's):



Modified protection against fuel assembly blockages (early 2010's)

Experiments supporting development of severe accident management

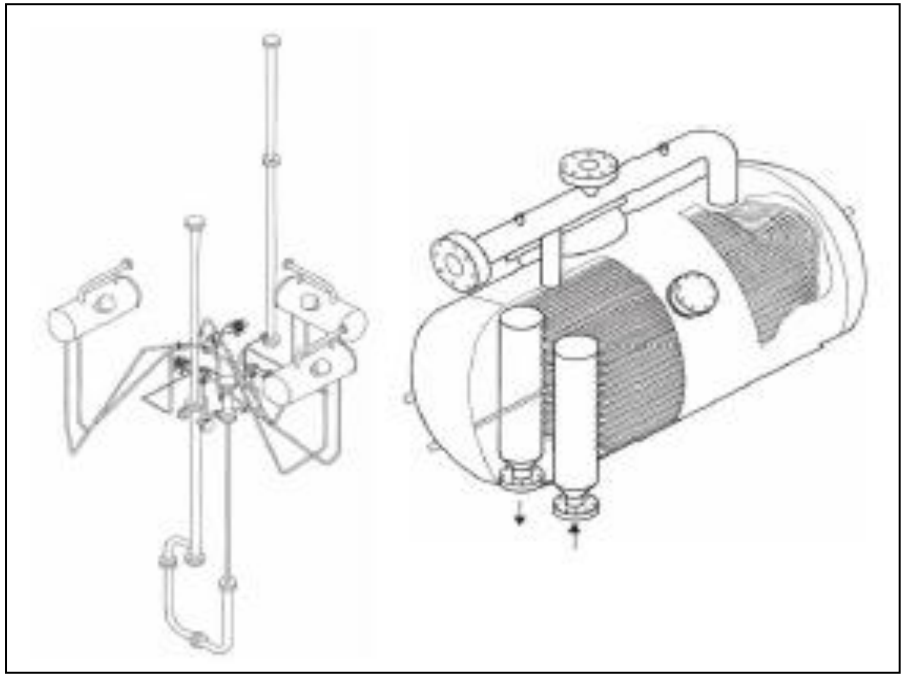
SAM safety function	Computer tools	Experiments
Primary system depressurization	APROS and RELAP5 (bleed&feed function)	PACTEL integral VVER-440 test facility, Lappeenranta University of Technology
Hydrogen management	VIRTA PHOENICS	VICTORIA ice condenser containment facility , Fortum's laboratory
In-vessel melt retention by external cooling	COPCOI	COPO melt pool heat transfer experiments, Fortum's laboraory
External spray	PREDEC	HDR containment experiments in Germany with external spray built by Fortum (assessing the dome wetability and in-containment heat transfer)

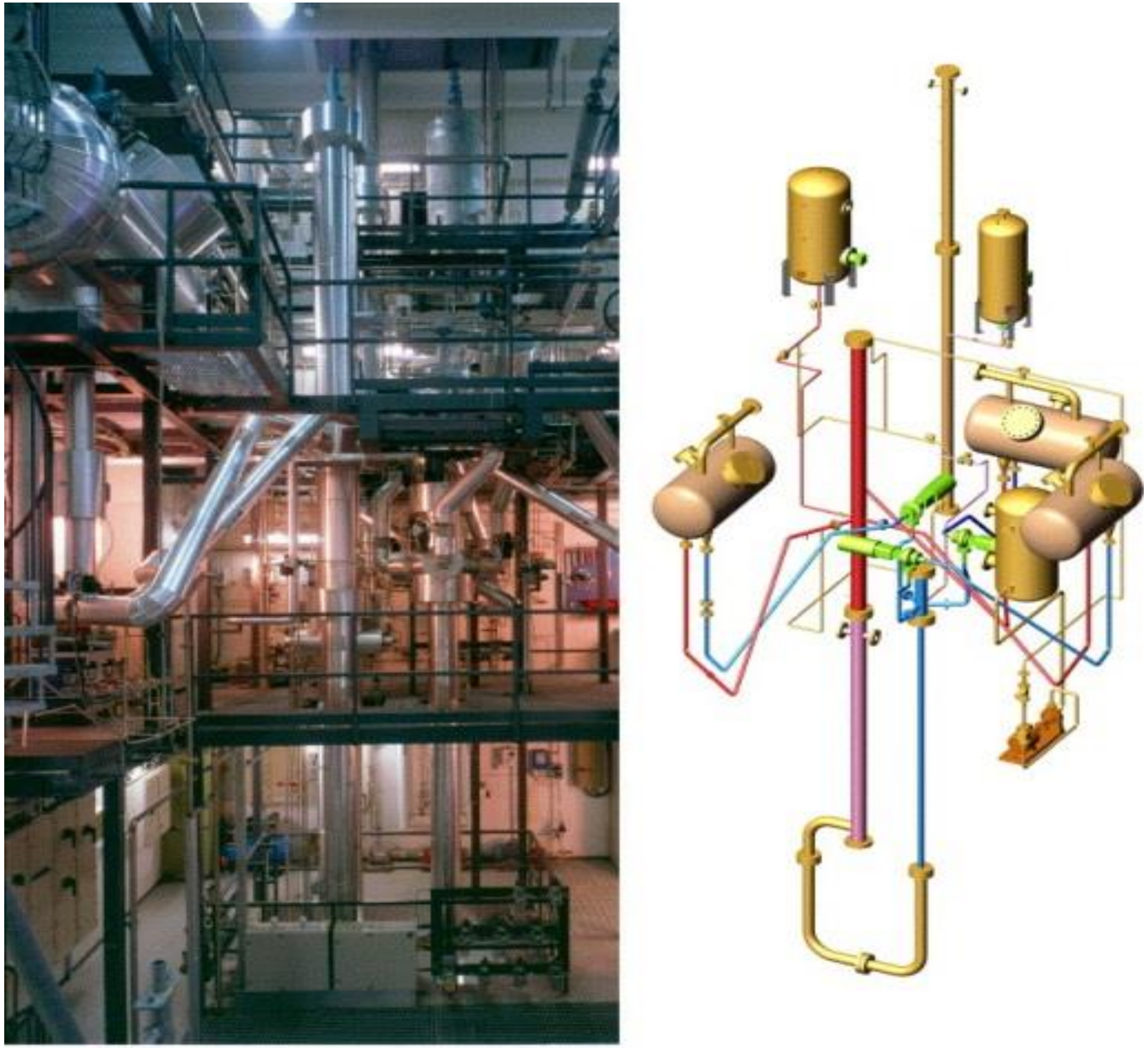
fortum

SAM: Depressurization

PACTEL integral test facility modelling VVER-440

At Lappeenranta University of Technology
Extensively used for assessment of APROS



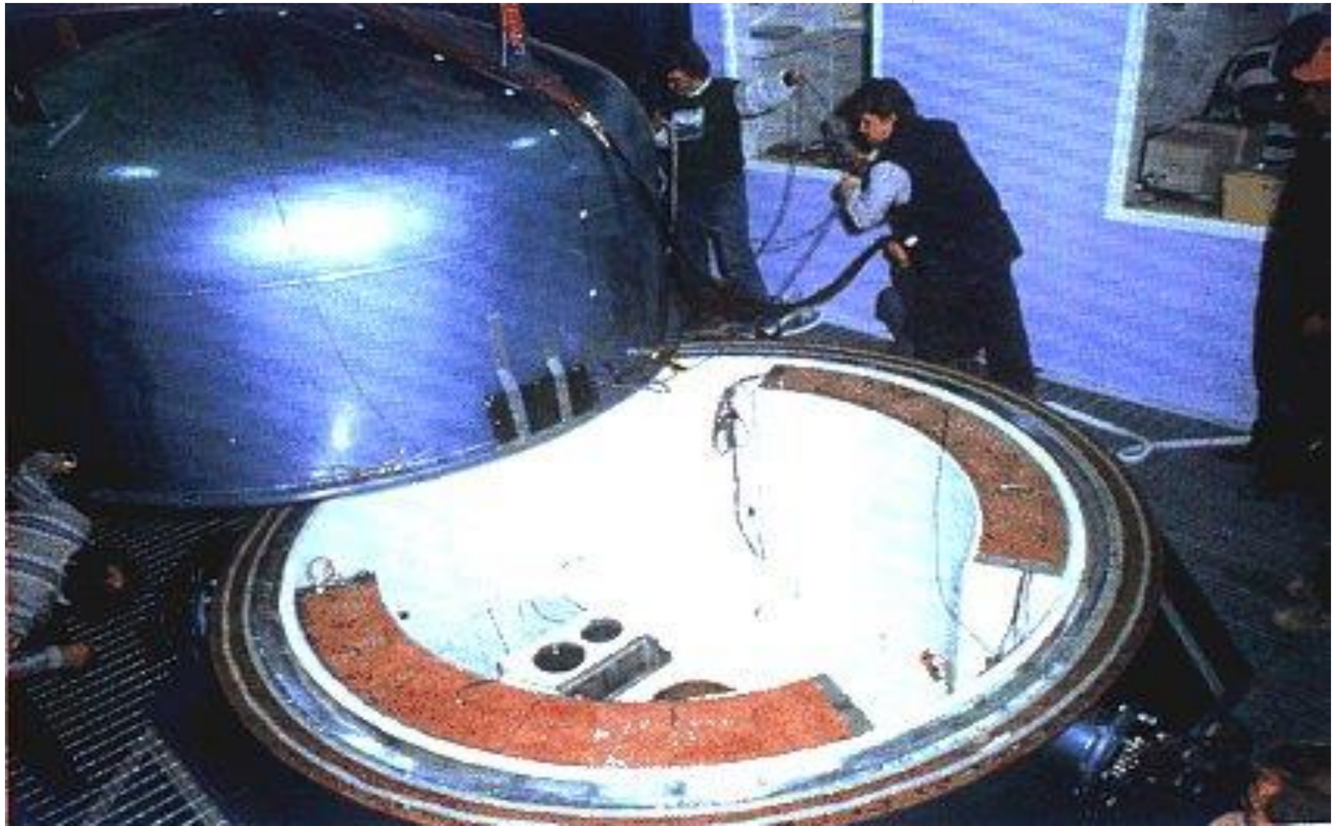


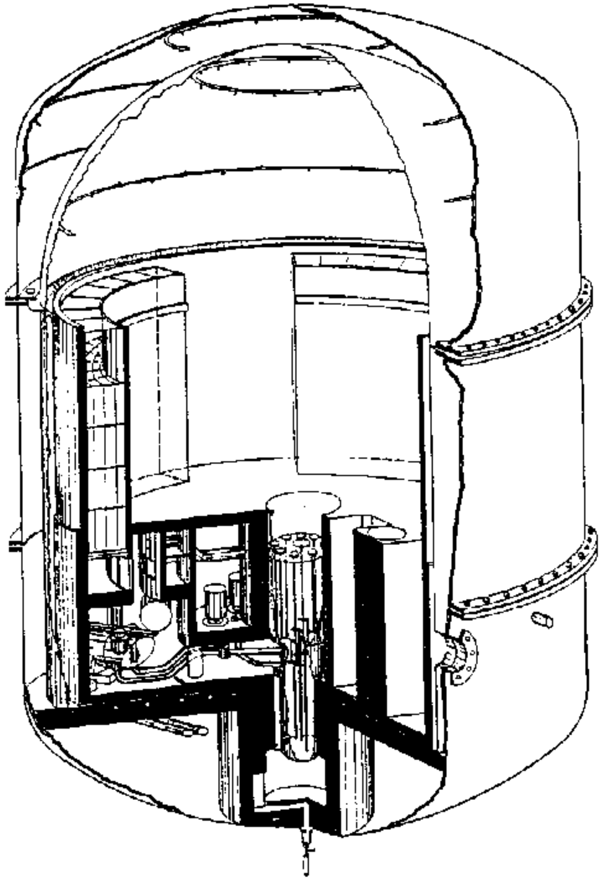
a b

SAM: Hydrogen Management

VICTORIA: Scale model of the Loviisa containment 1:15

- 3 test phases
  - ICC behaviour in SLOCA 1990-92
  - Operation of external spray 1993
  - H2 (simulated with helium) distribution 1993-95
- Aerosol experiments 1995-99





SAM: In-Vessel Retention

Thermal loads from a molten pool:

– **COPO experiments at Fortum**
  - 1:2 scale model of the lower head of Loviisa RPV
  - two-dimensional slice (10 cm thick)
  - maximum height 0.8 m, span = 1.77 m
  - $ZnSO_4$ - H_2O solution, Joule heating

Critical heat flux at the outer surface of RPV wall:
ULPU experiments at UCSB (USA)
- a full height loop (1-D)
- flow resistance scaled as at Loviisa

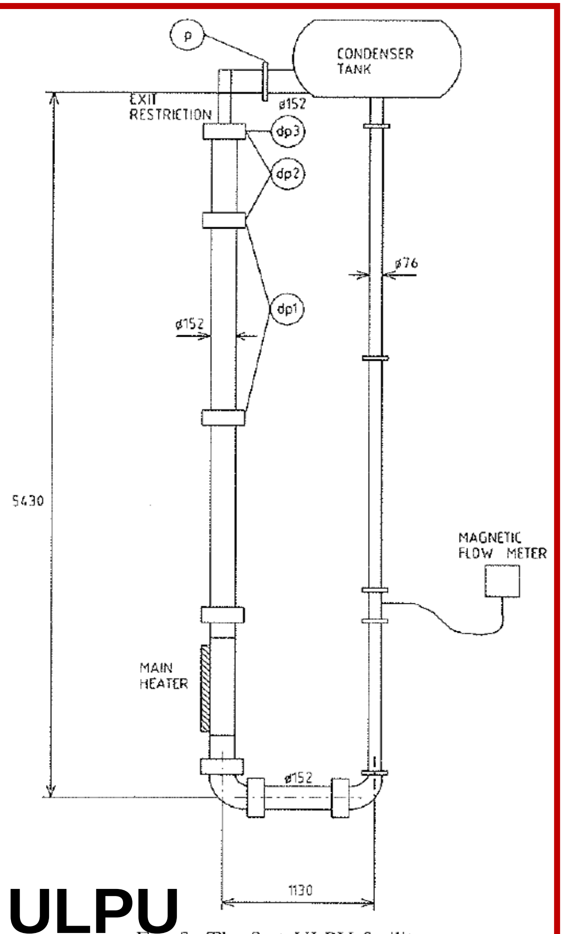
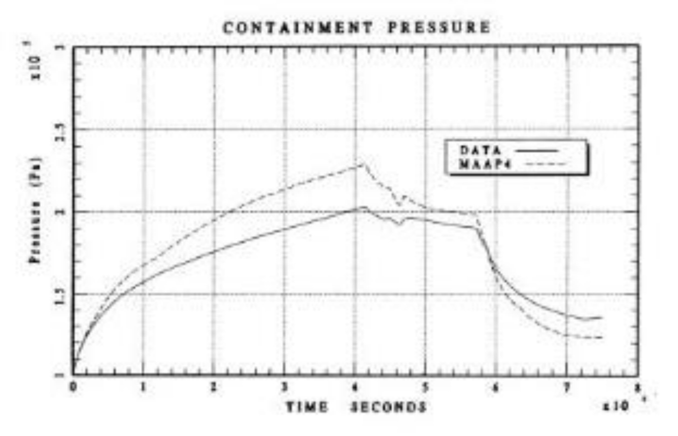


Fig. 3. The first ULPU facility.

SAM: Depressurization

HDR containment (Germany): Test E11.2 with external spray



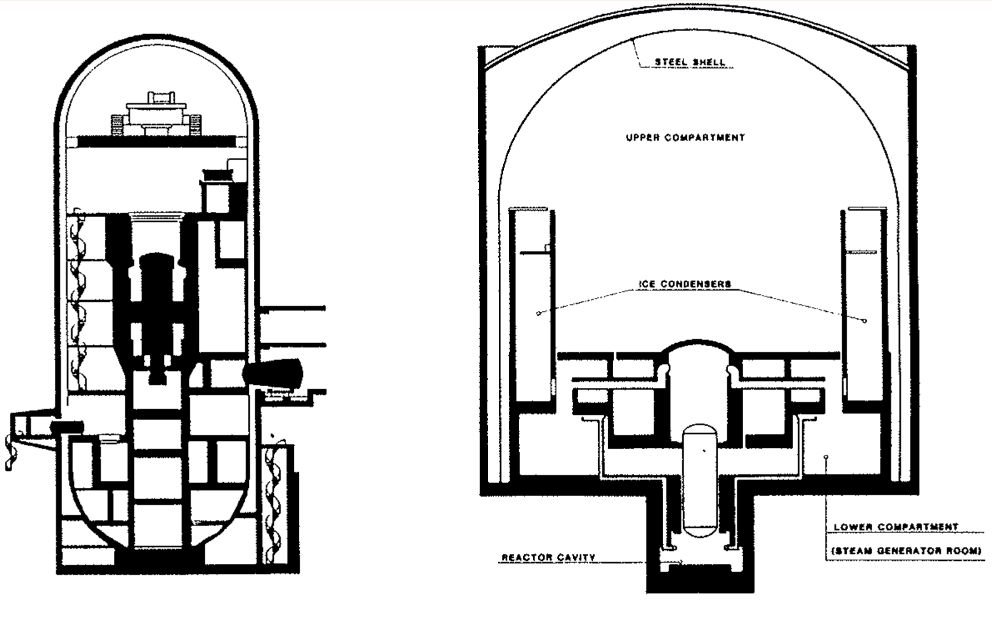
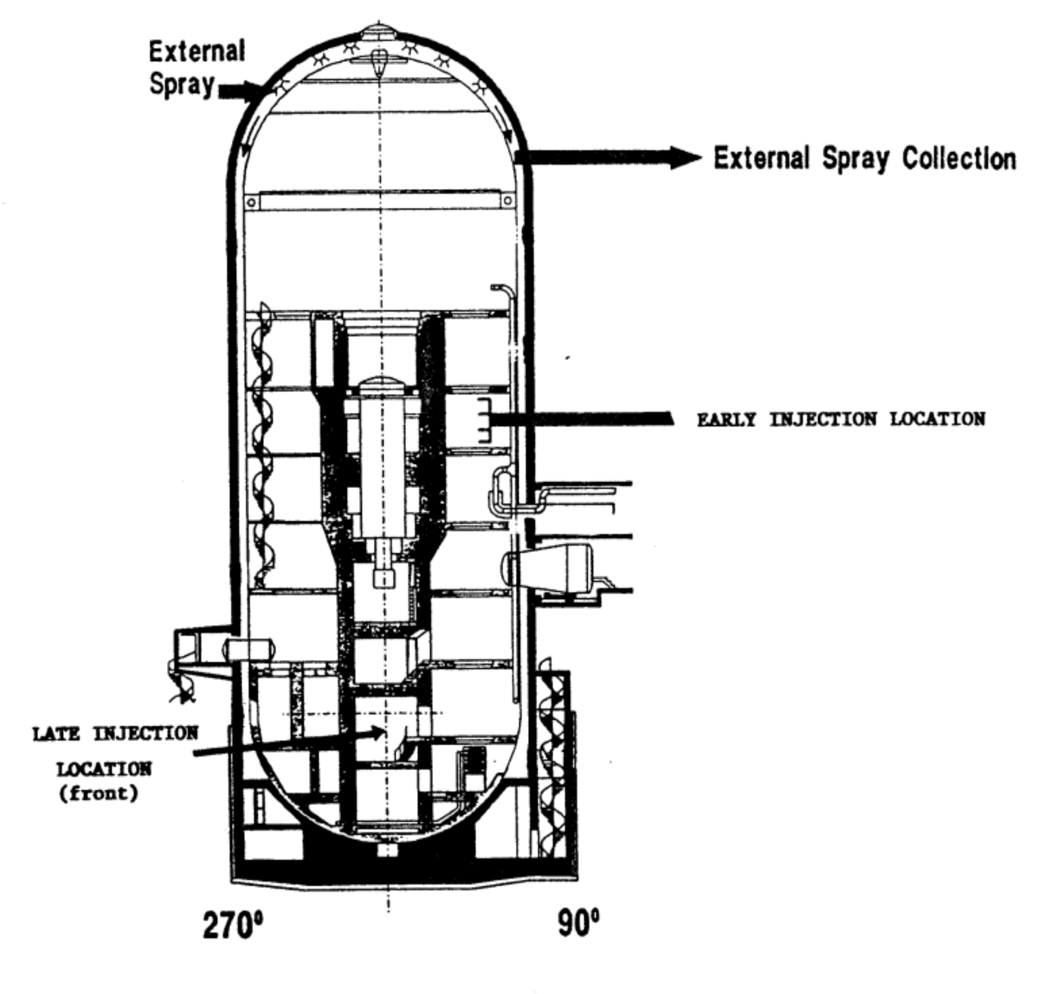


Figure 3. The scale comparison between the HDR and Loviisa containments



fortum

Fortum’s technology development in nuclear

Means

- Own R&D programs
- Participation in national and international R&D projects

Application areas

- Loviisa VVER-440
- New build concepts: SMR, Nuclear CHP
- Waste management

Tools

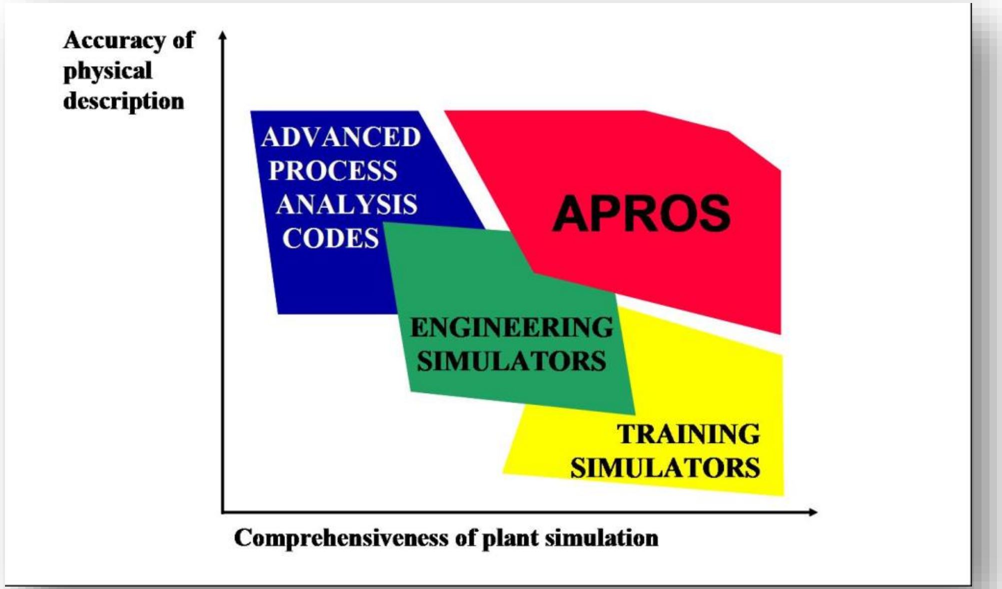
- APROS simulation environment
- PRA: full-scope living PSA
- Digital applications
- (Own laboratory for hydraulic testing until 2004)

Advanced Process Simulator (APROS)

APROS has been developed and maintained since 1986 as a joint effort of Fortum and VTT Technical Research Centre of Finland

The thermal hydraulic library contains 3- , 5- and 6-equation models for the calculation of 1D two-phase flow

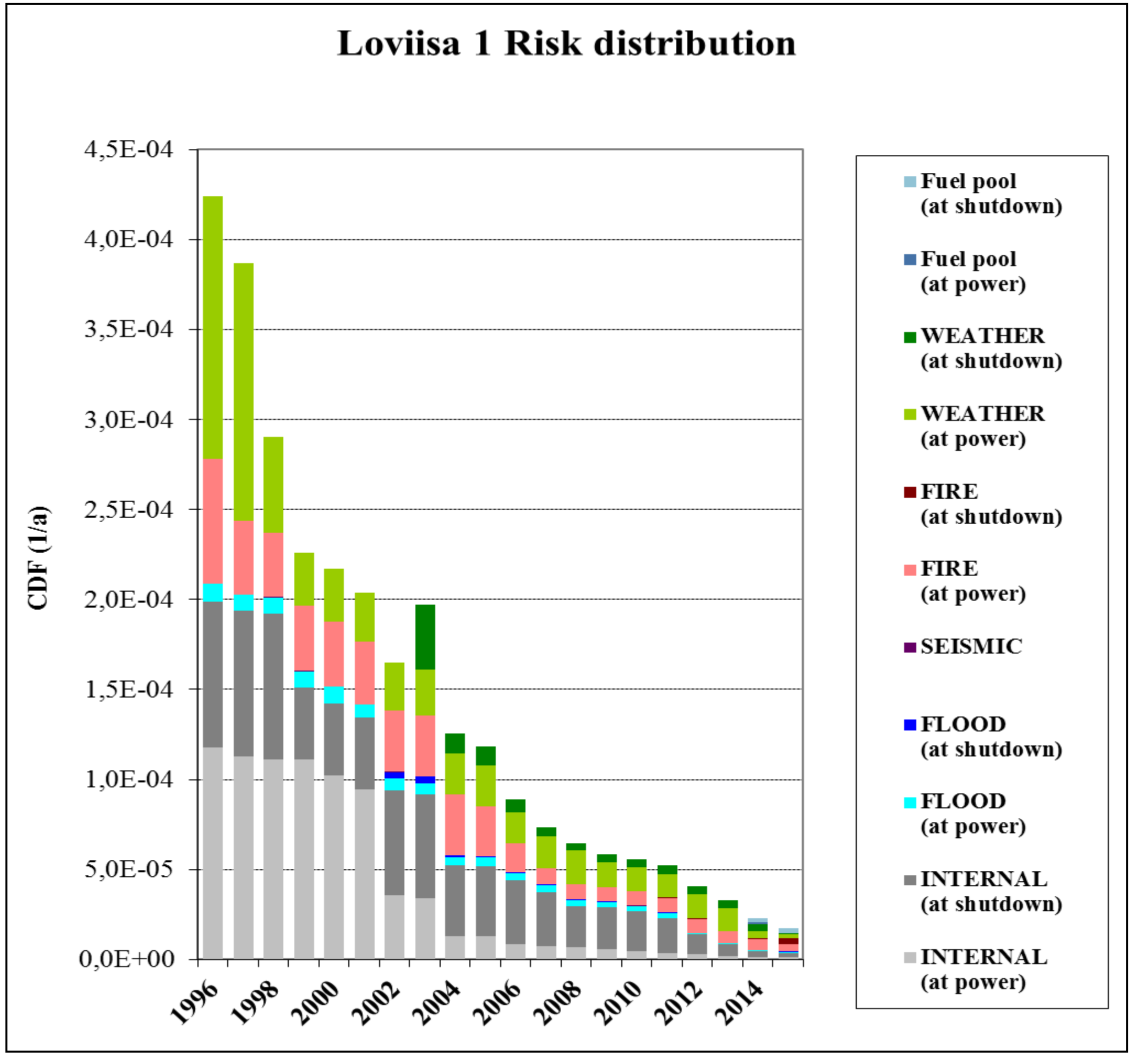
The component library includes an extensive set of ready-made process component models for the simulation of different kind of processes

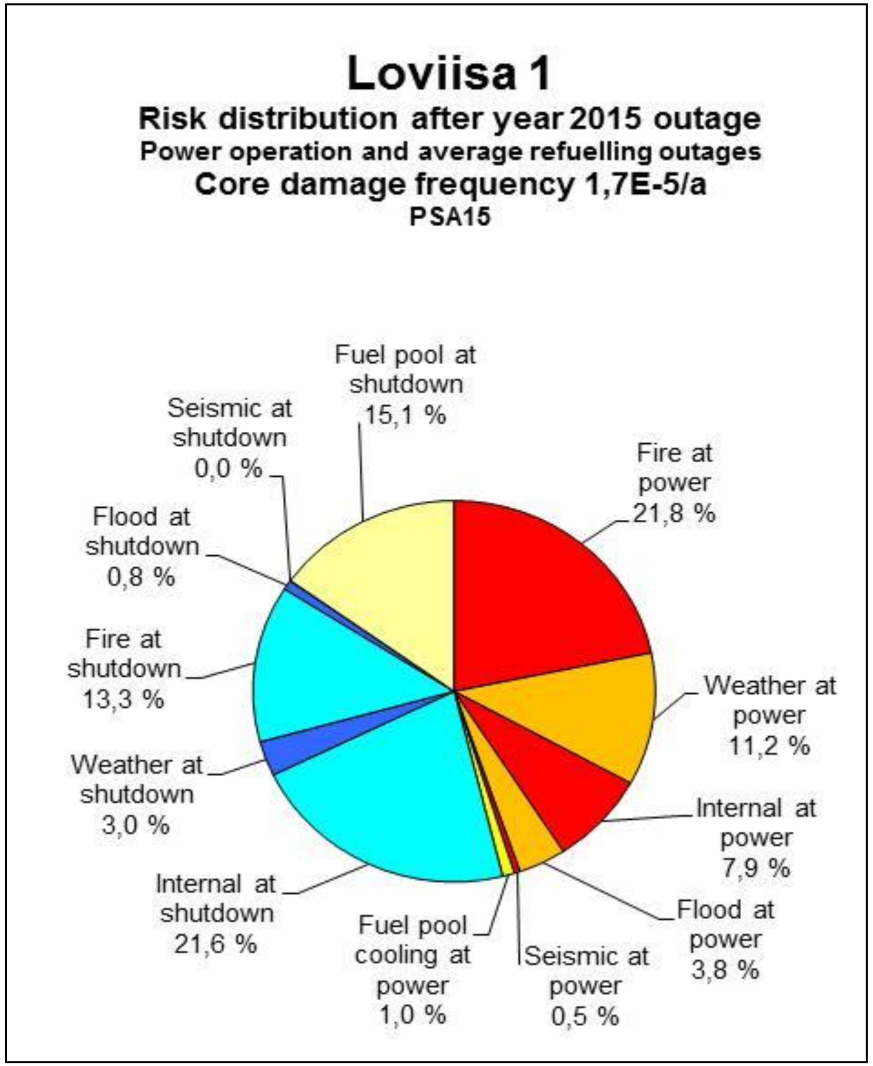


- Available for a fast, in-house assessment of all process, automation and electrical system changes
- Nearly all accident analyses in the Loviisa FSAR have been done with APROS
- Routinely used for conceptual and basic design of plant modifications
- Application examples:
  - **Extensively used in the Loviisa I&C renewal project 2004-2014**
  - **Modification of the ECCS parameters**
  - **Modifications of ESF actuation criteria**

fortum

Nuclear safety: Evolution of the Core Damage Frequency (CDF)





fortum

Concluding remarks

- Fortum has a good experience of operating the Loviisa VVER-440 units since 1977
- Plant modernization resulted in upgraded power 1500 MW_{th} and 500 MW_{e} (+9%)
- Own research efforts have extensively supported continuous plant improvements to
  - respond to operational experience,
  - manage internal and external hazards,
  - develop and implement severe accident management
  - respond to issues brought out by PRA
- Current operation licenses are valid until 2027 and 2030

fortum