Practical Elimination - Experiences for Units in Use, in Construction and in Design

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Principle of continuous improvement

- Introduced in the renewal of the Atomic Energy Act (356/1957) and publication of the Nuclear Energy Act (990/1987)
  - *“The safety of nuclear energy use shall be maintained at as high a level as practically possible. For the further development of safety, measures shall be implemented that can be considered justified considering operating experience and safety research and advances in science and technology.”*
- For operating NPPs
  - plant modifications based on operating experience, deterministic analyses, PSA, research and advances in science and technology
- For NPPs under design or construction
  - readiness for design changes

Practical Elimination in the Finnish Regulatory Guides

- *Events that may result in a release requiring measures to protect the population in the early stages of the accident shall be practically eliminated.*
- *Events to be practically eliminated shall be identified and analysed using methods based on deterministic analyses complemented by probabilistic risk assessments and expert assessments. Practical elimination cannot be based solely on compliance with a cut-off probabilistic value. Even if the probabilistic analysis suggests that the probability of an event is extremely low, all practicable measures shall be taken to reduce the risk.*
- *the mean value of the frequency of a release of radioactive substances from the plant during an accident involving a Cs-137 release into the atmosphere in excess of 100 TBq is less than $5 \cdot 10^{-7}$/year;*
- *the accident sequences, in which the containment function fails or is lost in the early phase of a severe accident, have only a small contribution to the reactor core damage frequency.*

- Practical elimination as defined in IAEA SSR-2/1 (Rev 1.)
  - The possibility of certain conditions arising may be considered to have been ‘practically eliminated’ if it would be physically impossible for the conditions to arise or <u>if these conditions could be considered with a high level of confidence to be extremely unlikely to arise</u>.

Practice

- Practical elimination is strongly linked to three disciplines:
  1. deterministic accident analyses,
  2. failure analyses and failure tolerance analyses,
  3. probabilistic risk analysis.

- Fulfillment requires
  - thorough analysis
  - search for possibilities to improve safety
  - experiences from operating experience

Fulfillment of probabilistic requirements

Unit	CDF < 10^{-5}	LRF < 5×10^{-7}	ERF is small fraction of CDF
Loviisa 1	No	No	Yes
Loviisa 2	No	No	Yes
Olkiluoto 1	Yes	No	No
Olkiluoto 2	No	No	No
Olkiluoto 3	Yes	Yes	Yes

Loviisa NPP units LO1, LO2

- Two VVER units, operated by Fortum Power and Heat Oy.
  - Connected to the electrical grid in 1977 (LO1) and 1980 (LO2).
  - Operation license valid until the end 2027 (LO1) and 2030 (LO2).
  - Nominal thermal power of the units is currently 1500 MW (originally 1375 MW).

- Several plant improvements during the lifetime of the plant, many of them based on the PSA
- Severe accident management (SAM) strategy was developed in the 1990s:
  - in-vessel retention of corium by reactor pressure vessel external cooling,
  - primary circuit depressurization,
  - hydrogen management.
- SAM strategy manages large fraction of severe accidents

- See presentation Laato & Jänkälä later in this session

Olkiluoto NPP units OL1, OL2

- Two BWR units operated by Teollisuuden Voima Oyj (TVO).
  - Commercial operation started in 1978 (OL1) and 1980 (OL2).
  - Operating license until 2018; extension to 2038 is currently under review in the Ministry of Economic Affairs and Employment
  - Current nominal thermal power of both units is 2500 MW. (originally 2000 MW).

- The strategy for severe accident management was established and major plant modifications were implemented in 1980's.
  - lower drywell flooding,
  - containment water-filling from an external water source,
  - containment pressure control through filtered containment venting.

Plant improvements according to CDF

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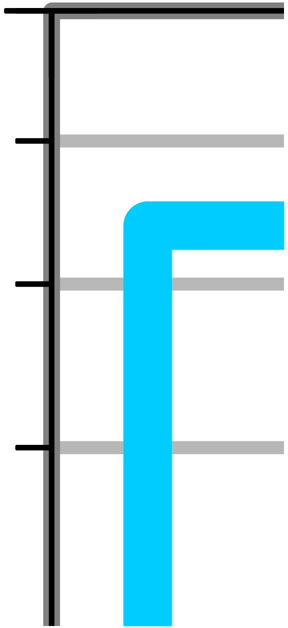

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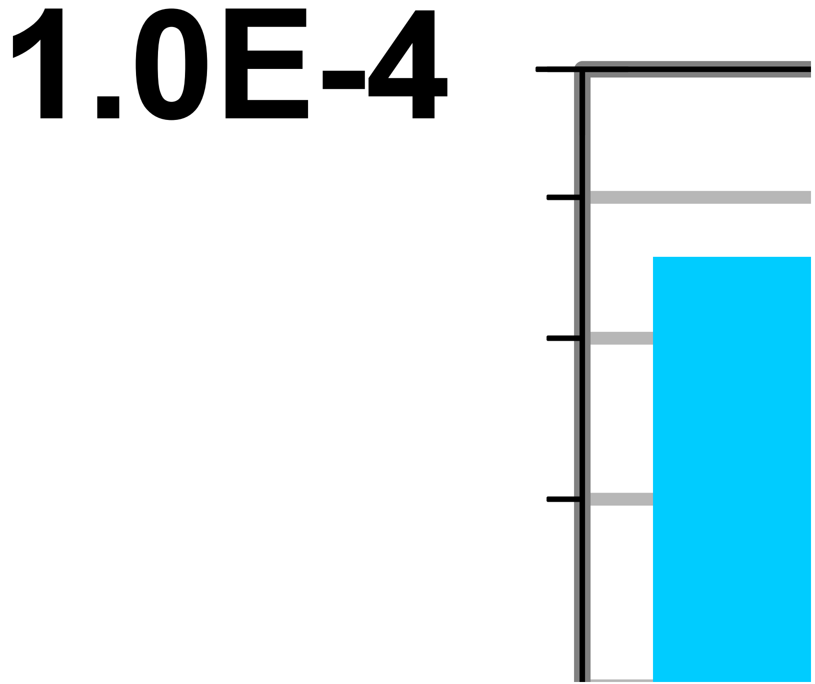
Plant improvements according to LRF



Practical elimination OL1 and OL2

- According to the 2017 practical elimination study, no further significant SAM provisions could be found
  - However the possibility to reduce the time when the containment is not inerted during the startup and shutdown is currently reviewed by TVO

- Early release frequency is roughly 20% of the CDF
  - Fraction is not small
  - Related to plant architecture; small volumes, strong dependency on electricity
  - Most efficient way to reduce the risk of early release is to decrease CDF
    - Currently ongoing modifications:
      - Steam turbine operated high pressure emergency injection system (also delays the starting point of releases)
      - Fire pump operated low pressure emergency injection system
      - Renewal of emergency diesels

Olkiluoto NPP unit OL3

- 1600 MWe European Pressurised Water Reactor (EPR) operated by Teollisuuden Voima Oyj (TVO)
- Operating licence currently under review
- Commissioning test are ongoing

- Severe accident management was incorporated as part of the EPR basic design

OL3 Release frequencies

- Large release frequency and early release frequency are small

Release types in Olkiluoto 3 PSA for Operating License.

Release type	Frequency 1/a	% Release
Large release before 3h	9.40×10^{-09}	0.3
Large release 3..10h	1.88×10^{-08}	0.6
Large late release	7.10×10^{-08}	2.2
Small release before 6h	≈0	≈0
Small release after 6h	3.18×10^{-06}	97

- Probabilistic safety criteria were reached,
  - However, the results of the initial PRA for operating license indicated some aspects of practical elimination for further analysis:
    - Overpressure transient during start-up with solid pressurized – PSA did not reflect operating procedures
    - ATWS – overly conservative ATWS criterion was used in the initial PSA

Conclusions

- Continuous improvement of the safety is applied to Finnish nuclear power plants.
- Even for operating NPP units, efficient provisions can be implemented to significantly decrease the frequencies of early releases and large releases.
- Safety improvement and practical elimination are achieved only when real weaknesses are identified and practical modifications are implemented.
  – It is a significant achievement of Finnish licensees that the core damage frequencies of older NPP units approach and even reach the quantitative criteria set for new NPP units.
- The continuous development of safety rests on the basic attitude that identified safety vulnerabilities are treated as candidates for further enhancement of safety.
  – Practical elimination does not happen by itself, but requires search for vulnerabilities and research for new possibilities to overcome those.
- In Finnish NPPs the releases remain small if the containment is intact or in case of small containment failure the containment sprays are operating