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Safety Upgrades at NPP's in Finland, Based on Lessons Learned from Foreign Operating Experience

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Report INSAG-23 by the International Nuclear Safety Group, IMPROVING THE INTERNATIONAL SYSTEM FOR OPERATING EXPERIENCE FEEDBACK, states:

"In developing the international OEF system and the process for its implementation, it is important to keep in mind the central purpose of OEF. ***Writing reports and collecting data are meaningful only when there is a direct coupling to risk reduction and the enhancement of operating safety.*** *Therefore, event reporting needs to be connected to programmes that transform the lessons learned into risk reducing measures, such as improvements in design, management of plant operations and ageing, operator training, operating procedures and safety culture."*

International Operating Experience provides insights for enhancing nuclear safety

International reporting on Operating Experience is a well established practice, and it provides a lot of information for those who want to learn from it .

In Finland, we are using this information to enhance operational safety. Safety is enhanced by

- upgrading plant hardware,
- improving staff competences and management of operations,
- focusing safety assessment and improving regulations.

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Principle of continuous safety enhancement

Already in the 1970's when the nuclear power plant operation in Finland was started, a strong **commitment to continuous enhancement of safety** was adopted.

This principle is applied to:

- operational activities
- modernisation and back-fitting of old plants
- design of new facilities
- regulatory oversight

Operating events, both at the Finnish plants and abroad, are analyzed – actions are taken as necessary to enhance safety.

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Statutory requirements on OEF and safety enhancement

Decision of the Government (395/1991) on General Regulations for the Safety of NPPs gave formally the rules on safety enhancement:

- **licensees shall systematically follow and assess**
  - **operating experience from NPPs**
  - results of safety research
- **for further safety enhancement, action shall be taken which can be regarded as justified**
  - **considering operating experience**
  - considering the results of safety research
  - considering the advancement of science and technology.

The same principle was transferred this year to the revised **Nuclear Energy Act** (990/1987, amendment 342/2008)

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Sources of IOE used in Finland

Event reporting

- multinational systems managed by IAEA/NEA: IRS and WANO
- nuclear reactor owners and users groups: NOG, BWROG, VVER
- information exchange between regulator groups: OECD/NEA/WG's, NERS, VVER-forum
- bilateral contacts with foreign regulators and plants
- IAEA/NEWS, WGPCNEWS used for transmitting early information

Multinational database systems: OECD/NEA Topical Databases

- ICDE, OPDE, FIRE, COMPSIS, SCAP, IAGE, ISOE (co-sponsored by IAEA)

Peer review missions organized by the IAEA and WANO

- IRRS, OSART, different WANO missions

CNS (International Convention on Nuclear Safety) **Review Meeting** reports

International OEF process at STUK

STUK is the national co-ordinator of IRS reports

- STUK has arranged to about 100 experts in different Finnish organizations (regulatory body, utilities, TSO, ministry) a direct access to the IAEA/NEA's web-based IRS system
- STUK's IOEF processes '**Use of IRS reports**' and '**IRS report preparation**' are described in STUK's Quality Manual
- STUK's international OEF group (full-time co-ordinator and ten participating experts) and other experts
  - review and assess
    - IRS-reports disseminated through the IAEA
    - other information or reports received directly from other sources
  - oversee the utilization of international OE by operators
  - prepare the IRS-reports on events at NPP's in Finland

Safety enhancing measures based on IOEF (1)

Most of the measures at operating Finnish NPP's, based on inputs through the international reporting systems **(IRS, WANO),** have been "soft" measures:

- additional safety assessment and analysis
- improvements in
  - management systems and operating practices
  - procedures and instructions
  - inspections and testing of equipment
  - staff training, including simulator training.

Safety enhancing measures based on IOEF (2)

Most plant modifications and smaller improvements in systems, structures, and components that are based on foreign experience,

- originate from **similar plants as those being operated in Finland:** VVER-440 and BWR plants designed by Asea Atom

In addition, a few widely reported foreign events have led to plant modifications

Examples on utilisation of IOE

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Among the foreign events that have initiated a process leading to plant modifications at Finnish NPP's are the following:

- Partial core meltdown (TMI 1979)
- ECC recirculation filter blockage (Barsebäck 1992)
- Disturbance in electrical power system (Forsmark 2006)
- Several large turbine building fires (Greifswald, Armenia, Vandellos, Chernobyl)
- Large primary to secondary circuit leak (Rovno 1992)
- Erosion corrosion damages of feedwater distribution pipes (Dukovany, Rovno)
- Rupture of the feedwater pipe (Mihama)
- Accumulation of radiolysis gases in systems (Brunsbuttel, Hamaoka)
- Cracks in a feedwater distributor of the reactor circuit (Swedish NPPs)

Three Mile Island accident in 1979 (1/2)

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The sequence of certain events - equipment malfunctions, design related problems and operator errors - led to a partial meltdown of the TMI-2 reactor core but only very small off-site releases of radioactivity.

Actions taken after TMI in Finland included both accident preventing and accident mitigating measures.

Accident preventing measures at Finnish NPPs were similar to those taken at US plants:

- backfitting of design: improved Control Room instrumentation including SPDS, reactor coolant system vents, etc.
- development and use of new analytical tools for
  - improved analysis of small LOCA's and transient events and
  - improved emergency operations and respective operator guidelines

Three Mile Island accident in 1979 (2/2)

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For severe **accident mitigation**, a strategy was developed at each plant to protect containment integrity against all identified threats.

For instance, the changes at Loviisa NPP addressed the following:

- high pressure meltdown - reliable high capacity pressure relief system
- molten core - provisions for passive external cooling of the RPV (core retained in the RPV)
- slow containment pressurization - fully independent external containment spray providing steam condensation on inner wall (large steel containment with wall thickness of 20 mm)
- hydrogen burn - first glow plugs to initiate slow burn, later on catalytic recombinators
- containment penetration leaks - improved sealing with high temperature resistant material
- dedicated I&C and control room for severe accident management

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Loviisa 1 & 2 plant modifications for severe accidents

- Development of a plant specific severe accident management strategy started in 1986
- Plant modifications to implement the strategy have been made in 1989 - 2004

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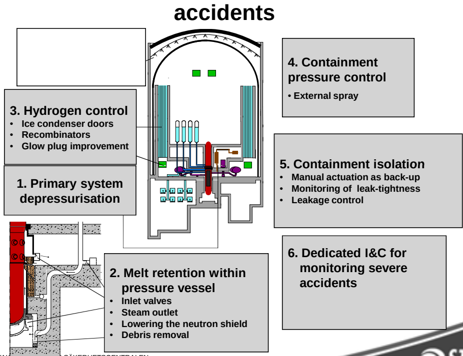
Loviisa 1 & 2 plant modifications for severe accidents



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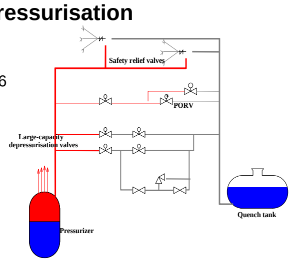
Loviisa 1 & 2 primary system depressurisation

- Two manually operated relief valves installed in 1996 at both plant units
- Valve capacity 30 kg/s at 137 bar
- Actuation criterion: core exit temperature > 450 °C

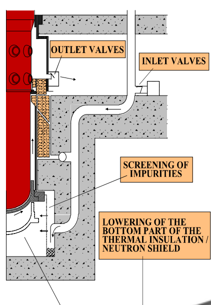


Melt cooling and retention within the pressure vessel

- Loviisa severe accident management (SAM) strategy provides melt retention and ultimate cooling within the pressure vessel
- Several plant features favour the solution:
  - Core power density is small
  - No penetrations in pressure vessel bottom
  - Passive flooding of the reactor cavity due to the melting ice from the ice condensers
- Experimental justification
  - COPO, heat flux distribution from melt to pressure vessel wall
  - ULPU, heat transfer at the pressure vessel external surface

Plant modifications for melt retention

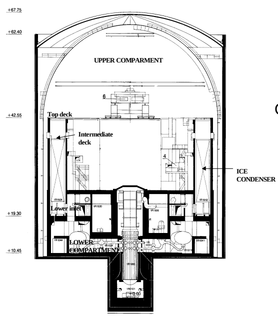
- Hydraulic system to lower the RPV bottom thermal insulation with remote control from the main control room. Actuated when core exit temperature exceeds 450 °C.
- New inlet and outlet valves to ensure natural coolant circulation
- Addition of screens for debris removal



Hydrogen mitigation

- Loviisa 1 & 2 hydrogen mitigation strategy is based on hydrogen mixing and hydrogen removal
- Mixing is ensured by forcing open the ice condenser doors
  - manually actuated form the main control room when core exit temperature > 450 °C
  - doors were modified for remote opening in 2000/2001
- Hydrogen is removed by glow plugs (20) in lower compartments and passive autocatalytic recombiners (154)
  - glow plug system was installed in 1981, modified in 2002
  - recombiners were installed in 2004

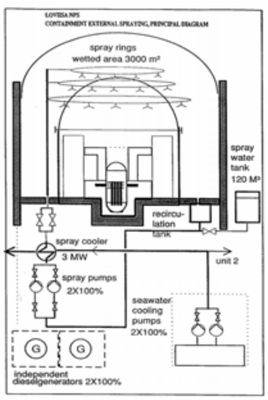
Ice condenser doors to permit hydrogen mixing in entire containment



Opening by pneumatic cylinders

Containment pressure control by external spray

- Two spray pumps & separate cooling system per unit
- Seawater system and diesels common for the two units
- Manually actuated when containment pressure exceeds 1.7 bar
- System was installed in 1989



Containment isolation

- Containment isolation was originally provided for the design basis accidents. It was later supplemented for severe accidents
- Plant modifications
  - isolation signals may be manually actuated
  - locking of isolation status has been enabled to prevent spurious valve opening
  - selected valves can be manually closed at local control points in case of loss of power and control system
  - leak-tightness monitoring system has been improved

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Dedicated I & C for severe accident monitoring

- A new severe accident control room was built in 2000 (common to both units)
- New or modified I&C for qualified for severe accidents:
  - core exit temperatures (modified)
  - hot leg temperatures (new)
  - primary system pressure (new)
  - water level in cavity (new)
  - water level in SG compartment (new)
  - temperature of water entering cavity (new)
  - containment pressure and temperature (new)
  - containment isolation signals

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Emergency core cooling (ECC) recirculation blockage at Barsebäck NPP in 1992 (1/2)

- coolant recirculation is required for long term post-LOCA cooling
- large break jets destroy / dislodge insulation and insulation debris transports easily with water and accumulate on sump screens
- original sump screens were developed late 70's for both Olkiluoto and Loviisa NPPs
- design of sump screens was based on extensive large scale experiments; tests were carried out using fresh mineral wool
- Barsebäck incident showed that amount of debris reaching the sump screens was underestimated because behavior of thermally aged insulation material in water is completely different from that of fresh material (brittle, migrates more easily, sinks more rapidly)
- it was obvious that the risk for early clogging of the sump screens after LOCA could not be ruled out without additional experiments and redesign of the screens.

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Emergency core cooling (ECC) recirculation blockage at Barsebäck NPP in 1992 (2/2)

Tests were conducted both for Olkiluoto and Loviisa

- tests showed that the design of existing sump screens at Olkiluoto NPPs was still adequate (met the pressure loss criteria) but not at Loviisa NPPs.
- new type of screens with significantly increased flow area (100m²) were installed at Loviisa NPPs in 1993
- nitrogen back flushing system for screen cleaning was designed and installed at all Finnish NPPs (operating BWR's and VVER's and new EPR).

Screen issue emerged again in German studies

- new concern was that material penetrating the sump screens could accumulate on fuel surfaces
- a new test program was conducted in 2008.
- based on the test, smaller mesh size of screens was recommended and changes will be installed in the next outage.

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Forsmark 1 incident on 25.7.2006

- A similar sequence is not possible in Finland, but transient behaviour of the on-site electrical systems is sensitive to different disturbances; therefore actions and studies were started promptly
  - main on-site electrical systems were modelled and their tolerability for the worst case off-site disturbances was analyzed
  - design bases for electrical systems was re-evaluated and modified
  - some studies are still ongoing and should be completed this year
  - modifications already implemented or decided for implementation in 2009 and 2010 are
    - improving equipment protections and selectivity in UPS systems (at all operating plants and in Olkiluoto 3)
    - decreasing dependencies on UPS systems by installing a DC bypass in-feed parallel to the UPS feed (from AC) to DC consumers (OL3).

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Examples of Loviisa 1 & 2 modifications based on foreign Operating Experience (1)

- **Large turbine building fires** (Greifswald, Armenia, Vandellos, Chernobyl)
  - construction of new fire walls in the turbine building, and improving fire resistance of existing walls and doors
  - provision of fast acting automatic spray systems to suppress turbine and transformer fires
  - provision of additional routes for electrical power supply to safety systems
  - installation of a diverse emergency feedwater system, with independent power supply and water storage tank, in a new building (original emergency feedwater system is in the turbine building).

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Examples of Loviisa 1 & 2 modifications based on foreign Operating Experience (2)

- **Large primary to secondary circuit leak** (three leaks opened in short intervals, each equiv. to more than 10 SG tubes) at Rovno NPP
  - installing improved boundary between primary and secondary circuits (inside steam generators)
  - doubling the volume of water available for ECCS injection mode, in order to provide enough time for fast depressurisation and cool-down of primary circuit.
- **Erosion corrosion damages of feed water distribution pipes** inside steam generators (Dukovany, Rovno)
  - OKB Gidropress together with Loviisa experts designed a new type of feedwater distribution pipe

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Examples of Olkiluoto 1 & 2 modifications based on Foreign Operating Experience (1)

- **Rupture of the feedwater pipe** (Mihama, 2004), caused by thinning of the pipe wall.
  - Licensee increased erosion / corrosion inspections in condensate system. The number of the pipe thickness measurements was not increased but the endoscope inspections of inner surfaces of the pipes were expanded.

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Examples of Olkiluoto 1 & 2 modifications based on Foreign Operating Experience (2)

- **Accumulation of radiolysis gases** (Brunsbuttel, Hamaoka)
  - Studies with Olkiluoto vendor revealed the risk of hydrogen gas accumulation in reactor vessel during cold shutdown
  - If the reactor is in a cold shutdown wirh closed vessel, and at least one day has passed since the steam blow down from the reactor vessel, the venting with nitrogen is performed. The venting is repeated once a day if the cold shutdown state continues.
- **Cracks in a feedwater distributor of the reactor circuit** (Swedish NPPs)
  - reactor pressure vessel nozzle joints containing similar weld material are inspected every 3-5 years, whereas normal weld joint inspection interval recommended in the applied international standard is 10 years.

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Modifications made in Olkiluoto 3 on the basis of operating experience, as compared with the original EPR design

- Steel liner added to inner containment (French N4 plants)
  - to ensure containment leak tightness
- Sump design and back flushing system (Barsebäck, 1992)
  - very large sump screen area (3 x 70 m^2) to ensure recirculation of the safety injection system
  - a nitrogen backflushing system (for cleaning the sump screen)
- Weather phenomena - protection of air intakes against snow storms, and heating of the sea water intake structures to prevent freezing (Finnish experience)
- UPS system design (Forsmark 1, 2006)
- Mechanical cleaning of condensate (French NPPs)
  - protect steam generators from impurities

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Conclusions

- the Finnish nuclear regulations imply continuous NPP safety enhancement, considering operating experience and results of safety research;
- STUK follows systematically the International Reporting System (IRS) and other sources
- major plant modifications have been conducted at Finnish plats to enhance safety;
- many modifications were started on the basis of international operating experience
- a major plant modification always requires plant specific confirmatory research to demonstrate the expected improvements