# Loviisa spent fuel storage risk analysis

PSAM16 / 26.6.-1.7.2022 / Jukka Koskenranta (Seismic), Ilkka Paavola (Internal events), Rasmus Hotakainen (HRA), Taisto Laato (Level 2)

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# Introduction

Loviisa Nuclear Power Plant

- Located in southern Finland
- 2 x 500 MWe VVER-440 units (1977/1980)
- Current operating license until 2027/2030
  - Extension applied for 2050 for both units



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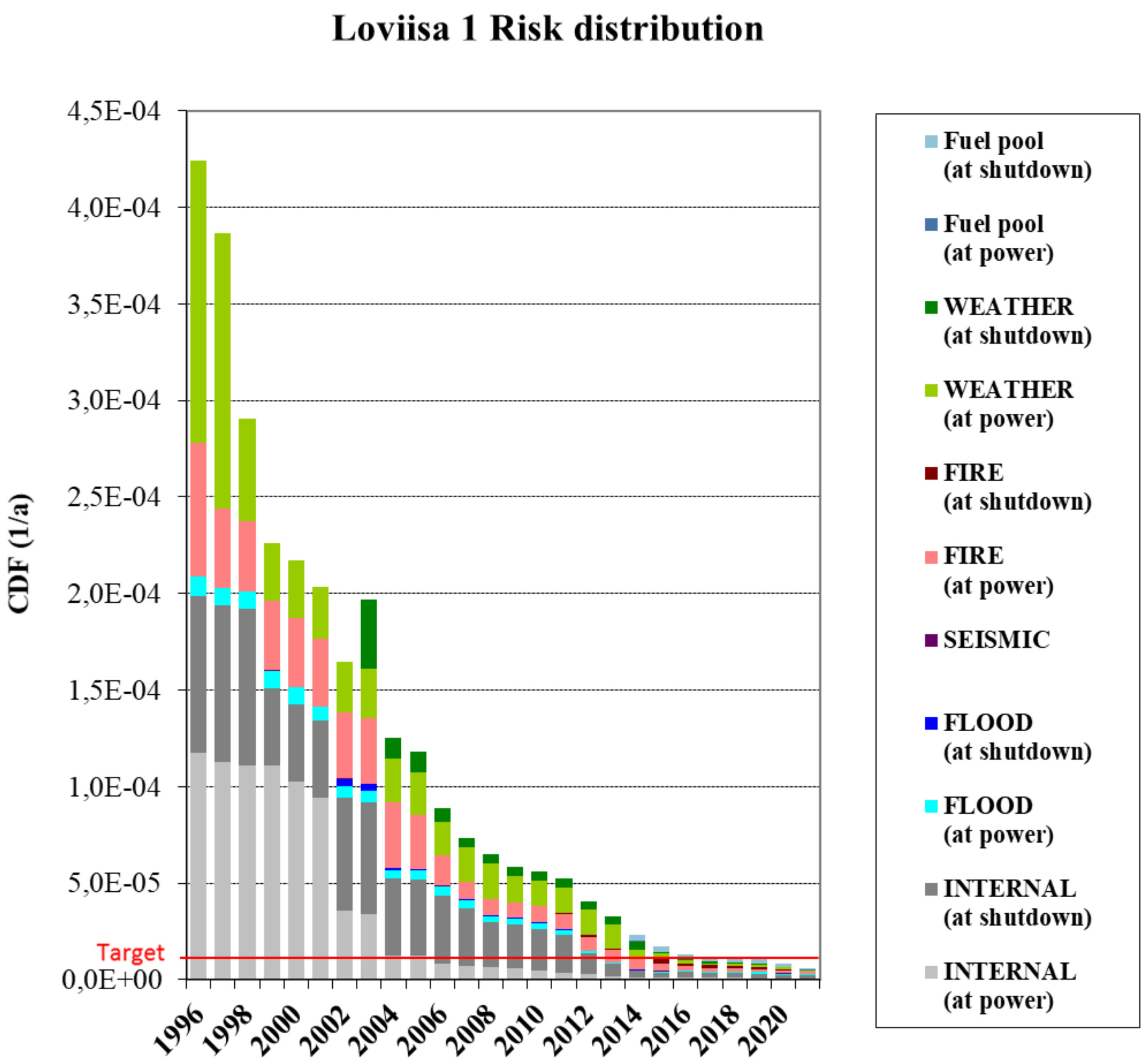
# Loviisa PRA

- Since early 1990's
- Includes
  - Level 1 and 2 PRA
  - Reactor, refueling pool, spent fuel storage
  - All operating and shutdown states
  - All types of initiating events
- Updated annually
- Significant upgrades to reduce risks

- Main source of initiating events for spent fuel storage risk analysis



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# Loviisa spent fuel storage PRA

- Details and background of Loviisa NPP SFS
- Loviisa SFS PRA analysis 2030 (2018, revised in 2021)
  - General scope
  - Results
  - Seismic initiating events
  - Need of further development



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# Loviisa spent fuel storage (SFS)

- Loviisa NPP spent fuel cycle:
  - 1. Refueling pool in reactor building 1 – 2 years
  - **2. Water pools in spent fuel storage 10 years – many decades**
  - 3. Final repository at Olkiluoto – First in the world, starting in few years

- History of Loviisa NPP SFS
  - About first 10 - 15 years of Loviisa NPP operation spent fuel was sent to Russia
  - After regulation changed Loviisa NPP needed to store more spent fuel at the site and expand the original SFS

- Two units in two buildings
  - SFS1 is original SFS: Build with same criteria as storage pools in reactor building
  - SFS2 has been build in two stages: 1981 … 1984 and 1996 … 1999
  - New upgrades or changes needed if Loviisa NPP continues operation after current license 2030

→Differences need to be taken into account in SFS PRA

# SFS PRA General scope

## Repair Consideration

- Recovery failure probabilities are calculated by formula EXP($-T_2/T_1$)
  - First row: Average time needed to recover ($T_1$)
    - Mainly based on engineering judgements
  - First column: Average time available to recover ($T_2$)
    - Based on heating power at maximum capacity of current license 2030
- Minimum value for recovery failure probability is 1E-6

| Time available $T_2$ | Time needed $T_1$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3 h | 6 h | 12 h | 24 h | 2 d | 4 d | 8 d |
| 1,5 h | 6.1E-01 | 7.8E-01 | 8.8E-01 | 9.4E-01 | 9.7E-01 | 9.8E-01 | 9.9E-01 |
| 3 h | 3.7E-01 | 6.1E-01 | 7.8E-01 | 8.8E-01 | 9.4E-01 | 9.7E-01 | 9.8E-01 |
| 6 h | 1.4E-01 | 3.7E-01 | 6.1E-01 | 7.8E-01 | 8.8E-01 | 9.4E-01 | 9.7E-01 |
| 12 h | 1.8E-02 | 1.4E-01 | 3.7E-01 | 6.1E-01 | 7.8E-01 | 8.8E-01 | 9.4E-01 |
| 24 h | 3.4E-04 | 1.8E-02 | 1.4E-01 | 3.7E-01 | 6.1E-01 | 7.8E-01 | 8.8E-01 |
| 2 d | 1E-06 | 3.4E-04 | 1.8E-02 | 1.4E-01 | 3.7E-01 | 6.1E-01 | 7.8E-01 |
| 4 d | 1E-06 | 1E-06 | 3.4E-04 | 1.8E-02 | 1.4E-01 | 3.7E-01 | 6.1E-01 |
| 8 d | 1E-06 | 1E-06 | 1E-06 | 3.4E-04 | 1.8E-02 | 1.4E-01 | 3.7E-01 |
| 16 d | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 3.4E-04 | 1.8E-02 | 1.4E-01 |
| 32 d | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 3.4E-04 | 1.8E-02 |
| 64 d | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 3.4E-04 |
| 128 d | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 | 1E-06 |

## Time windows/mission time

- From No time to recover
  - building collapse
- To 1 month (SFS1) or 2 month (SFS2)
  - stop of spent fuel pool cooling



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# SFS PRA General scope

## Success Criteria & End States

- Spent fuel rods are submerged
- Residual heat is removed by normal cooling system or by boiling and pool refilling
  - → Both are considered acceptable end states
  - → Lots of time to recover normal cooling system

## Criteria for results evaluation

- Fuel exposure or mechanical damage

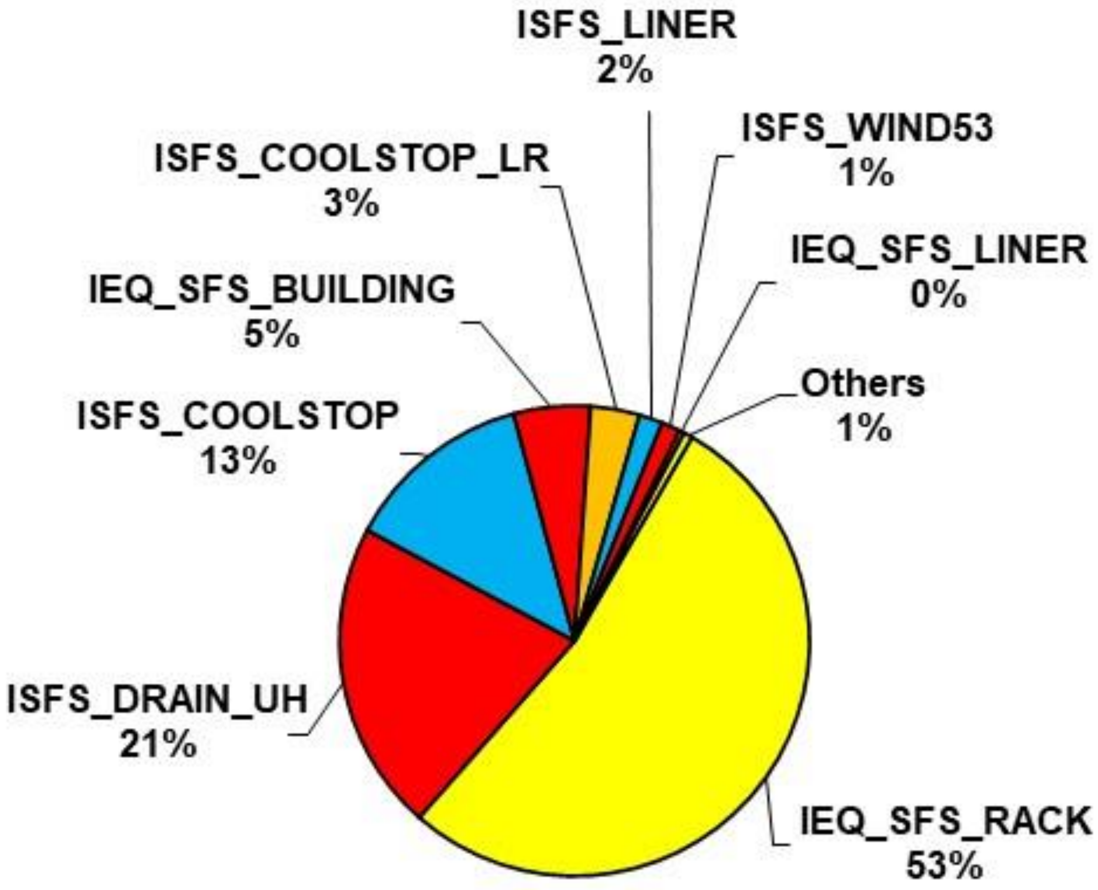
## Level 2 considerations

- Fuel damage is also large release
  - – No containment around SFS

# Spent fuel storage 1&2 PRA 2030 Analysis updated 02/2021

- SFS 1&2 Fuel damage frequency (FDF) 1,9E-7/a
  - 1 % of Lo1&2 ∑CDF
- SFS 1&2 Large release frequency (LRF) 1,9E-7/a
  - 2 % of Lo1&2 ∑LRF
- SFS 1&2 Early release frequency (ERF) 5,2E-8/a
  - 28 % SFS FDF
  - 10 % of Lo1&2 ∑ERF

| | |
|---|---|
| IEQ_SFS_RACK | SFS pool steel liner leak due to fuel rack movement and pool concrete structure crack due to EQ |
| ISFS_DRAIN_UH | SFS pool erroneous drainage due to operator error |
| ISFS_COOLSTOP | All SFS TG-cooling stop initiators (plant data) |
| IEQ_SFS_BUILDING | SFS building collapse due to EQ |
| ISFS_COOLSTOP_LR | SFS TG-cooling stop due to reactor CD and large release |
| ISFS_LINER | SFS pool liner leakage (plant data) |
| ISFS_WIND53 | High wind speed (>53 m/s) |
| IEQ_SFS_LINER | SFS pool liner and concrete structure leakage due to EQ |





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# Seismic initiating events

- Seismic initiating events cause 58 % of the total spent fuel storage fuel damage frequency
- Seismic initiating events like pool rupture or building collapse do not benefit low heating rate of the SFS like most of the other initiating events
- Most significant initiating event is fuel rack moving because of earthquake
  - Fuel rack rips steel liner while moving, earthquake cracks water leakages to concrete structures of the pool
  - Initiating event share from the total spent fuel storage fuel damage frequency is 53 %
- Collapse of the building because of seismic initiating event: 5,3 % of the total FDF
- Also some other seismic initiating events, mainly screened out or included in other events

# Spent fuel storage 1&2 PRA 2030 (updated 02/2021)
# Need of further development

- Most development needs are related to seismic initiating events

- SFS PRA is based on 2018 seismic hazard
- Seismic hazard was updated already late 2021 and it is slightly higher

→SFS PRA will be updated to consider the new seismic hazard

→SFS risks estimate increasing because of the seismic hazard update

- Loviisa NPP SFS has been built in three stages
  - Only some of the variations have been seismically evaluated: ¾ fuel racks, ½ buildings
  - Modelled with lowest known seismic capacities

→Uncertainties in SFS analysis are significant

→Absolute uncertainties are small compared to absolute uncertainties in reactor risk analysis



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# Thanks!

# Questions?