Olkiluoto 3 EPR
PSA Main results and conclusions – fulfillment of the regulatory requirements for operating license

Presented by: Heiko Kollasko – Framatome

Co-Authors:

Roman Grygoruk – AREVA

Gerben Dirksen – Framatome GmbH

Jari Pesonen, Lasse Tunturivuori, Antti Tarkiainen – TVO

Probabilistic Safety Assessment and Management PSAM
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OLKILUOTO 3 EPR MAIN FEATURES

OLKILUOTO 3 EPR NPP

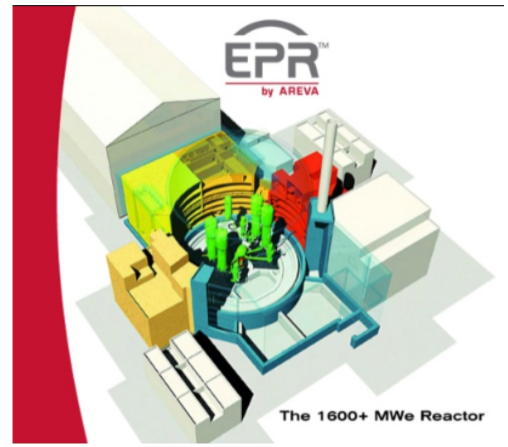
4 loop Pressurized Water Reactor 1600 MWe,
supplied by consortium of AREVA and Siemens to TVO

Safety approach consists of

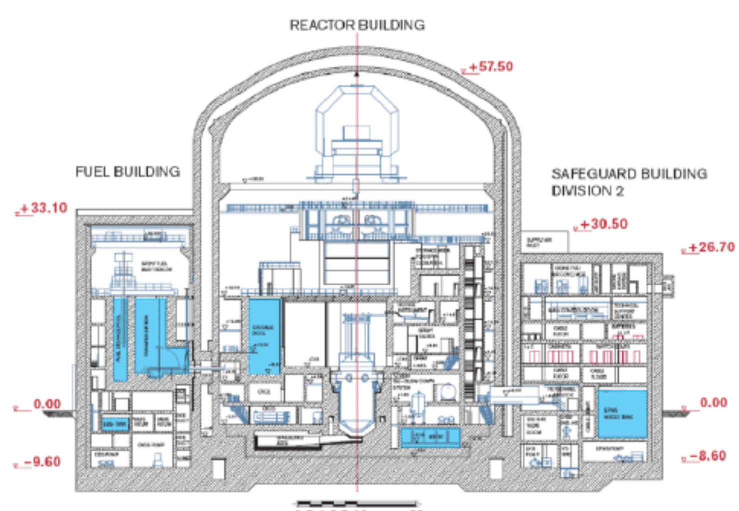
- improved preventive measures against accidents
- Mitigation features to cope with severe accident

Accident Prevention enforced by:

- Four redundant and geographically separated safeguard system trains (divisions)
- Diversity in system design and safety functions including back-ups to eliminate common mode failures
- Physical separation against internal & external hazards
- Increased grace periods for operator actions by large water inventories
- optimized man-machine interface by digital instrumentation and control systems
- Severe accidents are taken into account in the design



Nuclear Island building arrangement



REGULATORY FRAMEWORK

OL3 PSA
Regulatory Framework in Finland

- **Authority STUK supervises compliance with legislation and regulations**
- **Regulatory Guides on nuclear safety and security (YVL)**
- **YVL 2.8* - May 2003 – valid guideline for the operating license**
  „PROBABILISTIC SAFETY ANALYSIS IN SAFETY MANAGEMENT OF NUCLEAR POWER PLANTS“
  - **Requirements on a "PSA DURING THE DESIGN AND CONSTRUCTION OF A NPP"**
  - **Requirements on a "PSA DURING THE OPERATION OF NUCLEAR POWER PLANTS"**
  - **CONTENT AND DOCUMENTATION OF PSA**
  - **QUALITY MANAGEMENT**

→ Provides basic requirements on the scope and application of a PSA

* Replaced Nov 2013 by YVL A.7

OL3 PSA
Risk Application *

- **The Finnish YVL regulatory guide requires the use of the PSA during construction and commissioning by Risk-Informed application, e.g:**
  - In-Service Inspection (RI-ISI)
    “The PRA shall be used in the risk-informed development of the in-service inspection programmes of Safety Class 1, 2 and 3 as well as Class EYT system piping.”)
  - Periodic Testing (RI-PT)
    “The PRA shall be used in the risk-informed development of testing procedures for systems and components important to safety”
  - Technical Specification (RI-TS)
    “The PRA shall be used in the risk-informed development of the Operational Limits and Conditions (OLC) to assess their coverage and balance.”
  - Classification/categorization (RI-SSC)
    “The PRA shall be applied to determine the safety classification of structures, systems and components.”
  - Preventive Maintenance
    “The PRA shall be used … to develop preventive maintenance programmes”.
- **Furthermore the PSA shall be used for**
  - drawing up EOP and provide input for the staff training
  - provide potential risk related insides to the commissioning test phase and program

* See paper #162 on Lessons learned on RIA

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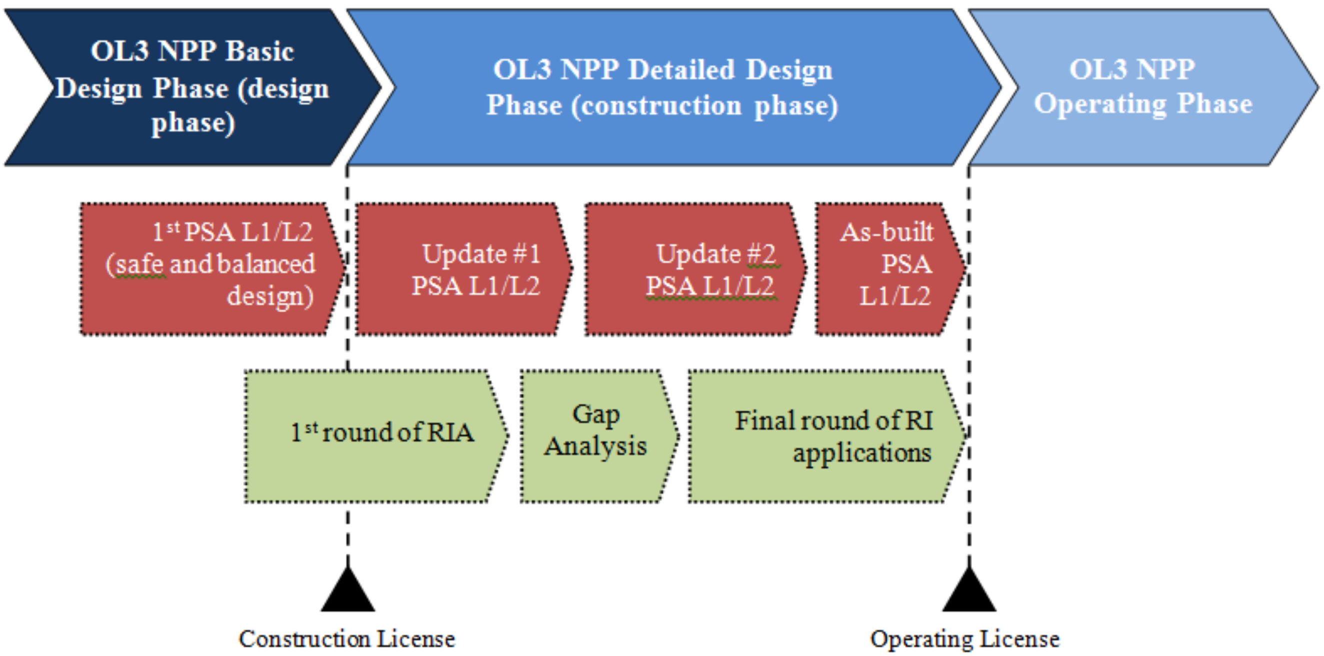
PROJECT EXECUTION



OL3 PSA
Project execution (1)

- **Design phase PSA**
  - A level 1 and 2 "Design phase PSA" is submitted for the application for construction license (CLA)
  - RiskSpectrum model (2004)
- **Detailed design phase**
  → contineous update of the PSA
  - to support the detailed design
  - to form a basis for the "Construction phase PSA"
  - Intermediate FinPSA model releases for reference configurations (e.g 2009, 2010, 2015
- **Construction phase PSA**
  - A level 1 and 2 "Construction phase PSA" is submitted for the application for operating license (OLA)
  - Releases 2015 + 2016 with an Extended Fire PSA and a conservative and realistic model
  - Last release in 2018 (update concerning design reference configuration integration authority comments on OLA PSA)

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OL3 PSA
Project execution (2)

- **Determination of methods on different topics in specific methodology reports**

  → included a STUK Review + Approval

  - **PSA**
    - internal flooding und internal fire
    - Common Cause Initiator
    - HRA
    - Seismic PSA plan
    - Developing of Seismic Fragilities
    - Consideration of spurious signals in PSA
  - **PSA based risk application**
    - Probabilistic Review of Safety Classification
    - Risk-informed Periodic Testing
    - Risk-Informed Technical Specifications
    - Risk informed Pre-Service and In-Service Inspection Methodology

→ ***Securement of the progressing PSA work for the final license process***

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TARGETS

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OL3 PSA Targets

- **According to the Government Resolution (395/1991) referred in YVL 2.8, *accidents leading to large releases of radioactive materials shall be very unlikely***
  - **In YVL2.8 the following numerical design objectives for the whole nuclear power plant are given**
    - The **mean value of the probability of core damage** is less than **1E-5/a**
    - The **mean value of the probability of a release exceeding the target value** defined in section 12 of the Government Resolution (395/1991) must be smaller than **5E-7/a**.
    - Definition of **large release**:
      - Atmospheric release of **cesium-137** exceeding **100 TBq**

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SCOPE AND MODELLING

OL3 PSA Scope

- **Level 1 and Level 2 PSA**
- **Plant operating states: at-power and shutdown**
- **Spectrum of initiating events :**
  - **Internal events: (e.g Transients; Secondary side breaks; LOCA)**
  - **Common cause initiators (based on screening analysis);**
  - **Internal hazards:**
    - Internal Fire;
    - Internal Flooding;
    - Load drop;
  - **External hazards:**
    - Seismic events
    - other external events (based on a screening analysis)
  - **Events affecting the heat removal from the spent fuel pool**

OL3 PSA Modeling

- **System modeling is based Failure Mode and Effects Analysis (FMEA) which includes**
  - Component failures by their specific failure modes,
  - Failure of dependencies
    - power supply of the component (electrical power supply, compressed air)
    - signals for actuation,
    - auxiliary systems (e.g. cooling water, room cooling, lubrication oil supply) ,
- Additionally fault tree modeling includes:
  - Scheduled test and maintenance unavailability of the component
  - Common cause failures
  - Human errors (pre-accident and post-accident)
  - Unavailability of components due to the initiating event (e.g. CCI and Hazards like fire, flooding)
  - undesired (spurious) emission of signals

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Modeling of I&C

- **Based on FMEA for I&C systems**
- **I&C reliability analyses to verify unavailability targets:**
  - Detailed FT-Modelling of I&C functions with basic events on hardware module level
  - modelling of software failure modes
  - Provides the basis for the I&C modelling in the PSA
- **Compact modelling of I&C in the PSA**
  - super components sub fault trees to create super-component basic events representing the failure of I&C system units
    - Not directly linked to the PSA model
    - Provide the failure probability for the I&C super-component basic events in the PSA
  - Super-components are then used for the I&C Fault tree modelling in the PSA (detected and undetected failures),
    - Signal conditioning
    - Processing units
    - Explicit modelling of dependencies on power supply, HVAC and indications in the control room for Diagnosis tasks

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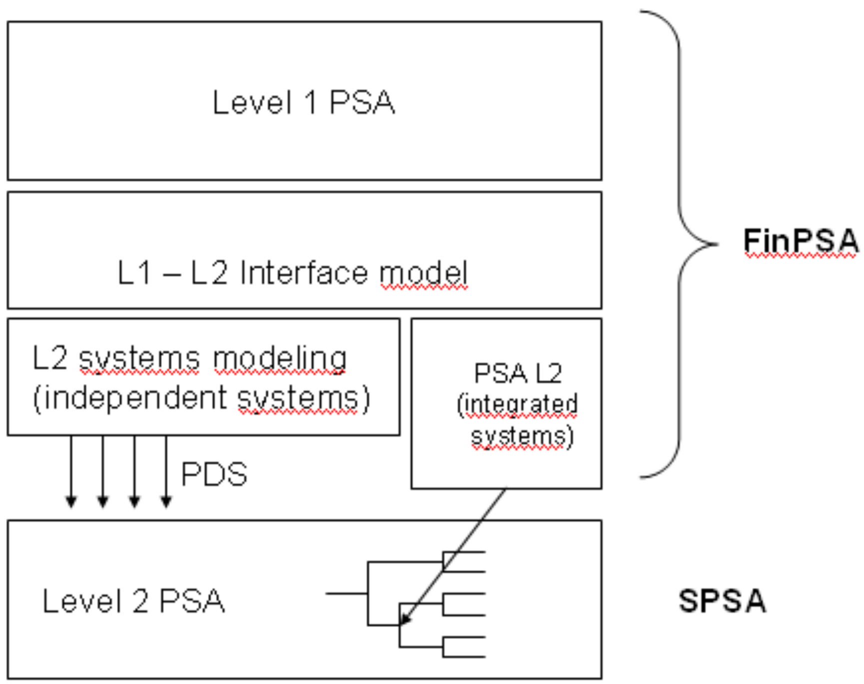
Treatment of uncertainties

- Quantitative based on the uncertainty distributions of parameters
  - initiating event frequencies
  - component failure rates
  - Parameters on common cause failures
  - Human error probabilities
- Qualitative
  - Discussion of modeling uncertainties (assumptions and simplifications)
    → includes an evaluation of the impact on the result
  - Tracking of model modifications with the reasoning and evaluation of the impact on the result
- Sensitivity analyses for the major uncertainties on modeling assumptions, methods and data e.g:
  - CCF Modelling according to US NRC MGL parameters versus EUR
  - Consideration of multiple spurious operations due to software failures
  - Sensitivity studies on assumptions made for ATWS modeling
  - Sensitivity studies on assumption in Fire PSA

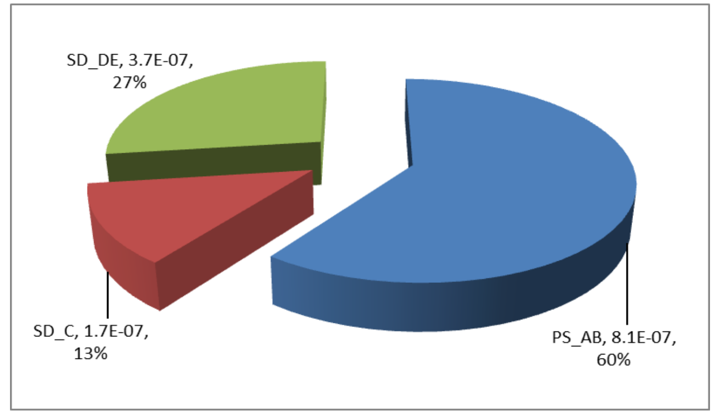
Level 2 PSA

- Non-integrated approach consisting of 3 parts:
  - Level 1 PSA model
  - Level 1 – Level 2 PSA interface model
  - Accident progression event tree model

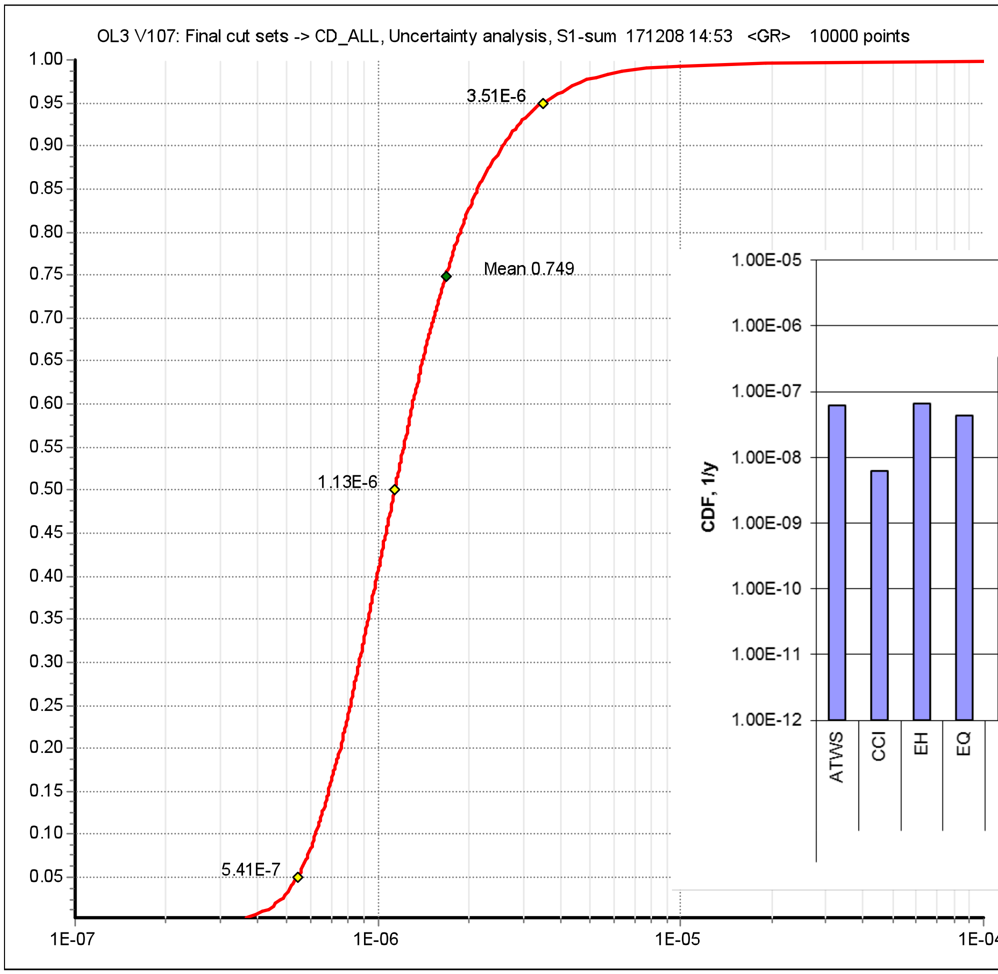


- Advantages:
  - modeling of the substantial uncertainties related to severe accident phenomena
  - possibility to calculate path-dependent source terms within the event tree model
  - exact quantification for large branch probabilities

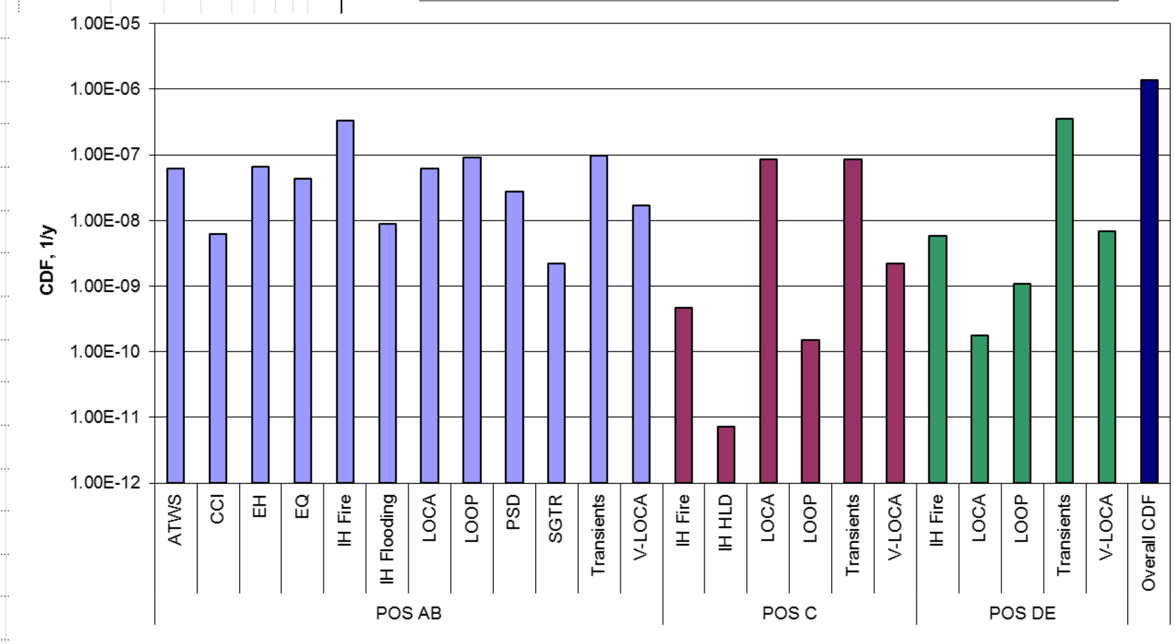
RESULTS



SD_DE, 3.7E-07, 27%
SD_C, 1.7E-07, 13%
PS_AB, 8.1E-07, 60%



OL3 V107: Final cut sets -> CD_ALL, Uncertainty analysis, S1-sum 171208 14:53 <GR> 10000 points
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
3.51E-6
Mean 0.749
1.13E-6
5.41E-7
1E-07
1E-06
1E-05
1E-04



CDF, 1/y
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
ATWS
CCI
EH
EQ
IH Fire
IH Flooding
LOCA
LOOP
PSD
SGTR
Transients
V-LOCA
IH Fire
IH HLD
LOCA
LOOP
Transients
V-LOCA
IH Fire
LOCA
LOOP
Transients
V-LOCA
Overall CDF
POS AB
POS C
POS DE

OL3 PSA Results *

- **Core damage frequency of the Level 1 PSA :**
  - **Mean value:** **1.7E-06/a**
    (Percentiles: 5% → 5.4E-7, 50% →1.1E-6, 95% → 3.5E-06)
  - **Point estimate:** **1.4E-06/a**

- **Fuel damage frequency (fuel pool events):**
  - **Mean value – 2.2E-08/a**

- **Large release frequency Level 2 PSA**
  - **Mean value (includes core and spent fuel pool)**

    (over 100 TBq of Cs-137) 7.7E-08/a,

  - **Core related ca 72%; spent fuel pool related ca 28%.**

* 2018 Release

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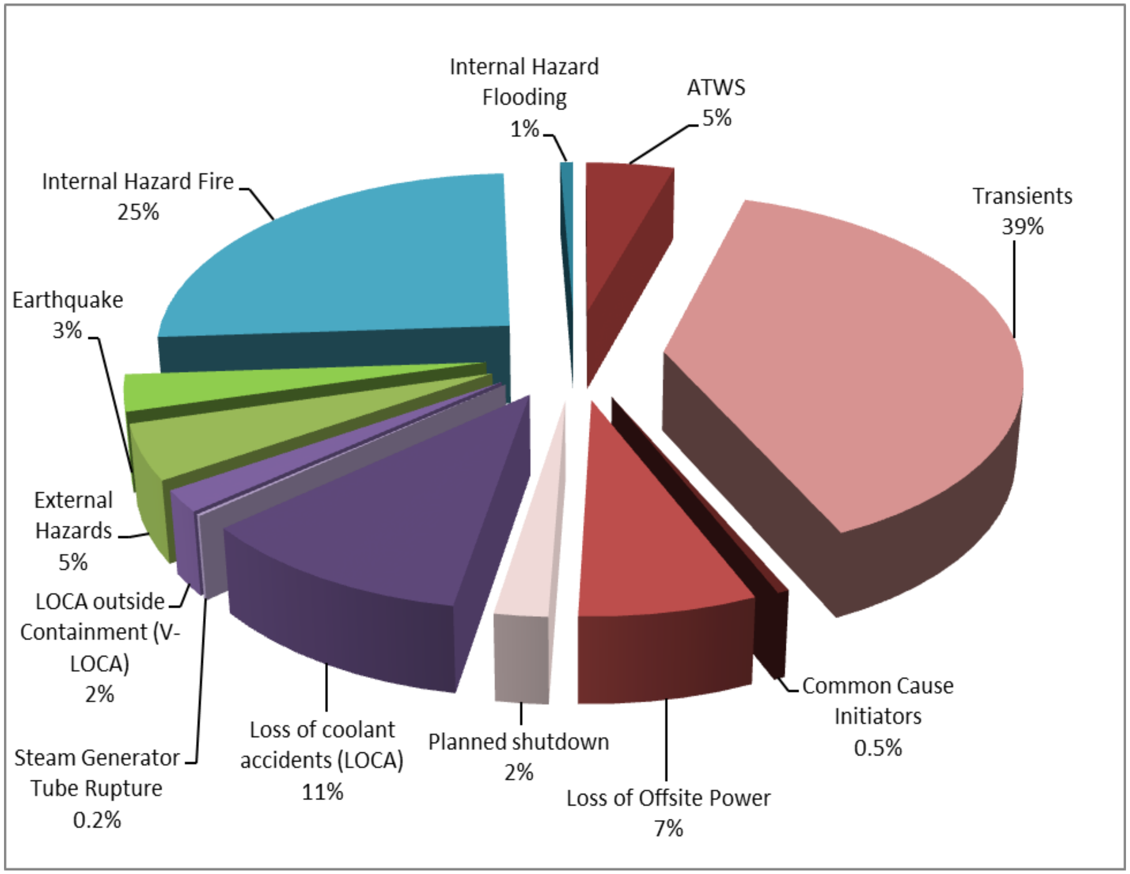
OL3 PSA
Main contributors to CDF



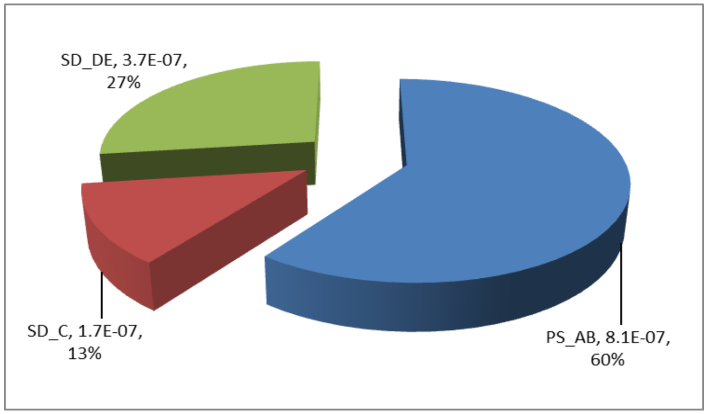
Internal events (Transients and LOCA) **66%**

Internal Hazards **26%**

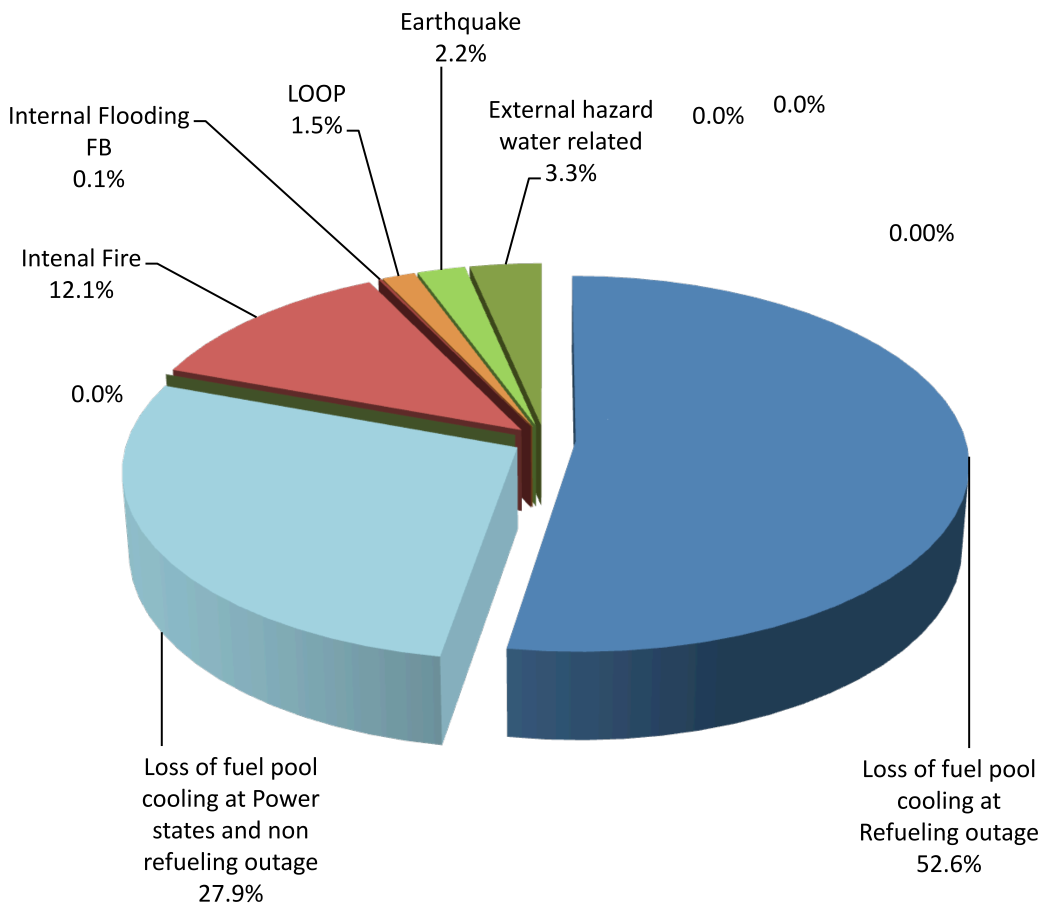
External Hazards **8%**

Power operation **60%,**

Shutdown states
with RPV closed **13%,**
with RPV open **27%**



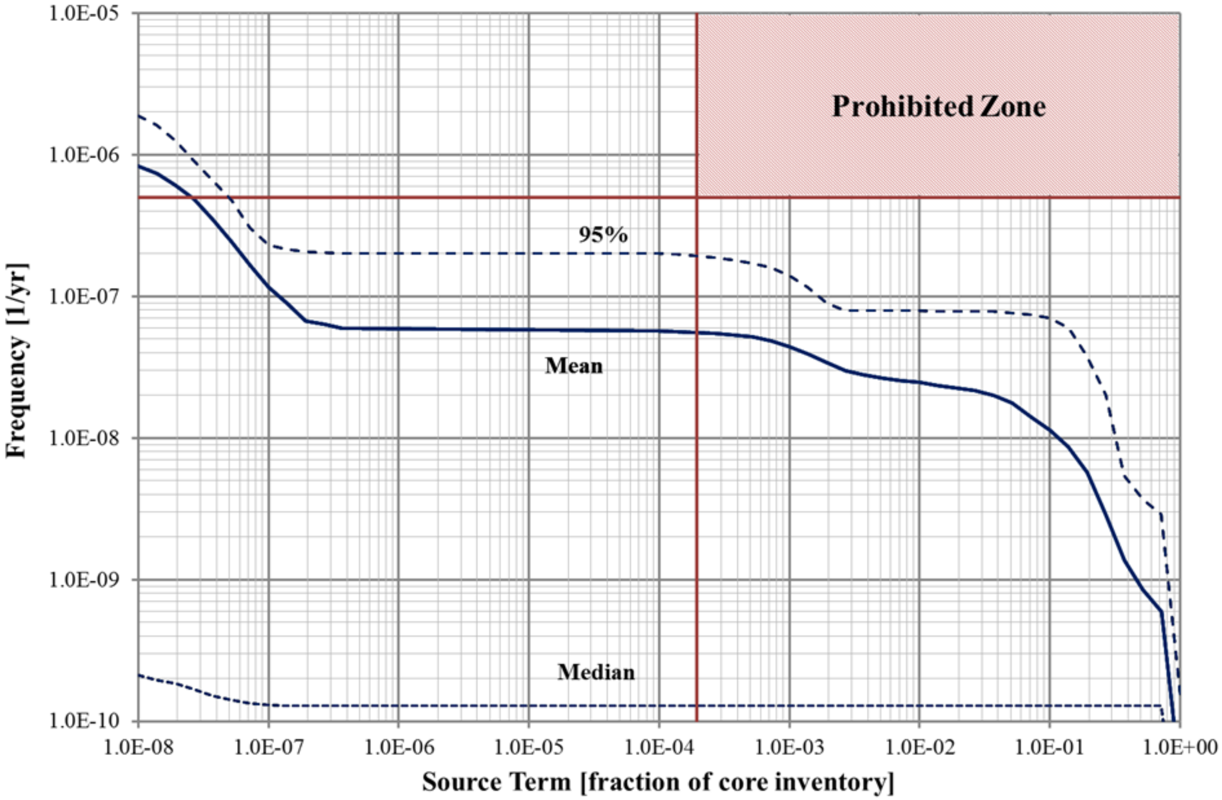
Relative contribution of events leading to fuel damage



Power operation and non refueling outage 47%,

Refueling outage 53%,

OL3 PSA
Release Frequency versus Cs-137 source term



- The prohibited zone is restricted by Guide YVL 2.8, where the frequency of releases exceeding 100 TBq of Cs 137 must be less than 5E-7 /a.

*) Basis 2017

OL3 PSA Conclusion

- Continuous update of PSA from the beginning of the Project to correspond to the progression during detailed design and provide insights to the design
- Results used to verify the plant design as well as verify/optimize operating and maintenance procedures and commissioning program by RI applications
- Latest PSA update was submitted to the regulatory body (STUK) in 2018 as part of the operating license application
  - Full scope PSA concerning spectrum of initiating events, plant operating states and modelling of systems (including dependencies)
  - Demonstration that the core damage frequency and the frequency of large releases is well below the target values required by finnisch regulation

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Thank You

Heiko.Kollasko@framatome.com

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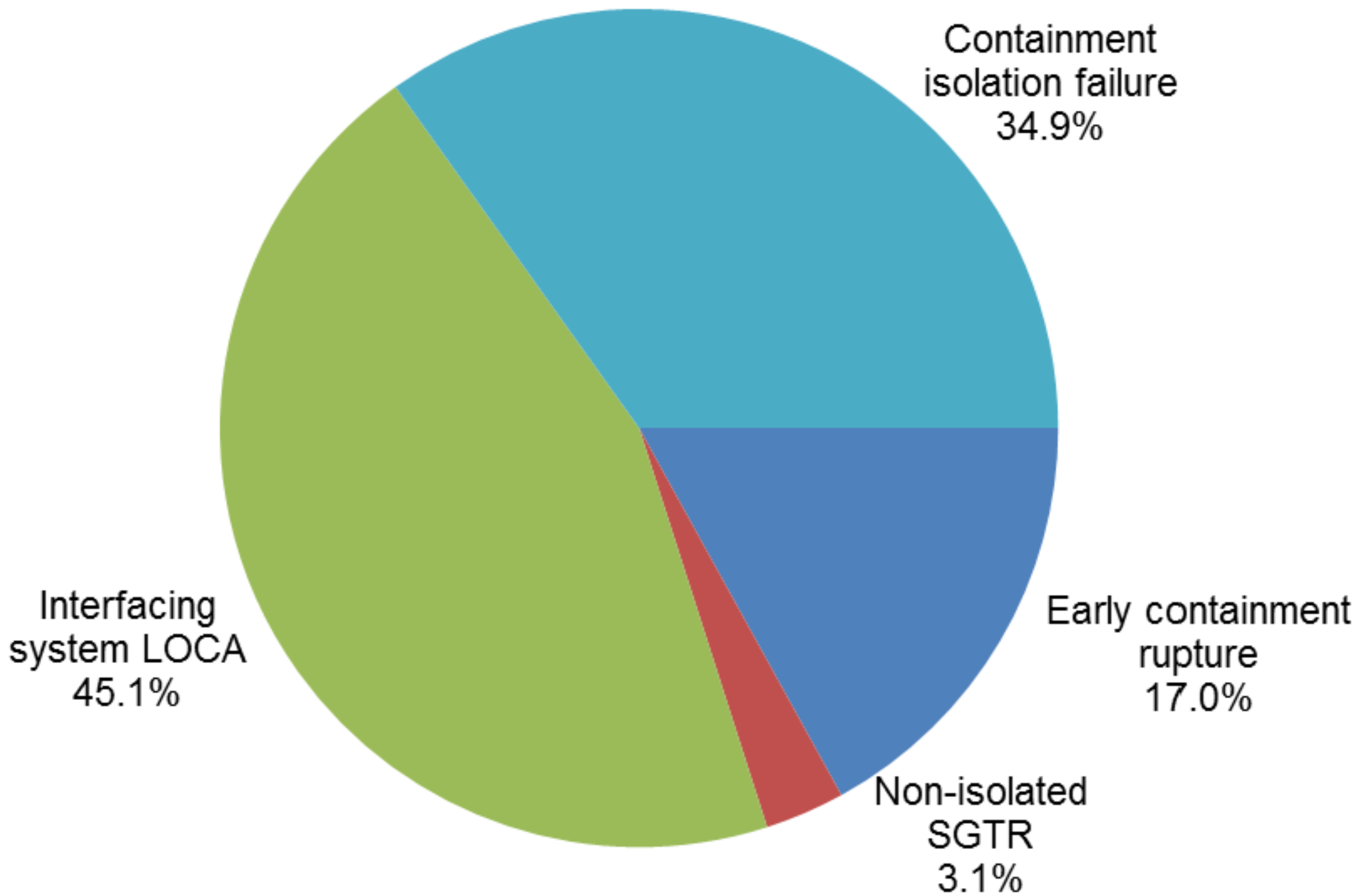
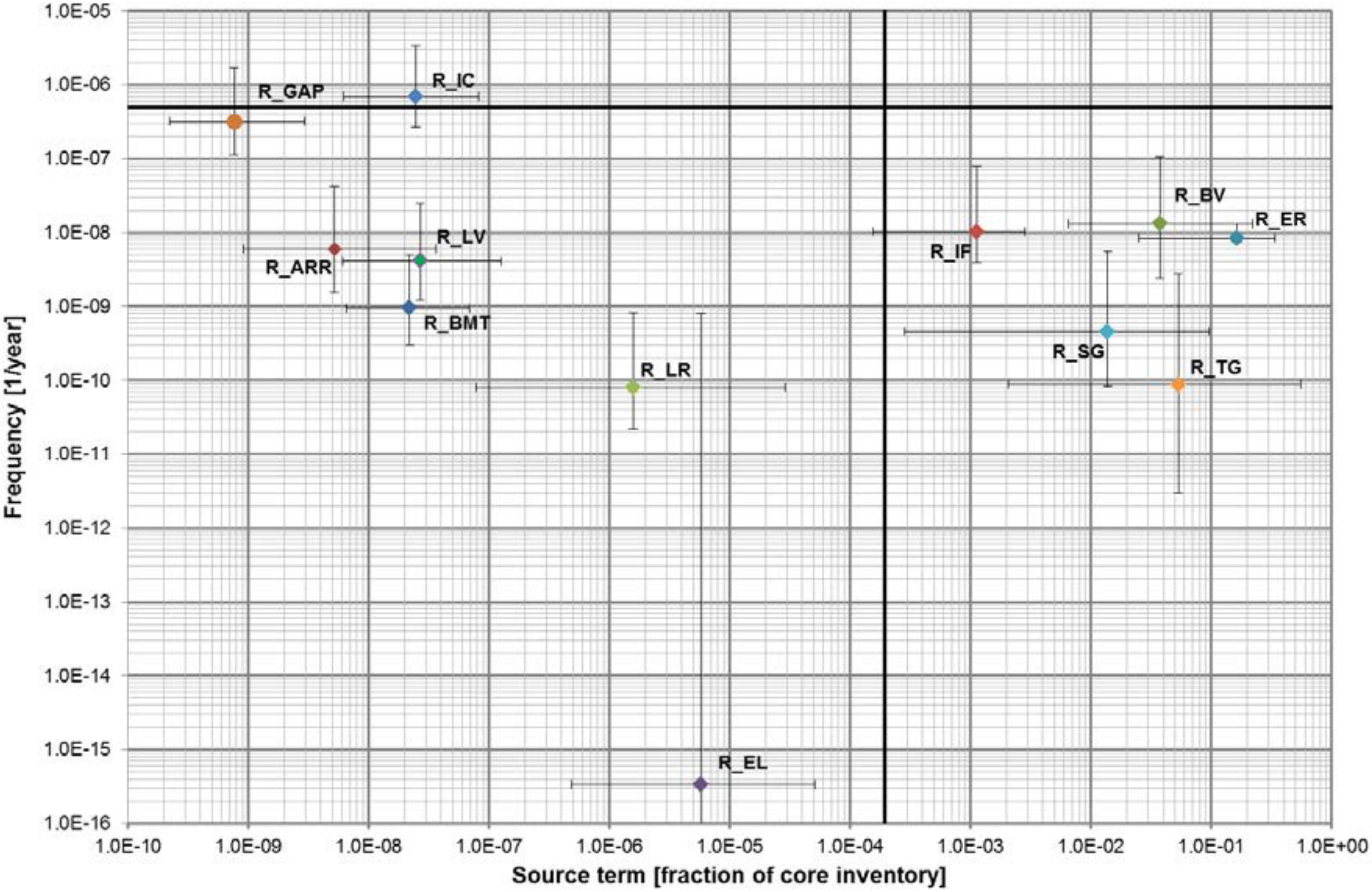
Back up

DISTRIBUTION OF LARGE RELEASE BINS



CS 137

FREQUENCY VERSUS SOURCE TERM, NON CUMULATIVE



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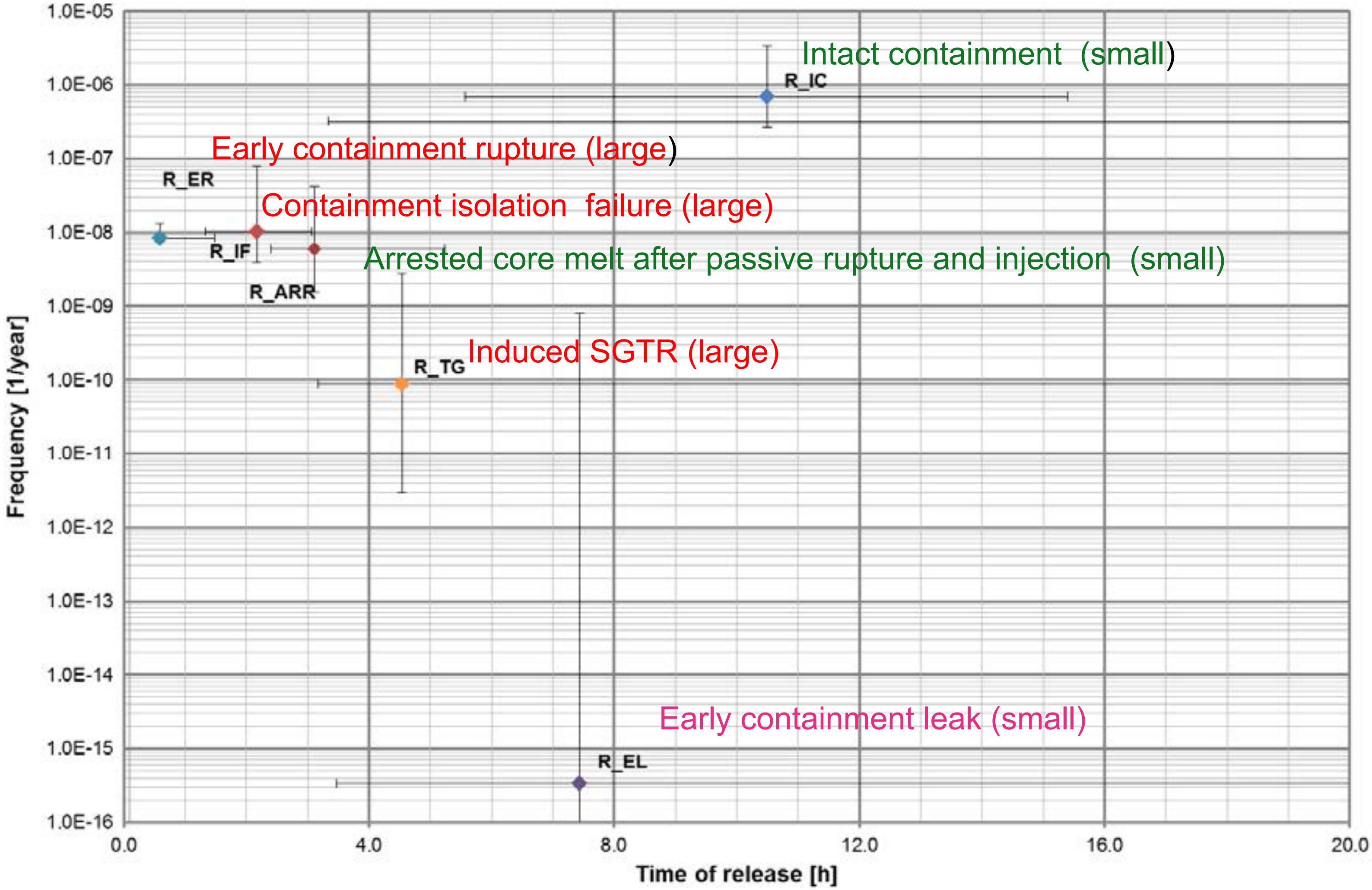
FREQUENCY VERSUS TIME OF RELEASE, Early (first 20h)



Component reliability data

- Reliability data assessment on **failure rates** including **uncertainty distributions** based on operating experience taken from reference plants N4 (France) / KONVOI (Germany)

If applicable for the respective equipment use of:

- Germany – ZEDB (centralized reliability data base)
- French data – EIReDA data base

Otherwise use of other data sources e.g:

- Nordic failure data provided in T-Book
- US operating experience

Modeling of Human actions

- Identification of relevant operator actions by a multidisciplinary HRA team
- Types of human action considered in the PSA:
  - Post IE errors on tasks required after an initiating event:
    - Automatic protection design precludes any need of operator action within the first 30 minutes after accident initiation
    - Post-IE operator failure relevant
      - the plant has to be brought into a safe shutdown condition in the longer term,
      - beyond design conditions due to failure of safety system functions,
  - Pre-IE errors during maintenance and repair (e.g wrong position of valves; miscalibration of measurements)
  - Inadvertent plant personnel performance may lead to initiating events,
    - errors of this type are of interest especially in the shutdown PSA
- THERP (Technique of Human Error Rate Prediction) method used to predict human error probabilities
  - very detailed analysis method using the decomposition of task (diagnosis and action)
  - recommended for NPP applications in several guidance, e.g European Utility Requirements and German PSA Guidelines

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