EC JRC Network on Use of PSA for the Evaluation of Ageing Effects on the Safety of Energy Facilities. Activities and results.

Andrei Rodionov,

Nuclear Design Safety Unit, EC JRC Institute for Energy, Petten, Netherlands,

Milan Patrick

Nuclear Research Institute, Rez, Czech Republic.

http://safelife.jrc.nl/APSA

1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
4. Conclusions

Motivations :

- NPPs are getting older
- Probabilistic safety goals have to be maintained for the LTO
- Application of Risk Informed Regulation

Questions :

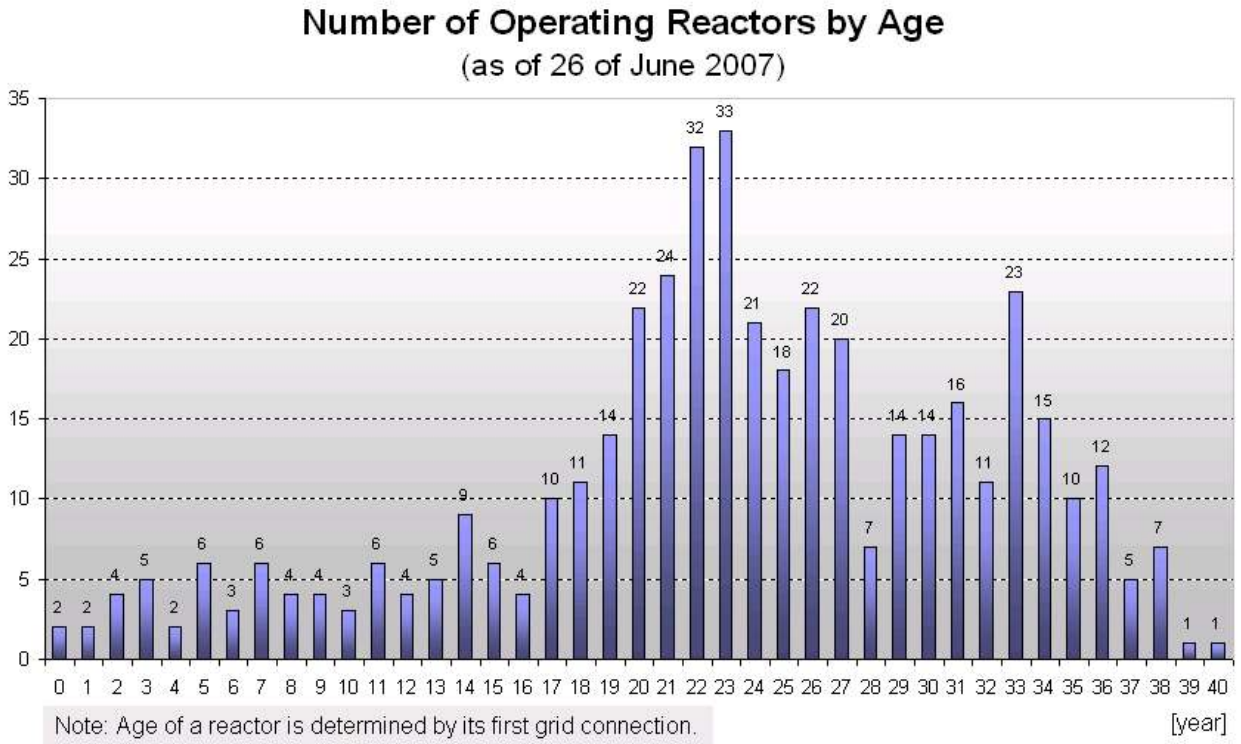
- Could PSA be applied to ageing assessments?
- How realistically do PSA models reflect important ageing issues?
- Are any modifications or revisions of PSA assumptions needed to apply a PSA approach to risk-informed decision-making with regard to ageing evaluation?
- What data are available and how representative are they with regard to important ageing issues?

Actual situation :

- **115 units** in operation are between **30** and **40** years old,
- **213** are between **20** and **30** years old,

In total : about 3/4 of the 438 reactors operated worldwide.

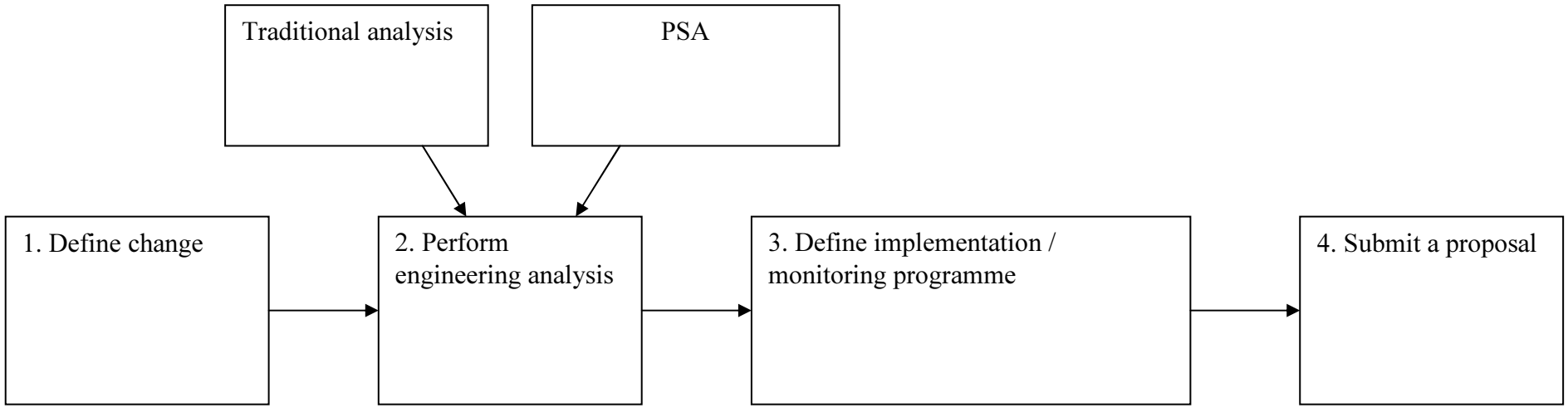
Long-term operation : on July 2006, **1/2** of the licensed NPPs in US had received or were under review for **license renewal**

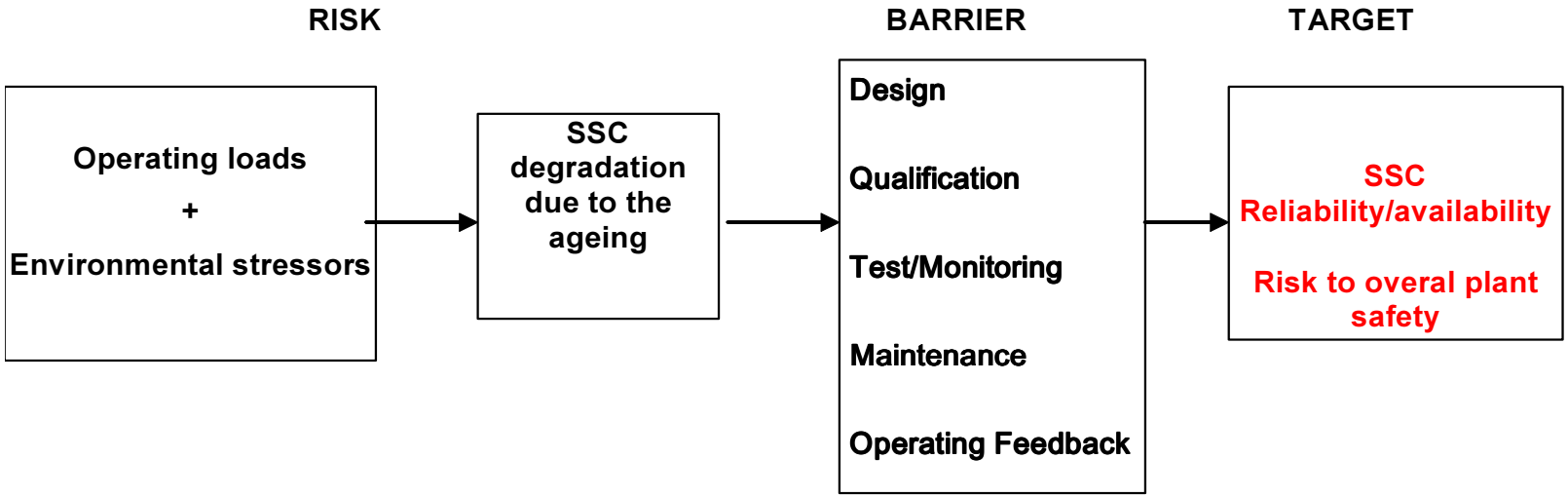


- Probabilistic Safety Goal (INSAG-12) :

  *"The target for existing nuclear power plants consistent with the technical safety objective is a frequency of occurrence of severe core damage that is below about **10–4 events per plant operating year**. Severe accident management and mitigation measures could reduce by a factor of at least ten the probability of large off-site releases requiring short term off-site response."*

- Risk Informed Regulation





Ageing effect on unit/SSC reliability and safety

Main activities related to the ageing management :

- Aging management
- Life time extension
- Surveillance and Maintenance optimisation

Current situation

- ✓ **Standard PSA tools do not adequately address important ageing issues as :**
  - **assumption on component reliability model λ=const,**
  - **reliability data may not adequately represent the current status of the plants,**
  - **existing PSAs overlook some components (e.g. cables, structures, etc.) as having a very low failure probability, but they may have increasing weight due to ageing effects.**

- ✓ **Limited experience with applying of PSA approach to evaluate ageing effects :**
  - **no commonly accepted methods,**
  - **all the studies are performed by relatively isolated organisations,**
  - **and publications on the subject are scarce.**

1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
4. Conclusions

EC JRC Network on Aging PSA : goals, tasks, working approach

Objectives :

Using common resources of Network participants to identify, develop and demonstrate methods and approaches which could help PSA developers and users

- **to promote the use of PSA for ageing management and risk-informed applications of Nuclear Power Plants,**
- **to incorporate the effects of equipment ageing into current PSA models to perform engineering analysis,**
- **in case where age-dependent PSA couldn't be applied (absence or non-adequacy of ageing probabilistic model, lack of data, etc.), to specify and prioritize reliability monitoring actions/approach to assure that potential decreasing of reliability of SSC would be identified and corrected in time**

EC JRC Network on Aging PSA : goals, tasks, working approach

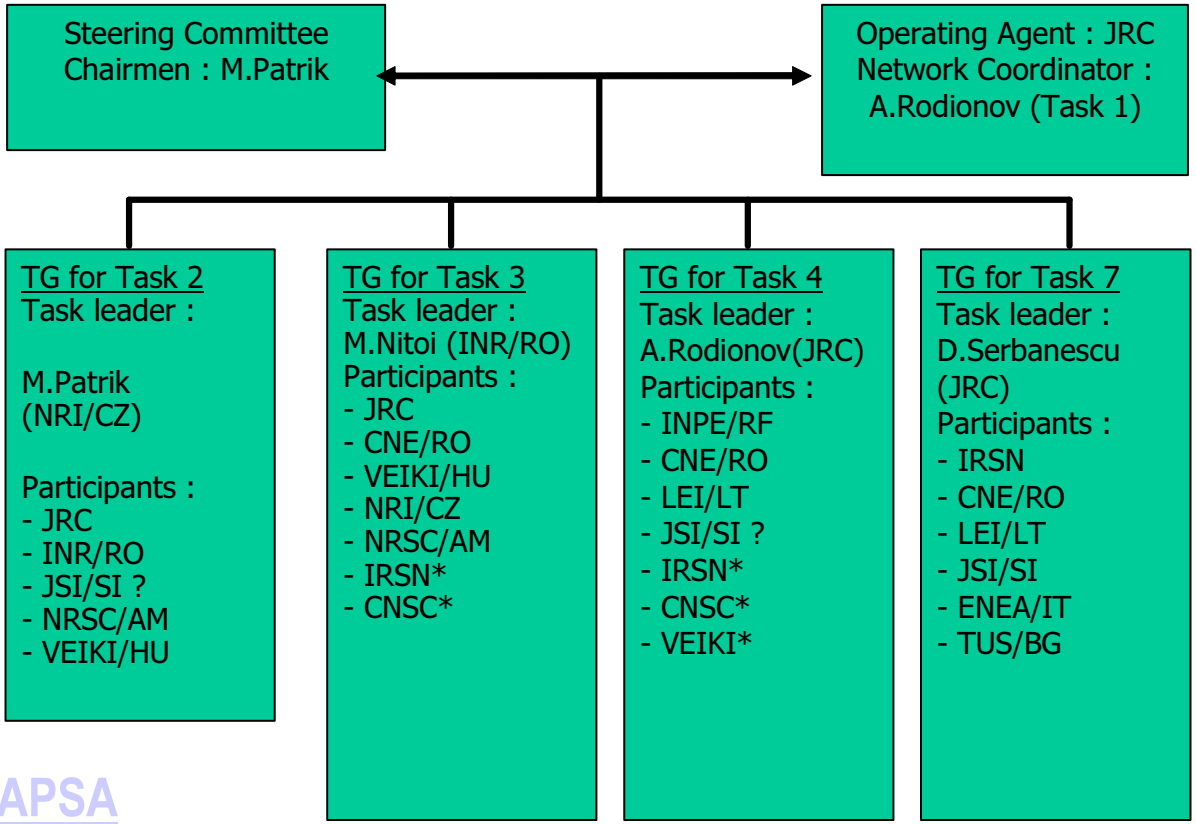
Main tasks : (Terms of references EUR 22645 EN)

- **Task 1. Organization and coordination of network activities.**
- **Task 2. Analysis of main PSA tasks with regards to Ageing PSA (in progress).**
- **Task 3. Selection of the SSC to be considered in Ageing PSA (in progress).**
- **Task 4. Reliability and data analysis for active components (in progress).**
- **Task 5. Reliability and data analysis for active components II. Common Cause Failures.**
- **Task 6. Reliability and data analysis for passive components.**
- **Task 7. Incorporation of age-depended reliability parameters and data into PSA model (in progress).**
- **Task 8. Ageing PSA development and applications.**

EC JRC Network on Aging PSA : goals, tasks, working approach

Participants :

- **14 organizations from EC MS, Swiss, RF, Armenia and Korea (network agreement). In addition, active participation from CNSC/Canada, INL/USA, NMRI/Japan.**



Network Operation :

- **Working groups**
- **Case studies and benchmark exercises,**
- **Steering Committee,**
- **Expert meetings,**
- **Workshops**
- **Web site : http://safelife.jrc.nl/APSA**

Ageing PSA Workshops :

- **APSA 2005** : International workshop on *"Practical applications of age dependent reliability models and analysis of operational data"*, IRSN, Fontenay aux Roses, France. EUR 21862 EN

- **APSA 2006** : EC E&I Workshop on *"Use of PSA for Evaluation of Impact of Ageing Effects on the Safety of NPPs"*. 2-4 October 2006, Bucharest, Romania. EUR 22514 EN

- **APSA 2007** (planned) : EC E&I Workshop on *"Use of PSA for Evaluation of Impact of Ageing Effects on the Safety of NPPs"*. 15-16 November 2007, Budapest, Hungary.

1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
   - Analysis of main PSA tasks with regards to Ageing PSA.
   - Selection of the SSC to be considered in Ageing PSA.
   - Reliability and data analysis for active components.
4. Conclusions

Activities and results : Analysis of main PSA tasks with regards to Ageing PSA (Task 2)

Topics under consideration :

State of the art and possible application of PSA results in the Ageing related activities :

- **PSR,**
- **Ageing Management,**
- **Lifetime Extension.**

Main directions of PSA applications on Ageing related activities (proposed) :

- **as a tool to demonstrate and monitor the current level of safety,**
- **in predictive risk evaluation.**

Developments and modifications needed

- **expert evaluation of main PSA tasks with regards to the modifications or revisions of PSA assumptions and models that could be needed to consider ageing issues in PSA**

PSA task / issue	Possible modifications in PSA
1. Definition of scope, objective of the study	
Level of detail	Depending on the specific application the level of detail could be revised. For example, for a risk-informing application, PSA has to be sufficient to characterise or/and model the impact of the relevant ageing issue. The specification of the problem should include establishing a cause-and-effect relationship to identify portions of the PSA affected by the issue being evaluated.
Scope of SSCs to address ageing effects	The selection of SSC to be modelled in Ageing PSA is not easy. The starting points could be the results of deterministic analysis performed under the Ageing Management programme, reliability trend assessments and the risk importance of SSC evaluated using the existing PSA model.
2. Initiating events analysis	
New initiators	"New" initiators may become important that may previously have been excluded due to low likelihood. Examples could include pipe breaks or flooding scenarios that were thought to be unlikely.
Initiator assumptions	Since ageing could incorporate failure modes or mechanisms not previously addressed, it is important to review the existing PSA initiator assumptions. Initiators that have been grouped (e.g., transients, main steam line breaks) may need to be broken out. New groups could be built up based on new common assumptions.

1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
   - Analysis of main PSA tasks with regards to Ageing PSA.
   - Selection of the SSC to be considered in Ageing PSA.
   - Reliability and data analysis for active components.
4. Conclusions

Proposed approaches

- **Risk Importance Factors :**

  (?) reflect the current/reference PSA and unit state, but ageing could change the importance of SSC,

- **Analysis of ageing trends :**

  (?) data collection covers only risk important components => no data available for all components potentially susceptible to ageing;
  also for many components statistical data are not enough,

- **Qualitative/expert assessments of ageing :**

  (?) systematic qualitative assessment based on expert evaluations, but very time consuming.

1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
   - Analysis of main PSA tasks with regards to Ageing PSA.
   - Selection of the SSC to be considered in Ageing PSA.
   - Reliability and data analysis for active components.
4. Conclusions

Possible sources of data :

- reliability **data for NPPs** (generic and/or specific),
- reliability data for similar components from **other industries**,
- accelerated ageing **reliability tests.**

Reliability data from fossil plants 20-40 years old (NERC and VGB data)

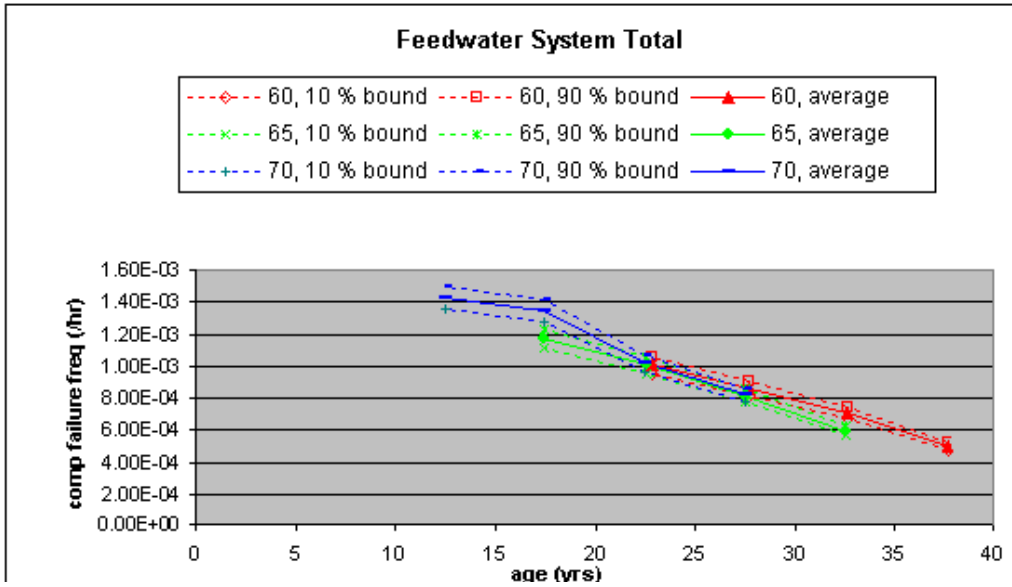
Main conclusions

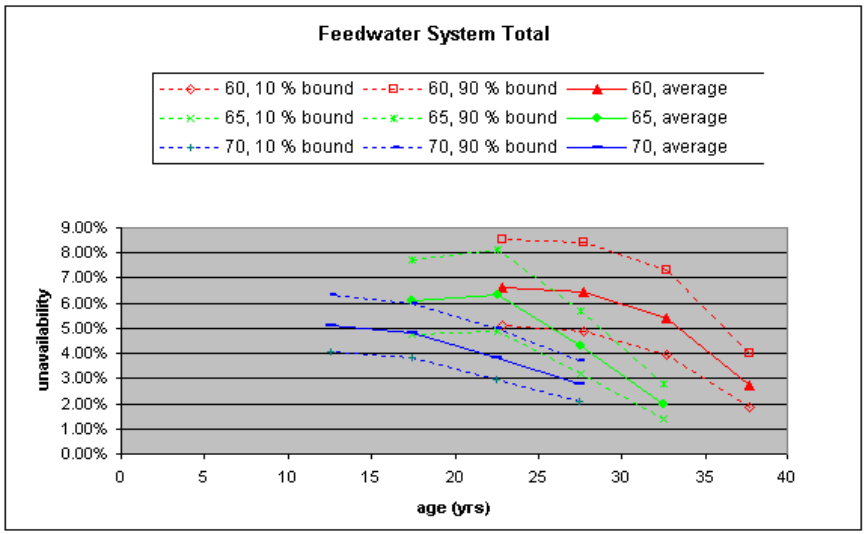
In general (good news), with age plants "learn" : availability and performance increase or maintained constant with the age of the plant

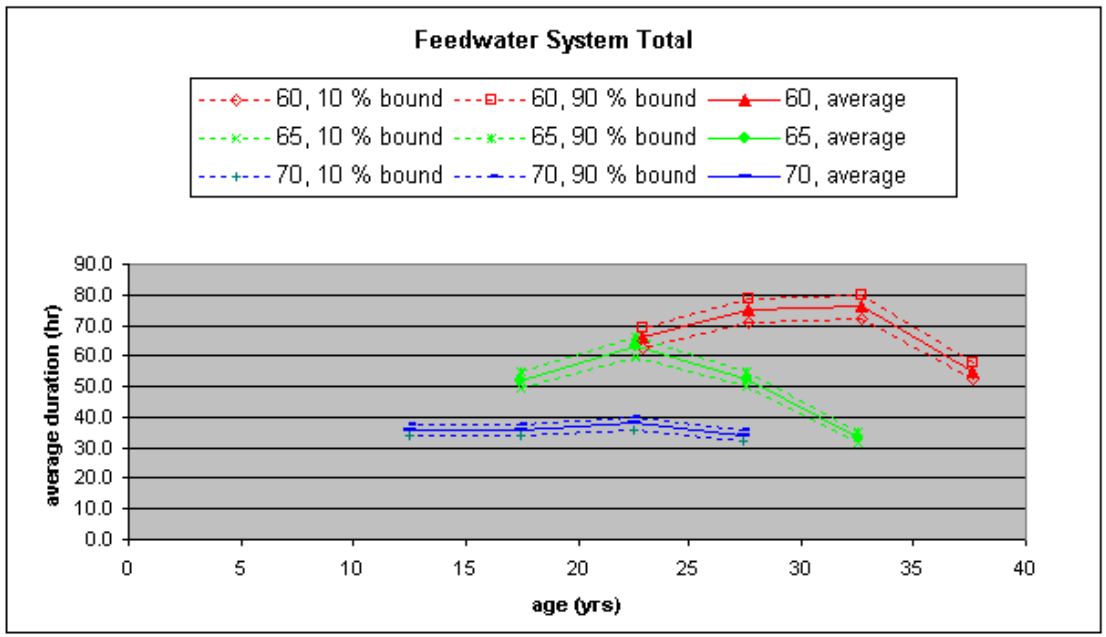
Particular cases of ageing :

- **increasing failure rates are identified for several types of components as pumps, funs, valves, switchers, boilers, heaters, etc. (ageing parameters for linear aging model are comparable with TRIGALEX data);**
- **"minimal repair" maintenance strategy could lead to increase in failure rate;**
- **even with decreasing or constant failure frequency, reliability of component could degrade with age because of increasing of repair frequency and its duration.**

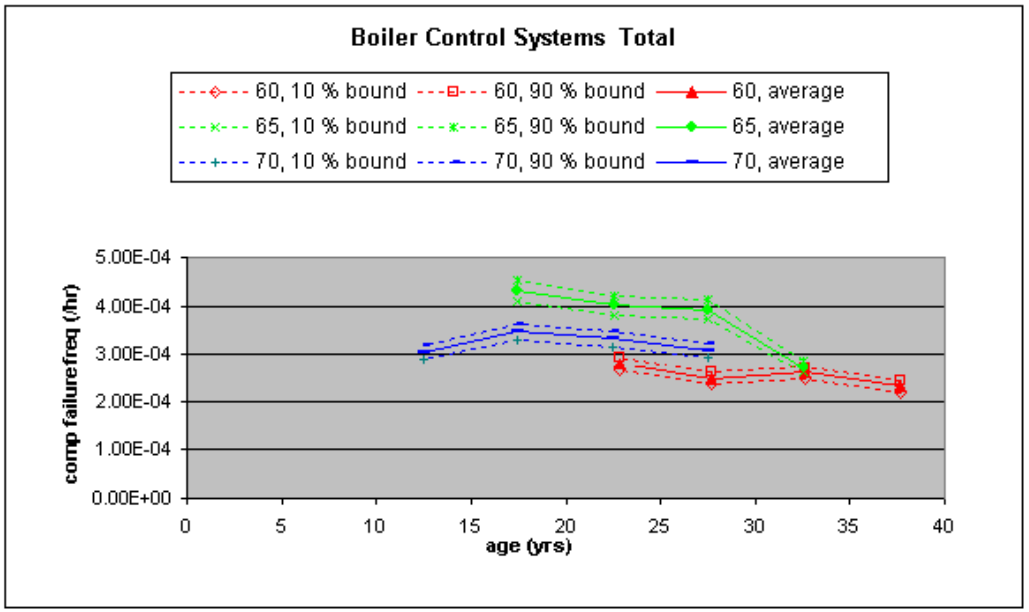
Activities and results : Reliability and data analysis for active components (Task 4)

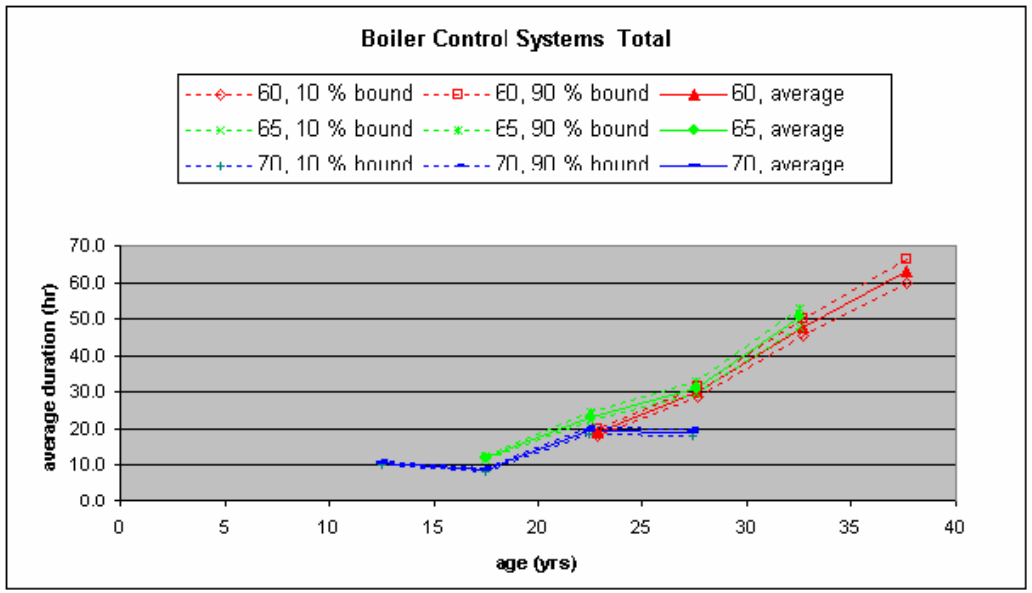


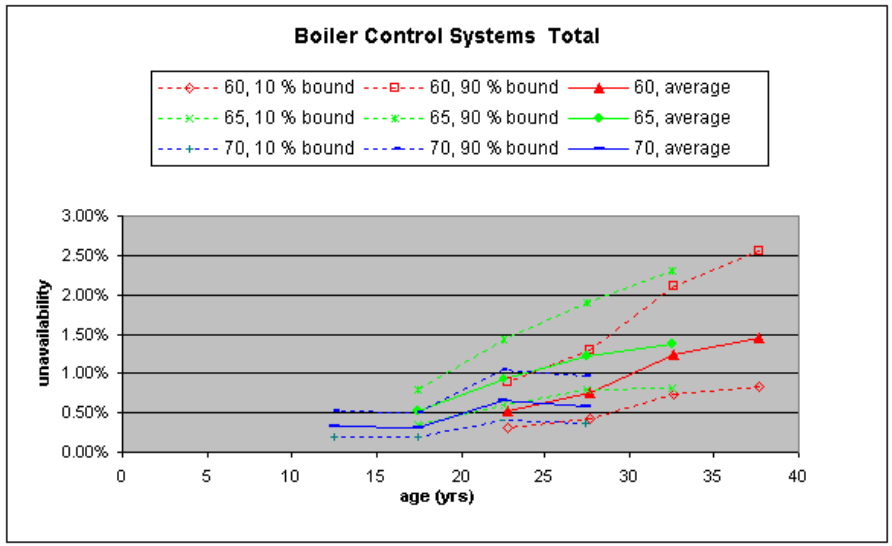




Activities and results : Reliability and data analysis for active components (Task 4)







Reliability data for NPPs:

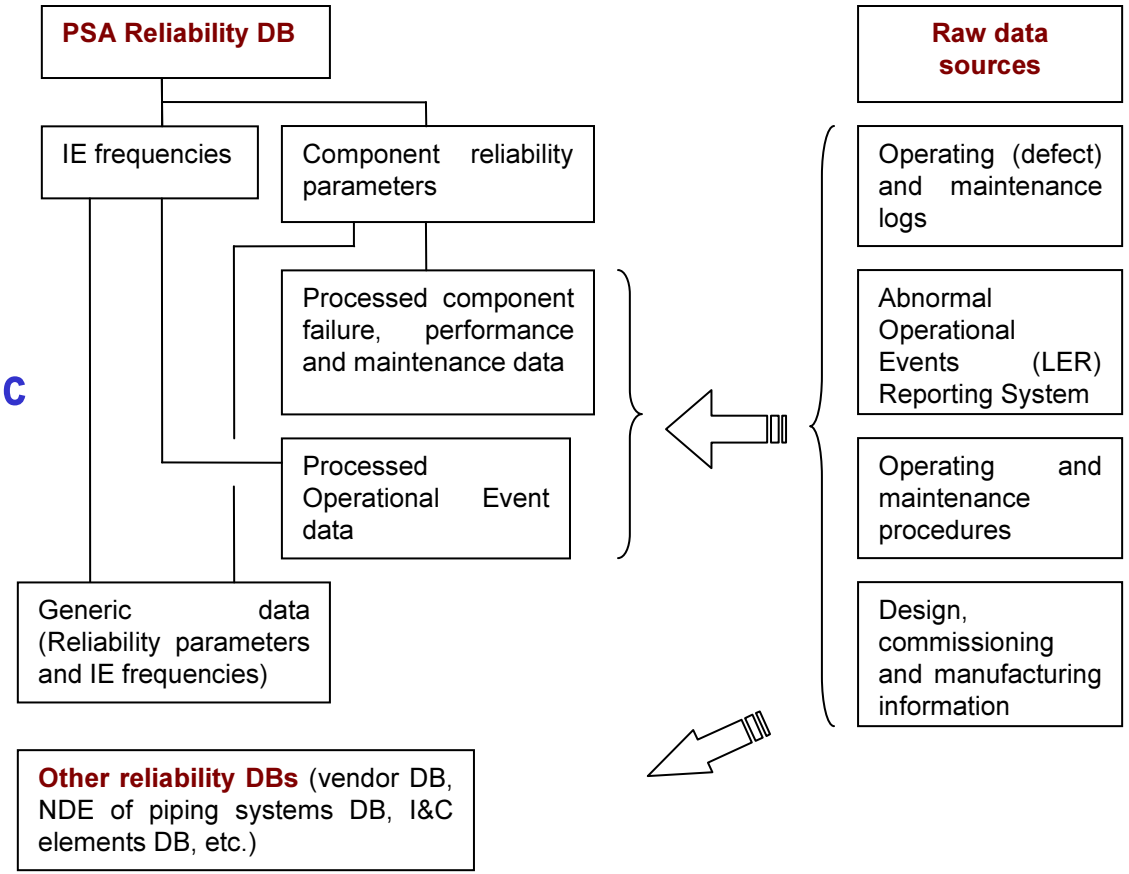
(questionnaire on data availability and accessibility - conclusions)

PSA reliability data

- **well structured and of high quality,**
- **easily accessible (DB or electronic docs),**
- **not sufficient for ageing assessments**

(λ=const => n + Σt)

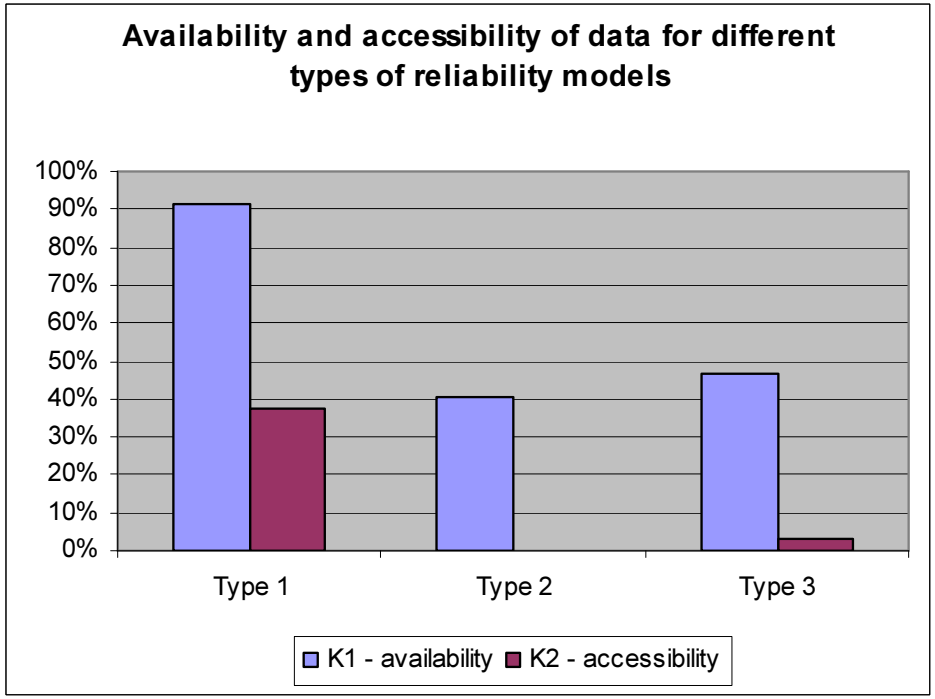
Additional data has to be extracted and processed from raw data



Activities and results : Reliability and data analysis for active components (Task 4)

Age-dependent reliability models :

1) simple models or trend assessment;
2) models which include test and maintenance evaluations;
3) comprehensive models.



Categories of additional data needed:

Type 1 models

- component commissioning date,
- failure/censoring times,
- component replacement date.

Type 2 models - data listed for Type 1, plus:

- tests and maintenance strategy
  – type and periodicity,
- degree of component renewal (CM and PM).

Type 3 - data listed for Type 1 and Type 2, plus:

- component lifetime,
- cumulative number of hours in operation, number of demands,
- average and extreme levels of operating and environmental stressors.

Activities and results : Reliability and data analysis for active components (Task 4)

Main conclusions :

- **Processed data about failures and component performance could be certainly used for age-dependent reliability analysis, but is not enough for this purpose**
- **PSA reliability data collection process does not include any requirement to perform a statistical validation of assumptions about constant failure rate or trend analysis**
- **Improving reliability data collection could greatly help with PSA and age-dependent reliability analysis applications in risk-informed decision making process**

Activities and results : Reliability and data analysis for active components (Task 4)

General scheme of data analysis :

- start with exploratory data assessment,
- perform ageing trend analysis,
- for the selected component groups, fit one of the parametrical models,
- if necessary, improve the results by Bayesian approach,
- evaluate the unavailability factors for given age values, taking into account model parameters, periodical tests and maintenance data.

Data types

- Individual times to failure
- Binned data on failure frequencies

Activities and results : Reliability and data analysis for active components (Task 4)

EQUIP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1													0	0	0	0	0	0	0	0	0	0	0	0
1												0	0	0	0	0	0	0	0	0	0	0		0
5									0	0	0	0	0	1	0	0	0	0	0					1
5							0	0	0	1	1	0	0	0	0	2	0							4
5							0	0	0	0	0	0	0	0	0	0	0							0
5							0	0	1	1	0	0	1	0	1	0	0							4
5										0	0	0	0	0	0	0	0	0	0	0				0
5									0	1	0	0	0	0	0	0	1	0	0					2
5									0	0	0	0	0	0	0	0	0	0	0					0
5									0	0	0	1	0	0	0	0	0	0	0					1
5										0	0	0	2	0	0	0	0	2	0	0				4
5										0	0	0	0	0	0	1	0	0	0	0				1
5									0	0	0	0	0	0	0	0	0	1	0					1
5									0	0	1	0	0	0	0	0	2	0	0					3
5						0	0	0	0	0	0	0	0	0	0	0								0
5					0	0	0	0	0	0	0	0	1	0	0									1
5										0	0	0	0	0	0	0	0	0	0	0				0
5										1	0	3	0	0	0	0	2	0	0	0				6
5									0	0	0	0	0	0	0	0	0	0	0					0
5									0	1	0	0	0	0	0	0	0	0	0					1
5						0	0	0	0	1	1	0	0	0	0	0								2
5						0	0	0	2	1	0	0	0	1	0	0								4
5			0	0	0	0	0	0	0	0	0	0	0											0
5		0	0	0	0	0	0	0	0	0	0	0												0
5						0	0	0	1	0	0	0	0	0	0	0								1
5					0	0	0	0	0	0	0	0	0	0	0									0
5						0	0	0	0	0	0	2	0	0	0	0								2
5					0	0	0	0	0	0	0	0	0	0	0									0
5							0	0	0	0	0	0	0	0	0	0	0							0
5							0	0	0	0	0	0	0	0	0	0	0							0
6				1	0	0	0	0	0	2	2	0	1	0										6
6			0	0	0	0	0	0	0	0	0	0	2											2
6					0	0	0	0	0	0	0	0	1	0	0									1
6					0	0	0	0	0	0	0	0	2	0	0									2
6				0	0	0	0	0	0	0	0	0	1	0										1
6				0	0	0	0	0	0	0	0	0	0	0										0
6				0	0	0	0	0	0	0	0	0	1	0										1
6			0	0	0	0	0	0	0	0	0	0	0											0
5		0	0	2	0	0	0	0	0	0	0	0												2
5		0	0	0	0	0	0	0	0	0	0													0
5			0	0	0	0	0	0	0	0	0	0	0											0
5		0	0	0	0	0	0	0	0	0	0	0												0
5	0	0	0	0	0	0	0	0	0															0
5	0	0	0	0	0	0	0	0																0
5	0	0	0	0	0	0	0	1	0															1
5	0	0	0	0	0	0																		0
5		0	0	0	0	0	0	0	0	0	0	0												0
5	0	0	0	0	0	0	0	0	0	0	0													0
5	1	0	0	0	0	0	0	0	0	0														1
5	0	0	0	0	0	0	0	0																0
	1	0	0	3	0	0	0	1	4	9	5	6	12	2	1	3	5	3	0	0	0	0	0	55
250	31.64	44.135	63.967	92.44	122.365	145.065	167.115	173.835	189.545	214.63	216.355	204.091	185.926	157.536	127.608	104.105	77.86	67	44.565	5.765	2	1.753	0.084	2439.385
	13%	18%	26%	37%	49%	58%	67%	70%	76%	86%	87%	82%	74%	63%	51%	42%	31%	27%	18%	2%	1%	1%	0%	

Activities and results : Reliability and data analysis for active components (Task 4)

Exploratory data assessment (visual examination) :

- **Cumulative failure plots** (times to failure)
- **Side-by-side 90% confidence intervals for λ** (binned data)

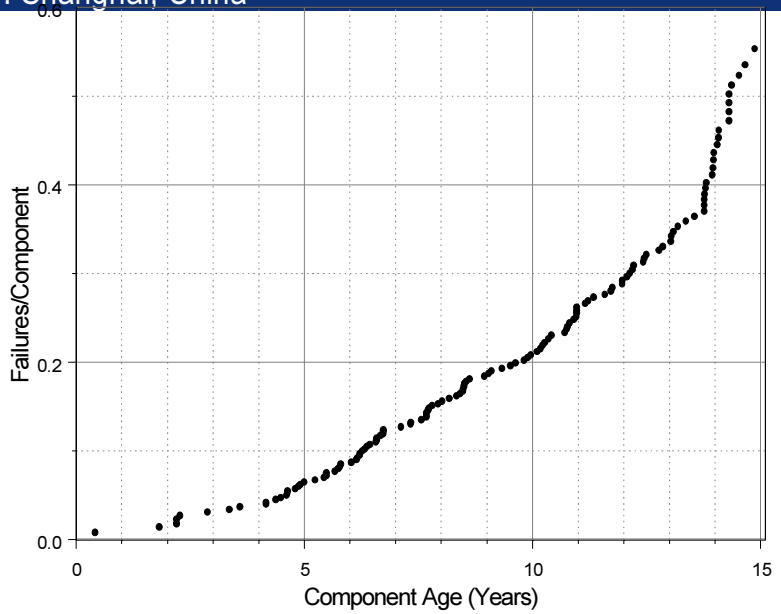
Trend analysis / hypothesis tests (nonparametric) :

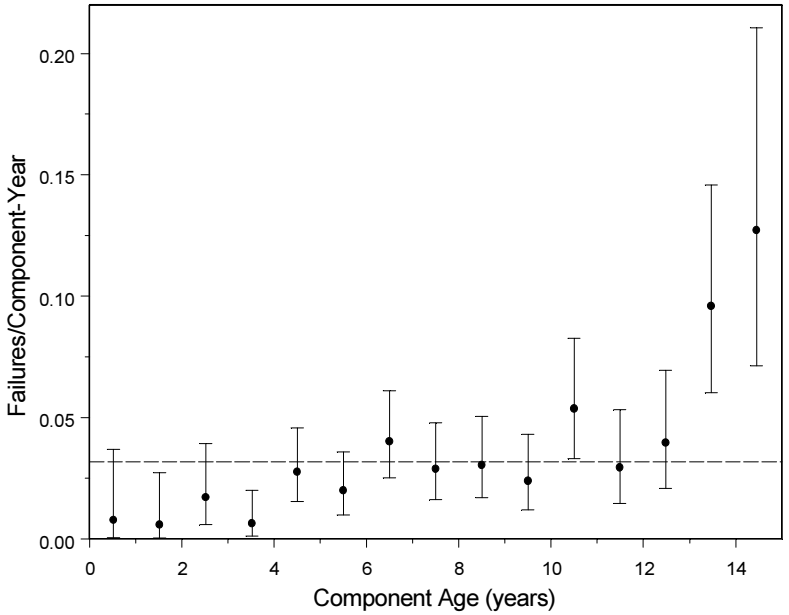
Times to failures

- **Laplace test**
- **Bayesian analog of Cramer-von Mises test**

Binned data

- **Inversion test**
- **Chi-square test**





Fit one of the parametrical models

Models for time trend in λ

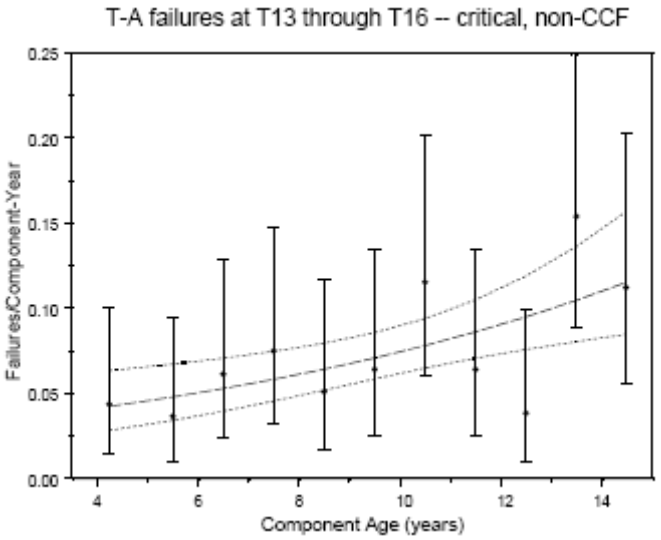
- **Linear : $\lambda(t) = \lambda_0 + \beta t$,**
- **Log-linear : $\ln\lambda(t) = a + \beta t$, or $\lambda(t) = \lambda_0 \exp(\beta t)$**
- **Power-law (Weibull) : $\lambda(t) = \lambda_0 t^{\beta}$, or $\lambda(t) = \lambda_0 \exp[\beta(\ln t)]$**

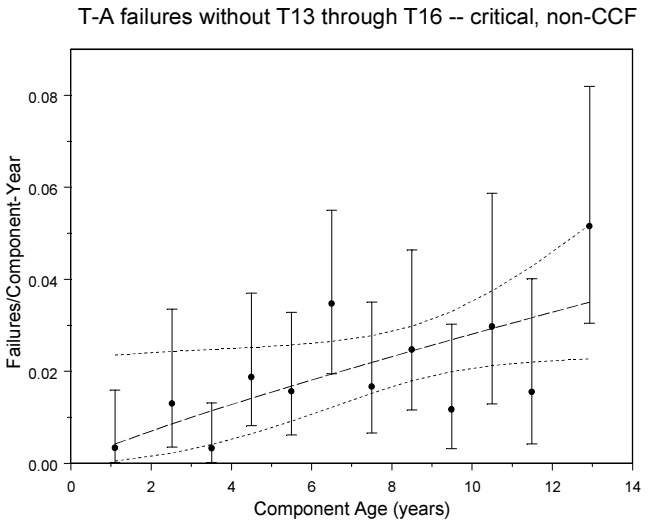
Models for time trend in p

- **Logistic : $\text{Logit}(p) = \log(p/1 - p) = a + \beta t$**
- **Probit : $\text{Probit}(p) = \Phi^{-1}(p) = a + \beta t$**

Here β is "ageing" parameter (β > 0 means increasing failure rate).

Significance level, p-value, characterize how good the model fits to the data





Activities and results : Reliability and data analysis for active components (Task 4)

Examples :

T-A data, units T13-T16

Fitted log linear $\lambda(t) = 2{,}81E\text{-}2 \times \exp(0{,}098t)$ p = 0,6

$\beta = 0{,}098$, standard error is 0,034 what is 2,87 standard errors from 0 which corresponds to 0,002 level of significance.

Means that H0 could be rejected with 0,002 level of significance

T-A data, others units then T13-T16

Fitted log linear $\lambda(t) = 5{,}94E\text{-}3 \times \exp(0{,}149t)$ p = 0,29

$\beta = 0{,}149$, standard error 0,039 what is 3,8 standard errors from 0 which corresponds to 0,0002 level of significance.

Activities and results : Reliability and data analysis for active components (Task 4)

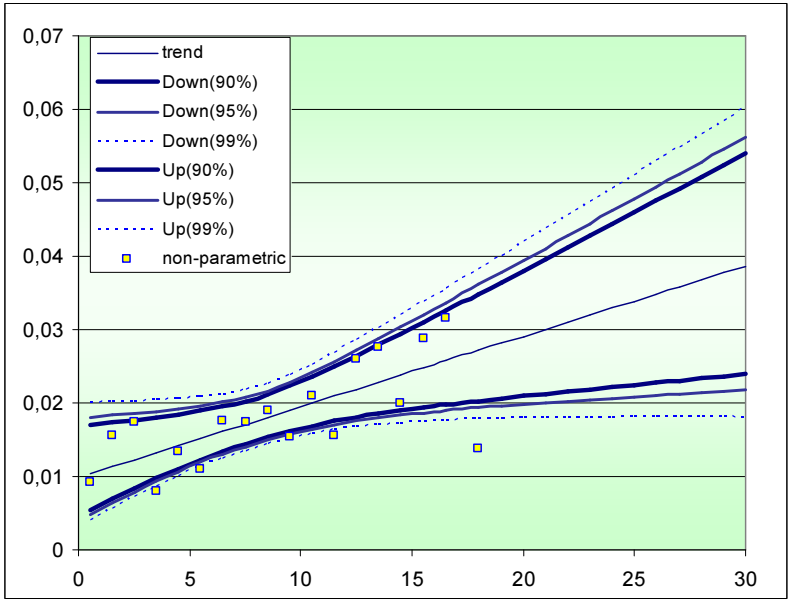
Fit one of the parametrical models

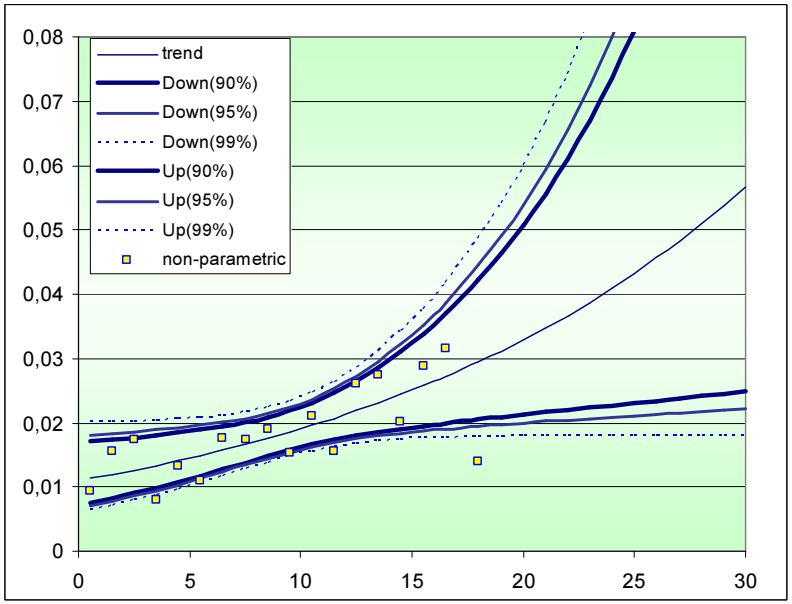
Parameters estimation techniques :

- **Times to failures - MLE, SEM,**
- **Binned data - Chi-2 minimisation,**
- **Bayesian with non-informative priors**

Important issues :

- **censored data**
- **assumption about renewal process**
- **uncertainties and extrapolations**



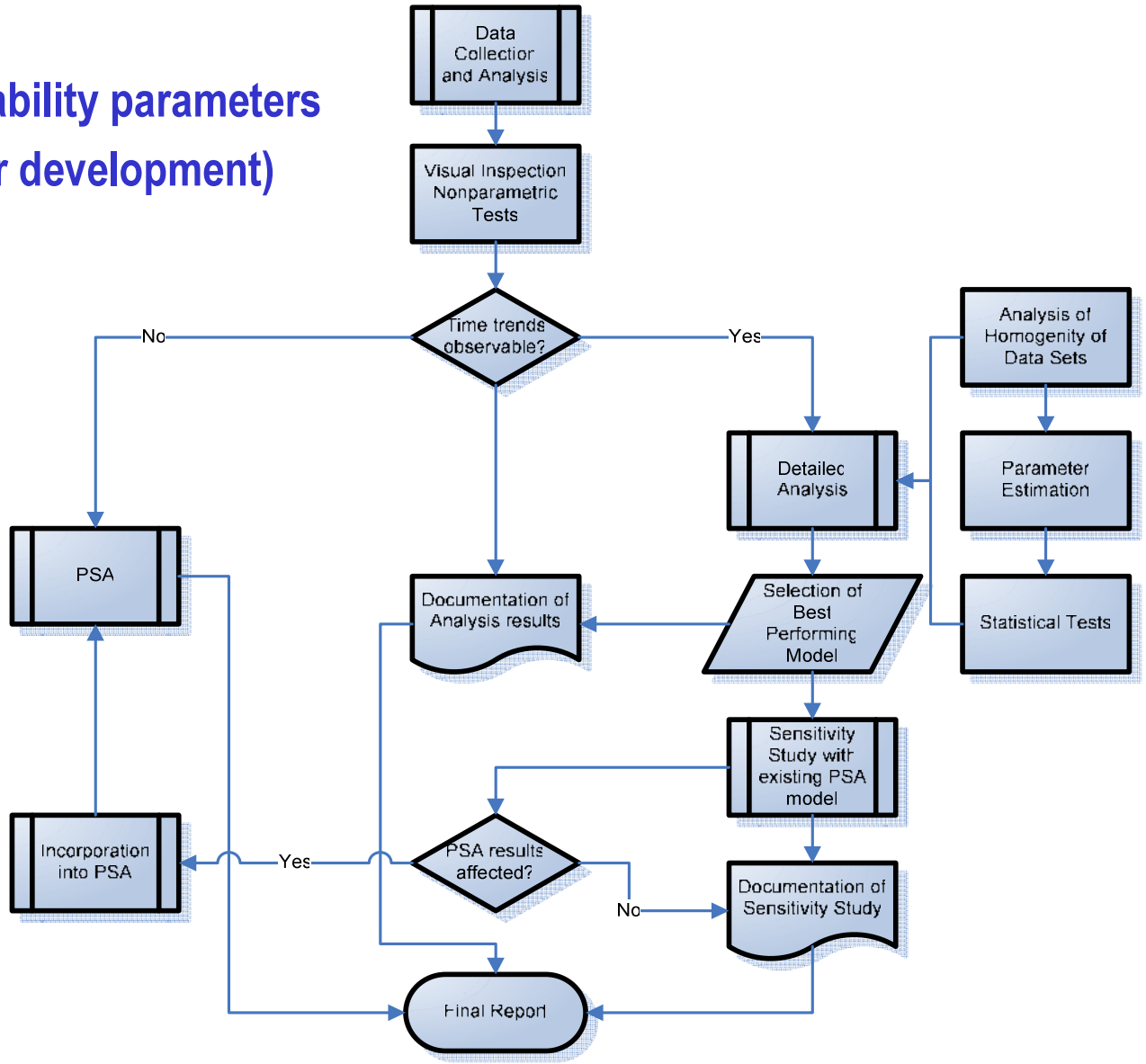


Activities and results : Reliability and data analysis for active components (Task 4)

Main conclusions

- **Parametrical tests are more complex but more powerful then non-parametrical ones.**
- **Goodness of fit test is necessary to choose the model and conclude about trend.**
- **Data homogeneity have to be verified (units, systems, environment, operating conditions, etc.) if possible.**
- **Burning-in failures, maintenance renewal, performed modifications could change the component reliability and impact significantly on data/results**
- **All conclusions are valuable since you have a large statistic, if not … ?**

Guideline on reliability parameters estimation (under development)



1. Introduction : background and motivations.
2. EC JRC Network on Aging PSA : goals, tasks, working approach
3. Activities and results
4. Conclusions

Conclusions

- **PSA could be used as a tool for ageing analysis. It enables a particular SSC ageing assessment to be linked to the overall plant safety effect via risk evaluation.**

- **the purpose of EC JRC Ageing PSA activities is to make available to PSA engineers practical approaches, methods and advices on how evaluate the importance of ageing issues by means of PSA modelling.**

- **The results of case studies performed demonstrate that the methods could be used in identifying and modelling ageing effects on active components where reliability data is available.**

Identified important issues :

- **the lack of existing PSA reliability data collection from an ageing assessment of point of view,**
- **statistical model uncertainties and extrapolation capabilities.**

These issues are under discussion and development in the Network

Conclusions

The following topics are planned for further development:

- **areas of possible PSA application in ageing management via risk-informed approaches,**
- **reliability data collection and parameter estimation : CCF,**
- **passive component age-dependent reliability models,**
- **the incorporation of ageing effects into the PSA model.**

APSA 2007 (planned) : EC E&I Workshop on *"Use of PSA for Evaluation of Impact of Ageing Effects on the Safety of NPPs".*

15-16 November 2007, Budapest, Hungary.

Thank you very much for your attention!