Overview of reliability data collection with regards to ageing reliability analysis applications.

(Ageing PSA Network Task 4 : Reliability and data analysis for active components)

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Abstract

This paper presents the state of the art of existed NPPs component reliability data collection systems which aimed to elaborate components reliability parameters to be used in Probabilistic Safety Assessments (PSA). A specific emphasis was done to the possible application of data in time-dependent reliability analysis.
The report was prepared by JRC IE in the frame of EC JRC Ageing PSA Network Task 4 activities and is based on analysis of responses of Network participants to the questionnaire.
Main conclusions and recommendations are presented in the report and they addressed to the data availability and accessibility, as well as to possible improvements of data collection and important issues to be considered in Ageing PSA Network work plan.

1. Background

In case of sufficient reliability data, age-dependent reliability models could be constructed and introduced into PSA.

For active components the age-dependent reliability parameters could be considered on the level of Fault Tree by assigning the time-dependent unavailabilities for correspondent Basic Events.

The Fault Trees included component time-dependent unavailability could be used as for calculation of probability of functional events, as well as for estimation of initiating event frequencies. Both of the cases have to be considered for input parameters specification.

Depending of available PSA code and expected applications the technique for introduction of time-dependent unavailability on the level of Basic Events could be different.

The general process of elaboration of age-dependent input data consists of fore steps:

1. Specification of unavailability type and attributes associated with BE,
2. Choose the model to be applied and data categories needed for parameters estimation,
3. Perform data collection and processing,
4. Estimate time-dependent unavailability factors to be considered in PSA.

Schematically this process is presented on the figure 1. The following paragraphs describe each step in details.

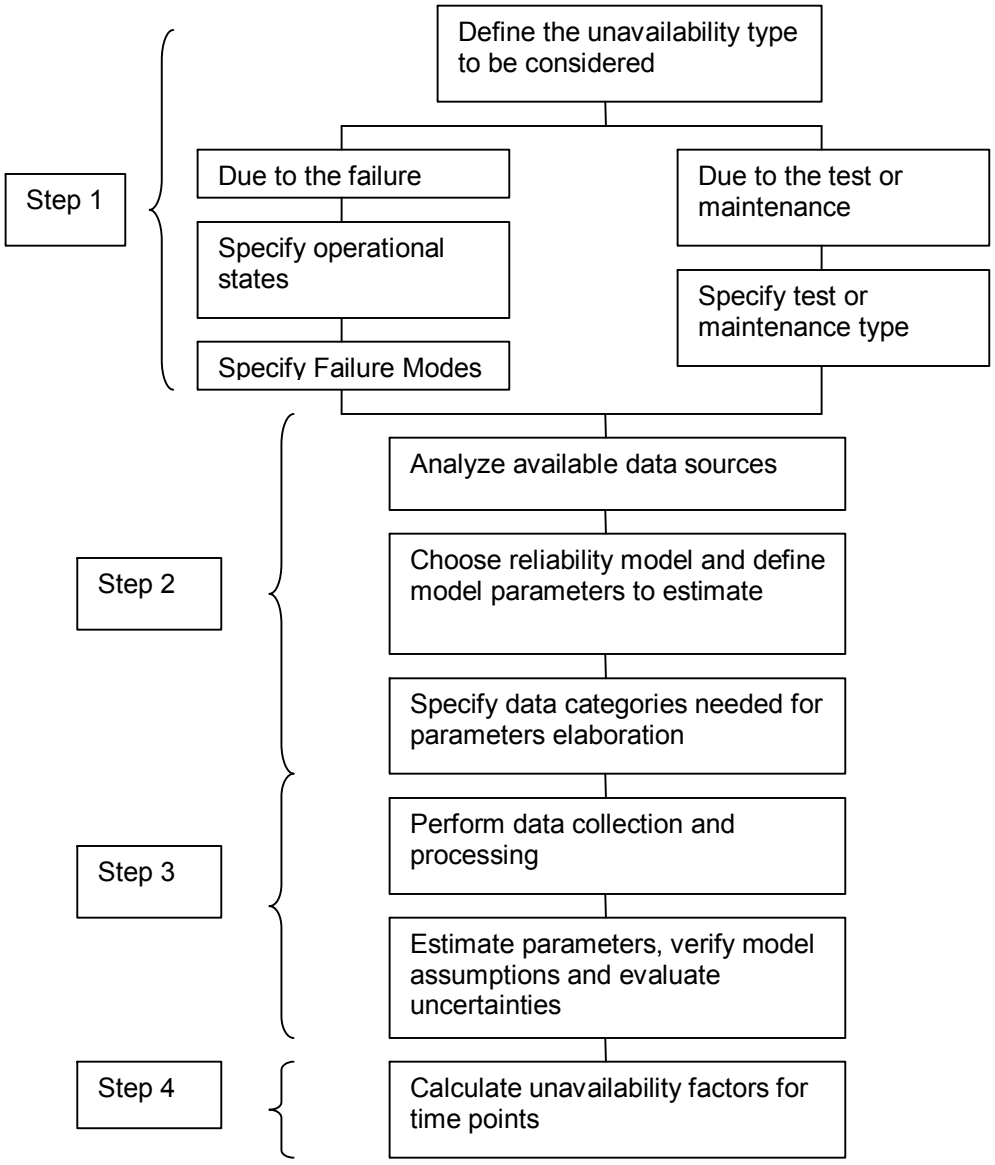

Figure 1 : General process of elaboration of age-dependent input data

This paper discusses the issue related to available data sources specified in Step 2.

2. Questionnaire about reliability data collection and availability

In order to understand the state of the art with reliability data collection, identify and characterize available data sources, JRC IE prepared a questionnaire about reliability data collection and availability [1].

Objectives of the questionnaire are :

- To collect and summarize the information about available PSA component reliability data and raw data collection systems,

- To understand the availability, accessibility and completeness/exhaustivity of information registered in raw data collection systems needed for ageing and maintenance advanced evaluations,

- To propose the recommendations what data could be used for age-dependent reliability models elaboration and the way to improve data collection for the purpose of ageing/risk assessments.

Content : all questions could be divided in two parts :
- Available PSA component reliability data
  - Level of data assessment,
  - Types of data available,
  - Data needed for ageing reliability assessment,
- Data needed to characterize uncertainties and quality of results
  - Processed reliability data for parameters elaboration,
  - Raw data collection.

Limits : the questionnaire is focused mainly on active mechanical, electrical and I&C components modeled in PSA level 1.
The initial considerations concerning the data and models needed to asses ageing into PSA are taking form the presentation [2] on Ageing PSA 2006 Workshop (Bucharest, October 2006).

Contributions : the questionnaire was distributed to the Task Group 4 participants (IRSN/FR, CNE/RO, INPE/RU, LEI/LT, JSI/SL) and to some of Ageing PSA Network partners (VEIKI-Paks NPP/HU, KGG/Swiss, KAERI/Korea, CNSC/Canada, NRI/ Czech Republic, Novator/Ukraine).
Following 8 organizations answered to the questionnaire :
- CNSC/CA,
- CNE/RO,
- KKG/SW,
- KAERI/KO,
- LEI/LT,
- NRI/CZ,
- Novator/UA,
- JSI/SL

This list includes one regulator (CNSC/CA), two utilities (CNE/RO and KKG/SW) and regulatory or utility support organizations dealing with PSA and data collection). So it was expected that the responses would provide quite good and representative picture of the state of the art.

3. Summary and analysis of responses

3.1. Reliability data collection description

As it is mentioned in previous section, the questionnaire deals with several types of data. Figure 2 presents in very schematic way relations between three types of data considered potentially available for age-dependent reliability analysis :
- PSA reliability data,
- Others reliability data,
- Raw data.

The engineers involved in PSA development and application familiar with PSA reliability data, which include Initiating Events frequencies and component reliability parameters. These data are directly used in PSA Event Trees and Fault Trees models.

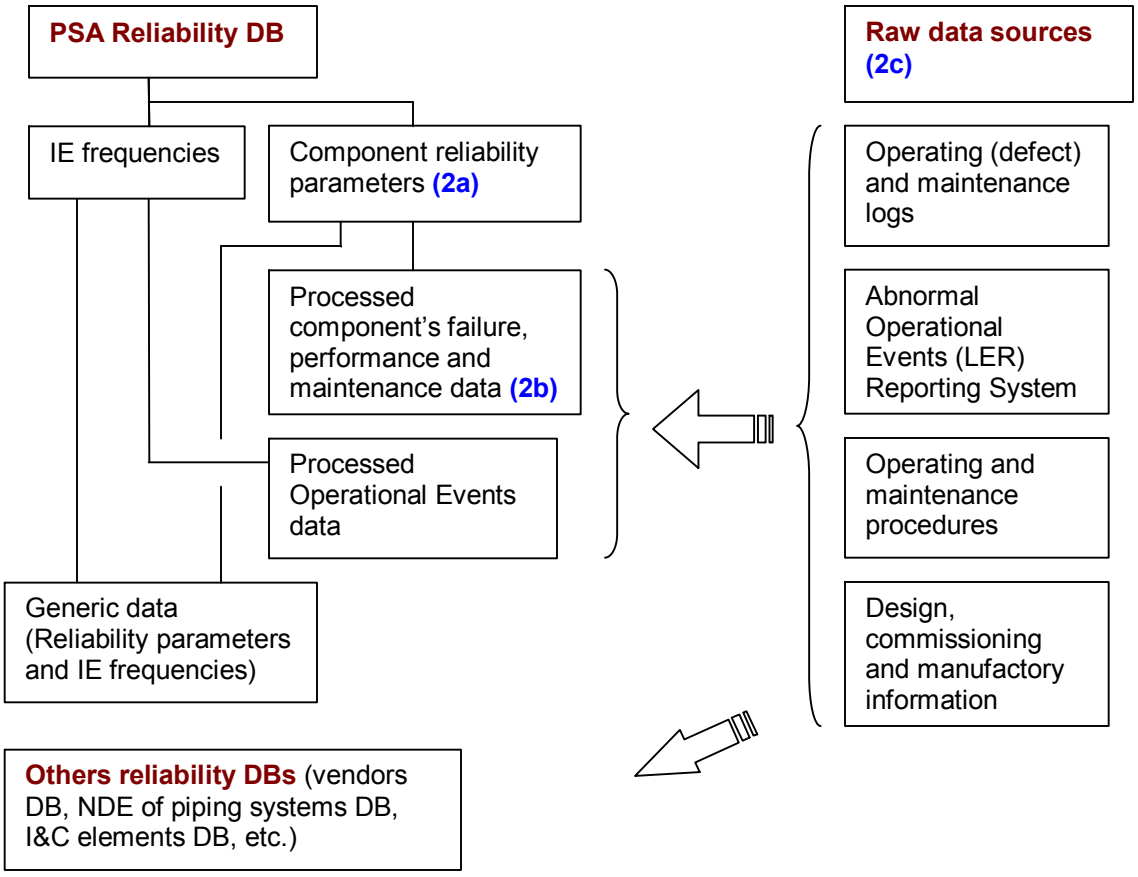

Figure 2. Potential data sources for age-dependent reliability analysis.

Most important information collected and treated during parameter's elaboration normally documented in IE frequencies and Component Reliability Parameters Evaluation task reports and/or databases. These processed data are usually well structured and have a high quality. Processed data about failures and component performance could be certainly used for age-dependent reliability analysis.

Another potential data source presented on Figure 2 is non-PSA reliability DBs. These data cover the component types, which not included in PSA model. It could be of interest in case if some component has to be modeled in PSA or if it will be necessary to enlarge statistic for similar PSA component group.

Third type of data, could be used for age-dependent reliability analysis, are the raw data collected on the plant, as well as operational, maintenance and design documentation.

Nota : the data concerning IE and non-PSA reliability DBs are not explicitly discussed in the questionnaire, so some additional clarification could be needed in the future.

The examples of data recorded in operating logs and processed failure data considered for parameters estimation are provided by the participants. It has to be recognized that there is considerable amount of efforts to process data available in operational logs to the format needed for parameters estimation. At all, it makes data collection process quite expensive and resources consuming.

Now, to perform age-dependent reliability analysis additional data have to be elaborated as well. It could be specified what data are needed for construction of reliability model, but it is not clear

- if those data are available in any of listed sources,
- how easy it will take to extract and process them
- and what will be the quality/completeness of obtained information.

Analysis of responses to the questionnaire provides some clarifications on these issues.

3.2. PSA component reliability data.

It was supposed that all participants have some kind of PSA Reliability Data Collection system. Also, it is known that PSA reliability data are usually a good quality and well documented. These statements are confirmed by most of the participants. So, in most of the cases, PSA Reliability Data are ***available in electronic or DB forms***. Collection and treatment of data are performed in accordance to correspondent written procedure. In most of the cases the data are updated regularly with the periodicity of PSA updating : usually each 5-10 years. In addition, the participants who apply "living PSA" or some specific reliability programs update data on annual basis.

Remark/conclusion/proposal 1. *In the most of the cases, PSA Reliability Data have a good quality, are available in electronic or DB forms and updated regularly. Collection and treatment of data are performed in accordance to the written procedure. It should be a good basis for the following ageing reliability analysis and improvement of data collection system.*

Form other hand all of the participants, except KKG/SW, stated that the procedure does not include any requirement to perform a statistical validation of the assumption about constant failure rate. That means that up to now there are no formal requirements for trend analysis, methods of assessments and data needed. It could be certainly the areas where Ageing PSA network could provide a real contribution to the plant performance and safety improvements.

Remark/conclusion/proposal 2. *As soon as PSA Reliability Data Collection procedures does not specify formal requirements for exponential or binominal models validation, as well as for verification of ageing trends. It could be recommended to include such an analysis into the procedure. Corresponded guideline with methods and approaches could be proposed by Ageing PSA network.*

It will be also interesting to learn recent KKG/SW experience concerning this subject.

As it was mentioned in Task 4 specification (see Ageing PSA Terms of References [3]) age-dependent reliability models require more data than actually applied PSA component reliability models. 'More data" means not only nomenclature (additional data about maintenance, operational and environmental stressors, etc.), but also more large statistic and especially data for long-term operated components (covered age windows).

It is important point to see the possible sources of "generic" data or possible ways of cooperation between Ageing PSA partners to get more large statistical samples, because it could be very difficult or even impossible to build any age-dependent reliability model by using only plant specific data collection. From the answers of the participants, it is appeared that except KAERI/Korea, all participants have plant specific data collections. Total cumulated operating experience could be presented by reactor types as follows :

- PWR about 113 r.y. (KKG/SW - 24 r.y. + KAERI/KO – 67 r.y. + JSI/SL – 20 r.y.),
- VVER about 330 r.y. (NRI/CZ – 90 r.y. + NOV/UA – 240 r.y.),
- CANDU – not clear but has to be quite large if take into account Canadian experience,

- RBMK about 20 r.y. (LEI/LT).

It was not asked in the questionnaire, but it is important to mention that 7 form 18 PWR reactors and 14 from 21 VVER reactors presented by participants are already (or will be at the end of this year) more than 20 years old (see IAEA PRIS database at http://www.iaea.org/programmes/a2/).

Remark/conclusion/proposal 3. *Taking into account actual state and availability of PSA Reliability Data collection it would be interesting to specify and to perform some case studies in order to demonstrate possible ways to enlarge statistical base for age-dependent models construction using different sources of primary data by organizing exchanges between the Ageing PSA participants. It could help for understanding the differences and to formulate the requirements to improve data collection.*

3.3. Data availability and accessibility (difficulty to extract and process)

From the responses to the questions it follows that in most of the cases scope of the reliability data collection is limited by PSA-related components. In some of the cases, for example KKG/SW, the statistical samples include others (non PSA) components. In some case (KAERI/KO) safety related components of secondary systems also are within the scope of reliability data collection. There is only one response about collection of information for all safety and safety related components at Ukrainian NPPs, but the actual status of this data base has to be clarified.

It is assumed that for ageing assessment applications PSA models would include (or at least some preliminary analysis and selection has to be done) some passive components and active components which are not presently modeled in PSA (in some cases, for example, I&C components).

Remark/conclusion/proposal 4. *The reliability data collection systems do not cover passive components and active components which are not presently modeled in PSA, but would be modeled in Ageing PSA. Some additional efforts could be needed to collect and process the data for these types of components.*

In this perspective, some effort have to be done to evaluate possible generic data sources (like OCDE/NEA Piping Reliability DB, etc.) and others (non-PSA) reliability data collected on the plants.

To perform ageing trend or reliability analysis different data categories are needed. Table 1 present an evaluation from given responses concerning the availability and degree of accessibility of data (how easy it to extract and to process) for each category.

Table 1

Data category	Availability								K1	Accessibility (easy to extract and process)								K2
3a - Component commissioning date (age 0)	1	1	1	1	1	1	1	0	87%	0	0	1	0	1	1	1	0	50%
3b - Failure/censoring times	1	1	1	1	1	1	1	0	87%	0	0	0	0	1	1	1	0	37%
3c - Component replacement – date and cause	1	1	1	1	1	1	1	1	100 %	0	0	0	0	1	0	1	0	25%
3d - Characteristics of applied tests and maintenance strategy – type and periodicity	1	1	1	0.5	0.5	1	0,5	0,5	56%	0	0	0,5	0	0	0	0	0	0%
3e - Degree of component	1	1	0	0	0	0	0	0	25%	0	0	0	0	0	0	0	0	0%

renewal during the maintenance					,5		,5	,5								,5		
3f - Component lifetime	1	1	1	0	1	1	1	0,5	75%	0	0,5	0	0	0	0	0	0	0%
3g – real cumulated number of hours in operation, number of demands	1	1	1	0,5	1	1	0,5	0,5	62%	0	1	0,5	0,5	0	0	0,5	0	12%
3h – information about average and extreme levels of operating stressors	0	0,5	0,5	1	1	0,5	0,5	0,5	25%	0	0	0	0	0	0	0	0	0%
3i - information about of average and extreme levels of environmental stressors	0	0,5	0,5	1	1	0	0,5	0,5	25%	0	0	0	0	0	0	0	0	0%

Response of each expert was evaluated by three degrees : 1 – clear positive statement, 0,5 – partial answer or different cases exists, 0 – negative or unclear answer.

The coefficients K1 and K2 represent the ratios of positive responses in total number of answers and they basically reflect some “average” situation. For example, for data category 3c all participants answered that data are available (K1 = 100%), but in most of the cases it very difficult (means quite costly) to extract and to process them form existed data sources (K2 = 25%).

The results presented in the table show that in exception of data related to degree of component renewal during the maintenance (3e) and information about operational and environment stressors (3h, 3i), all others data needed for ageing reliability analysis are available in many cases. Surprising foundlings are that data about component commissioning date (3a) and component lifetime (3f) are considered as highly available (K1 is 87% and 75%).

Unfortunately, all these data are not easily extractable. In exception of failure/censoring times and component commissioning dates (K2 is 37 and 50%), all others data categories are rather difficult to access and to process.

Some of participants indicate that recent data often more available and accessible because of computerized data collection and processing systems are implemented last years. In these cases, old data for earlier periods of operation of NPP are very difficult to extract.

Remark/conclusion/proposal 5. *From the statistical point of view the fact of unavailability of data for the beginning of operation, means that we deal with left censored data and it has to be considered for the parameters estimation technique.*

From applications point of view, availability and accessibility of data for different types of reliability models are shown on the figure 3.

Three cases are specified on the figure :

- Case 1 : simple age-dependent reliability model or trend analysis. Types of data needed are 3a, 3b, 3c.

- Case 2 : age-dependent reliability models including test and maintenance evaluations. Types of data needed are the data for Case 1 and 3d, 3e (evaluation given only for additional data).

- Case 3 : comprehensive age-dependent reliability models. Types of data needed are the data for Case 1 and Case 2, and 3f, 3g, 3h, 3i (evaluation given only for additional data).

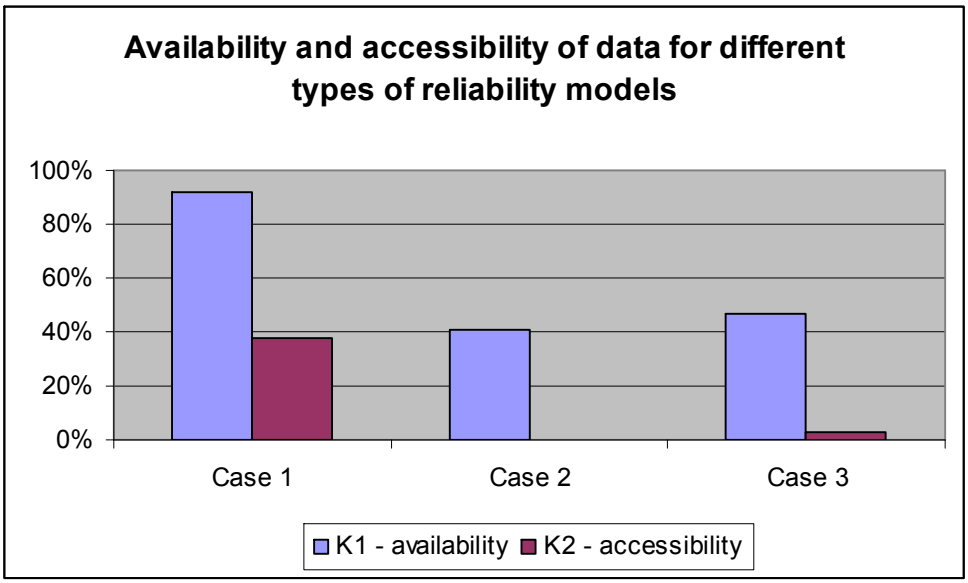

Figure 3. Availability and accessibility of data for different types of reliability models

Remark/conclusion/proposal 6. *This diagram demonstrate that even for simple age-dependent reliability assessments for which most of the data are available, the cost of data processing could be quite high. If ones would apply reliability models for maintenance analysis and optimization, or for lifetime evaluation and prediction, a large additional investment for data collection and processing have to be envisaged.*

This remark has to be taken into account as for further Ageing PSA activities on models development, as for the specification of additional efforts needed in data collection.

Answering to the questionnaire participants proposed additional data categories needed for ageing evaluation. Some of this categories have normally to be addressed in PSA reliability data analysis, as for example :

- for each component failure, information on failure mechanism and cause,
- component type : active or passive components,
- type of failure: incipient (degradation) or sudden failure (failure).
- suspicion of common cause failure mode (CCF-candidate).

Others are more specific to the ageing characterization and surveillance activities :

- component life cycle or ageing management strategy (for instance, monitoring and inspections are missing in 3d and 3e),
- information on component degradation mechanisms,
- information on component failure precursors (prevented before the component really failed as a result of preventive inspection/maintenance),
- results of non-destructing testing of passive components

- plant history of component failures of all component types, aging is planned being considered for, including date of failures.

- relation between random failures and ageing dependent failures.

Remark/conclusion/proposal 7. *Relevance, availability and accessibility of data from proposed categories have to be discussed and evaluated within Task 4 working group. Results of this evaluation have to be considered for the case studies specifications and for data collection improvements recommendations.*

3.4. Raw data quality and availability

It was shown in previous section that most of the data needed for ageing assessment are not easily accessible. In general, that means that some information is collected and stored as raw data and requires additional efforts to process it. If ones will decide to work with raw data he has to understand first if those data are available and if he could obtain useful information from processing.

As stated in the responses to the questions all participants have written requirements for raw data collection. Table 2 presents an evaluation of answers given to question about requirements for raw data collection. Supposing that formal requirements could, in certain way, assure some availability and quality of collected data, coefficient K3 provides some idea about how often we can find available and good quality raw data of each category.

Table 2.

Data category	Availability K1	Accessibility K2	Required by Data Collection Procedure								Availability / Quality K3
3a - Component commissioning date (age 0)	88%	50%	0	0	1	0	0	1	1	0	38%
3b - Failure/censoring times (age in the moment of failure/censoring).	88%	38%	0	1	1	0	0	1	0	0	38%
3c - Component replacement – date and cause	100%	25%	0	1	1	1	0	1	1	0	63%
3d - Characteristics of applied tests and maintenance strategy – type and periodicity	56%	0%	0	1	1	0	0	1	1	0	50%
3e - Degree of component renewal during the maintenance (corrective maintenance, preventive maintenance).	25%	0%	0	1	1	0	0	0	0	0	25%
3f - Component lifetime (design/manufacture specification, qualification tests results).	75%	0%	0	0	1	0	0	1	1	0	38%
3g – real cumulated number of hours in operation, number of demands	63%	13%	0	1	0	1	0	1	1	0	50%
3h – information about average and extreme levels of operating stressors	25%	0%	0	0	0	0	0	0,5	1	0	13%
3i - information about of average and extreme levels of environmental stressors	25%	0%	0	0	0	0	0	0,5	0	0	0%

Two participants provided their expert evaluation in more comprehensive way by answering to the question about availability and quality of raw data. The results of these evaluations (with some adaptations done for easier comparison) are provided in Table 3.

Table 3.

Category	NRI/CZ (availability and quality by component type)			CNE/RO (all types of components)	
	Mechanical components	Electrical components	I&C components	Availability	Quality
3a - Component commissioning date (age 0)	low	very low	very low	low	medium
3b - Failure/censoring times (age in the moment of failure/censoring).	very low	very low	very low	low	medium
3c - Component replacement – date and cause	good	medium	medium	medium	very good
3d - Characteristics of applied tests and maintenance strategy – type and periodicity	very good	good	good	very good	very good
3e - Degree of component renewal during the maintenance (corrective maintenance, preventive maintenance).	very good	good	medium	medium	very good
3f - Component lifetime (design/manufacture specification, qualification tests results).	good	medium	low	good	good
3g – real cumulated number of hours in operation, number of demands	very good	good	medium-low	good	medium
3h – information about average and extreme levels of operating stressors	medium	good	medium-low	low	good
3i - information about of average and extreme levels of environmental stressors	good	good	medium	medium	good
History of component failures of all component types	medium	medium	low	-	-

Table 3 reflects the situation with raw data collection at two different utilities. It seems like both of them have rather intensive data collection process. The results show high availability and good quality for the data categories of 3d, 3e, 3f (except I&C components), 3g and 3i. For the categories of data as 3a, 3b, it rather opposite situation is reported. Of cause, these evaluations correspond to the specific situation on particular power plant and it sometimes not confirms the foundlings presented in previous sections. But this reflects also the diversities in raw data collection processes.

Remark/conclusion/proposal 8. *Taking into account a diversity of responses and uncertainty with the availability, accessibility and quality of raw data it could be proposed to apply the following scheme for case studies specification :*

1. *Specify PSA model possible modifications related to ageing consideration,*
2. *Propose reliability models to apply and specify parameters needed,*
3. *Formulate requirements for data for parameters estimation,*
4. *Perform data collection and processing to demonstrate the feasibility,*
5. *Characterize availability, accessibility and quality of data for each case and provide recommendations for data collection improvements.*

5. Final conclusions and recommendations

Remark/conclusion/proposal 1. *In the most of the cases, PSA Reliability Data have a good quality, are available in electronic or DB forms and updated regularly. Collection and treatment of data are performed in accordance to the written procedure. It should be a good basis for the following ageing reliability analysis and improvement of data collection system.*

Remark/conclusion/proposal 2. *As soon as PSA Reliability Data Collection procedures does not specify formal requirements for exponential or binominal models validation, as well as for verification of ageing trends. It could be recommended to include such an analysis into the procedure. Corresponded guideline with methods and approaches could be proposed by Ageing PSA network.*

It will be also interesting to learn recent KKG/SW experience concerning this subject.

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In this perspective, some effort have to be done to evaluate possible generic data sources (like OCDE/NEA Piping Reliability DB, etc.) and others (non-PSA) reliability data collected on the plants.

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This remark has to be taken into account as for further Ageing PSA activities on models development, as for the specification of additional efforts needed in data collection.

Remark/conclusion/proposal 7. *Relevance, availability and accessibility of data from proposed categories have to be discussed and evaluated within Task 4 working group. Results of this evaluation have to be considered for the case studies specifications and for data collection improvements recommendations.*

Remark/conclusion/proposal 8. *Taking into account a diversity of responses and uncertainty with the availability, accessibility and quality of raw data it could be proposed to apply the following scheme for case studies specification :*

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- *Characterize availability, accessibility and quality of data for each case and provide recommendations for data collection improvements.*

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