ARIES

Accelerator Research and Innovation for European Science and Society

Horizon 2020 Research Infrastructures GA n° 730871

NOTE

Bibliography and state of the art of reliability information systems

WP6: Accelerator Performance and Novel Concepts (APEC)

ABSTRACT

Reliability and availability have been identified as a key topic for cost and energy efficient operations in research of industrially used particle accelerators and medical particle facilities.

The scope of this document is to reference documents of existing reliability information systems in industries, lists of relevant standards and best-practices and a summary with an assessment of those documents, which can be considered suitable for a reliability and availability information system in a multi-national, collaborative technical research infrastructure environment.

For more information on ARIES, its partners and contributors please see http://aries.web.cern.ch

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1 Introduction

Reliability and availability have been identified as a key topic for cost and energy efficient operations in research of industrially used particle accelerators and medical particle facilities.

To improve the availability of complex systems it is important to have good knowledge of the status of the used components, their charcteristic reliability and the cost structure for maintenance and repair.

The aim of this project is to develop an open reliability information system to provide a common platform for storing and sharing accelerator system reliability information of existing systems and components. Building of redundancies and good practices of maintenance will help to improve availability of the planned system and should by already considered in the design phase.

The focus in the project “Reliability & Availability Information System” is to build up an open database for components typically used in particle accelerators and medical particle facilities. Research and industry partners should commonly share reliability characteristics of used modules and components for simulation and planning purposes.

Existing industry standards (also from other domains) are taken into account as starting point as much as possible, for instance ISO 6527, OREDA Handbook or ISO 14224.

Data quality annotation today is carried out mostly manually, it was found that it does not scale. Therefore, the information system shall foresee approaches to automate or assist data quality annotation with different algorithms (e.g. expert knowledge, machine learning, statistical correlations). This feature should help that the data quality continuously improves with the number of additional participants from different accelerator facilities and with the time data are gathered.

This work package should collect information of existing solutions in different areas and find out the strengths of these solutions. This should be a starting point for the analysis and the design of the ARIES information system.

2 Standards and best practices

2.1 Criteria for analysis

In this section, criteria used for the analysis of the standards, handbooks and other documents (see columns in Table 1) will be described.

- Domain of application
  For which domains, the standard or document is intended (e.g. nuclear industry, oil and gas industry)?

- Anonymity Concept
  Is an anonymity concept described in the analysed standard (e.g. access restrictions)?

- Reliability prediction model
  Is a reliability prediction model available in the respective document? Are environmental conditions (e.g. temperature, status of operation, power, radiation level) or reliability indicators (e.g. MTTF or MTBF) described in the document?

- Data Quality
  Is data quality described in the respective document? Is data quality described in the respective document? If so, at which level of detail? And is this adequate for our purposes?

- Taxonomy
  Is there a suggestion for a taxonomy in the respective document? If so, at which level of detail? And is this adequate for our purposes?

- Last update (Date of publication)
  How old is the standard? Is it still valid?

In the following chapter 2.2 the investigated documents are listed and annoted according to their appropriateness for the ARIES project regarding the described criteria for analysis.

2.2 Overview Table

The documents listed in the following Table 1 were gathered and analysed during the course of the literature research for this deliverable. The documents listed are having the nature of standards, guidelines, handbooks, papers or reports.

Table 1: Overview Table

Nr.	Document type	Document name	Domain of application	Anonymity Concept	Reliability prediction model	Data Quality	Taxonomy (level of detail)	Last update (Date of publication)
1	Standard	ISO 6527 Nuclear power plants - Reliability data exchange - General guidelines	Nuclear industry	No	Condition: Yes Reliability: No	No	Only an example in Annex	2015 (1982)
2	Standard	ANSI/IEEE Std 500-1984, Guide to the collection and presentation of electrical, electronic, sensing component and mechanical equipment reliability data for nuclear power generating stations	Nuclear industry	no (not applicable)	Condition: Partly Reliability: Yes (less detailed)	No (not applicable)	From entire machines like e.g. generators and major devices like pipe heaters or transformers down to single relays, sensors or instruments.	1984 (withdrawn)
3	Standard	DIN EN ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment (ISO 14224:2016)	Petroleum-, Petrochemical- & Natural Gas Industry	Yes (not in detail)	Condition: No Reliability: Yes (references to the standard ISO/TR 12489:2013)	Yes	Detailed: major devices like electric generators, but also stators, rotors, pumps, valves, …	2016
4	Handbook	MIL-HDBK-217F Reliability Data Handbook	general. (origin: defense)	No (not applicable)	Condition: yes Reliability: yes (very detailed)	No (not applicable)	electrical, electronic and electro-mechanical parts;	1995
5		FIDES 2009 EdA	all domains using electronics		Condition: yes Reliability: yes (detailed)	No (only product / process quality)	electrical, electronic and electro-mechanical parts;	2009
6	Handbook	RIAC HDBK-217Plus	general. (origin: defense)		Condition: yes Reliability: yes (coarse)	No (only product / process quality)	electrical and, electronic parts;	2006

7	Handbook	Offshore Reliability Data Handbook (OREDA) - 6th Edition	Offshore oil & gas production facilities	Not described in the handbook	Condition: yes Reliability: yes (very detailed)	Not described in the handbook, but data quality assurance is executed by the consortium	Detailed: major devices like compressors, but also filters, valves, coolers, …	2015 (6th Edition)
8	Several Reports	WInD-Pool	Wind energy plants	Yes (with trusted organization in the middle)	Condition: Yes Reliability: Yes	Data approval process: Validation and qualification of the data, final acceptation by trustee	Yes: Very detailed, classes, type and subclasses (function, category and location)	2016
9	Paper	FCFR-DB - Fusion component failure rate database	Nuclear industry. Fusion facilities, fusion power plants	No, but the access is restricted to IEA members and regulated by UserId and Password distributed by ENEA	Conditions: No Reliability: No	Data approval process: Qualification/Validation of the data, approbation, final acceptation by FCFR-DB administrator	Yes: Family name, type and 4 subclasses	2006
10	Paper	Component failure rate data base for fusion applications	Nuclear industry. Fusion facilities, fusion power plants	No	Conditions: No Reliability: No	Only once shortly mentioned	Yes: Family name, type and 4 subclasses	2000

2.3 ASSESSMENT OF DOCUMENTS

2.3.1 ISO 6527 Nuclear power plants

ISO 6527 Nuclear power plants - Reliability data exchange - General guidelines

Identifies the typical parameters of a component that permit it to be characterized unequivocally and to allow the corresponding reliability data to be associated with those of other components having equivalent typical parameters. Parameters refer to technical characteristics including the physical principle of operation and quality level and to actual operating conditions and maintenance and test intervals. Data may be represented both in a historical and in a statistical form.

For use in ARIES, the Standard ISO 6527 is not directly applicable as it provides no reliability models and nor the question of data quality nor of anonymity is described in the standard. But this standart give us an usefull example of the factor Environmental conditions. Figure 1 shows the main parameters that shall be subject to engineering judgement in order to define the equevalence.

Figure 1: Environmental conditions (ISO 6527)

Condition	Range
Temperature	Normal or inside specification Cycle Shock Outside normal range or outside specification Maximum operating temperature
Humidity	Normal Dry (humidity control) Damp or wet conditions
Vibration	Not present or insignificant Intermittent Continuous or long periods Shock present
Nuclear radiation	High (over 10 R/h) Medium (between 0,1 and 10 R/h) Low (below 0,1 R/h)
Corrosive atmosphere	Not present or insignificant Salt spray Chemical Industrial (sulphur compounds) sand/dust present
Fungus, etc.	Not present Fungus or mould growth Pests

2.3.2 ANSI / IEEE Std 500-1984

Guide to the collection and presentation of electrical, electronic, sensing component and mechanical equipment reliability data for nuclear power generating stations

Dating back to 1984, IEEE 500 Std Reliability data is even older than the above mentioned military handbook MIL-HDBK-217F. This may still fit for nuclear plants which have been operational for decades, but synchrotrons and LINACs at CERN are less old. IEEE is still able to supply the standard but actually it has already been withdrawn.

The standard provides reliability data for typical (often large) components and machines used in the nuclear power industry. Data were compiled from various nuclear industry and supplier industry sources, partly based on applying probabilistic reliability models. No details are given on individual suppliers, data sources are referenced in general, not disclosing any individual events. The original data were reviewed according to the Delphi method by experts, who also jumped in in areas where empirical values were lacking.

Failure modes are, where appropriate, distinguished for different severities (catastrophic, degraded, incipient). For each failure mode of a component/machine type, three reliability values are given: the lower, the upper, and the recommended estimate; the triplet of reliability values is given in failures per 10^6 hours and partly per 10^6 cycles (for demand probabilities), additionally repair times are indicated. The listed values shall be multiplied with an environment factor (referring to high temperature, humidity and radiation), which is individual for each device or machine.

For application in ARIES, the IEEE 500 standard would fit mostly wrt. the level of granularity, and the kinds of components listed as well as the typical loads fit partly: Particle radiation is covered well, temperatures conditions down to 3K, however, are not considered by IEEE 500. In general, the standard provides a less detailed reliability model then MIL-HDBK-217F. Like the latter, it provides no nomenclature of reliability related data, but the environment factor for the considered items may be useful fot developing the reliability model in ARIES.

2.3.3 EN ISO 14224

“Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment (ISO 14224:2016)”.

The scope of the standard is to provide a comprehensive basis for the collection of reliability and maintenance data in a standard format for equipment in all facilities and operations within the petroleum, natural gas and petrochemical industries during the operational life cycle of equipment.

The standard describes the following main topics:

- Data collection principles
- Associated terms and definitions
- Failure modes
- Data quality control and assurance practices.

The main categories of data are to be collected:

1) Equipment data, e.g. equipment taxonomy, equipment attributes;
2) Failure data, e.g. failure cause, failure consequence;
3) Maintenance data, e.g. maintenance action, resources used, maintenance consequence, down time.

The main areas where such data are used are the following:

1) reliability, e.g. failure events and failure mechanisms;
2) availability/efficiency, e.g. equipment availability, system availability, plant production availability;
3) maintenance, e.g. corrective and preventive maintenance, maintenance plan, maintenance supportability;
4) safety and environment, e.g. equipment failures with adverse consequences for safety and/or environment.

An excerpt of the paramaters mentioned in the standard is given below:

- Active maintenance time
- Active repair time
- Availability
- Critical failure
- Down time
- Equipment class
- Equipment data
- Equipment type
- Failure data
- Mean time to failure (MTTF)
- Mean time to repair (MTTR)
- Etc.

Exchange of Reliability and maintenance data

The standarad presents a concept for dealing with **sensitive information**:

- “blank” such data;
- make such data anonymous.

The anonymization can be reached by defining anonymous codes representing the data element where only authorized persons know the conversion between the codes and the actual data. This is recommended if these data fields are essential for the data taxonomy.

Quality of data

The collected reliability and maintencance data and analysis are dependent on the quality of the data collected. High-quality data are characterized by the following points:

1) completeness of data in relation to specification;
2) compliance with definitions of reliability parameters, data types and formats;
3) accurate input, transfer, handling and storage of data (manually or electronic);
4) sufficient population and adequate surveillance period to give statistical confidence;
5) relevance of the data to the need of the users.

There are also other checks listed for data quality ensurance e.g. origin of the data should be documented or the recorded data should fit within the defined equipment boundary. The complete list of this checks is not listed in this document.

Taxonomy

The classification of items into generic groups in a systematic way is called a taxonomy. Factors could be location, use, equipment subdivision, etc.. This classification of data to be collected in is shown in Figure 2. Definitions of each segment are provided in the standard.

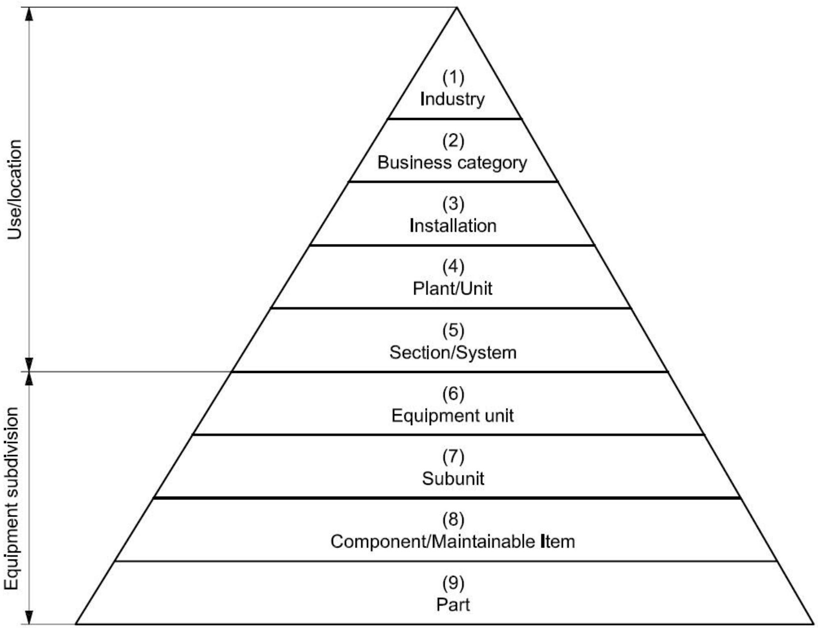


Figure 2: Taxonomy classification with taxonomic levels from ISO 14226:2016

The RM data shall be collected in an organized and structured way. The major data categories for equipment, failure and maintenance data are the following:

- Equipment unit data
  - classification data, e.g. industry, plant, location
  - equipment attributes, e.g. manufacturer's data
  - operational data, e.g. operating mode, operating power
- Failure data
  - identification data, e.g. failure record number
  - failure data for characterizing a failure, e.g. failure date
- Maintenance data

- identification data, e.g. maintenance record number
- maintenance data

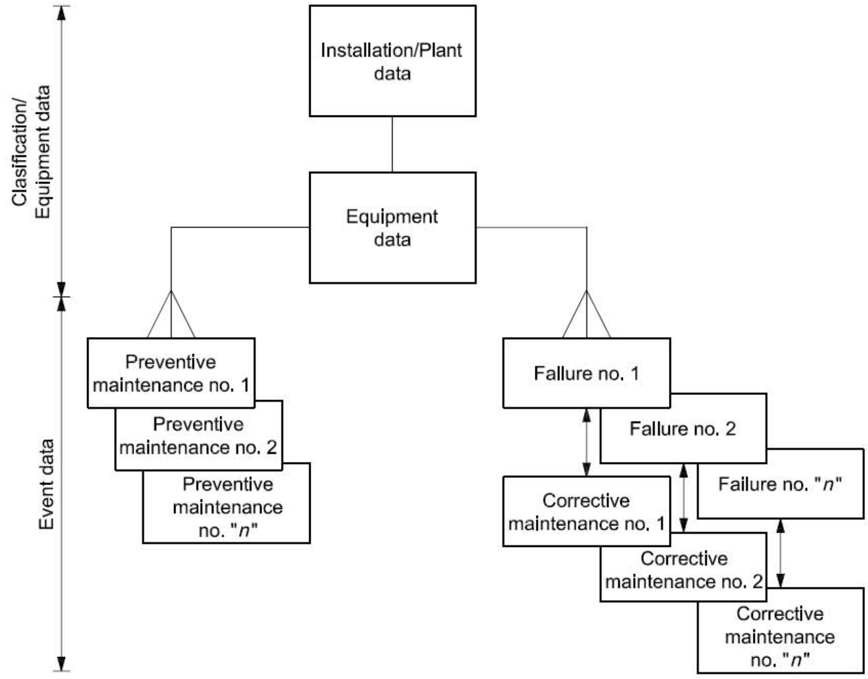


Figure 3: Logical data structure example from ISO 14224:2016

Failure and maintenance paramaters

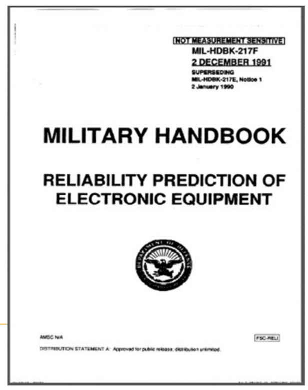
The standard contains in detail a description of failiure mechanisms, failure interpretation, failure cause, failure modes and maintenance activity.

Overall it can be stated that some concepts (e.g. data quality, data anonymization) of the ISO 14224:2016 can be used for ARIES.

2.3.4 MIL-HDBK-217F

MIL-HDBK-217F Reliability Data Handbook

This handbook was compiled by the US DoD and has been the basic pillar of reliability prediction for more the 50 years. It was updated the last time in 1995; to date no plans for future updates (by the military) are known.



The reliability data derived from it must therefore be considered conservative as a considerable gain in component production quality has been achieved since then. Nevertheless, the MIL handbook is still in use.

Its advantage is its high level of detail and its availability at zero cost.

The drawback, in turn, is its age; The last update of the handbook was in 1995, An additional consequence is that modern complex integrated circuits arte possibly not covered to a satisfactory extent (CMOS VLSI models are available).

The MIL-HDBK-217F handbook contains several empirically developed failure rate models based on historical component failure rates for a wide variety of component types. Models are available for virtually all electrical/electronic components and also some electro-mechanical ones, also wiring, soldering, sockets, connectors, and others.

Predicted values give the reliability in failures per million hours of operation assuming an exponential distribution (constant failure rate), which allows adding the failure rates in order to determine high-level device reliabilities.

Two prediction models are available:

1. **Part stress analysis prediction method:** It requires knowlege of the individual stress level of each part in order to determine the overall failure rate
2. **Parts count method:** It assumes just average load in order to enable reliability estimation in the early design phase.

The handbook distinguishes between 14 different work environments - spanning from „Ground, Benign“ over e.g. „Naval, Unsheltered“ and „Space, Flight“ (for satellites etc.) till „Missile, Flight“, „Missile, Launch“ and even „Cannon, Launch“ (with extreme acceleration and jerk).

Typical factors for determining the component failure rate (given in tables) include

- a temperature factor Π_T,
- a power factor Π_P,
- a stress factor Π_S,
- a quality factor Π_Q, and
- an environment factor Π_E,
  (remark: Π_E does not include the effects of ionizing radiation).

in addition to the base failure rate λ_b.

Example: Model for a resistor:

$$\lambda_{Resistor} = \lambda_b \cdot \Pi_T \cdot \Pi_P \cdot \Pi_S \cdot \Pi_Q \cdot \Pi_E \ .$$

- Also many device-specific factors exist like
  Π_A = Application factor (DC/AC),
  Π_F = Function factor (Voltmeter, Amperemeter, Other),
  Π_C = Complexity factor (No of circuit planes),
  Π_M = Mating/Unmating factor (No of mating/ unmating cycles of a connector), etc.

Models for many types of resistors are available:

SECTION 9: RESISTORS

9.0	Introduction
9.1	Fixed, Composition (RCR, RC)
9.2	Fixed, Film (RLR, RL, RN (R,C, or N), RN)
9.3	Fixed, Film, Power (RD)
9.4	Network, Fixed, Film (RZ)
9.5	Fixed, Wirewound (RBR, RB)
9.6	Fixed, Wirewound, Power (RWR, RW)
9.7	Fixed, Wirewound, Power, Chassis Mounted (RER, RE)
9.8	Thermistor (RTH)
9.9	Variable, Wirewound (RTR, RT)
9.10	Variable, Wirewound, Precision (RR)
9.11	Variable, Wirewound, Semiprecision (RA, RK)
9.12	Variable, Wirewound, Power (RP)
9.13	Variable, Nonwirewound (RJ, RJR)
9.14	Variable, Composition (RV)
9.15	Variable, Nonwirewound, Film and Precision (RQ, RVC)
9.16	Calculation of Stress Ratio for Potentiometers
9.17	Example

For use in ARIES, the MIL-HDBK-217F is not directly applicable as it provides no nomenclature of reliability related data and no guidance which of them or on which level they shall be collected. Moreover, the handbook provides reliability models at a very fine granularity, which fits for only part of the groups in CERN. Other CERN groups consider e.g entire vacuum pumps as the item under consideration for reliability data, which is not supported by the models in the MIL-HDBK-217F.

The question of anonymity is related the used base data, which are not published in detail in the handbook.

However, the different factors associated to the models in the handbook give a good hint how the collected data can be merged to obtain a valid mean value: The reliability raw data shall be weighted depending on the operating conditions like stress, thermal and environmental conditions, etc. in order to make field date obtained under very different conditions comparable.

2.3.5 FIDES Guide

The FIDES methodology was formed by French industrialists from the fields of aeronautics and defense under the supervision of Délégation Générale pour l'Armement, specifically for the French Ministry of Defense. It was compiled by AIRBUS France, Eurocopter, GIAT Industries, MBDA France, Thales Airborne Systems, Thales Avionics, Thales Research & Technology, and Thales Underwater Systems. The FIDES Guide aims "to enable a realistic assessment of the reliability of electronic equipment, including systems operating in severe environments (defense systems, aeronautics, industrial electronics, and transport). The FIDES Guide also aims to provide a concrete tool to develop and control reliability" (FIDES Group, 2009).

The FIDES model is applicable to all domains using electronics like Aeronautics, Navy, Military, Production and distribution of electricity, automotive, railway, space, industry, telecommunications, data processing, home automation, household appliances. and others. It models failures with intrinsic (item technology or manufacturing and distribution quality) as well as extrinsic origin (specification / design / selection / procurement / production / system integration of the equipment).

Items treated by FIDES comprise elementary electronic components as well as entire modules or electronic subassemblies with a well-defined function like printed circuit boards, hybrids and multi chip modules, LCD and CRT screens, hard disks or keyboards.

The terminology comprises the following levels: System – Subsystem – Equipment – Subassembly - Electronic component (also printed circuit board) – Product – Item. The methodology deals also with non-functioning phases (dormant periods between use or storage).

The scope of modelled failures is wide; it comprises development and manufacturing errors as well as electrical, mechanical, or thermal overstresses related to the application (the causing user remains hidden). Not treated by FIDES are Software failures, unconfirmed failures, failures related to omitted preventive maintenance operations, and failures related to accidental aggressions when identified or proven (failure propagations, different kinds of misuse). Except for some sub-assemblies, FIDES assumes a constant failure rate, i.e. infant mortality and the wear-out phase are not modelled. All of the life-cycle environmental conditions are considered (operating temperature, amplitude and frequency of temperature cycles, vibration amplitude, relative humidity, ambient pollution level, exposure to accidental overstress (application type)). In the prediction results, FIDES identifies confidence levels and sources of uncertainty. In contrast to MIL-HDBK217F and also to RIAC-HDBK-217Plus, failure modes and failure mechanisms are identified.

The model composes the failure rate from a physical failure rate and two factors, a processes management (quality & control) factor, and a project management (quality of manufacturer, quality of component, experience of supplier) factor. The physical failure rate is computed from the sum of partial failure rates for each accelerataing factor (thermal, electrical, temperature cycling, mechanical, relative humidity, chemical), multiplied with the Induced factor (representing overstress due to placement, application, ruggedizing, sensitivity).

The FIDES Guide contains the above mentioned reliability prediction model for electrical, electronic, and electromechanical components in the phases development, production, field operation and maintenance, and a reliability process control and audit guide. The reliability process control guide deals with the procedures and organizations throughout the life cycle. The audit guide uses three questions as a basis to “measure its capability to build reliable systems, quantify the process factors used in the calculation models, and identify actions for improvement”.

For use in ARIES, the FIDES Guide can be used simiar to the above described MIL-HDBK-217F handbook. The reliability model can give advice for judging on how to take into account the conditions, and, as an advantage, FIDES is based on much more recent reliability data. Quality factors are modelled in more detail than in MIL-HDBK-217F. A terminology is given but not detailed further. Reliability data collection is not a theme, so anonymity during data collection is also out of scope. Instead, the standard uses previously collected data, which are anonymized.

2.3.6 Handbook of 217Plus™ Reliability Prediction Models

The 217 Plus prediction model incorporates the component failure rate prediction models developed by the RIAC (Reliability Information Analysis Center), which are sponsored by the Defense Technical Information Center and operated by several companies and university laboratories. It was updated to develop a replacement prediction methodology for MIL-HDBK-217 "Reliability Prediction of Electronic Equipment," the widely used approach since 1995. The model aims at estimating the "rate of occurrence of failure" related to a component's primary failure mechanisms, taking care of accelerating factors within an acceptable degree of accuracy.

The reliability prediction model starts according to the parts-count method by summing up all component failure rates; this estimate is then modified in accordance with system level factors, which account for non-component, or system level, effects.

Compared to MIL-HDBK-217F, the standard treats a smaller variety of parts, namely (opto)electronic devices, connectors, transformers, relays and switches (but no lamps, meters, rotating devices and the like). HDBK-217Plus considers many influencing factors like Year of Manufacture, Duty Cycle, Cycling Rate, Ambient Temperatures (operational and non-operational), and other part specific variables. As a result, the user can perform tradeoff analyses amongst duty cycle, cycling rate, and other variables.

Other than MIL-HDBK217F, the 217Plus standard does not account for life-cycle environment conditions, but it identfies sources of uncertainty and confidence levels for the prediction results. And it allows the incorporation of own reliability data and experience. For software, even a Software Failure Rate Prediction Model is available.

One of the major advantages of HDBK-217Plus is that the reliability data are based on more recent observations than HDBK-217F, ant they can be expected to be more accurate for today's production quality.

For using the RIAC HDBK-217Plus standard in ARIES, similar considerations apply like for MIL-HDBK-217F. There is no nomenclature available, and no guidance is given on which data or on which level they shall be collected. The fine granularity of the models is not usable for part of the groups in CERN, which need entire systems or equipment (e.g entire vacuum pumps) as the item under consideration for reliability data.

The question of anonymity is on the one hand related the used base data, which are not published in detail in the handbook. For incorporationg own reliability data, the Bayesian method of weighed averaging is used which also enables anonymity. The latter method can be of use for ARIES, too.

2.3.7 OREDA Handbook 6th Edition

The OREDA (Offshore REliability DAta) project was initiated in 1981 by the Norwegian Petroleum Directorate (now: Petroleum Safety Authority). The primary objective was to collect reliability data for safety equipment. It was agreed that OREDA was to be run by a group of oil companies in 1983. The objective of OREDA was subsequently expanded to collect experience data from the operation of offshore oil & gas production facilities to improve the basic data in safety reliability studies.[1]

As mentioned before, the companies are coming from the oil industry. In the beginning there were nine oil companies with worldwide operations, but now eight companies from the oil and gas industry are remaining, which can be seen in Table 2.

Table 2: Oil companies active in OREDA[2]

Participants in OREDA							
BP	Engie	Eni	Gassco	Petrobas	Shell	Statoil	Total

The main purpose of OREDA is the collection and exchange of reliability data among the participating companies. OREDA acts also as the forum for co-ordination and management of

[1] http://www.oreda.com/history/ (last access: 10.09.2017)

[2] http://www.oreda.com/participants/ (last access: 10.09.2017)

reliability data collection within the oil and gas industry. OREDA has established a comprehensive database with reliability and maintenance data. The data presented in the OREDA handbook are on maintenance, equipment availability and safety improvement needs on offshore oilrigs. The intention of the handbook is to provide both quantitative and qualitative information as a basis for RAMS (Reliability, Availability, Maintainability and Safety) analysis. OREDA divides into Topside Data and Subsea Data, whereby the main data categories are the same, but the content is not always the same. In this Deliverable it will not be distinguished between subsea and topside data.

The OREDA Data Structure

The following part refers to **the topside data structure** of the OREDA database.
In order to collect data and analyse them in a consistent manner, a taxonomy description has been developed in the OREDA project. For each equipment category the database is split into three separate database files: an **Inventory part**, a **Maintenance part** and a **Failure part**.

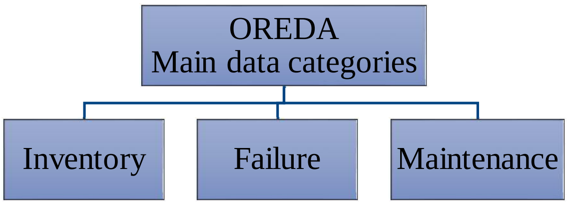


Figure 4: Main data categories from the OREDA database[3]

The various items are classified into equipment categories termed Equipment classes e.g. pumps, compressors, valves etc. Each individual item within a class is termed an Equipment Unit (e.g. one pump). Each equipment class is further classified according to its design characteristics and type of service (system). Table 2 gives an example for the two equipment classes Pumpsand Fire & Gas detectors. Equipment within an equipment class is subdivided in two lower indenture Ievels, called subunits and maintainable items (MI). This subdivision is purely hierarchic and has the following interpretation:

- **Level 1 - Equipment Unit**: The highest Ievel used in OREDA and typically includes an equipment unit with one main function, e.g. pump, compressor.

- **Level 2 - Subunit**: An equipment unit is subdivided in several subunits, each with one function required for the equipment unit to perform its main function. Typical subunits are e.g., cooling, lubrication. The subunits may be redundant, e.g., two independent start units.
- **Level 3 - Maintainable Item (MI):** These are subsets of each subunit and will typically consist of the lowest Ievel units that are due for preventive maintenance.

[3] OREDA (2002), Handbook 4th Edition, ISBN 82-14-02705-5

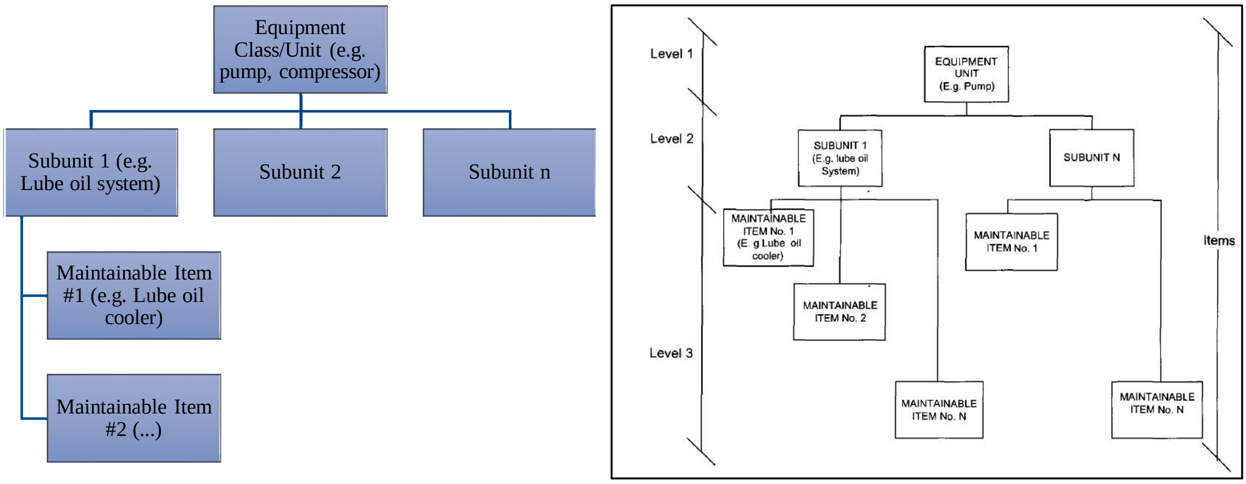


Figure 5: System hierarchy for Topside data structure, right figure taken from the OREDA handbook

EQUIPMENT CLASS	PUMPS				
SUBUNITS	Power transmission	Pump unit	Control and Monitoring	Lubrication system	Miscell-aneous
MAINTAINABLE ITEMS	• Gearbox • Bearing • Seals • Lubrication • Coupling to driver • Coupling to driven unit	• Support • Casing • Impeller • Shaft • Radial bearing • Thrust bearing • Seals • Valves • Piping • Cylinder liner[1] • Piston[1] • Diaphragm[2]	• Control unit • Actuating device • Monitoring unit • Internal pwr supply • Valves	• Reservoir • Pump w/ motor • Filters • Cooler • Valves • Piping • Oil	• Purge air • Cooling/ heating system • Filter, cyclone • Pulsation damper • Others

Figure 6 : Subdivision in Maintainable Items, Pumps from the OREDA Handbook

OREDA Reliability Data (Numeric Failure and Maintenance Data)

The biggest part of the OREDA Handbook is the presentation of numeric failure and maintenance data for the various equipment classes as can be seen in Figure 7. The equipment classes are categorised in 5 major categories which are machinery, electric quipment, mechanical equipment, control and safety equipment and subsea equipment.

System	Equipment class
Machinery	- Compressors - Gas Turbines - Pumps - Combustion engines - Turboexpanders
Electric equipment	- Electric generators - Electric motors
Mechanical equipment	- Heat exchangers - Vessels - Heaters and boilers
Control and safety equipment	- Fire &Gas detectors - Process sensors - Valves
Subsea equipment	- Common components - Control systems - Manifold - Flowline - Subsea Isolation System - Risers - Running tool - Wellhead & X-mas tree

Figure 7: Equipment classes of OREDA

The equipment classes are also splitted in more narrow taxonomy classes (e.g. centrifugal compressors. The split into taxonomy classes may vary between equipment classes. The guiding rule has been to retain a population of similar design, size, performance and any other characteristics that has been deemed appropriate and at the same time keeping the size of the book within a manageable level.

EQUIPMENT CLASS		DESIGN CLASS		SYSTEM	
Description	Code	Description	Code	Description	Code
Pumps	PU	Centrifugal Reciprocating Rotary	CE RE RO	Water fire fighting Sea water injection Oil handling Gas utilities Gas processing	FF WI OH GU GP ....
Fire & Gas detectors	FG	Smoke/combustion Heat Flame Hydrocarbon gas H2S gas	BS BH BF AB AS	Fire detection Gas detection	FD GD

Figure 8: Split of equipment classes

In the OREDA handbook average failure rate estimates and repair time estimates are presented. One example is shown in Figure 9.

The tables include factors like:

- Taxonomy number and Item
- Installations

- Failure mode
- Number of failures
- Failure rate
- Etc.

Taxonomy no 2.1.1.1.2	**Item** Electric Equipment Electric Generators Motor driven (diesel, gas motor) Emergency power (1000-3000)kVA									
Population	**Installations**	**Aggregated time in service (10⁶ hours)**					**No of demands**			
12	3	**Calendar time** * 0.3703		**Operational time** † 0.0987			1470			
Failure mode	**No of failures**	**Failure rate (per 10⁶ hours).**					**Active rep.hrs**	**Repair (manhours)**		
		Lower	**Mean**	**Upper**	**SD**	***n/τ***		**Min**	**Mean**	**Max**
Critical	**5***	**0.06**	**25.86**	**102.47**	**38.23**	**13.50**	**9.0**	**2.0**	**9.0**	**18.0**
	5†	**247.63**	**4942.87**	**14801.03**	**4941.65**	**50.65**				
Fail to start on demand	2*	0.02	9.59	38.19	14.27	5.40	8.0	2.0	8.0	14.0
	2†	94.14	1966.76	5895.82	1974.63	20.26				
Spurious stop	3*	0.03	15.00	59.63	22.27	8.10	10.0	2.0	10.0	18.0
	3†	145.30	2958.78	8864.81	2963.64	30.39				
Degraded	**11***	**14.26**	**31.83**	**55.06**	**12.64**	**29.71**	**12.2**	**2.0**	**22.6**	**116.0**
	11†	**394.62**	**4497.46**	**12472.62**	**4050.92**	**111.43**				
External leakage - Utility medium	1*	0.01	4.22	16.62	6.19	2.70	12.0	12.0	12.0	12.0
	1†	43.25	974.82	2927.34	985.62	10.13				
Fail to stop on demand	2*	0.02	9.59	38.19	14.27	5.40	13.0	12.0	13.0	14.0
	2†	94.14	1966.76	5895.82	1974.63	20.26				
Fail to synchronize	4*	1.03	10.26	27.72	8.89	10.80	10.0	2.0	5.5	10.0
	4†	33.54	935.44	2826.09	965.32	40.52				
Faulty output voltage	1*	0.13	3.04	9.13	3.08	2.70	19.0	38.0	38.0	38.0
	1†	0.03	281.73	1289.18	514.58	10.13				
Low output	1*	0.03	2.40	7.63	2.74	2.70	-	-	-	-
	1†	0.42	9.98	30.00	10.13	10.13				
Minor in-service problems	1*	0.13	3.04	9.13	3.08	2.70	6.0	12.0	12.0	12.0
	1†	0.03	281.73	1289.18	514.58	10.13				
Vibration	1*	0.03	2.40	7.63	2.74	2.70	-	116.0	116.0	116.0
	1†	0.42	9.98	30.00	10.13	10.13				
Incipient	**45***	**8.58**	**198.29**	**595.82**	**200.96**	**121.52**	**7.4**	**1.0**	**9.9**	**37.0**

Figure 9: Example taken from the OREDA Handbook

2.3.8 WInD-Pool (Wind Energy Information Data-Pool)

A Model of Cooperation

WIND pool Windenergie-Informations-Datenpool	It's the purpose of the WInD-Pool, to support the stakholders in the wind energy sector with information about ther installations to reduce costs for the production of electricity.

Structure of cooperation

The basic principle of the WInD-pool is very simple. The so-called data suppliers (e.g. operators) record their operating and maintenance information in a uniform format, in the WInD pool operated by the Fraunhofer IWES as a data trustee. After verification and validation of the data, standardized benchmarks and evaluations will be drawn up and finally made available to the data supplier, ensuring confidentiality and anonymity.

If any abnormalities or potential for optimization become apparent, detailed investigations and solutions can be developed in cooperation with the Fraunhofer IWES and the Ingenieurgesellschaft Reliability and Process Modeling (IZP) Dresden, as can be seen in Figure 10

The WInD pool guarantees the legal security of all parties involved through a standardized cooperation agreement and thus creates the basis for a good and trusting cooperation.

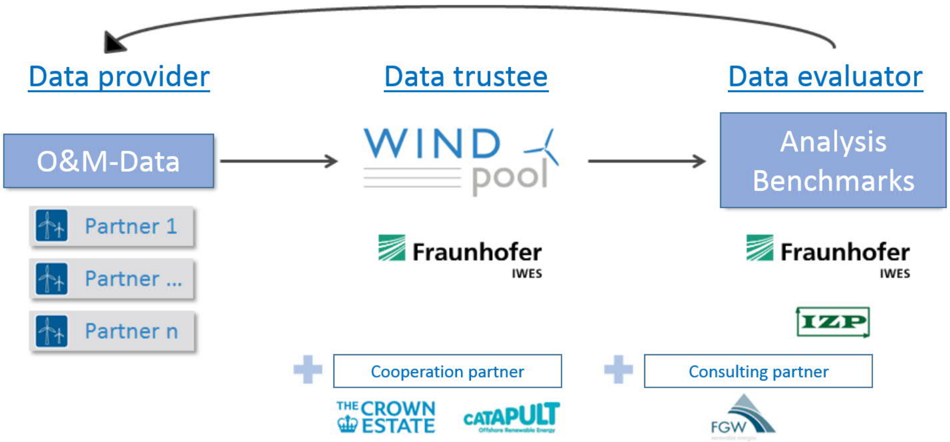


Figure 10: Principle of WInD-pool

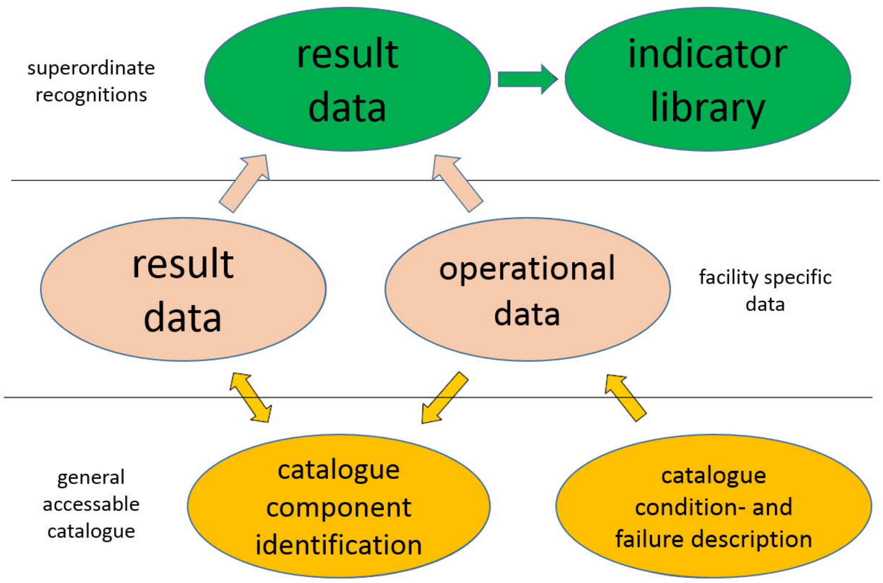


Figure 11: Scheme of data structure in WInD-pool

The master data mainly includes general information on wind farm and plant. Apart from assignment features, such as a unique asset ID, information about asset type and location information is collected. The maintenance-relevant parameters, such as e.g. Performance class and age group are also part of this category.

For a clear assignment of damage to the components of a wind energy plant, a uniform marking of all components is necessary. In all probability, the RDS-PP labeling system ("Reference Designation System for Power Plants") will be used in the future. For the sake of importance, a subchapter will be devoted to the RDS-PP.

RDS-PP – a norm for an identification system of components

The reference indicator system for power plants – shortly RDS-PP - is the consistent further development of the successful power plant identification system KKS. Typical characteristics are:

- applicable to all power plant types,
- consistently for the full life cycle,
- applicable by all departments of cooperation
- language independent.

The technical standard fully meets the basic principles of structuring, which can be done after different aspects. The Power plant is named after the aspects "function", "product" and "place".The Function aspect looks at an object, how it works, the product aspect, how it is composed.

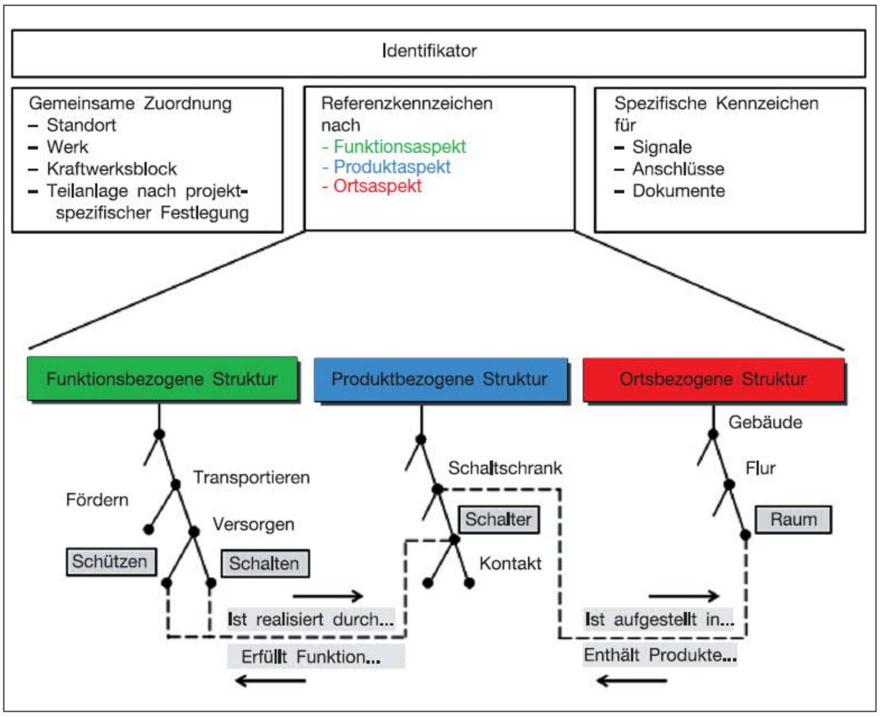
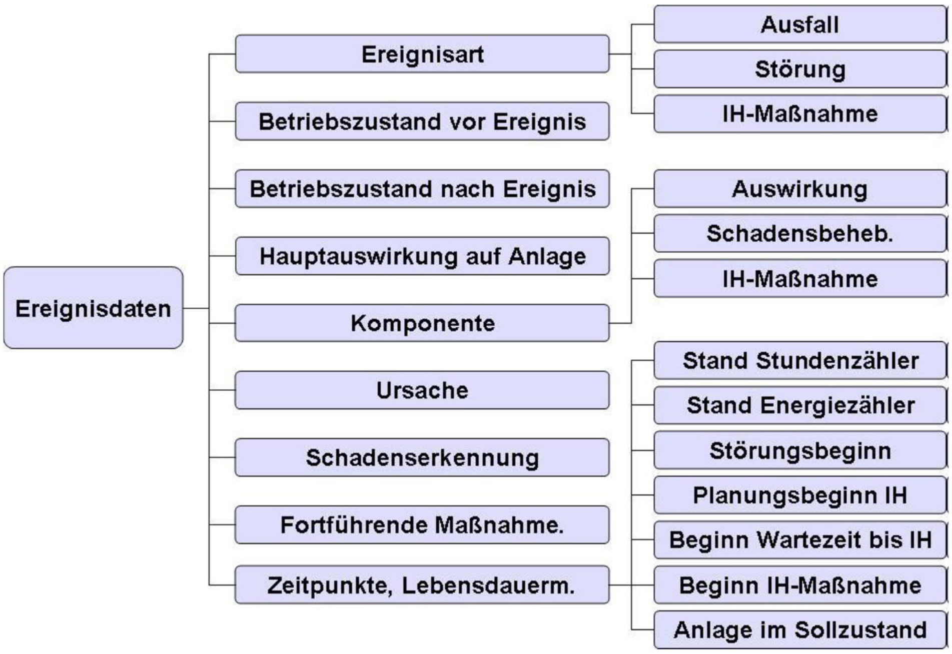
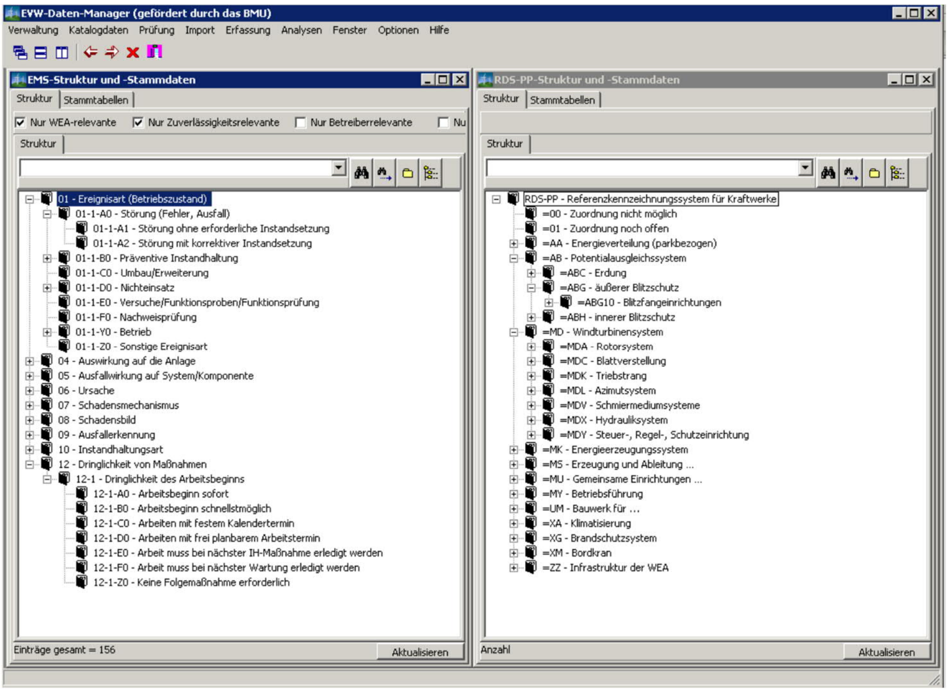


Bild 3. Maximaler Umfang des Kennzeichens, Aspekte, Struktur und Relationen

Catalog state and error description

The task of classifying the event data is carried out by the so-called event-feature key system (EMS). The EMS is a detailed description of all events. In this case, an event is understood to mean all planned or unplanned measures, with or without interruptions to operations. The EMS, in its original form, is divided into twelve groups with the aim of defining the event in such concrete and detailed detail that further analysis is possible. However, sometimes these groups contain more information than is actually needed for an event description. In addition, some groups find only partial or no use in describing the events of a WEA (Win Energy Installation).





2.3.9 Fusion component failure rate database (FCFR-DB)

A fusion component failure rate database (FCFR-DB) has been set up. Failure data of typical components in the systems of a generic fusion power plant have been collected, processed and recorded. The data sources have been existing fusion facilities (JET, TFTR, DIII-D, TLK, etc.) and other technological experiences like fission power plants or industrial systems. Records in the database contain, among other information, component boundaries, design features and application field; failure and repair rate values; uncertainty distributions and indications about possible use of the data in designing and assess fusion device. The database is now accessible “on line” by the way of an Internet browsers and Lotus Notes application for analyst or designers developing reliability and probabilistic safety assessments. The link to the database is http://spx595.frascati.enea.it:8080/se-home.nsf. The number of records in FCFR-DB is foreseen to grow as new data from operating fusion devices will be evaluated.

For use in ARIES is the paper not directly applicable. However, the paper gives good ideas about data quality and data approval process and about taxonomy.

2.3.10 Component failure rate data base for fusion applications

Due to the small number and the innovative aspects of fusion devices, in general, not much information is available in the literature about availability and reliability of their components. To perform probabilistic safety assessment of fusion devices, analysts have to consider use of reliability data originating from different technological experiences. To set up all the available information and create a dedicated data source on components typically used in fusion facilities, a specific database system has been developed. Data collection and data distribution activities have been established in the context of the International Energy Agency Agreement on the Environmental, Safety and

Economic Aspects of Fusion Power (IEA ESE). This database development has been carried out to pursue the objective of creating a reference databank for the international fusion community. This paper briefly describes the database structure, the adopted generic component classification, and the fusion specific component breakdown. It also describes the procedure to gain consensus on data between interested IEA participants.

For use in ARIES is the paper not directly applicable. However, the paper gives good ideas about taxonomy.

3 Maintenance data collection at CERN

3.1 Data Collected by Involved Groups at CERN

In this chapter examples are given from discussions at CERN during meetings.

- Radio Frequency
- Cryogenics
- Power Converters

3.1.1 Radio Frequency Group

Two system levels have to be distinguished:

(1) the High Level RF System, comprising the RF system itself, the Cavity, the Amplifier, and the Cooling, and
(2) the LOW Level RF System, which means Software and the embedded systems.

Relevant is the low level RF electronics, which is a low power equipment, controlled e.g. by feedback loops. So, for the reliability investigations, only (1) shall be considered, but the question whether (2) is critical is of interest.

Up to now (Nov. 2017), historical data have been collected in an ad-hoc way because systems are very diverse. Each of the component types is managed by a different team.

For instance, there are different types of cavities in use, some are normal conducting (e.g. copper) cavities, others are superconductive cavities, there are moreover travelling wave cavities, and ferrite coated cavities. As another example for the high degree of diversity, the PS (the Proton Synchrotron feeding the LHC) uses five different RF systems at five frequencies, each with a different number of cavities, for instance 11 cavities for 10 MHz.

There is also a wide range of amplifiers to be treated in the reliability data: Higher power vacuum tube amplifiers realizing n x 10kW, there are Klystrons operated at high frequencies between 400 MHz and several GHz with the biggest between 4 and 5 m high. In the finite system, Proton Synchrotron Booster or ELENA, solid state amplifiers are used with towers containing several hundred transistors in parallel.

The terminology used in the RF group is well-introduced. The terms System and Equipment are used synonymously, a Subsystem is e.g. a single RF line, an amplifier, a cavity, or similar. It is rather a special case that some equipment types used by the RF group are not repaired at CERN but sent to the manufacturer for refurbishment; this applies to klystrons.

A typical failure mode is a vacuum leak due to ceramic windows. Tracking the reliability down to the fine granularity of individual components like tubes is meaningful, and a novel system like the one planned in ARIES should allow this granularity. The RF group knows Infor AE, which has recently (Sept. 2017) been presented to them. Using it means an investment in time, and the return on investment is not clear. In any case, a much finer granularity would have to be implemented to make Infor AE useful for the RF group. Summarizing, they expressed interest in such a new database but they cannot promise that they would actually use it in the future.

3.1.2 Cryogenics Group

There are 5 cryogenic islands (8 helium cryogenic plants) around LHC, one plant serves one sector.The system has wide range of cooling power.

There are 2 types of refrigerator, 4,5K refrigerator (18kW @ 4,5K) and 1,8K refrigerators (2,4kW @ 1,8K), an individual refrigerator unit can be switched to different distribution lines.

In case of a failure, a warm-standby machine is available.

There is an effective maintenance program, progressively implemented for the LHC and retroactively for older installations, supported by a computer aided maintenance management system. There are few short technical stops for critical corrective maintenance interventions. Preventive maintenance is performed during one month yearly shutdowns or every four to five years during major year-long shutdowns. There are 40.000 equipment types in cryogenics and 20.000 work hrs per year. Complete cryogenics inventory and hierarchy management (what else is affected if one equipment fails) is available.

There are various types of issues tracking:

- Issues tracking 1 : Logbook
  All operation activities shall be tracked in logbook to allow the follow up but some action or events have not been tracked and data capture in free text makes difficult the post processing
- Issues tracking 2: SCADA
  All alarms are recorded and can be exported for futher processing but only the effect and not the cause of the problem are recorded and not all types of failures can be captured.
- Issues tracking 3: INFOR reporting
  All work orders are recorded in INFOR_EAM, statistics on the type of intervention and the equipment affected can be extracted, but the closing code definition is not yet satisfactory to define the precise nature and root cause of the failures.
- Issues tracking 4: New logbook

The new logbook is integreted with INFOR-EAM allowing a direct link with work orders, will integrate a closing code classification to allows statistical analysis and the implementation of automated resgistration from the SCADA system can be foreseen.

Cryogenics Availability Analysis (short/medium/long cryogenics failures were classified) from 2010-2017 show increase of availability from 94.8% to 97.2%, but any possibility for improvement are looked. For ARIES database following goals, problems and questions were identified:

- Problem is the tool and the spacial diversity (people at different places, double input of data has to be avoided)
- Environment conditions is very important
- What level of granularity should the database have?

Summarizing, interest in such a new database was expressed, but the database must have a very easy to use interface.

3.1.3 Power Converters Group

There are more than 4500 power converters at CERN, with large spectrum of technologies, from few kW to hundreds of MW. With large geographical distribution of equipment and with limited and difficult access to equipment. On-call 24/24 service for 1st line intervention is requested, Maintenance cycle are based on Injectors & LHC schedules.

The TE/EPC group has 8 secions and 70 staff.

There are two types of maintenance:

- Corrective maintenance
  - Emergency maintanance (unplanned)
  - Corrective maintenance (planned)
- Preventive maintenance
  - Calendar based maintenance
  - Condition based maintatance

For the standby service, there are

- Three 1st line intervention teams (to face to the large geographical dispersion and to the large spectrum of technology of equipment)
- Two additional teams on standby (to support the 1st line team)
- Experts on call

<u>1st line intervention:</u>
If an equipment is faulty, CCC calls TE/EPC Piquet, Piquet intervenes to fix the problem, then operation test of equipment with CCC is done and beam is recovered. Next steps are feedback (logbook), improvement (consolidations, corrective actions, maintenance activities) and ebtry in database, documents etc.

The TE/EPC database centralizes all data relating to the management of maintenance activities, is connected to other CERN databases, constitutes a CMMS with specific users interfaces and provides a support to maintenance teams and all those involved in the operation. Parts are registered in the data-base and labelled with an equipment code following the LHC convention and validated by “Naming-Service”, pictures of each part are systematically added to the DB.

The TE/EPC Databases supports the teams that are involved in the operation of the converters, is a CMMS composed of Oracle database and asp.net (users interfaces) andis open to other CERN systems, many exchanges are already in place (EN / EL, layout and naming DB, GIS, MTF ...).

There is tracking of interventions, of exchanged parts and of repaired parts. Equipment history, intervention reports and failure forecasts are used to plan maintenance activities in order to increase the availability of the machine.

Statistic comparison of year 2012 versus 2011 shows, that in 2012 injector faults are about the same, but outside working hours decreased by ~7%.

CERN provides analysis of interventions records, from model down to individual component

Two key performance indicators are used to monitor power converter performance regarding machine availability:

- Uptime proportional to reliability

  MTBF = Observation time period / Number od intervetions

- Downtime proportional to maintainability

  MTTR = ∑ Intervention time / Number of intervetions

Weilbull analysis is used, but under development.

3.2 Existing Data Collection Systems

3.2.1 Accelerator Fault Tracking (AFT)

The aim of the Accelerator Fault Tracking (AFT) system is to increase availability, both short and long-term, by dealing with issues as soon as possible. The complete and consistent tracking will allow to identify the following:

- Problems as early as possible (timely mitigation)
- Key issues, which will limit the performance of accelerator equipment (e.g. LHC).

The system tracks two areas:

- Directly affecting accelerator operation – identify root causes
- Equipment faults independently of immediate impact on accelerator operation

The High-Level Overview of AFT is represented in Figure 12. The operators are able to open the AFT with a web interface.

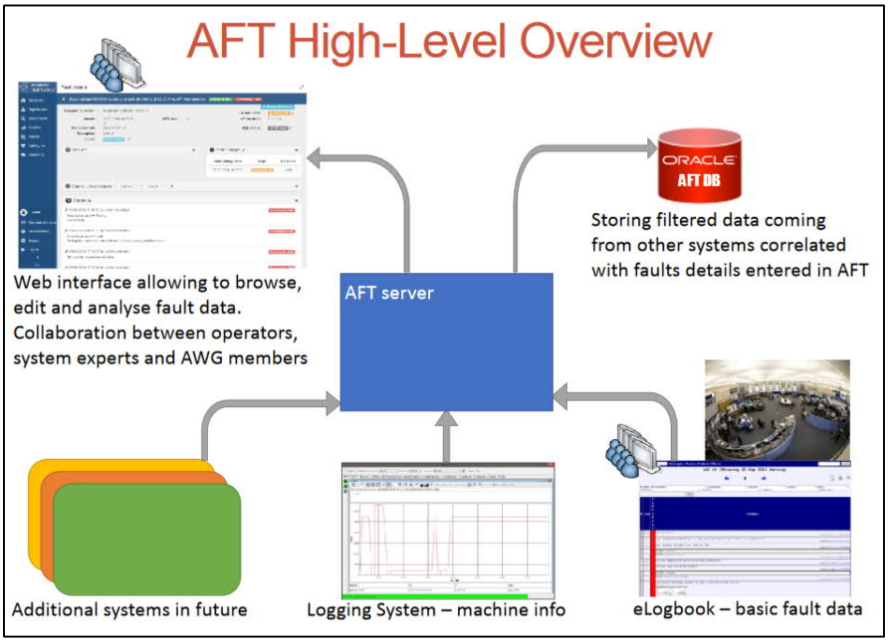


Figure 12: AFT High Level Overview[4]

One main outcome is the cardiogram, which shows downtimes of the LHC accelerator as represented in Figure 13. Other outcomes are fault statistics and reports.

[4] C. Rodderick, "Accelerator Fault Tracking", Weblink: https://indico.cern.ch/event/651934/contributions/2653520/attachments/1525847/2385823/AFT_Fault_tracking_at_the_LHC_accelerator_complex.pdf (last acces: 20.11.2017)

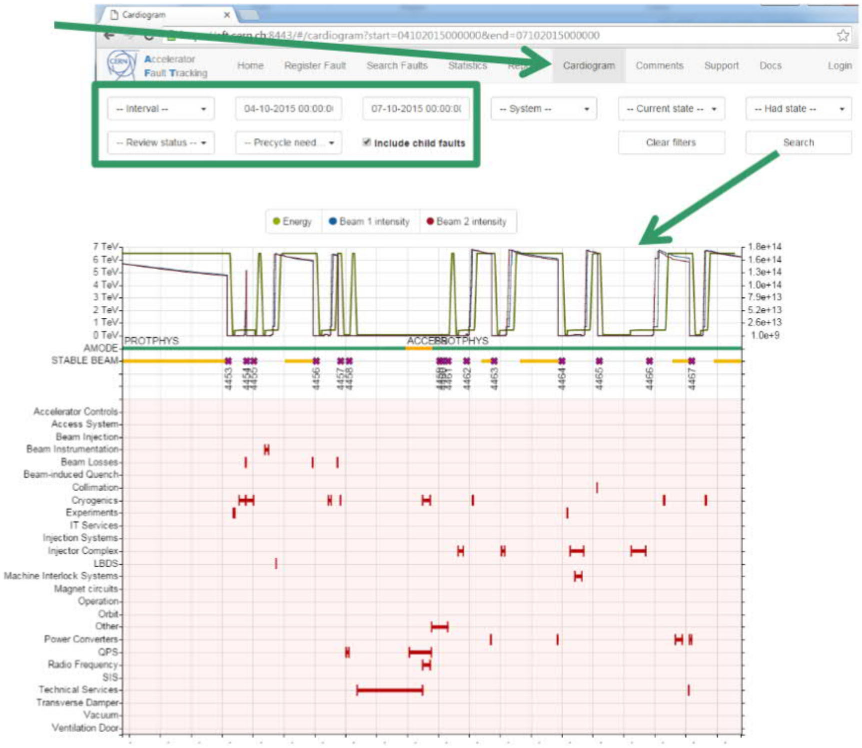


Figure 13: Screenshot from AFT, LHC Cardiogram

The AFT is one possible source as input for ARIES.

3.2.2 InforEAM

The InforEAM system can be used CERN wide. At the moment groups of CERN are using InforEAM as depicted in Figure 14.

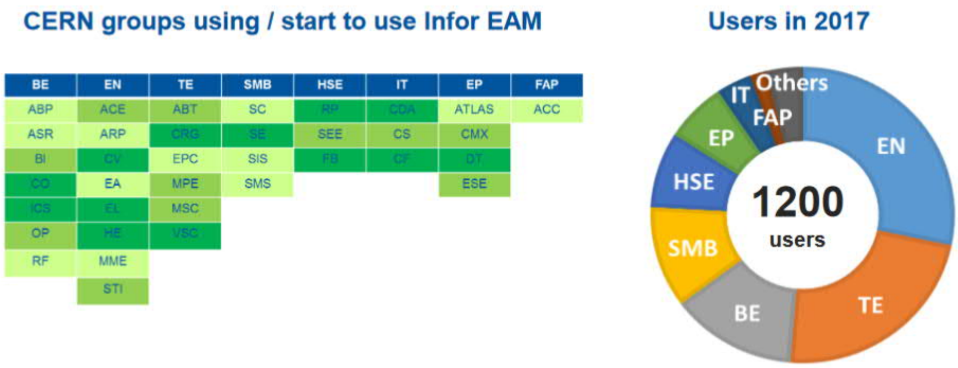


Figure 14: Usage of InforEAM at CERN in 2017

Within the system calculations can be made for example for the MTBF as given in Figure 15. Graphical interpretation is possible within the system.

Mean Time Between Failures (MTBF) - (01-01-2011 - 01-01-2016)					
Class	Class Description	Category	Category Description	Objects	Period
HAS	ASCENSEURS	All	-	128	1,826

Closing Code	Closing Code Description	Ocurrences	MTBF (days)
FFHP	HYDRAULIQUE	2	116,864
FFME	MECANIQUE	7	33,390
FFPN	PNEUMATIQUE	4	58,432
HAUT	AUTOMATISME - ELECTRONIQUE	29	8,060
HELA	ELECTRIQUE - ALIMENTATION	57	4,100
HELC	ELECTRIQUE - COMMANDE	307	761
HHYD	HYDRAULIQUE	1	233,728
HLIS	LIAISON AU SOL	1	233,728
HMEE	MECANIQUE - ENTRAINEMENT	235	995
HMES	MECANIQUE - STRUCTURE	5	46,746
	Any failure code	**648**	**361**

Figure 15: MTBF from InforEAM

Figure 16 shows a High-Level Overview of the possible input sources for InforEAM.

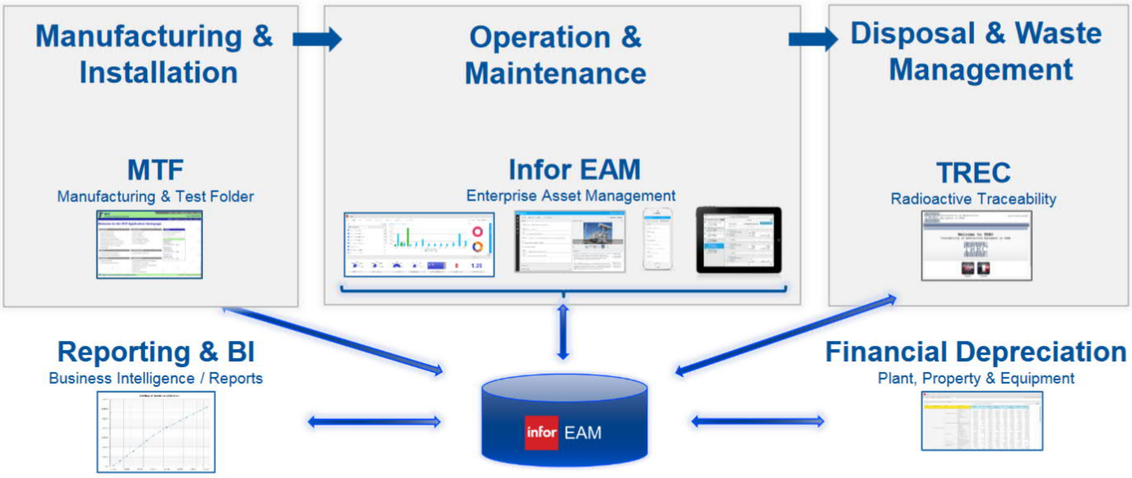


Figure 16: InforEAM High-Level Overview[5]

InforEAM is one possible source as input for ARIES.

3.2.3 Data from Excel Files

Groups at CERN are also dealing with data gathered in excel files. These data will be discussed with groups at CERN directly.

4 Conclusion and Outlook

The following section concludes the deliverable with a summary of and assessment of the investigated documents.

Taxonomy/Thesaurus

Some of the investigated documents are describing taxonomies in the respective domain for example oil and gas industry. The most important point is to adapt these ideas and make it usable for the purposes of the CERN ARIES project. The classification of categories in equipment, units, sub-units, classes, sub-classes or components is similar in some of the documents e.g. the OREDA handbook, ISO 14224 or reports from WIND-pool have a very detailed scheme proposed for such a taxonomy and could be a starting point for generating the ARIES taxonomy. Of course, this has to be done together with groups at CERN.

[5] D. Widegren, "Reliability Analysis & InforEAM", Weblink: https://indico.cern.ch/event/651934/contributions/2653524/attachments/1525615/2385406/InforEAM-Reliability.pdf (last access: 20.11.2017)

Data quality

One of the requirements for a future reliability and availability information system is to ensure adequate quality of the gathered data. This issue is described in some of the investigated documents, but not in detail. General statements such as completeness of data in relation to specification or compliance with definitions of reliability parameters, data types and formats are given for example in the standard ISO 14224. The aim is to adapt such rules for the ARIES information system to automate or assist data quality annotation with different algorithms (e.g. expert knowledge, machine learning, statistical correlations).

Anonymity

Sharing of reliability and availability data is of certain interest for equipment and component providers. One of the aims of the ARIES project is to share such data between research institutes like CERN and HIT, but also industrial providers are of interest. The sensitivity of exchanging these data is given, because this could be an issue of prohibition agreemnts, competitor agreements or law prohibitions. Therefor an anonymization concept for shared data is needed which is for example described in ISO 14224 or in reports of WIND-pool. The system will have a role based access structure with different roles in the consortium e.g data provider or administrator.

Model for conditions

The outcome of the ARIES information system should be probability distributions of systems, subsystems, equipment or components. For this purpose the environmental conditions (e.g. temperature, status of operation, power, radiation level) are of certain interest. Approaches for qualifying data sets according to their environmental conditions were found in nearly all of the documents e.g. OREDA or MIL-HDBK-217F. Such models have to be applied for the ARIES information system.

Model for reliability prediction

For the purpose of calculating probability distributions of systems, subsystems, equipment or components reliability information e.g. Mean Time To Failure (MTTF) or Mean Time To Repair (MTTR) are necessary. Approaches for calculating such parameters are described in nearly of all of the investigated documents. The usage of such parameters for the purposes of the ARIES information system has to be discussed with groups at CERN.

5 References

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