MYRRHA project - ADS reliability requirements

5-10% current fluctuations are allowed but any more significant drop causes a SCRAM (prompt neutron population drops to zero, temperature drop, thermal stress)

- Allowing 10% availability loss due to SCRAMs means accepting 10 SCRAMs per period of 3 months at MYRRHA :

< 10 accidental beam interruptions > 3s per 3 months period

→ Need for R&D decision-taking control systems

Circular ADS machines challenges

Circular candidates: cyclotrons , FFAGs, synchrotrons (low-to-higher complexity)
FFAGs: difficult injection/extraction, high intensity not demonstrated
RCSs have demonstrated respectable high intensity performance (JPARC)
Critical for cyclotrons:

- electrostatic elements (HV breakdowns, poor vacuum), loss tuning, RF system breakdowns
- injection/extraction schemes

implementation of redundancy difficult in circular accelerators
cyclotrons with CW operation should have best stability and could reach high availability

It would be interesting to perform availability studies on cyclotrons (PSI?) as was done for SC linacs (SNS), comparing simulations and data from operation

Linacs – challenges

-reliability guidelines needed from design phase (simple strong design, redundancy, repairability)
Critical for reliability:

- HV/RF systems & ion source (avoid high voltage & pulsed operation)
- LLRF: obsolescence of electronics needs to be anticipated
- NC cavties are less reliable than SRF
- MEBT fast switching magnet
- 2.4 MW MEBT beam dump
- Diagnostics reliability and false signals suppression
- Fast and automated controls procedures for fault compensation & reconfiguration
- Integrated maintenance management program

Achieved by MAX programme :

- Reference design of linac
- R&D on 176MHz RFQ & cavities (CH, elliptical, solid state amplifiers)
- Final report published

H2020 MYRTE programme: build injector demonstrator (source+RFQ)

MYRRHA accelerator studies

RF cavities retuning feasibility in case of multiple failures has been studied with Tracewin simulations.
The fault-recovery scheme is a priori feasible everywhere in the MYRRHA SC linac to compensate the failure of a single cavity or even of a full cryomodule (local retuning solution).
Retuning affects the longitudinal acceptance and can create important emittance growth. An optimization of the retuning algorithm is in progress with comparison of different optimization criteria.

SNS Linac availability study (2014) showed that the most critical systems are RF, electrical systems failures, power supplies and their controllers, the front-end, diagnostics and controls. The same analysis applied to the MYRRHA Linac showed that:

- A doubled injector improves significantly the overall reliability
- Automatic cavities re-adjustment of deviation from the field parameters is key to a good fault tolerance
- Classical parallel redundancy is key to avoid critical failures
- Most critical SCL/HEBT components are magnet power supplies and power supply controllers, tuners and ion pumps.
- Special attention should be devoted to reliable and accurate diagnostics and controls systems

PSI operation

The PSI cyclotron delivers 1.3 MW beam power in CW mode and has run with 87% average beam availability over the past 10 years.
Most critical systems for downtime are infrastructure, personal safety system and RF. High dark currents at the electrostatic deflector caused damage to insulators. High power RF causes discharges, multipactoring and plasma generation. Molten contact springs were discovered on RF feedthroughs. Multipactoring was cured by Aquadag coating against secondary emission. Problems with a flat-top cavity were shown by an increase of X-rays emission. The cavity was removed and vacuum and water systems were improved.
Steps taken to improve reliability:

- New better performing ECR ion source
- Removal of aperture limitations
- Protective shielding of electrostatic elements
- Optimised operation and maintenance planning

A major performance step was achieved by raising the gap voltage using the new cavities in the ring

LHC

Identify hazards and estimate risk of a failure as function of its impact on beam operation
Design a MPS to prevent failures or mitigate their consequences
The time constant of the failure determines the technology to adopt (ns to seconds)
A comprehensive understanding of all aspects of the accelerator is fundamental

Strategy of the LHC MPS is to detect a failure at hardware level (or before it's too late) and stop beam operation by inhibiting injection or extracting/stopping the beam.

- Active equipment and beam monitoring to detect faults
- reliable transmission of signals
- Failsafe logic (active signals are needed for operation, lack of signal causes interlock)
- Personnel interlocks separated from machine interlocks
- Redundancy/duplication of interlocks signals

A fault tracking project was launched at the LHC to capture a complete and consistent picture of faults data, and be a single source providing standardised faults statistics and analysis and an interactive graphical overview of faults (machine cardiogram). Fault data is entered by operators on the machine logbooks and filtered weekly by Availability Working Group experts.
Further foreseen developments are integration with other CERN data management systems and use for dependability predictions.

A Monte Carlo model was developed to assess beam availability at the LHC: based on observed failure distributions, it reproduced LHC operation with 1% accuracy. Input data comes from several sources: logbooks, post-mortem, group-specific databases. Faults are analysed in terms of systems and sub-systems decomposition. The reliability of the systems is modelled as probability density distributions, depending on time and operation modes.
Probabilistic methods for RAMS engineering analyses exist since 1996; a collaboration has been established between CERN and RAMENTOR company in Finland to apply the ELMAS software tool to accelerator reliability studies.
The main steps involved are:

- Definition of availability observables
- Process modelling
- Monte Carlo simulations of operational sequences
- Analysis of effects
- Estimate of the associated costs (unavailability costs + availability improvement costs)

An extension of the model is being developed for FCC studies.

ESS reliability requirements have been defined from users’ needs, with a goal of 90% beam availability for the kinetic experiments (and 80% average beam power for the duration of integrated-flux experiments). The distribution of failures is more critical than the average figures: beam trips of <1hour can easily be accepted, failures of the order of a few hours are the most problematic and failures of the order of days will imply rescheduling of the experiments. Failures have been classified according to their duration and a maximum number of trips has been set for each category in order to reach the global availability goals. Direct comparison with SNS operational data has been used to rescale the allowed probabilities for each class of failures. Further input from experts’opinions and failure tracking was taken to come up with a more realistic allocation of the number of allowed trips of a specified duration for different systems (accelerator, services, target, controls). A reduced proton beam power is most often preferred by users to beam unavailability.

A Failure Mode and Effect Analysis was carried out to simulate the occurrence of trips for specific subsystems, their consequences on beam and type of actions involved in terms of maintenance (times for interventions, availability of spares, preventive/corrective actions etc). Different types of failures are studies: catastrophic, “normal behaviour” and wear-out of components. Degraded modes of operation have been studied for assessing machine flexibility. Results of these RAMI analyses have been used as input to orient choices in the design of the machine.

Due to its unprecedented complexity, the ITER interlock system has been designed as a 4-tier architecture with different technological choices: PLC solutions for slow time response, FPGA systems, current loops and other solutions still being investigated for higher complexity. Most of the components will be provided as in-kind contributions from up to 36 different member countries, and a strong effort has been put in place to coordinate and integrate all activities.
Final design will be completed in March 2016 and construction will subsequently take place in Korea.
Specific to ITER operation are that the interlock design should allow early internal failure detection followed by a controlled sequence of actions; a triggered interlock not only affects beam availability but has a consequence on the tokamak lifetime.
Failures and related interlocks have been classified in 4 categories according to the impact on machine availability, costs and event likelihood. A dependability analysis of the system has already been studied, but a final strategy is still evolving.

RAMI analyses are carried out with the BlockSim tool, studying availability over 16 months and 20 years periods. Results are directly fed into maintenance plans and system integrated logistics support plans. Standard RAMI studies for failure probability assessments are not weel suited to complex high-dependeability systems like ITER. A commissioning-oriented design has been put in place to build some flexibility in the system. New methodologies like STPA analysis tools are also being explored.

IFMIF is an accelerator based neutron source using the D-Li stripping reaction to produce an intense neutron flux for material irradiation. The LiPAC accelerator prototype up to 9MeV will be completed by June 2017 in Japan.
IFMIF goal availability can be expressed as 70% percent of the design damage rate. RAMI analyses have been used to calculate failure probabilities of various elements, identify critical points and produce design recommendations in an iterative process.
Beam availability is defined as the product of hardware/machine availability and beam effectiveness. Availability needs to be quantified to be able to allocate requirements on individual subsystems. Understanding the impact of failures is necessary for that as well as an improved modelling to reduce uncertainties on maintenance procedures, recovery times etc. The LipAC prototype will be used as testbed for these studies.
It is important that RAMI result be incorporated in the design of a machine, creating consciousness about the importance of reliability from the early stages.
A Fusion Roadmap was prepared and later approved in the Horizon 2020 framework for development of a neutron source (ENS) for DEMO materials qualification at IFMIF (IFMIF-DONES), to be ready for construction 2018-2020.

General remarks

Reliability needs to be built in the machine from design stage, starting from the definition of availability requirements, to simulation of a machine lifecycle including reliability and continuously improving by iteration.
Availability requirements need to be distributed to systems and sub-systems in a clear and objective way.
A design lifecycle needs to be modelled which is adapted to the organization and includes reliability.
Run-in commissioning and maintenance plans need to be optimised to reduce failure rates of the system.
In reliability studies it is critical that each system is broken into more elementary components, that should be analysed in terms of failure modes, failure mode ratios and MTBFs, determining the impacts and probabilities of each failure mode happening.
Dependability studies give a benchmark for performance and on the other hand, operational figures and fault tracking should be used as input for studies in a continuous iterative improvement.

Classic failure diagnosis is based on monitoring conditions and is inherently reactive, limited and expensive.
Probability based diagnosis is independent of condition and solely based on previous usage statistics.
Availability of usage data and data weighting increase predictions.
A first combination method consists in weighting similar data according to expert knowledge, known standards etc.
In a second method, more diverse usage data are first normalised to have similar magnitude dimensionless numbers.
Weighting parameters are then applied to map usage data over true wear-out mechanisms and minimize the spread in probabilities with an optimization algorithm (evolutionary optimisation).
The method was successfully applied to real field data.
Economic benefit depends on exterior factors (cost of premature exchange vs cost of failure).

Conclusions

In conclusion of the workshop it was discussed and agreed to send to M Vretenar, Eucard project coordinator, an expression of interest to participate to the next EuCard3 call for proposals with a request for funding and resources for a reliability working group with the aim of compiling a comprehensive failure database for different machines, inclusive of detailed information on operational conditions. R Schmidt volunteered to put together a letter of intent.

It was also agreed that some effort should be done in cross-checking and comparing all the different RAMI analysis software tools that are currently being used in the community.

One of the outcomes of the recent US ARW2015 workshop was an agreement on the construction of a Confluence-Wiki webpage platform where interested parties can exchange information on operational and reliability data, start open or private discussions, ask questions to the community, publish workshops information, contact people etc.
E Bargallo` gave a quick presentation of the utility (still under construction) and will circulate the link and all relevant usage information to the workshop participants once it will be broadly published.