Life-cycle and Reliability of accelerators

JUAS 2018

part 1: life-cycle

<u>part 2: reliability</u>

Samuel Meyroneinc
Centre de Protonthérapie – Orsay
Institut Curie

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summary

1. Reliability & Accelerators

2. Reliability during life-cycle of Accelerators

quizz

3. Examples

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Your experience in reliability

Definition of reliability

1st basic approach

$$\text{Reliability} = \frac{\text{Time the systems works} - \text{Time of breakdowns}}{\text{Time the system works}}$$

Definitions of reliability

The **reliability** is the ability of a system or component to perform its **required functions** under **stated conditions** for a specified **period of time**

The reliability (R(t)) is the probability to have no failure at the time t.

MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair

The **availibility** of the system is the ratio of the time when the system is operational by the time it was supposed to be operational

$$\text{Availibility} = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

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exercise

An accelerator is used from 10:00 to 20:00

During this time, there were:

- **10 small failures of ion sources lasting 5 min for each**
- **2 times (15h and 19h) a failure of a magnet power supply, requiring 30 min to retune the beam**

What is the MTBF ?

What is the problem to solve first to do the best « physics » ?

correction

Hours planned: 20-10 = 10h

Failures

10 failures of 5 min for ions sources = 50 min

2 failures of 30 min for PS = 1h00

So 12 failures   (and 13 sequences between failures) of 1h50= 110 min

MTBF = 10 x 60 min / 13 ~ 46 minutes

MTTR = 110 min / 12 ~ 9 min

Avaibility ~   46 / (46 + 9) = 83,5 %

What is the problem to solve first to do the best « physics » ?

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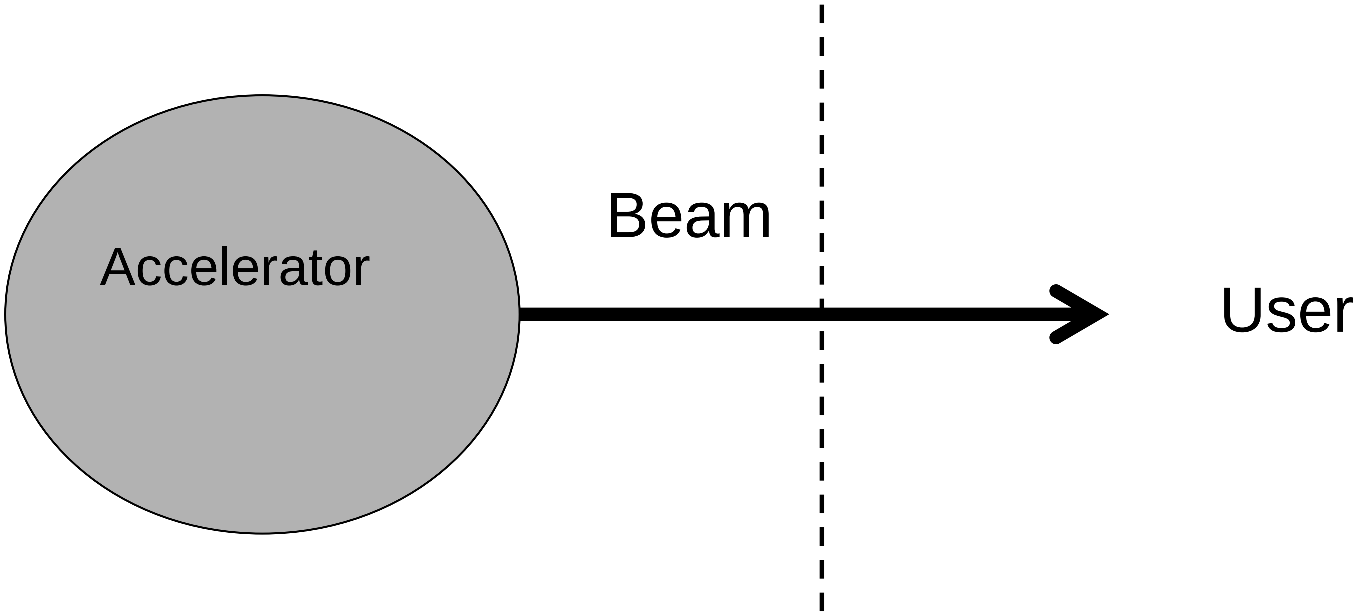

What is the **product (service)** delivered ?
What is the **quality** defined ?
Who is defining the reliability ?

Reliability and Accelerators

- Power- Energy & Motion

Electricity, cooling, regular motion systems

-**Critical and/or sensitive Technologies**

Radio-Frequency, vacuum, electronics, cryogenics, software, …

- **Risks**

radiation-protection, costs, …

-**Complexity**

mix of technologies, %research%production, regulations

- **Using &Users (Customers / Providers)**

beams: current, energies, duration, …

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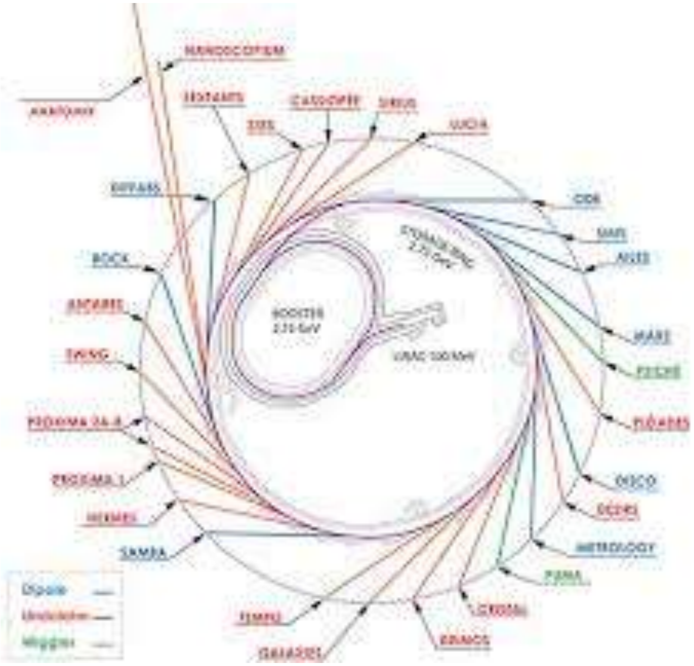
Synchrotron: first real approach for reliability

synchrotron Soleil



Reliability for synchrotron

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Annex 3
Metrics for synchrotron-sources of light

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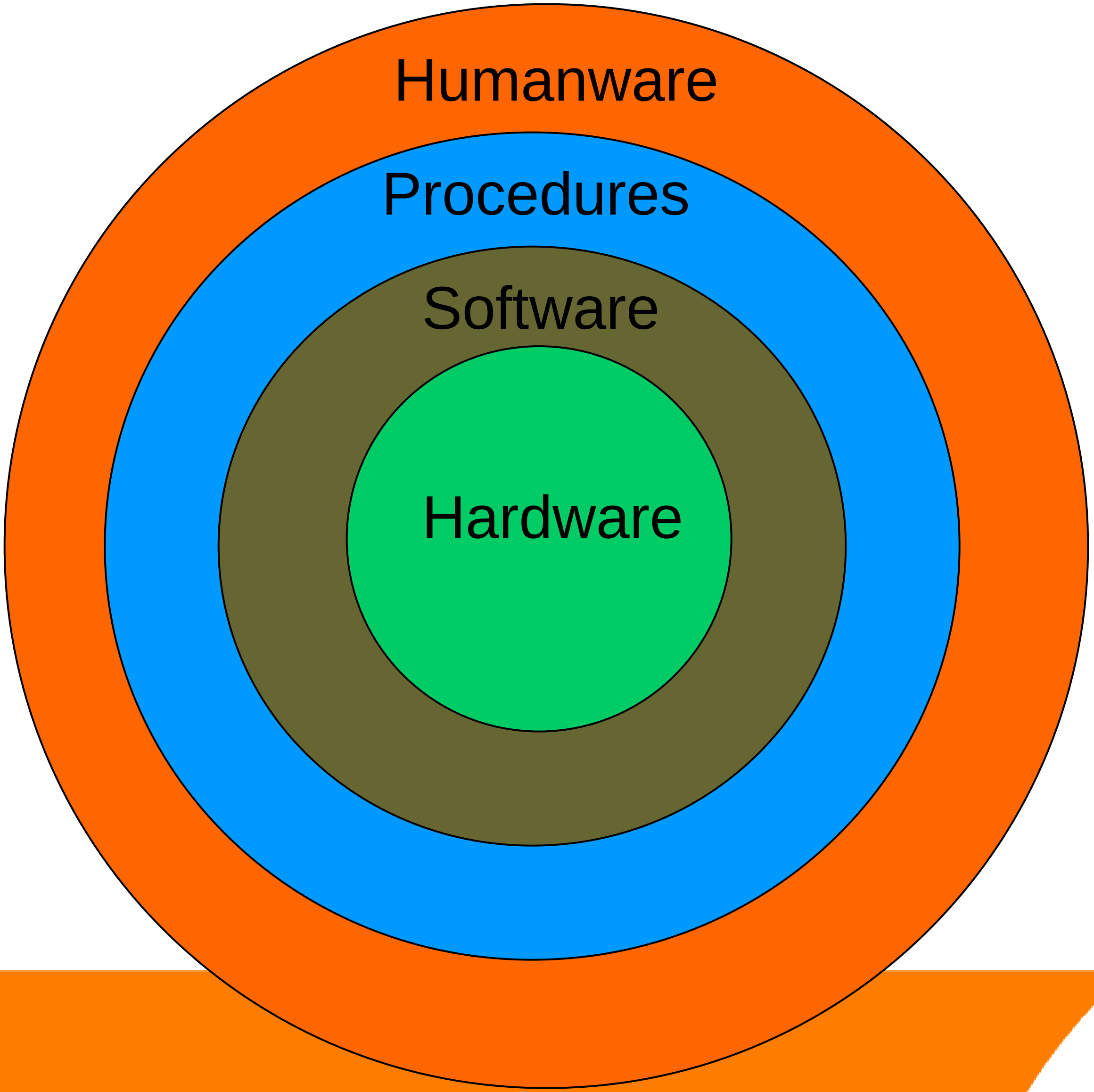
the 4 layers of reliability



2. Life-cycle of accelerators and reliability

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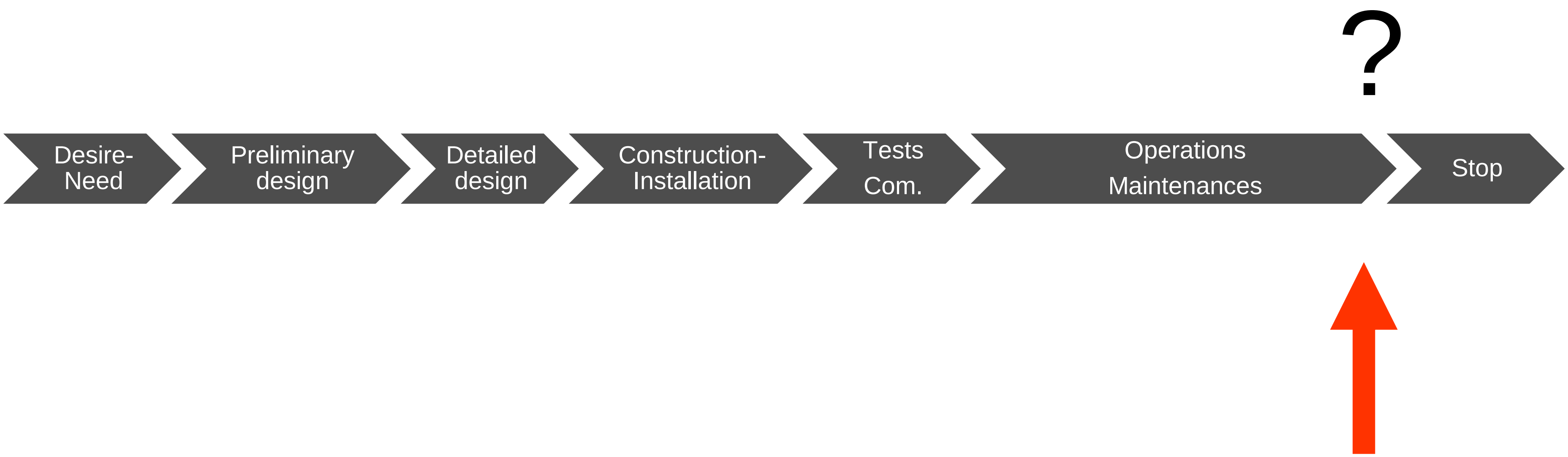
Life-cycle of accelerators

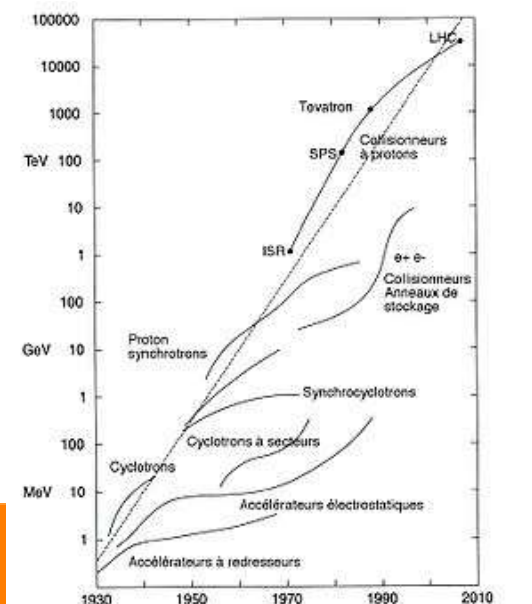


A failure – a small (or big) death

Connection (ESRF)

Main coil (SC200-Orsay)

Obsolescence



Orphan system

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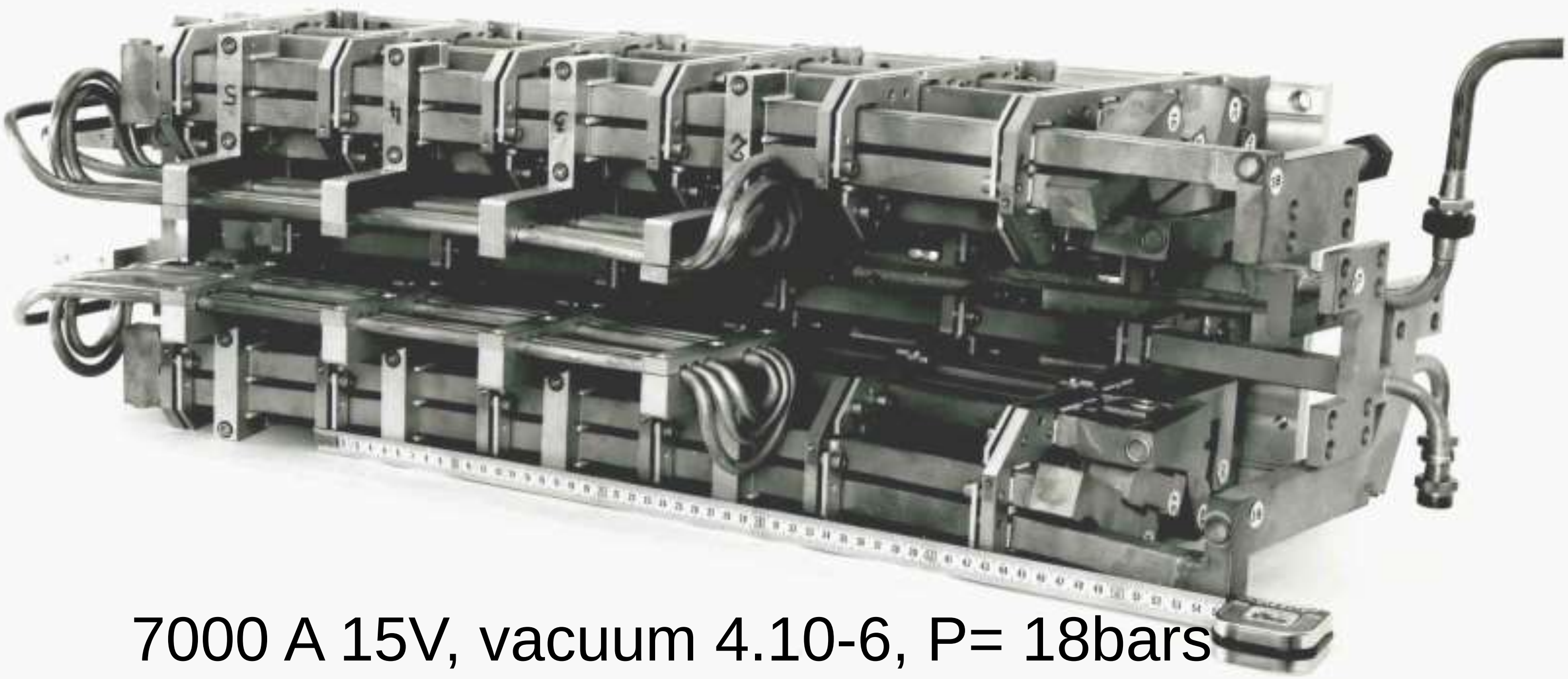
Electromagnetic channel (with septum) of synchro-cyclotron of Orsay



7000 A 15V, vacuum 4.10-6, P= 18bars
« work of artist »

Example of document IUCF annex 4

first page
3)budget
last page « Is the capability … »

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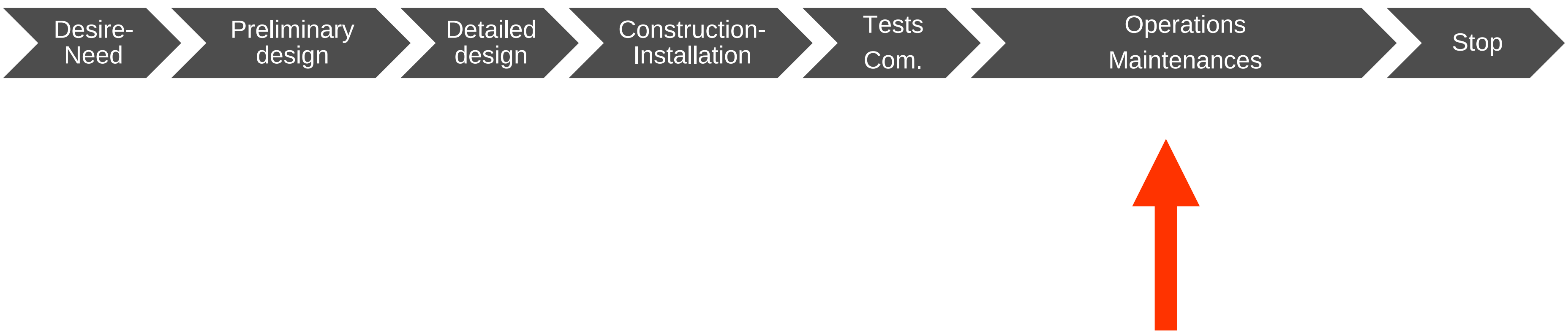
Life-cycle of Large Instruments



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Control room (ex: PSI)

The « operations » for an accelerator

- **All the process to be managed in order to deliver the required beam (and associated services) during the planned period**

This includes:

- Startup of the system, Tuning of the beam
- check of the normal behaviour of the systems during
- monitor and record parameters (automatic or manual, log-books, …)
- fix any unplanned event (troubleshooting, corrective actions level 1,2,…)

- planning of the activities (discussion with users): day, month, year
- managing the documentation (procedures, drawings, …)
- training of operators level 1, 2, …

- in direct relation with maintenance and project issues

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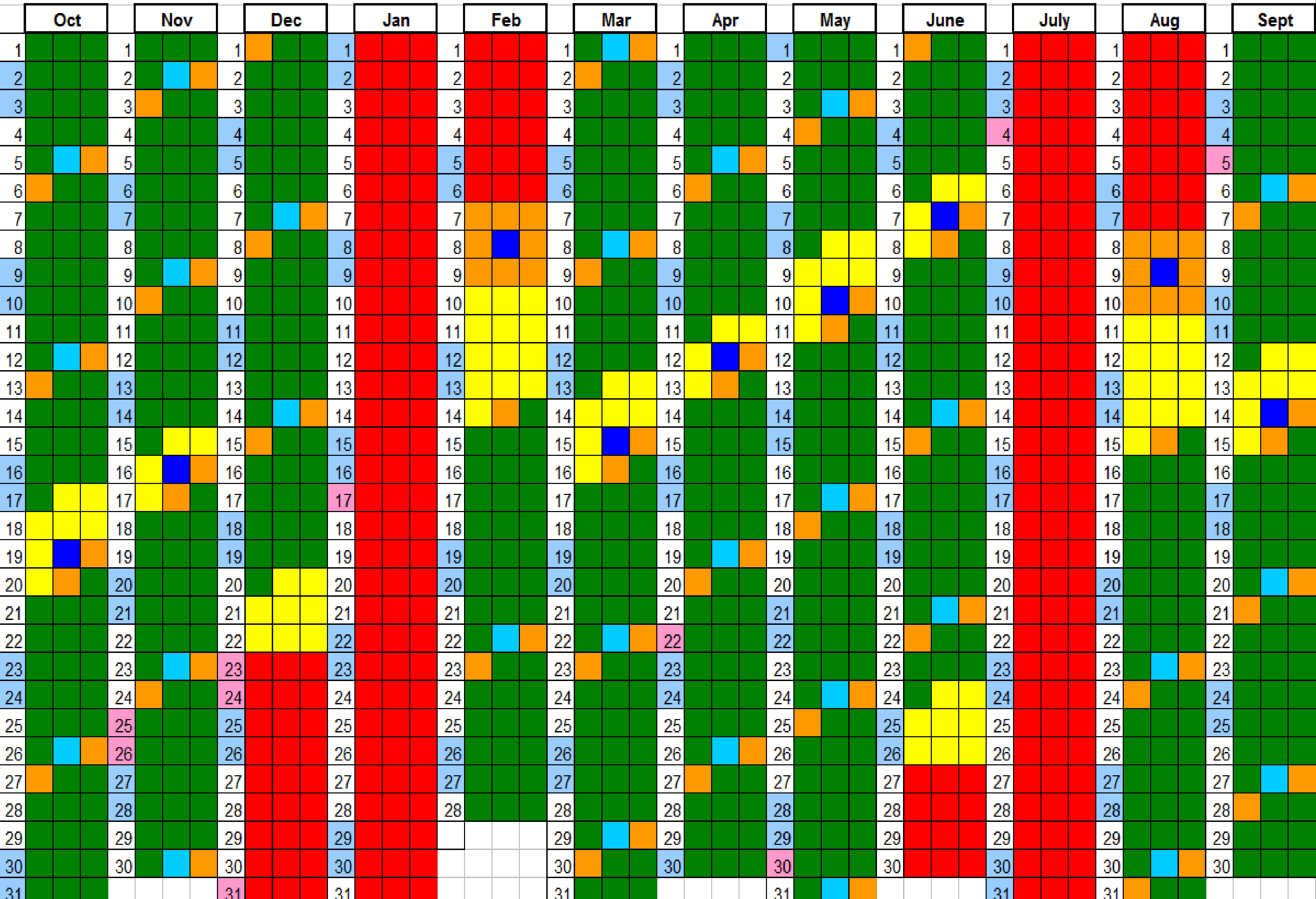
Run Schedule for FY 2011



Accelerator Physics
Accelerator Startup/Restore
Optional Maintenance Periods
Neutron Production
Machine Downtime Major Periods(Maintenance/Upgrades)
Scheduled Maintenance
Holiday

Operations / Projects

Goal: keeping a process stable

Key Performances Indicators (KPI): **reliability**, production outputs for users (ex: hours of beam)

Goal: reaching a specific target (new)

Key Performances Indicators (KPI): Milestones (dates), level of completion achieved, performances reached,**reliability** of planning …

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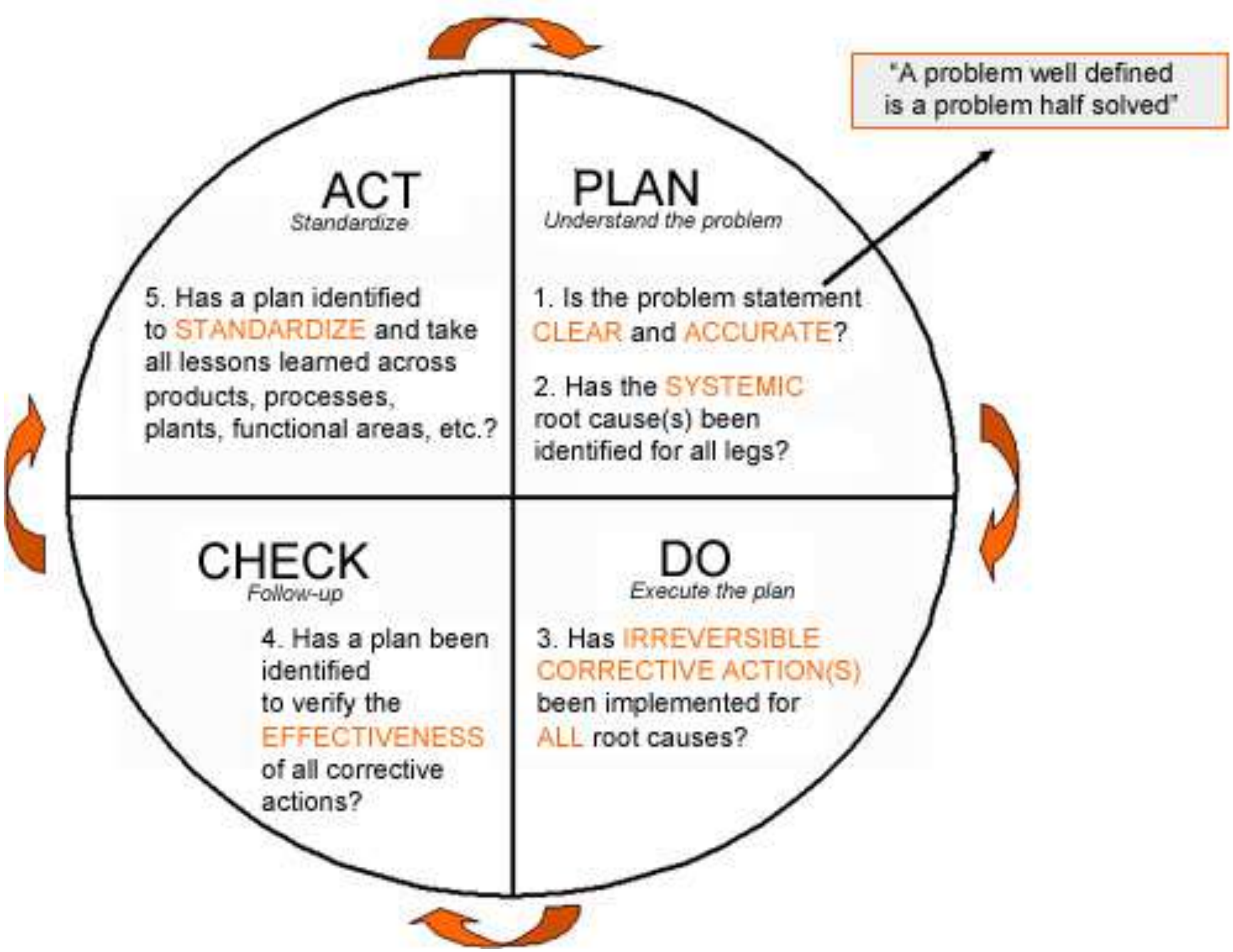
Plan – Do –Check – Act (PDCA)
(to manage Operations)



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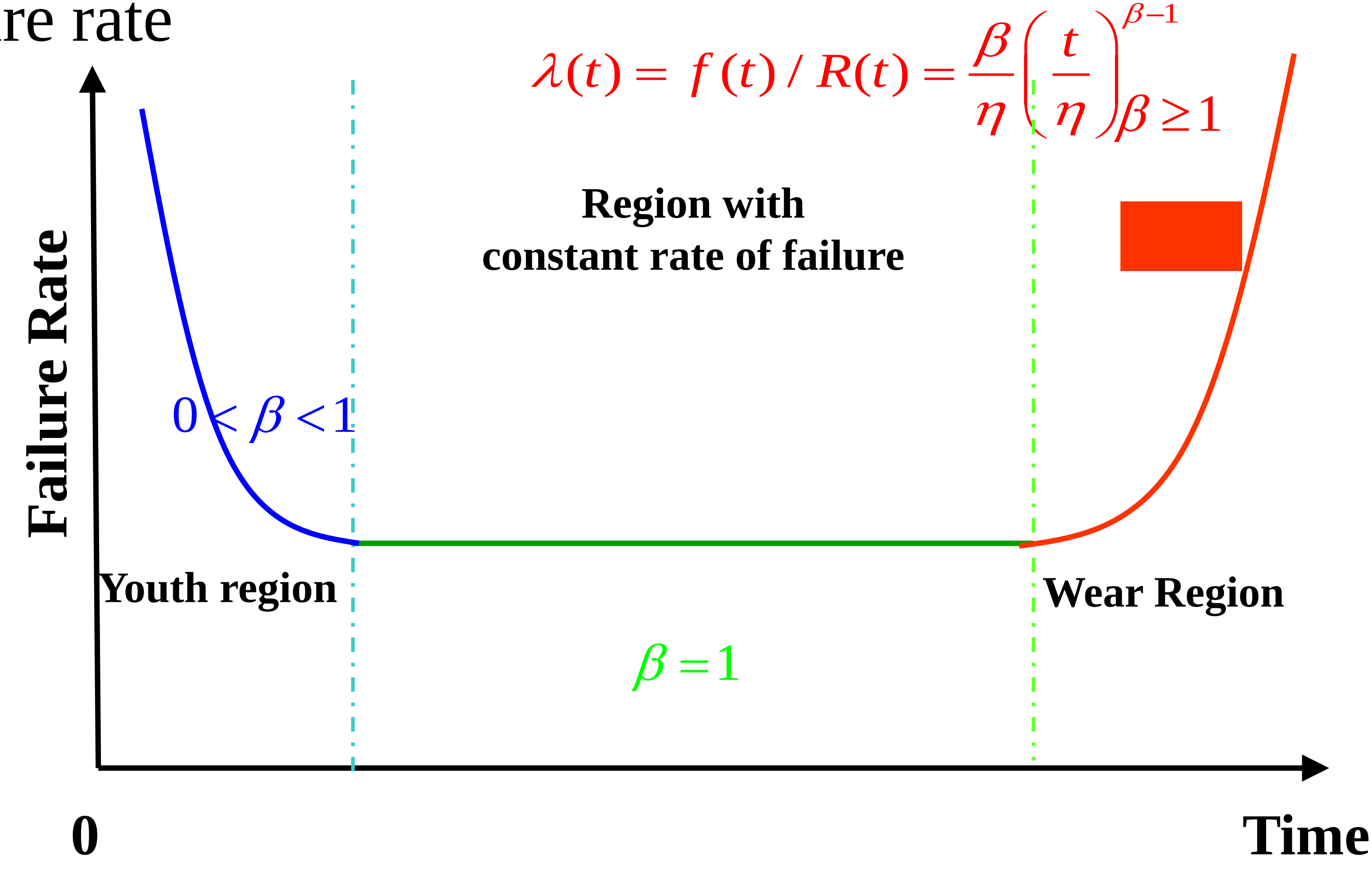
The reliability Weibull Model

Failure rate



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Series Components – Part Count

An integrated circuit board consists of the following components each having a CFR.

Component	a-Failure Rate(10^{-5})	b- Quantity	(a) x (b)
Diodes, silicon	.00041	10	.0041
Resistors	.014	25	.3500
Capacitors	.0015	12	.0180
Transformer	.0020	2	.0040
Relays	.0065	6	.0390
Inductive devices	.0004	12	.0048
		total	.4199 x 10^{-5}

$$R_{system}(t) = e^{-\sum_{i=1}^{n} \lambda_i t} = e^{-0.000004199t}$$

$$MTTF_{system} = 1/\lambda_{system} = 1/(0.4199 \times 10^{-5}) = 238152$$

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Maintenances

Modelisation, experience

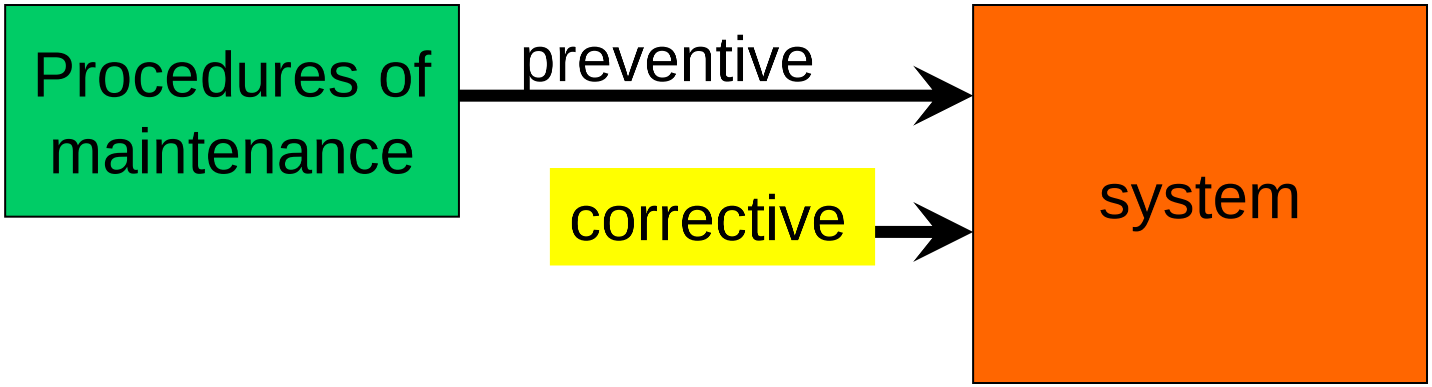
Procedures of maintenance → preventive → system

Inspect, clean, check, lubrify, calibrate, read, replace, test ,…

< 20% with high periodicity
Ex: Ions Sources

Maintenances

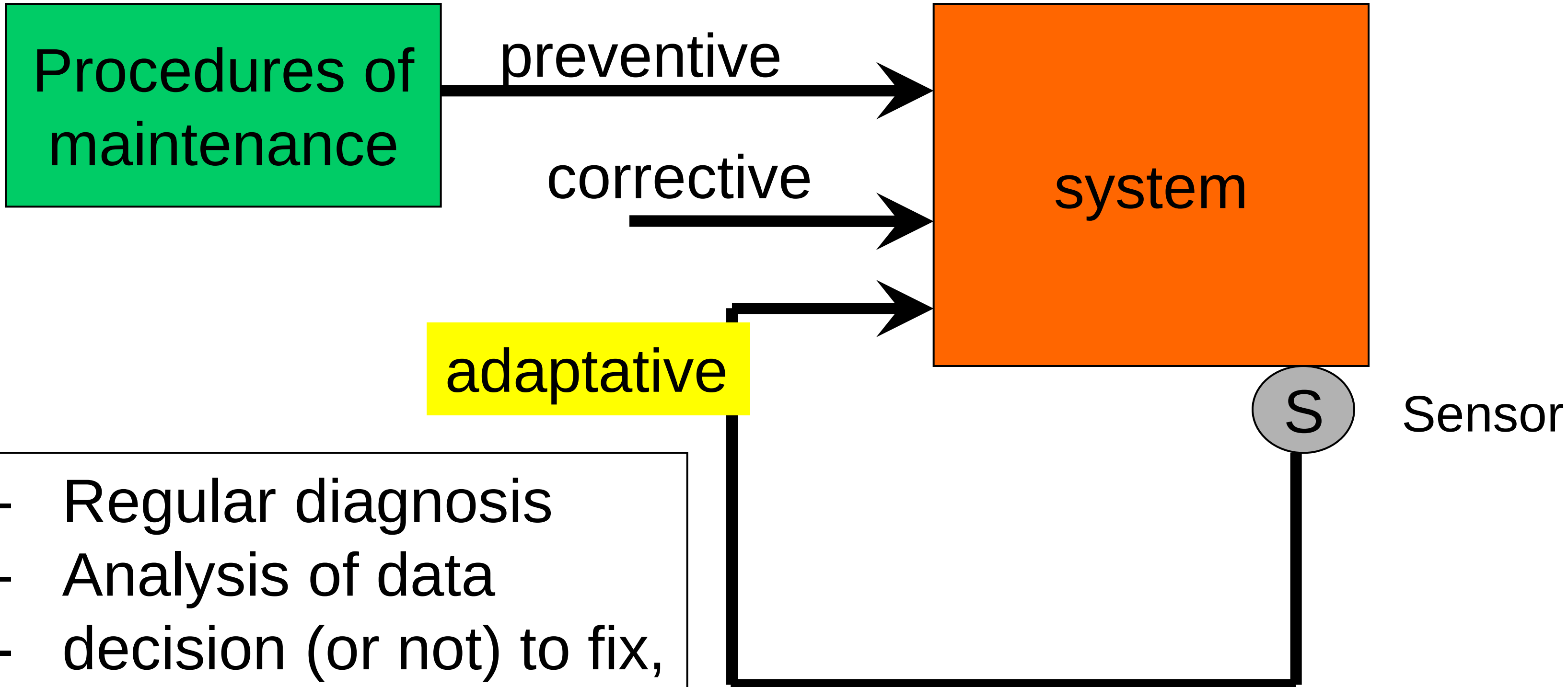
Modelisation, experience



- Awareness of problem(s)
- Diagnosis
- Fix-replace
- test

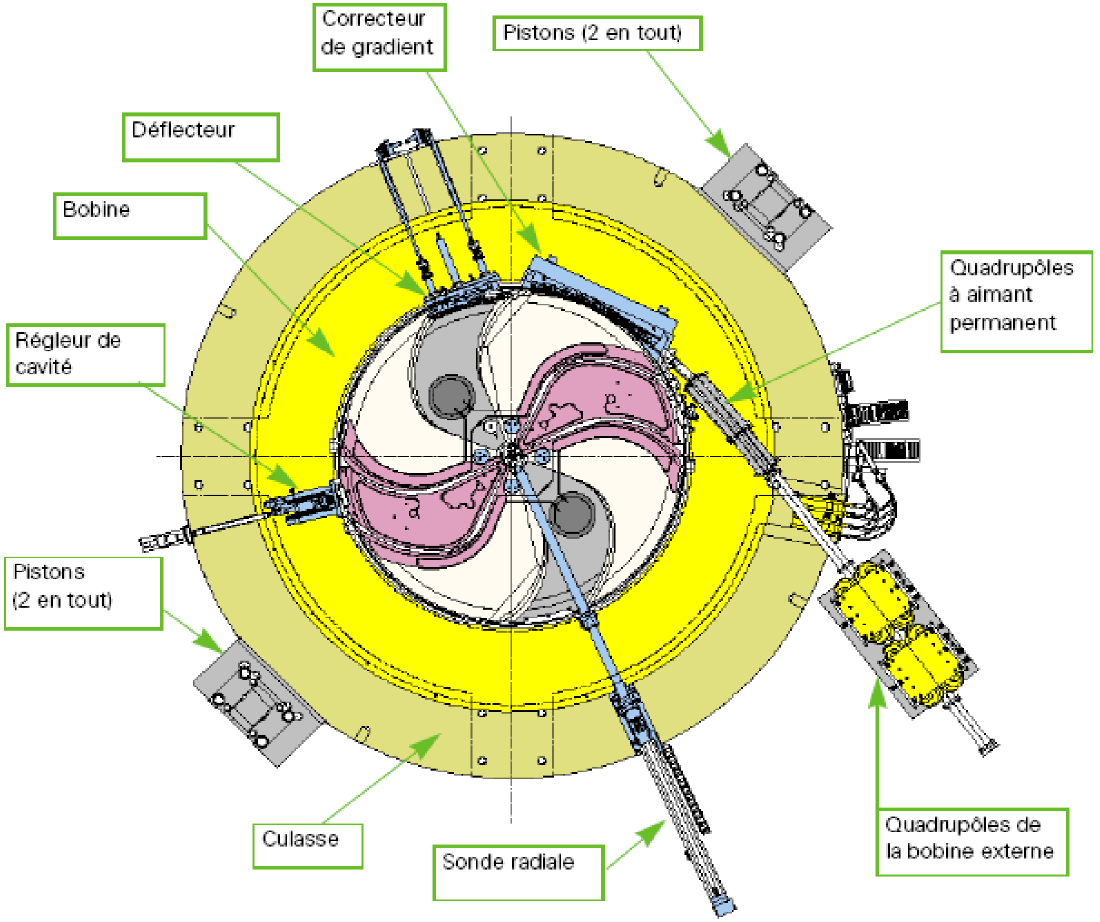
Maintenances

Modelisation, experience



- Regular diagnosis
- Analysis of data
- decision (or not) to fix, inspect, more analysis

Diagnostic of beam inside cyclotron: the radial probe



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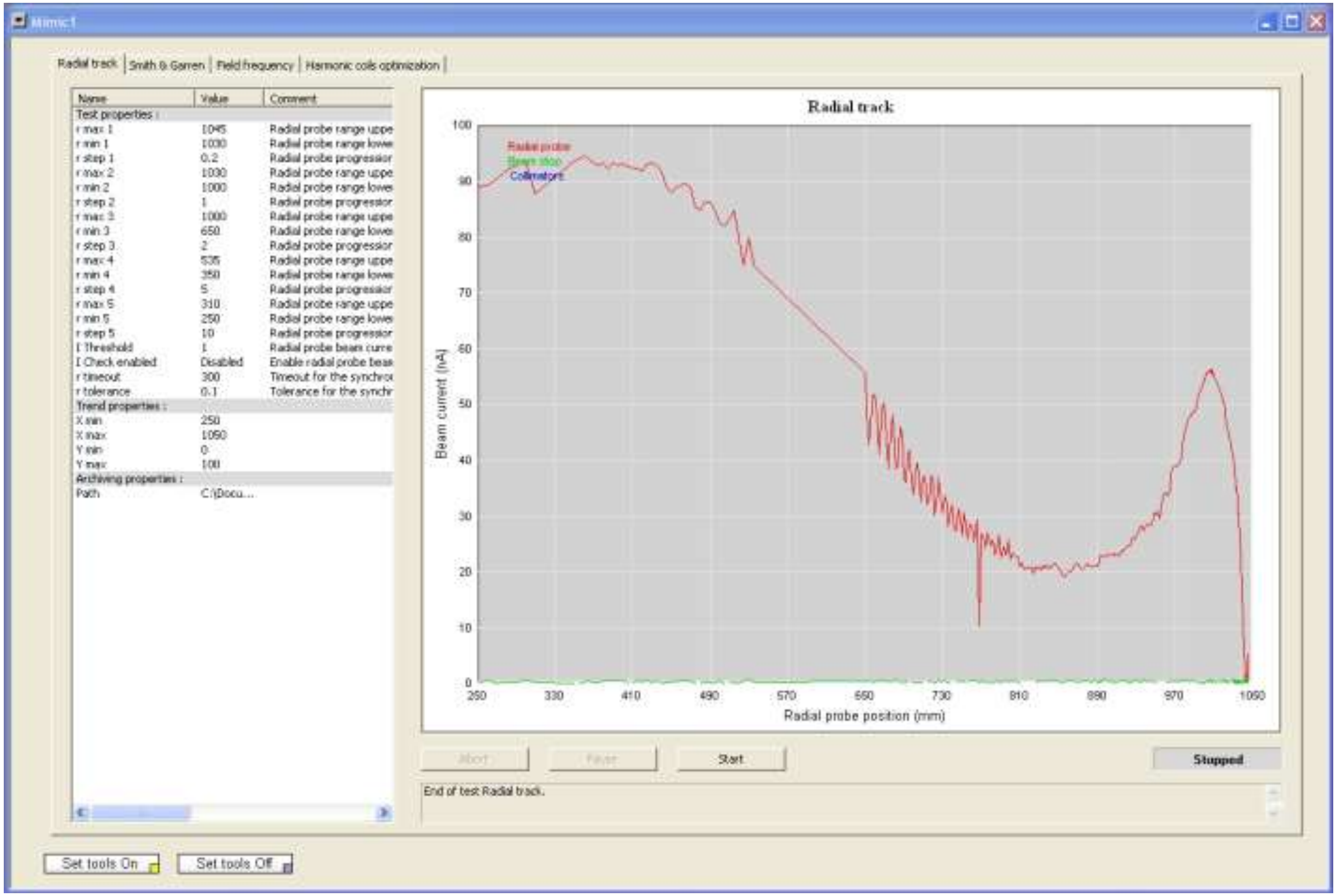
Example of result of radial track (C230IBA@CPO)



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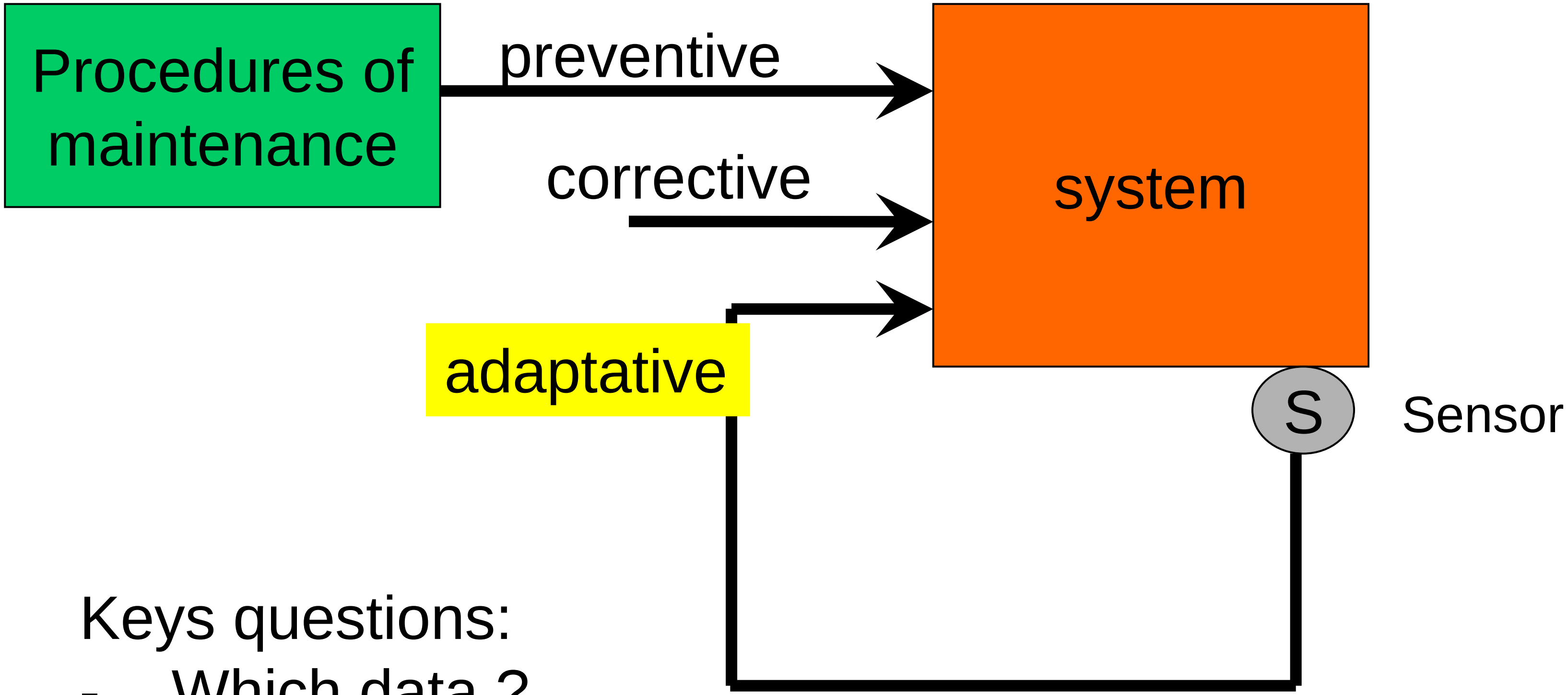
Maintenances

Modelisation, experience



Keys questions:

- Which data ?
- Which sensors ?

Thermography inspection C230 @ CPO

LIR

Cyclotron thermographie du 13 octobre 2011

°C

70°C

s	
	0.95
	20 °C

nter bobines 3 et 4
rieures. Point chaud
n sp1 A surveiller

13/10/2011 06:32:34

IR_0069.jpg

13/10/2011 06:32:34

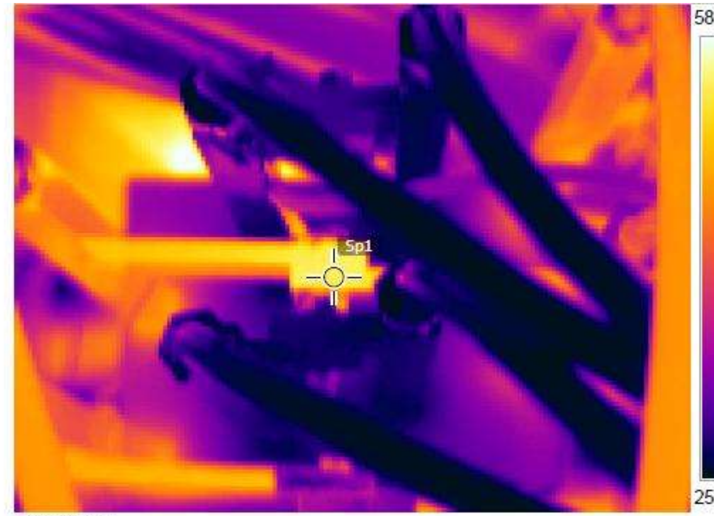
DC_0070.jpg

Sp1	54°C

Paramètres

Emissivité	0.95
Temp. réfl.	20 °C

Bobines inferieurs 3 et 4



IR_0219.jpg

08/11/2011 07:15:17

DC_0220.jpg

History of the aircraft maintenance

Maintenance concept had been changing

Overhauled

Decision logic(MSG) provide a tasks

MSG-1 → **MSG-3**

The Boeing 747
A four- engine
Produced 1970-Present

The Douglas DC-8
A four- engine
Produced 1960-1972

The Boeing 767
A twin-engine
Produced 1982-Present

The Boeing 787
A twin-engine
Produced 2011-Present

Year → 1960 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015

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Comparing Maintenance Strategies

Comparison of the availability analysis

	Mechanical Component with wear out	Electrical Component
Run to Failure	95%	98%
Preventive Replacement	98%	97%

Provided by RelaSoft corp.

$$\text{Average Availability} = \frac{\text{Uptime}}{\text{Operating Time}}$$

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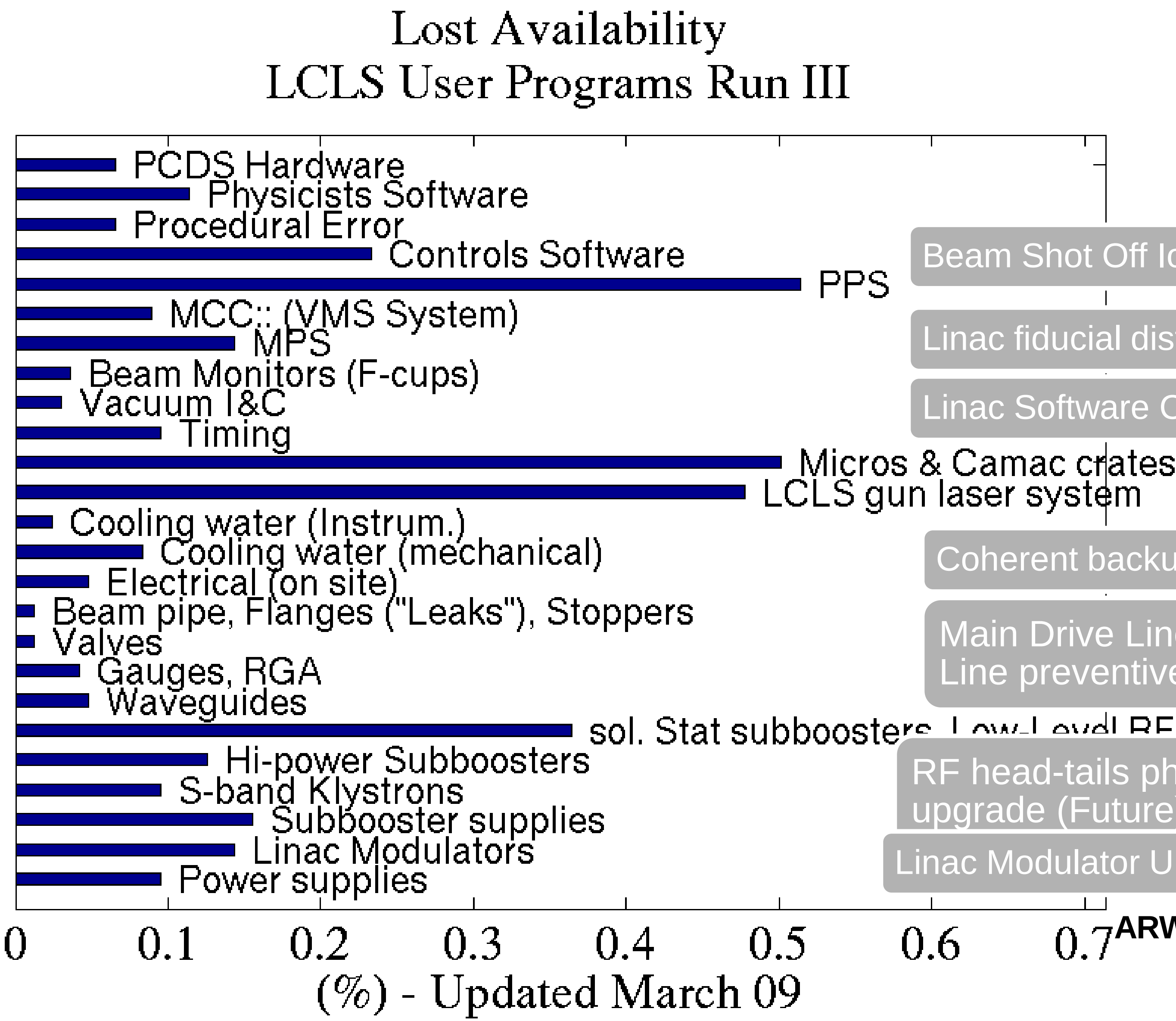
Downtime Statistics and future upgrades



Beam Shot Off Ion Chamber

Linac fiducial distribution

Linac Software Controls Conversion

Coherent backup Laser

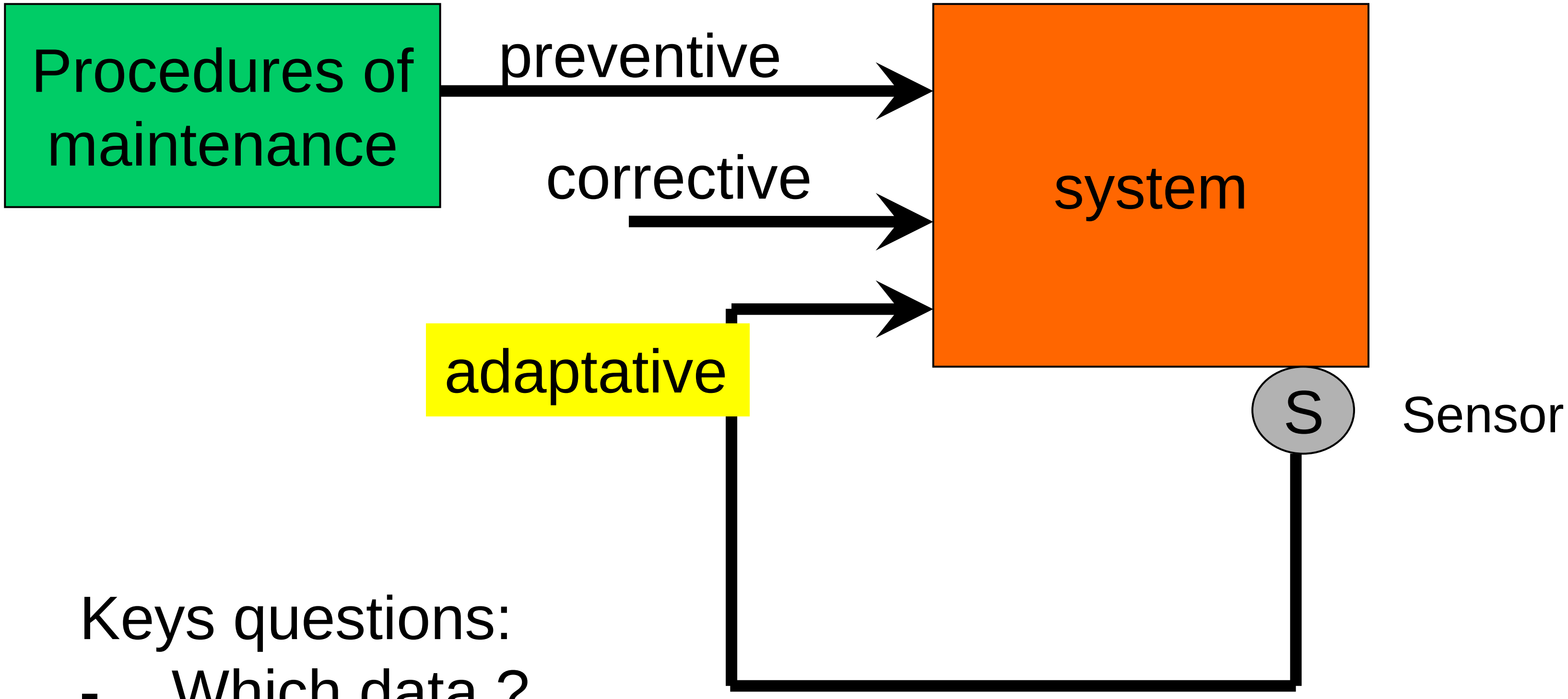
Main Drive Line and Sub-Drive Line preventive maintenance

RF head-tails phase monitor upgrade (Future)

Linac Modulator Upgrade

Maintenances

Modelisation, experience

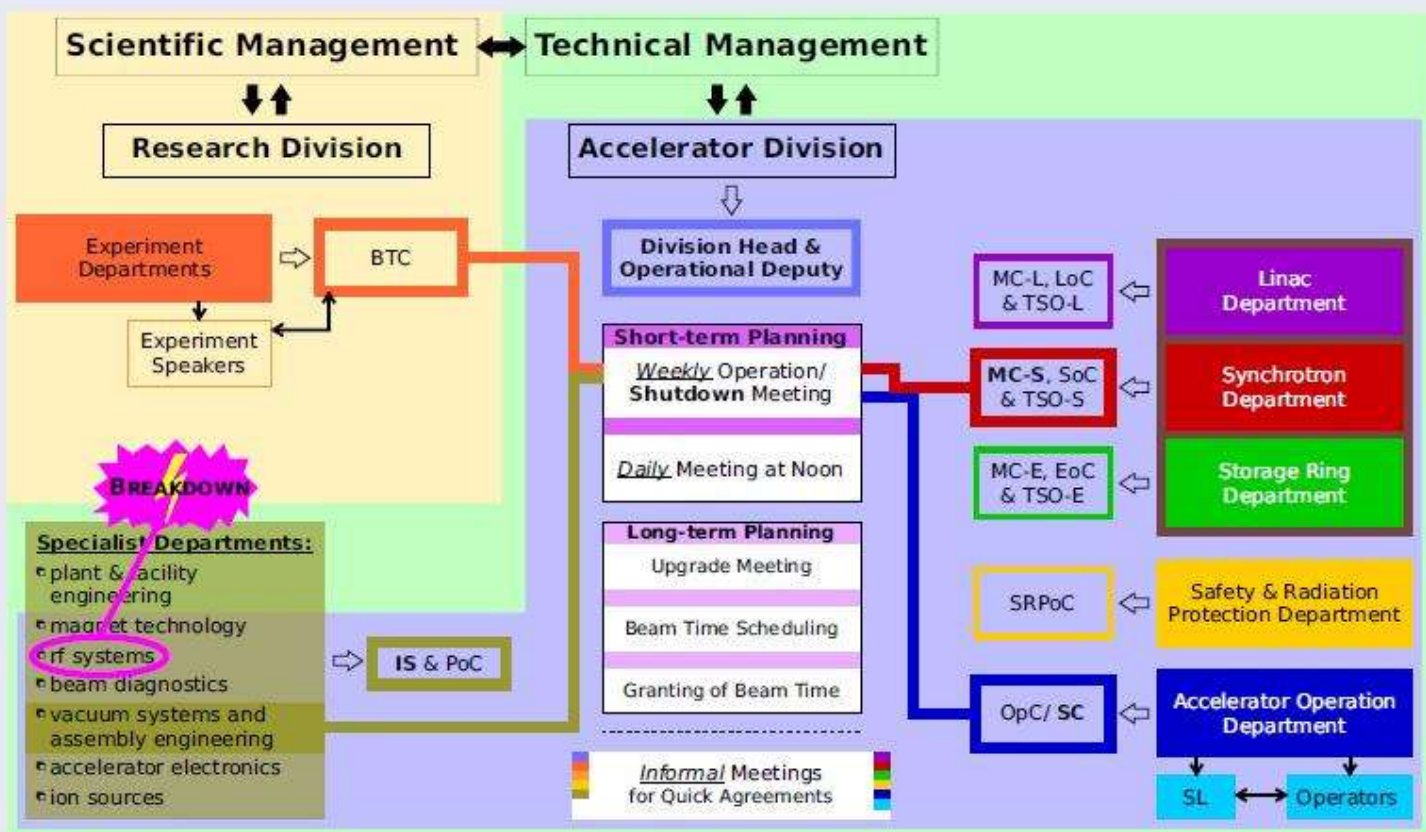


Keys questions:

- Which data ?
- Which sensors ?

Reactivity of organisation–transmission of information

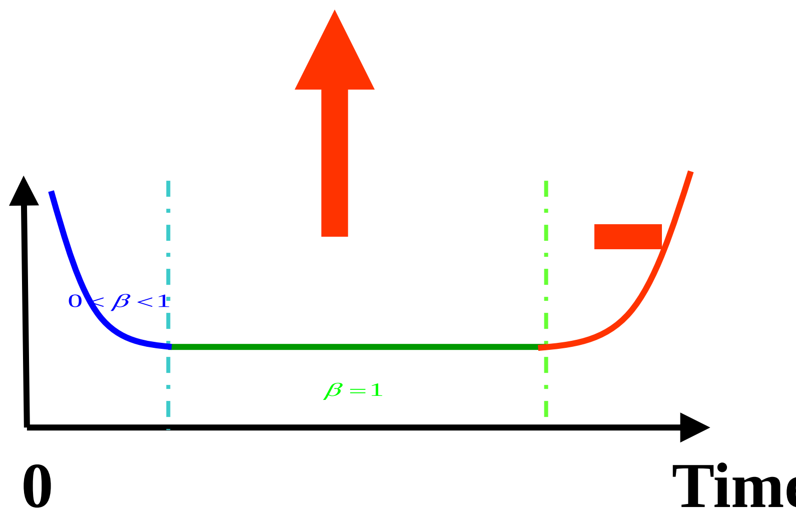
Example of Failure Handling – Short-term Planning

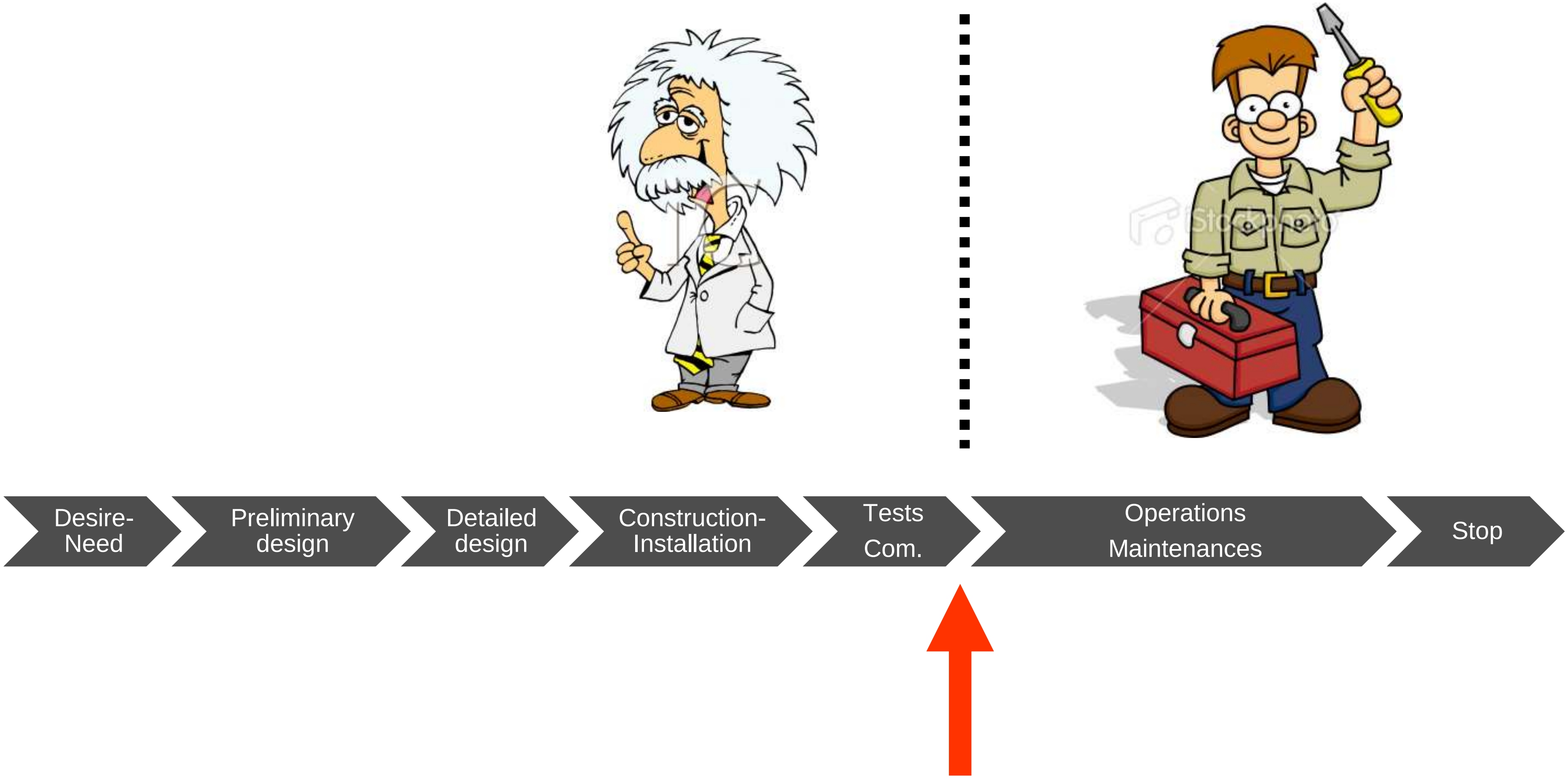


Updated shutdown schedule discussed in shutdown meeting, beam time coordinator informed

Life-cycle of Large Instruments

Desire-Need → Preliminary design → Detailed design → Construction-Installation → Tests Com. → Operations Maintenances → Stop




Desire-Need
Preliminary design
Detailed design
Construction-Installation
Tests Com.
Operations Maintenances
Stop

« the» CERN event (september 2008)

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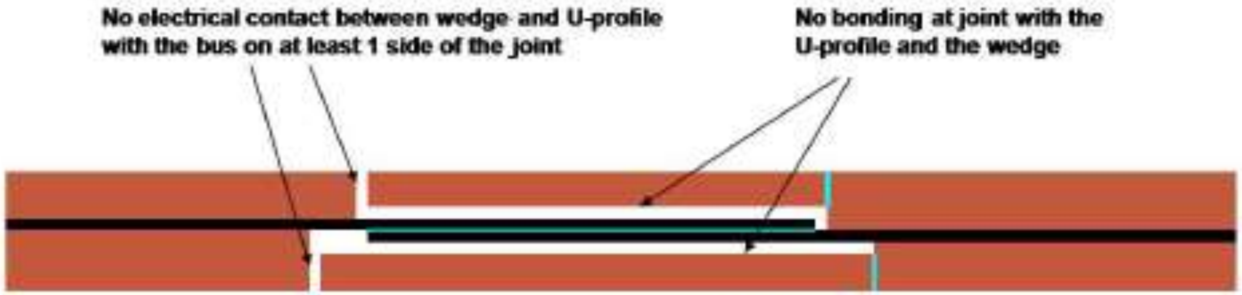

Figure 7: Model of resistive joint in bus bar
with bad electrical and thermal contact with the stabilizer

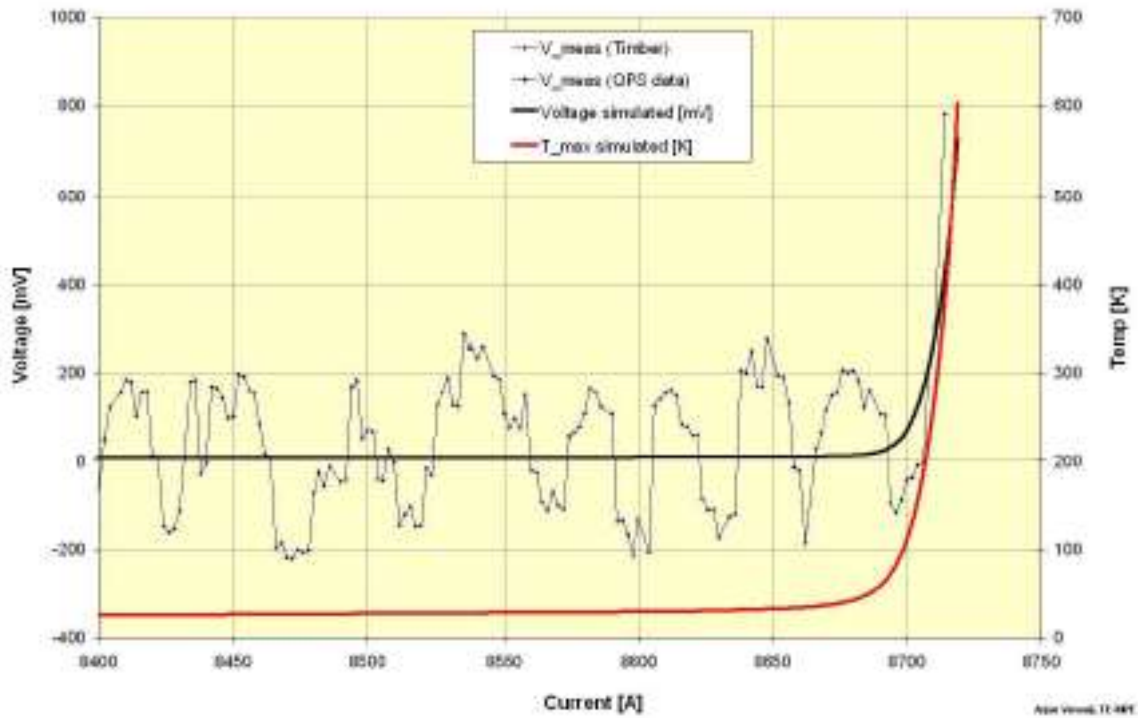

Figure 8: Measured and simulated parameters of the incident

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Why transition « project » to « operation » is so critical ?

- ALL the systems must be ready AND OK (ancilaries, control system, …)

- often, the first time in « REAL » conditions

- Atmosphere of « pressure »:
  - Important milestone for contract (penalties)
  - users « wants » the beam

Why transition « project » to « operation » so critical ?

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~~Maintenance~~ → Projects to set, keep, improve the operations

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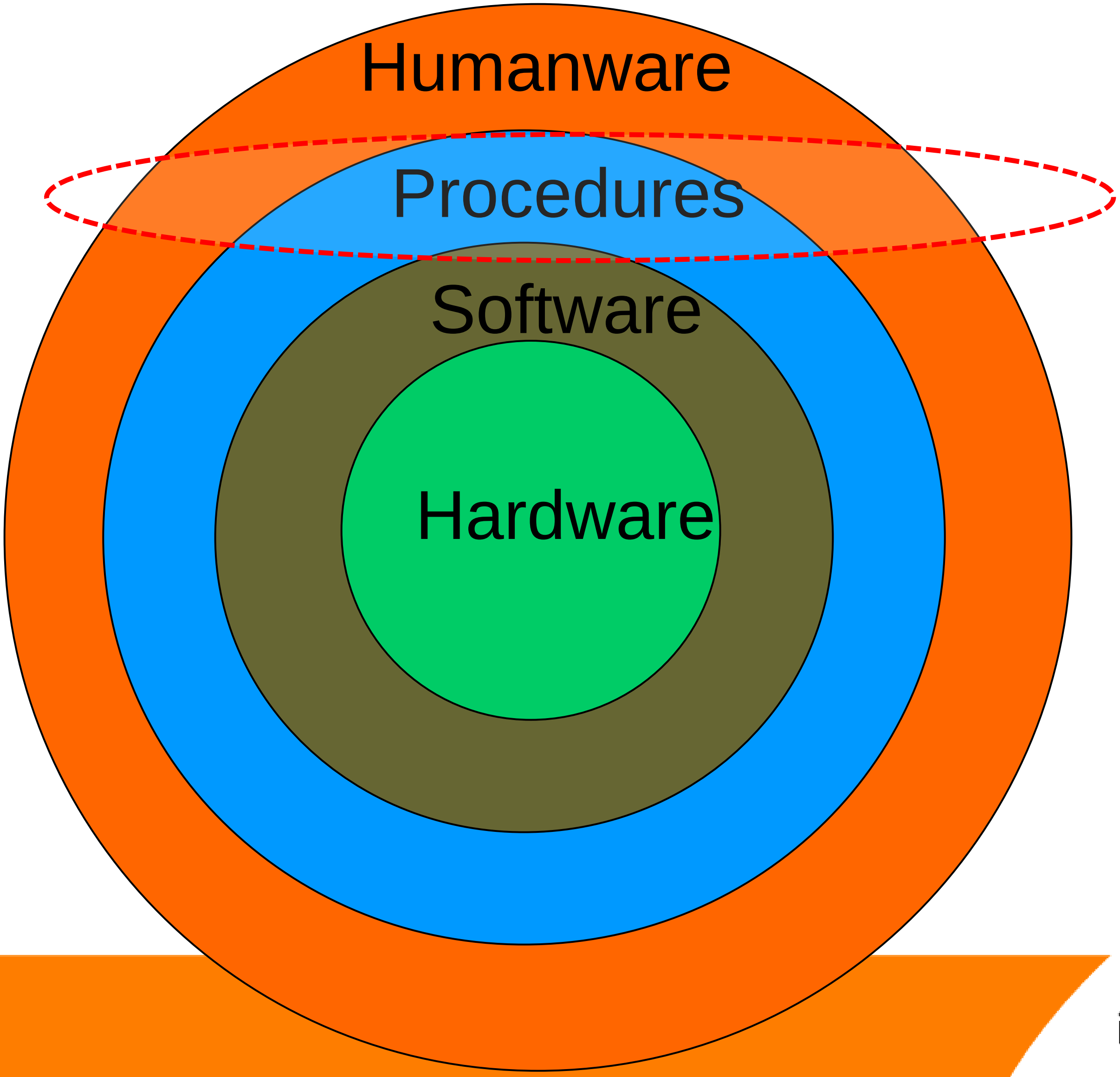
Event @CPO: july 2010, Cyclotron C230

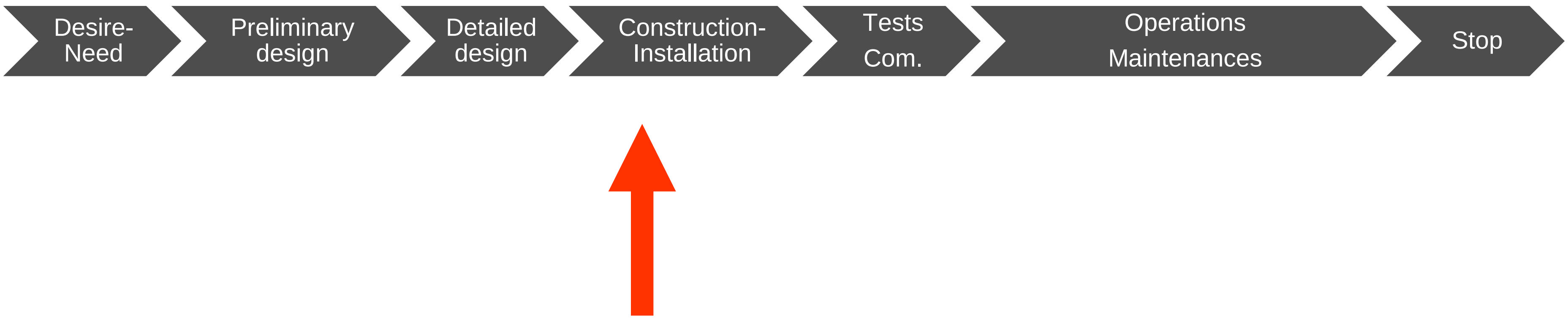
Ion Source pollution
+ RF event
+ deflector pollution
+ RF tube + PS RF …

5 days OFF

➡ **small RF event**
+ mix of <u>simultaneous</u>
inappropriated conditioning
(Ion Source ,RF, Deflector)

The 4 layers for reliability




Desire-
Need
Preliminary
design
Detailed
design
Construction-
Installation
Tests
Com.
Operations
Maintenances
Stop

planning

Magnet
RF
Power Supplies

Integration
Test
Commissioning

planning

Building
Ancilaries

Magnet
RF
Power Supplies

Integration
Test
Commissioning

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planning

Building
Ancilaries

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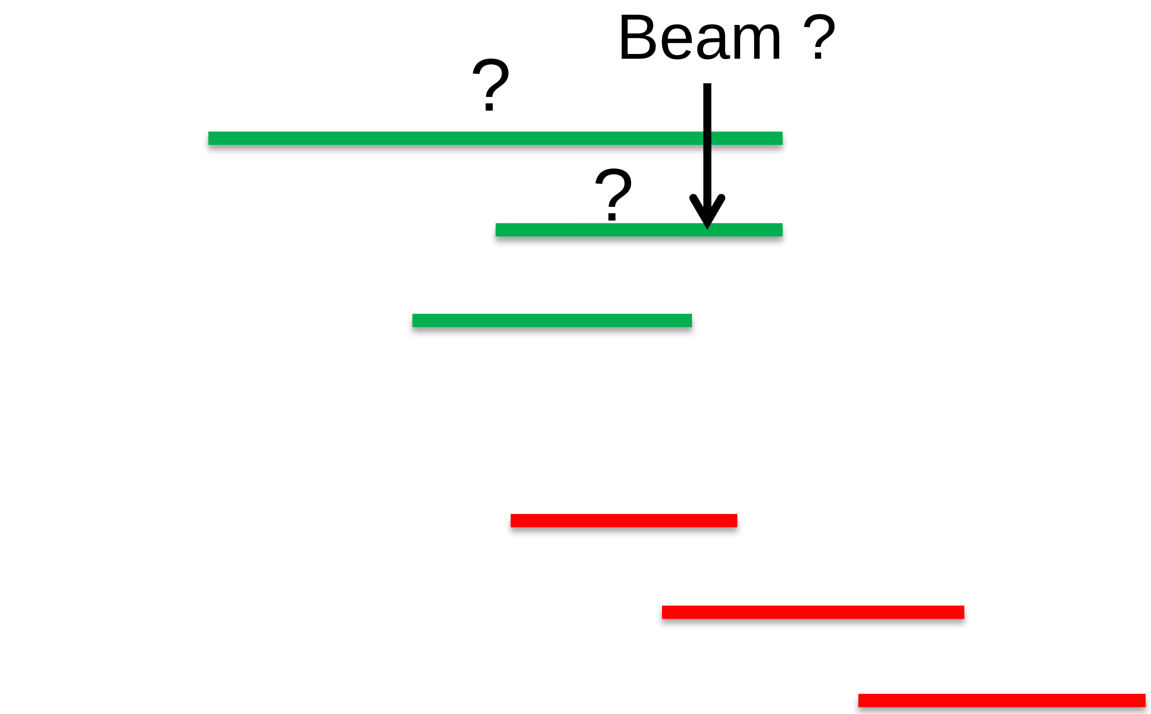
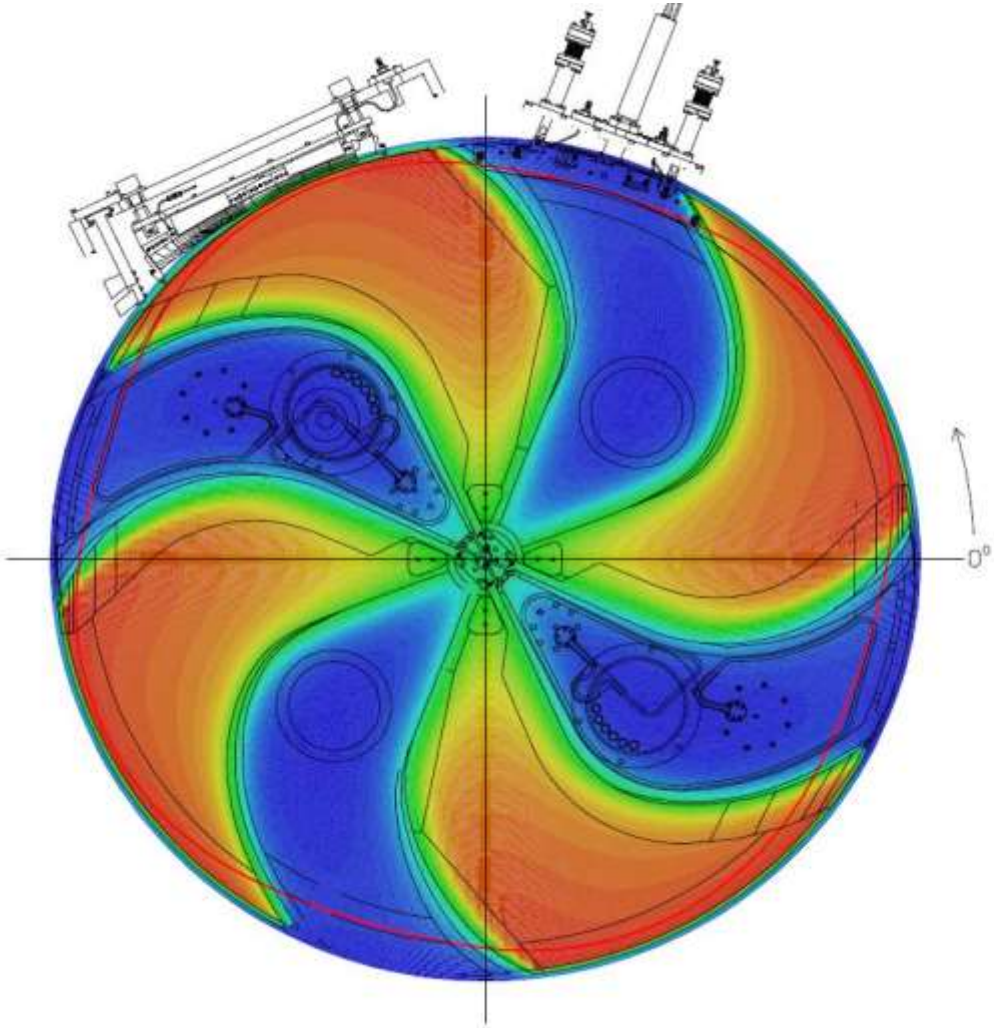


Mapping C230

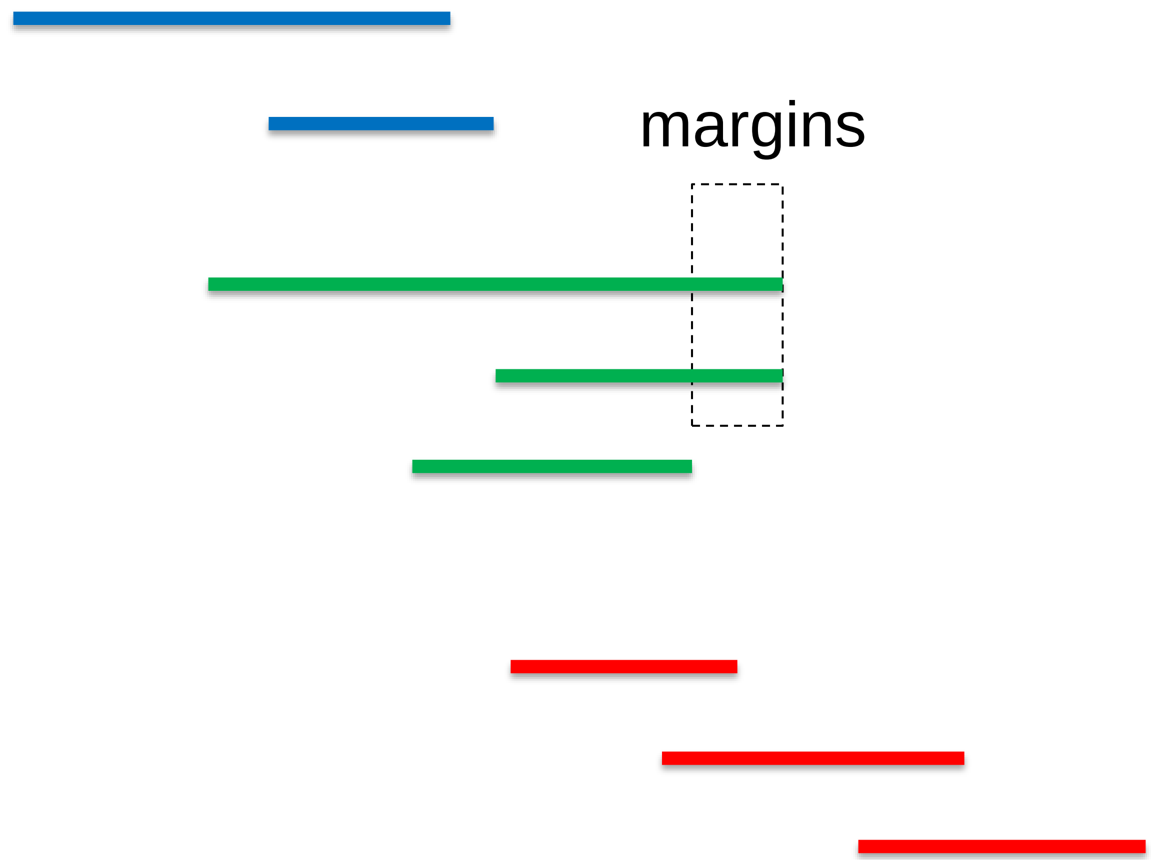


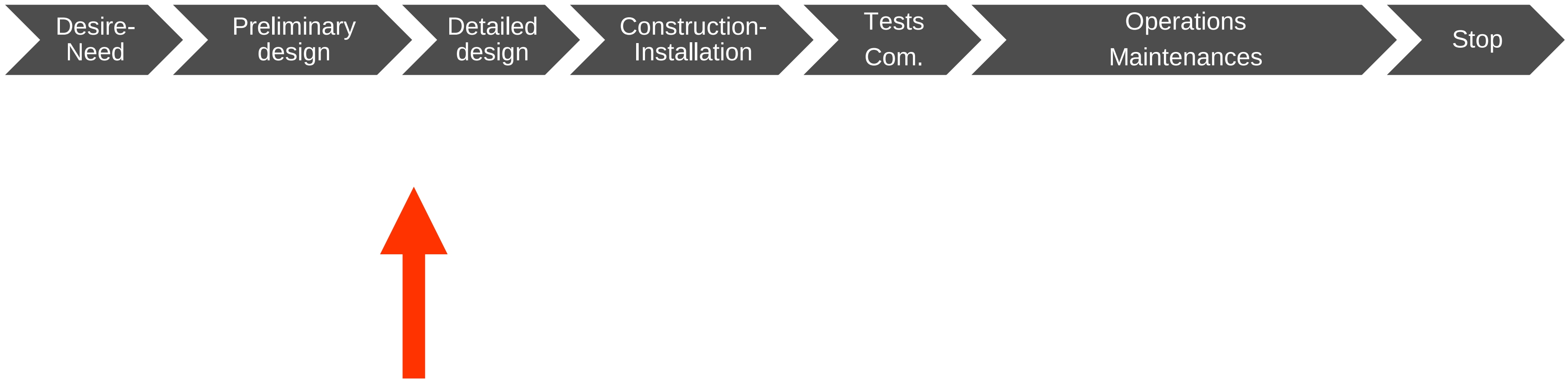
planning

Building
Ancilaries

Magnet
RF
Power Supplies

Integration
Test
Commissioning




Desire-
Need
Preliminary
design
Detailed
design
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Installation
Tests
Com.
Operations
Maintenances
Stop

Development – the V cycle

Needs Analysis

System Specification

Sub-systems Design

Preliminary Design

Detailed Designed

Realisation

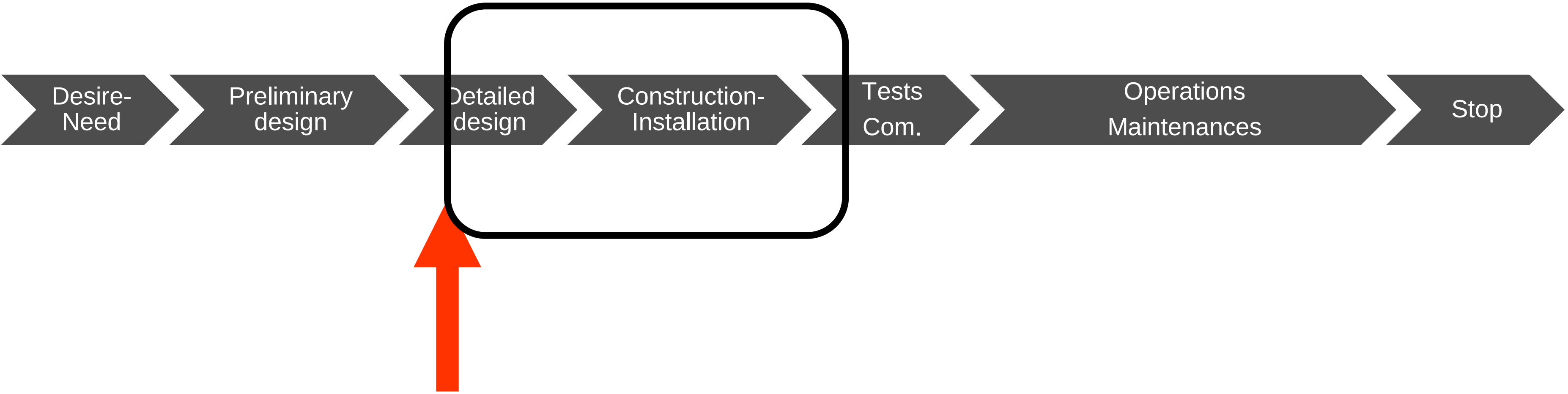
sub-system Tests

Tests & integration

Sub-systems Validation

System Validation

Operations maintenance


Desire-
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Stop

contract

Contracting with

With the provider of the accelerator

- performances and acceptance tests
- contents and limits of interfaces (beam, building , control, …)
- training - documents
- budgets (bonus / penalties)
- maintenance contract

With the provider of building and ancilaries

With the users (« real » needs, constraints, freedoms, evolutions…)

With the payers (budget and resources)

- for investment
- for ramp-up and contengencies
- for operations, maintenance, …

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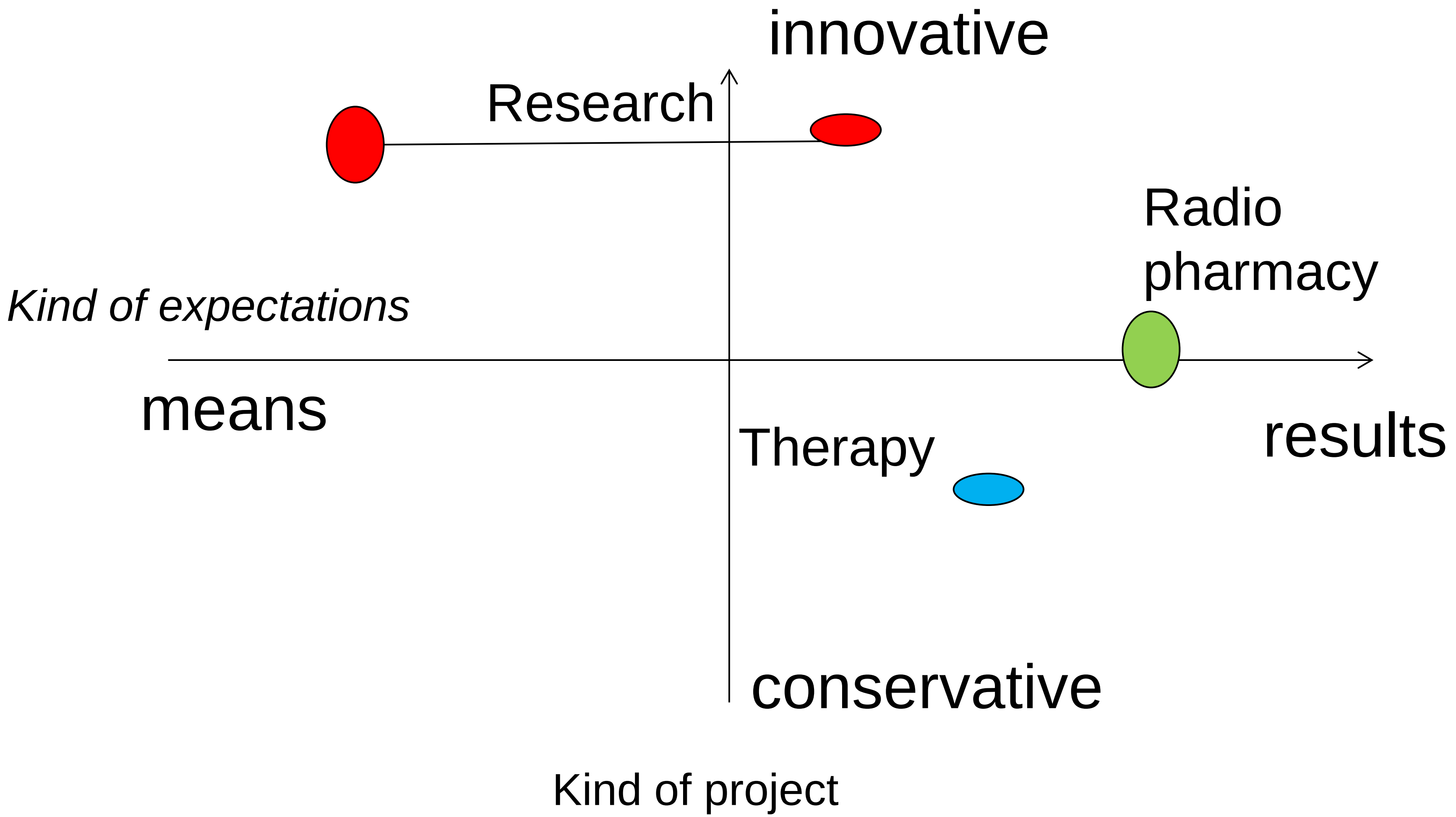
Science of Organisations

Henry Mintzberg: different kinds of coordination

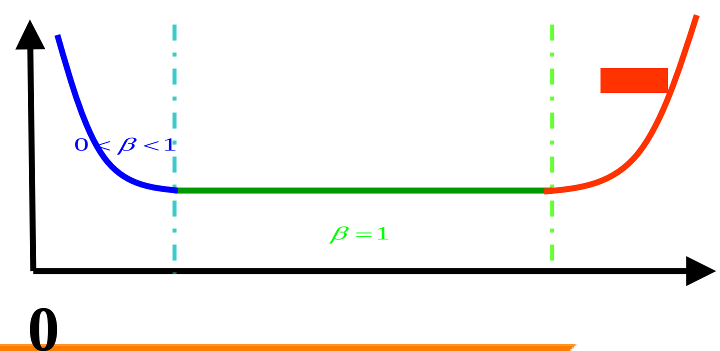
- **Mutual adjustment**
- **Direct supervision**
- **Standardization of work processes**
- **Standardization of outputs**
- **Standardization of skills**
- **Standardization of norms**


innovative
Research
Radio
pharmacy
Kind of expectations
means
results
Therapy
conservative
Kind of project

+ Quality Assurance

Desire-Need → Preliminary design → Detailed design → Construction-Installation → Tests Com. → Operations Maintenances → Stop

contract



SSC: The Super Superconducting Collider

South of Dallas - 89 km – 80 TeV protons

Starts 1991-1993
Then cancelled

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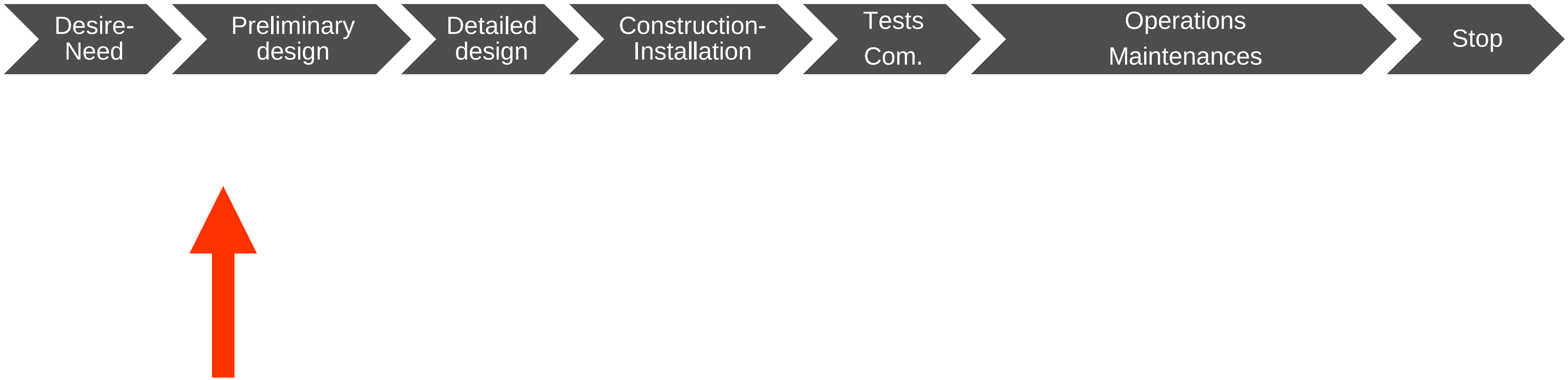
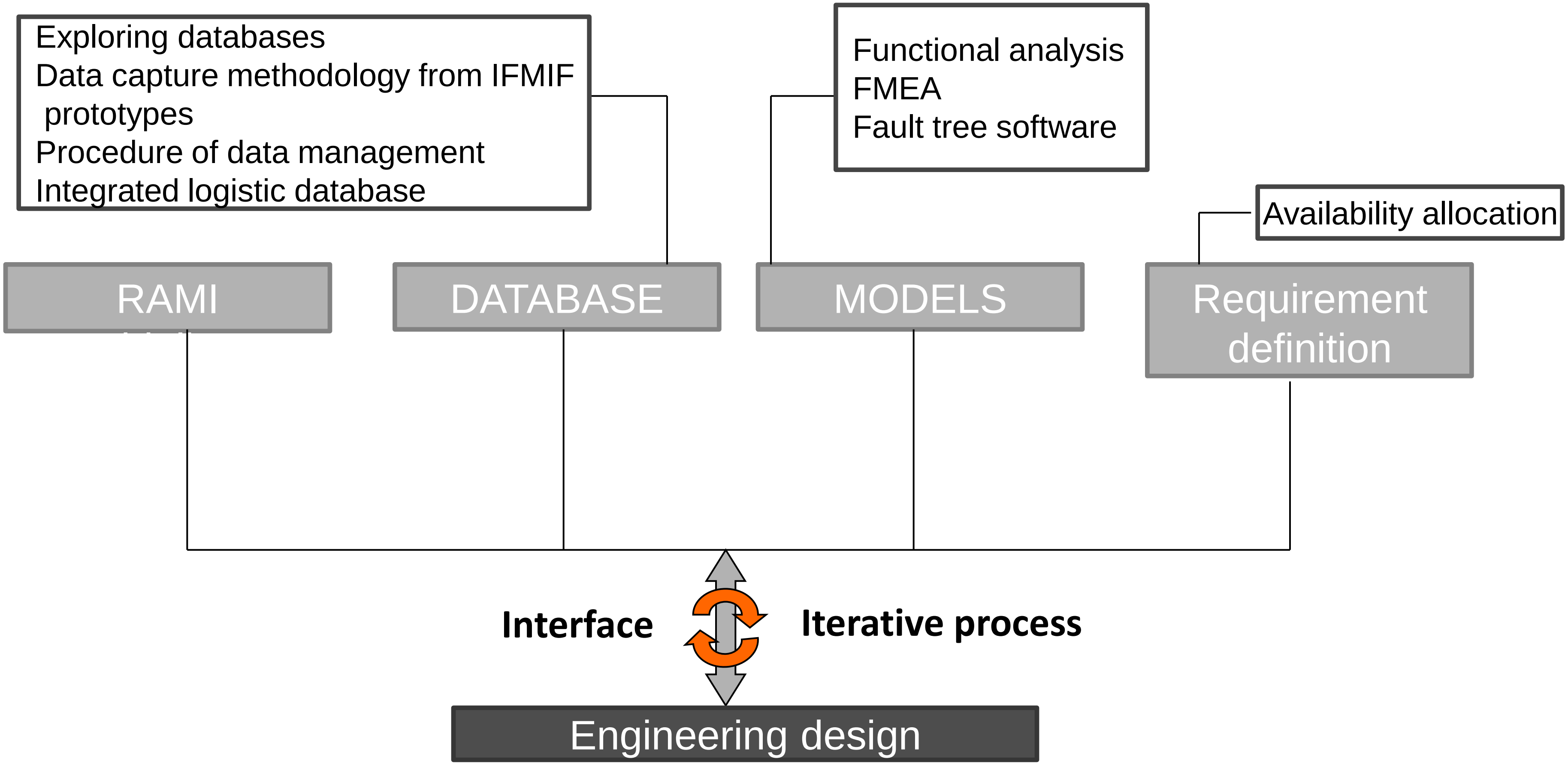
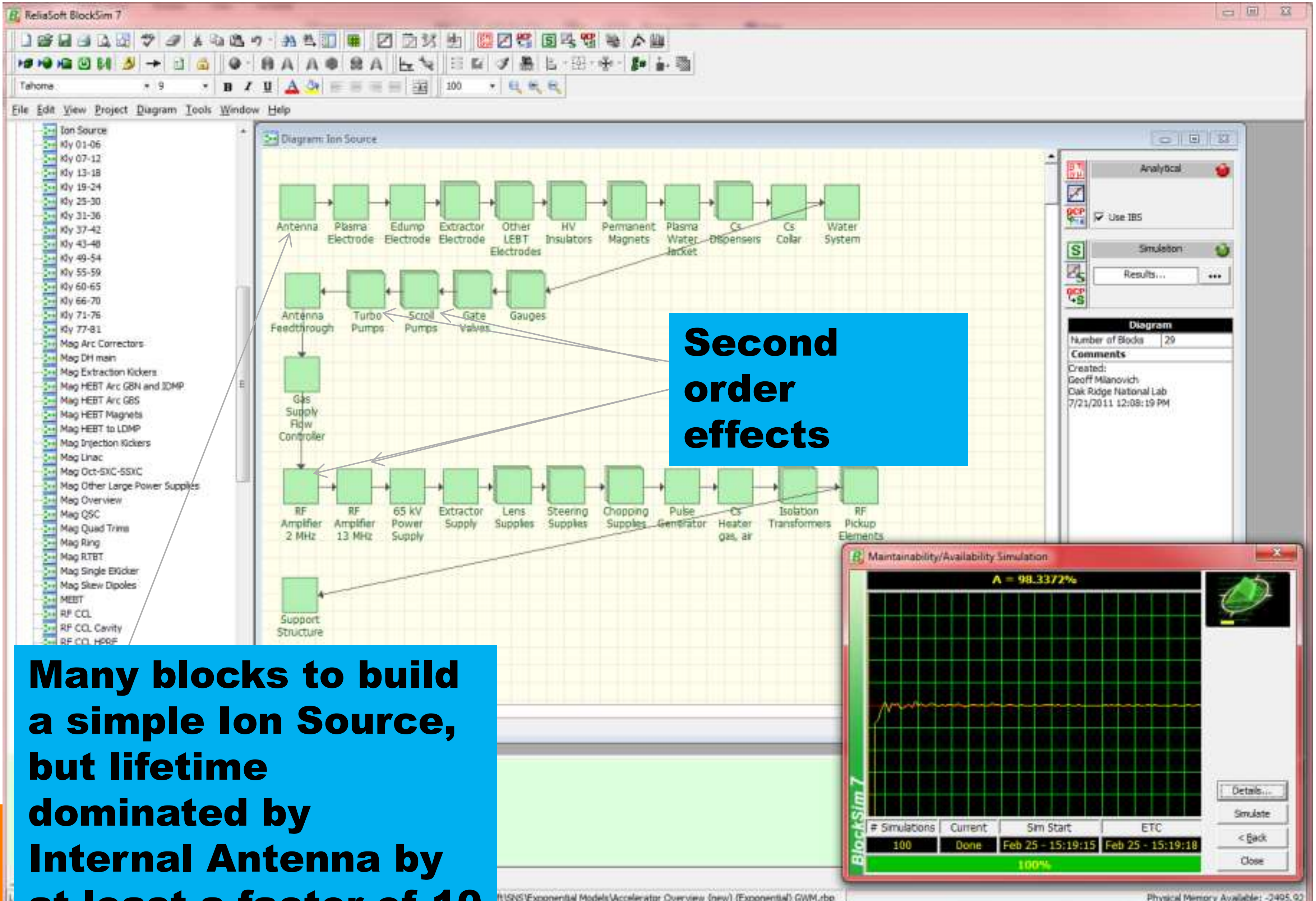
Life-cycle of an accelerator



RAMI approach (Reliability, Availability, Maintainability, Inspectability) for project IFMIF



Use the blocks to build a System



Second order effects

Many blocks to build a simple Ion Source, but lifetime dominated by Internal Antenna by at least a factor of 10

Concepts and reliability

Principles to increase reliability:

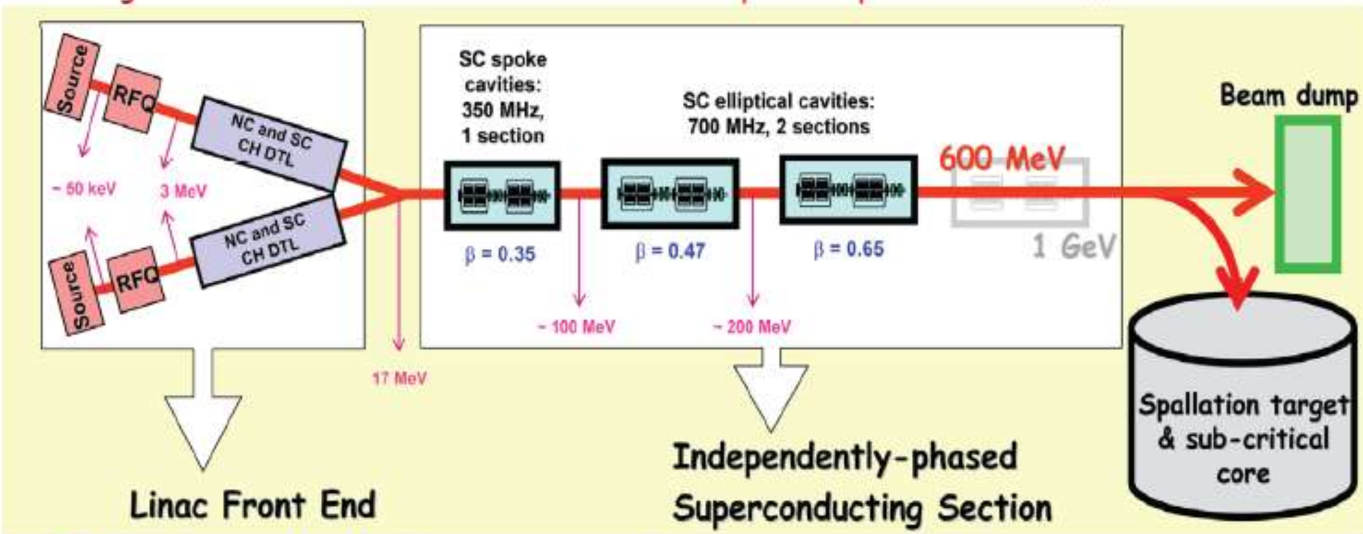
- **Redundancy**
- **accessibility**
- **over -engineering**
- **maintainability**
- **…**

Parameters increasing risks on reliability

- **Technological innovations**
- **Lonely experience**
- **Number of specific interfaces**
- **pressure on quality, budget, delay**
- **…**

MYRRHA

- ADS (Accelerator Driven System) pour la transmutation des déchets radioactifs
- Multi-Purpose hYbrid Research Reactor for High-tech Applications (SCK), horizon ~2023
- Challenge #1 : faisceau CW multi-MW : 2.5 mA (4 mA to compensate burn-up), 600 MeV
- Challenge #2 : fiabilité extrême : moins de 10 trips > 3 s pendant 3 mois !!



- **Injecteur redondant**
  - "fault-tolerance" non applicable
  - nb éléments minimisé
  - injecteur "spare" avec aiguillage rapide
- **Linac supra modulaire**
  - concept valable demo→transmuter
  - éléments contrôlés indépendamment
  - fault-tolerance : élt défaillant remplacé par ses voisins

Life-cycle of an accelerator

Desire-Need → Preliminary design → Detailed design → Construction-Installation → Tests Com. → Operations Maintenances → Stop

The (wellknown) recipes for a good reliability

A system (hardware & software) well designed
- specifications, model of developpement, tests
- principles of reliability, a lot of diagnosis

A well-maintained system
- Preventive, real, adaptative, reactivity for corrective
- Spare parts (a lot, ready for use)
- time dedicated for operations

Human resources and good organization
- people trained, skilled, enough, here when required
- efficient and clean organization, data-base, Knowledge Management

Briefly: resources (men, budget), consistency, willingness…

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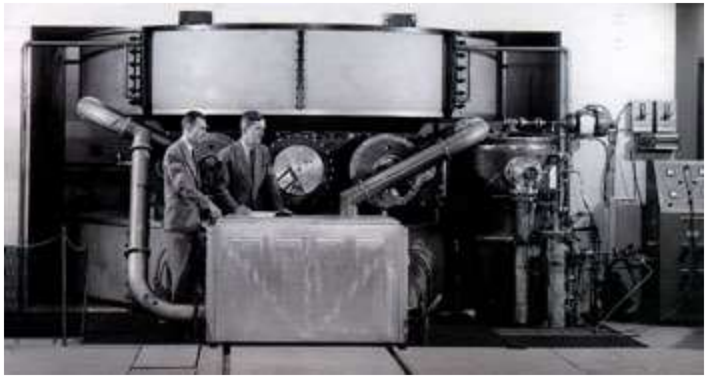
Accelerators champions of lifetime

Synchro-cyclotron - HCL
Harvard (1949-2003)



Cyclotron 88 inch - LBL
Berkeley (1961 - …)

Cyclotron PSI (590 MeV)- CH
designed for 100 µA (1974)
an now at 2,2 mA (2012)

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Summary

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Reliability and accelerators

- **Concepts**: principles to increase reliability, risks to consider

- **Definition** : Importance to agree on (what, how, mode, constraints/freedoms, …)

- **Maintenance**: % determinist (mechanical, cooling, …) % based on monitoring (systems + organisations)

- **Responsabilities**: to etablish and clarifiy (systems, organization, Quality assurance, test, …)

- **Information**: how to get as soon as possible (other experiences, test, …), how to keep during the life of accelerator.

QUIZZ

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questions	Answers
Defintion of avaibility Why it is more significant than reliability	
3 Concept in the design to increase reliability	
3 reasons because transition from project to operations so critical	
3 kinds of maintenances and the more important one for accelerators	
2 main reasons of a definitive stop of an accelerator	

questions	Answers
Defintion of avaibility Why it is more significant than reliability	A= MTBF (MTBF+MTTR) Includes only the time where users need the systems
3 Concept in the design to increase reliability	Redundacy, over-design, maintainability, accessibility, diversity, level of test, benchmarking, technology maturity, …
3 reasons because transition from project to operations so critical	All the systems must be ready, first test in real conditions, pressure to start (contract, users)
3 kinds of maintenances and the more important one for accelerators	Preventive, corrective, adaptative (the more important to develop through monitoring)
2 main reasons of a definitive stop of an accelerator	political-finance, orphan systems