Life-cycle and Reliability of accelerators

JUAS 2017

part 1: life-cycle

<u>part 2: reliability</u>

Samuel Meyroneinc
Centre de Protonthérapie – Orsay
Institut Curie

9 th March 2017

institutCurie

summary

1. Reliability & Accelerators
2. Reliability during life-cycle of Accelerators
3. Examples

Your experience in reliability

Definition of reliability

1st basic approach

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

institutCurie

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

Availibility = MTBF / (MTBF+ MTTR)

institutCurie

exercise

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

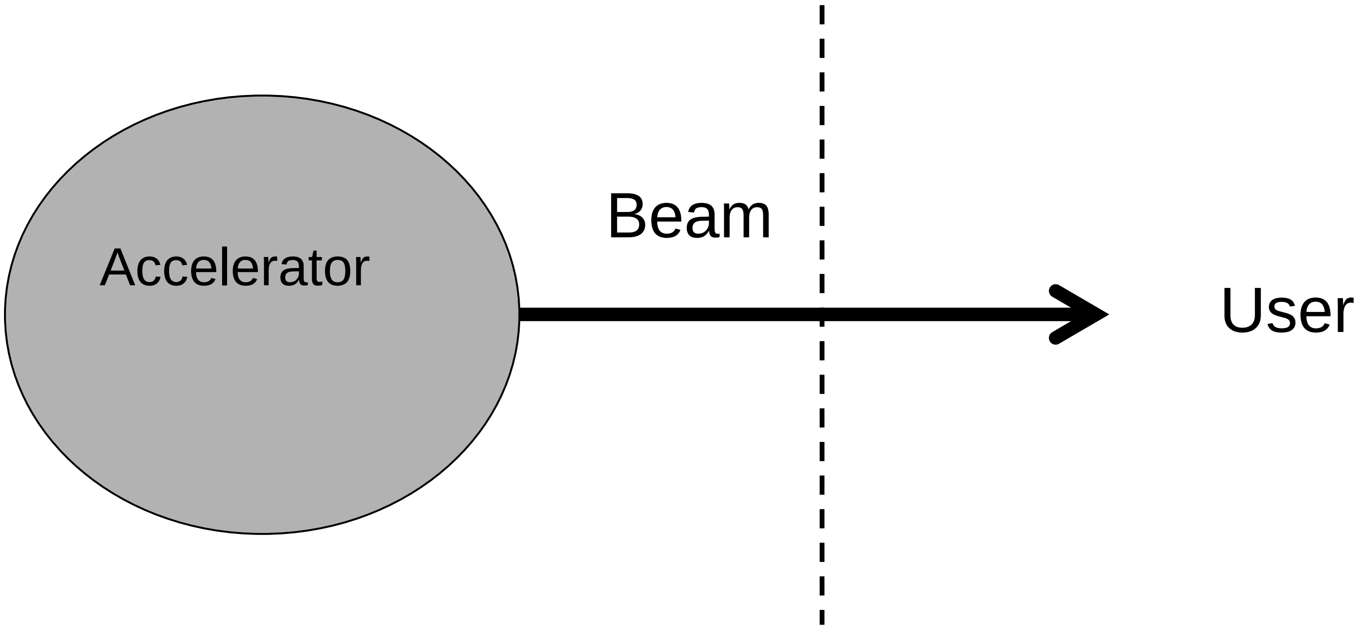
During this time, there were:

- **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 » ?



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

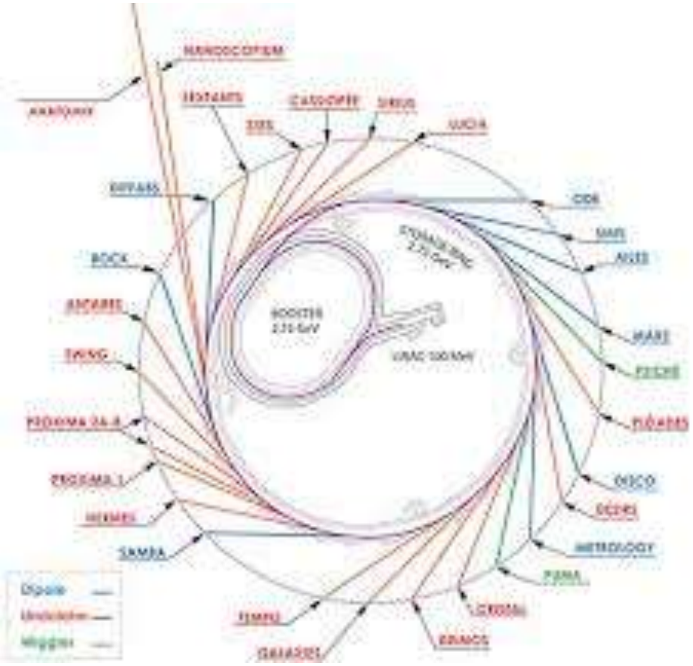
- **Using &Users (Customers / Providers)**

beams: current, energies, duration, …

institutCurie

Synchrotron: first real approach for reliability

synchrotron Soleil



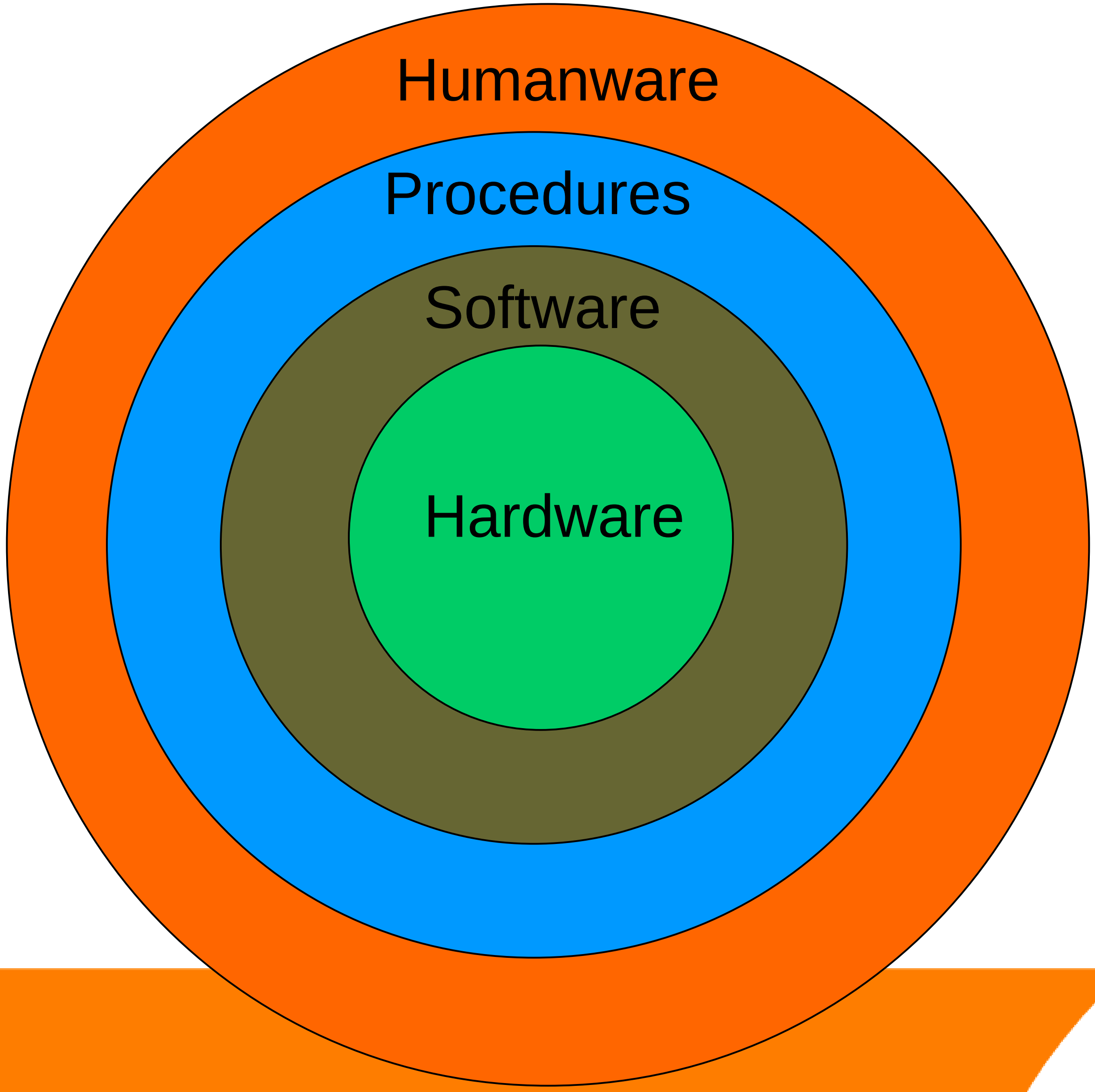
institutCurie

Reliability for synchrotron

institutCurie

Annex 3
Metrics for synchrotron-sources of light

the 4 layers of reliability

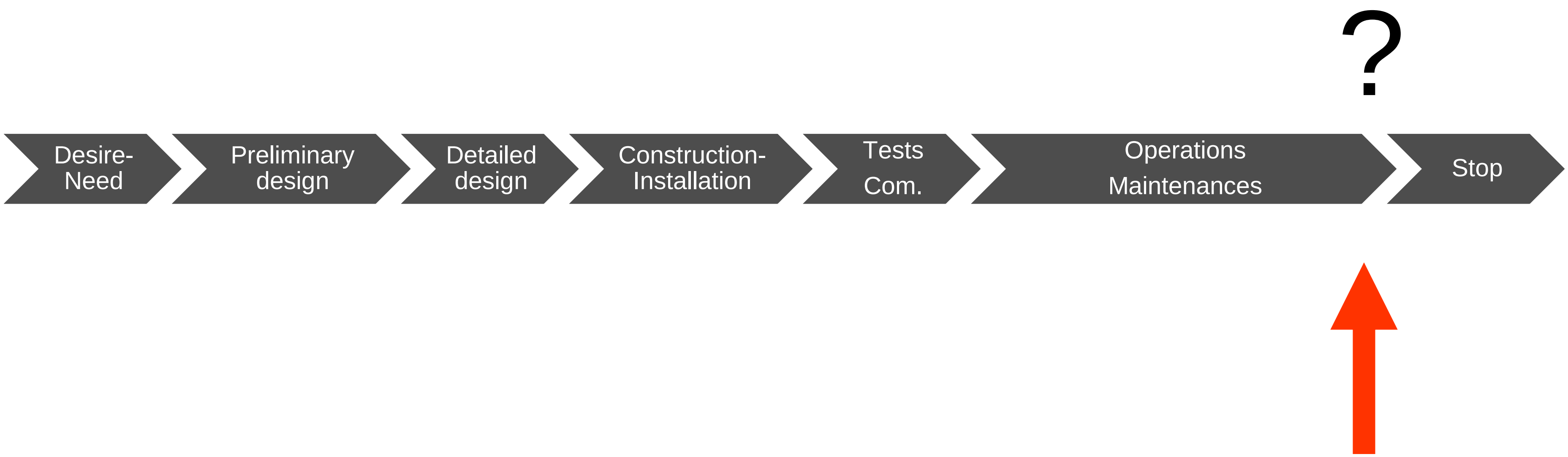


institutCurie

2. Life-cycle of accelerators and reliability

institutCurie

Life-cycle of accelerators

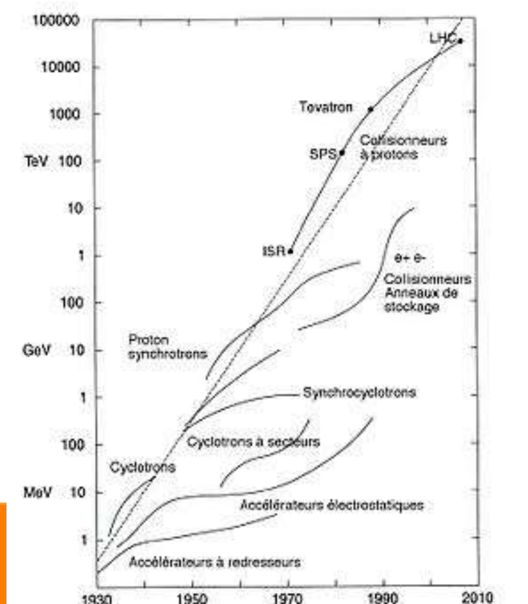


A failure – a small (or big) death

Connection (ESRF)

Main coil (SC200-Orsay)

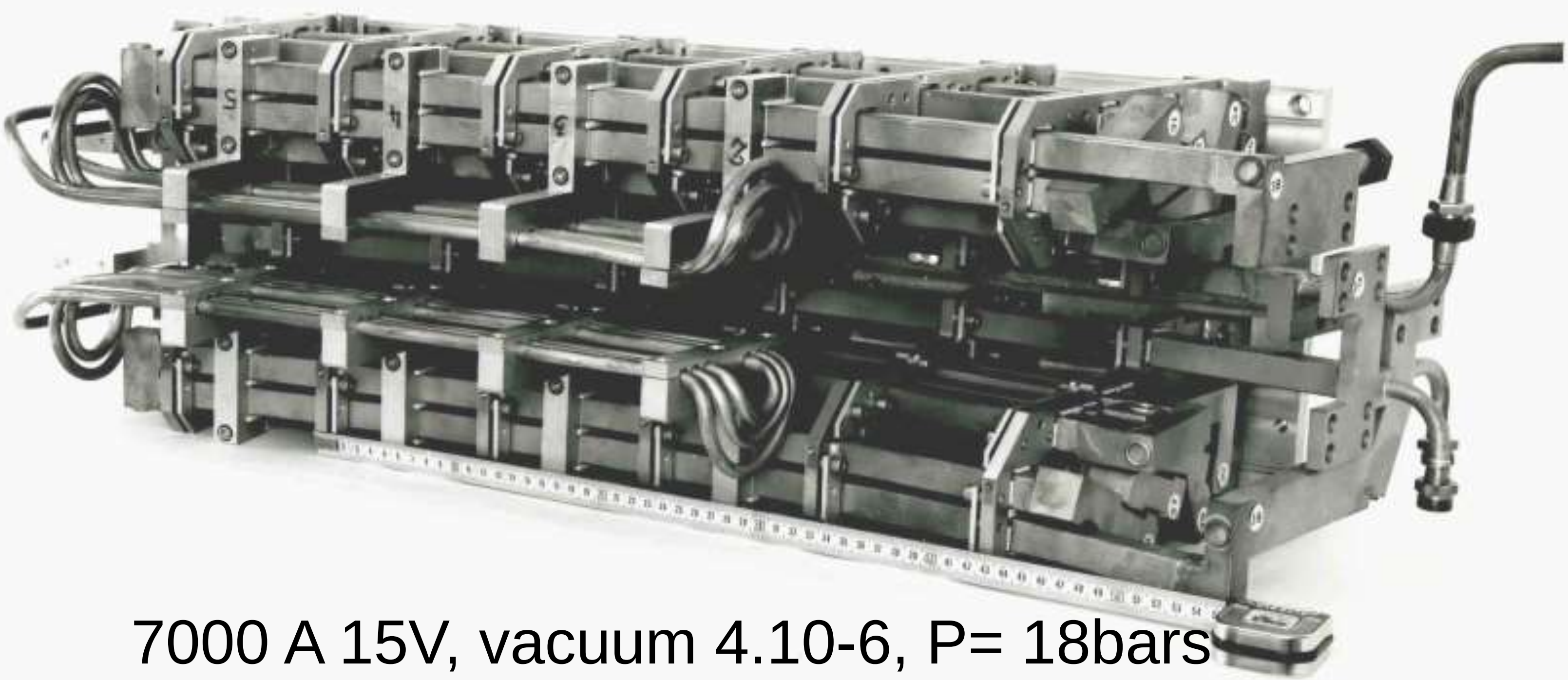
Obsolescence



Orphan system

institutCurie

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

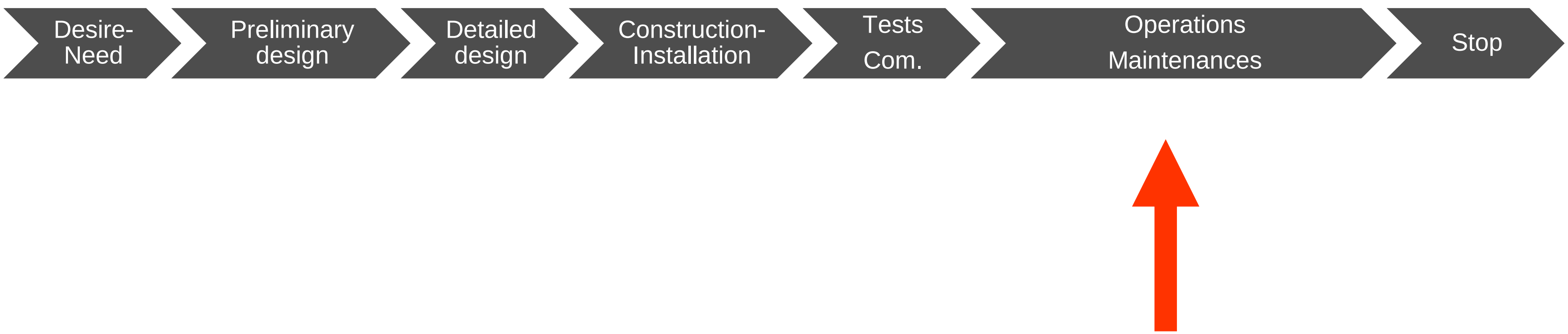


7000 A 15V, vacuum 4.10-6, P= 18bars
« work of artist »

Example of document IUCF annex 4

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

Life-cycle of Large Instruments



Control room (ex: PSI)

institutCurie

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**

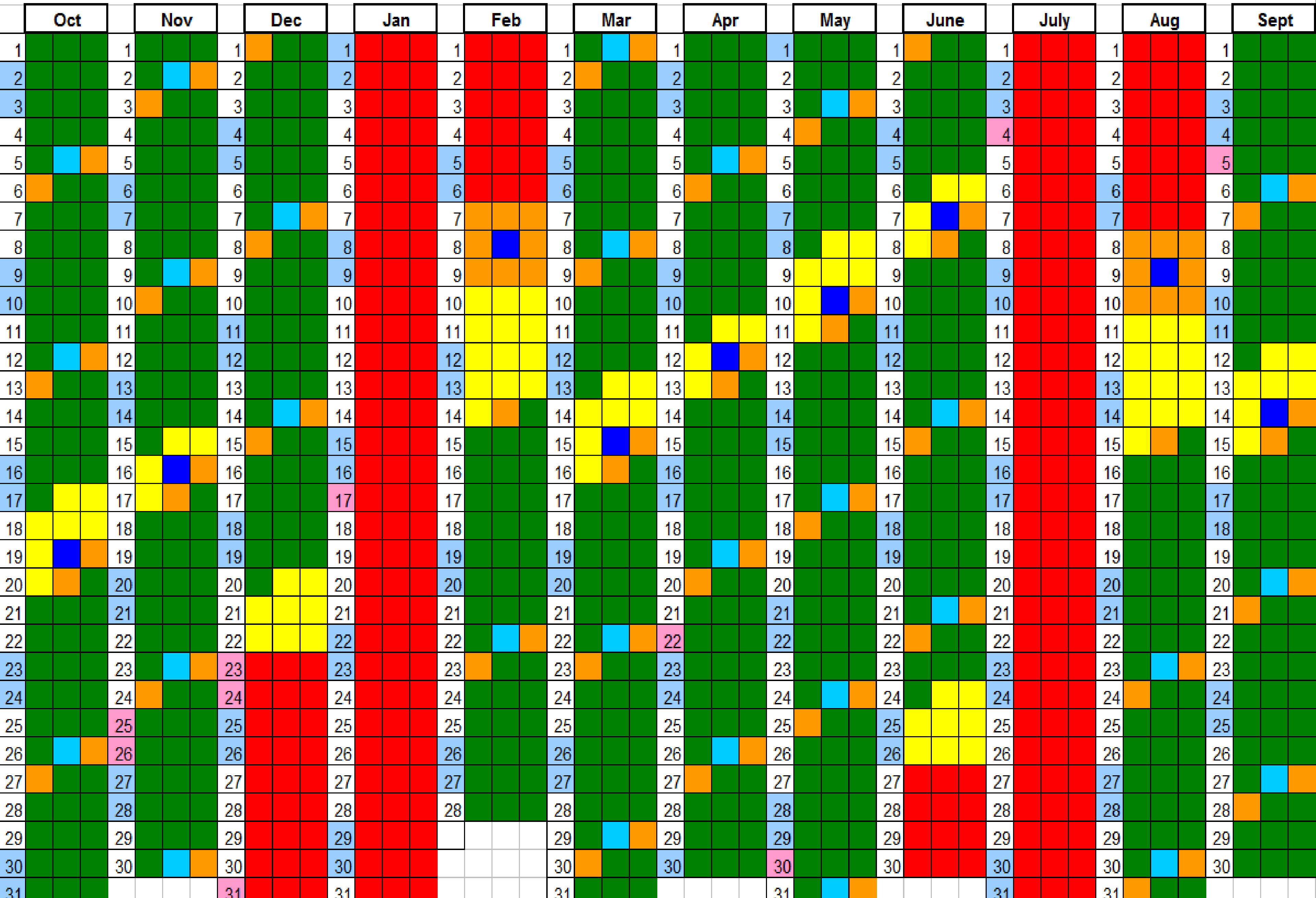
This includes:

- 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

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

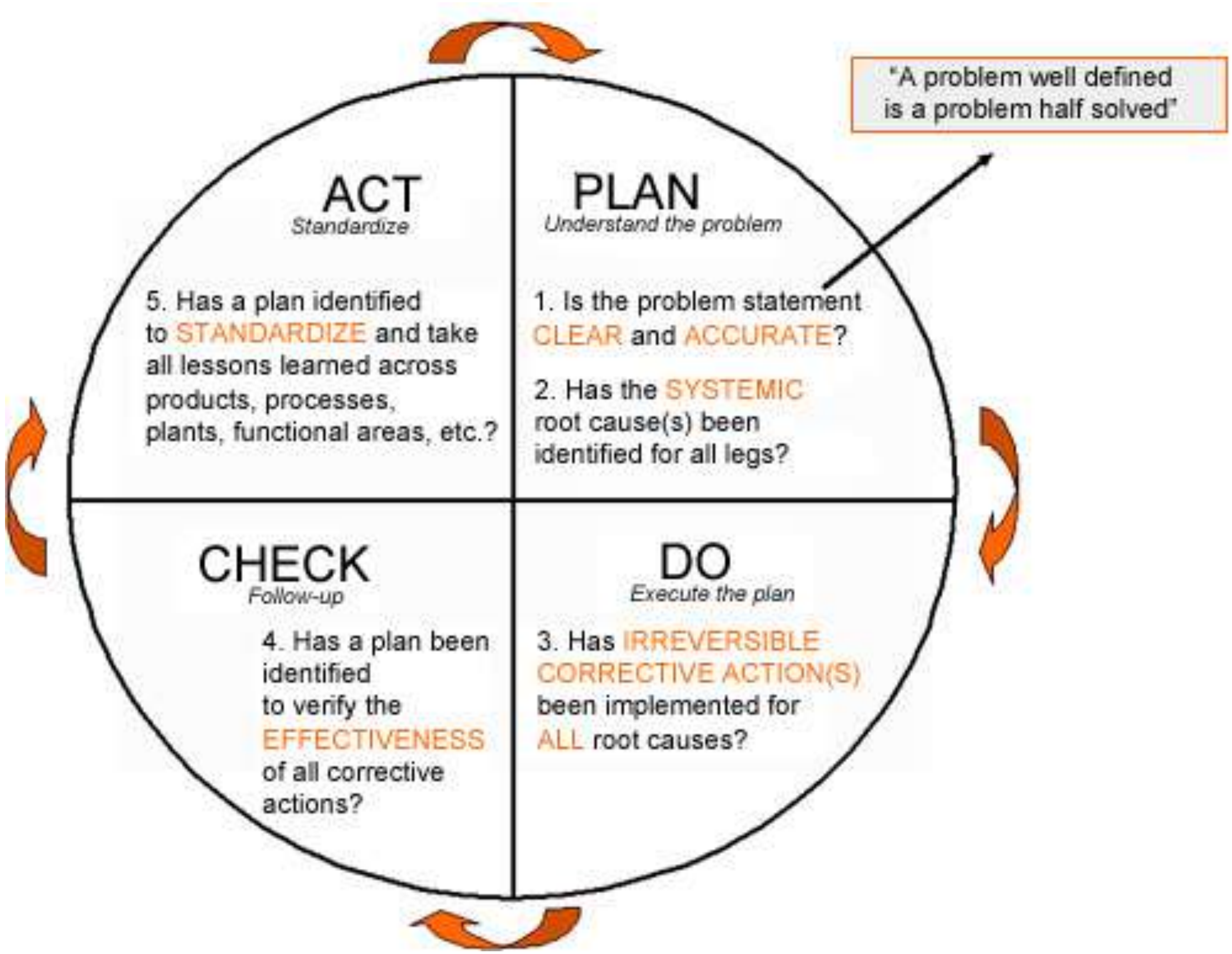
Key Performances Indicators (KPI): **reliability**, production outputs for users (ex: hours of beam)

Goal: reaching a specific target (new)

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

Plan – Do –Check – Act (PDCA)

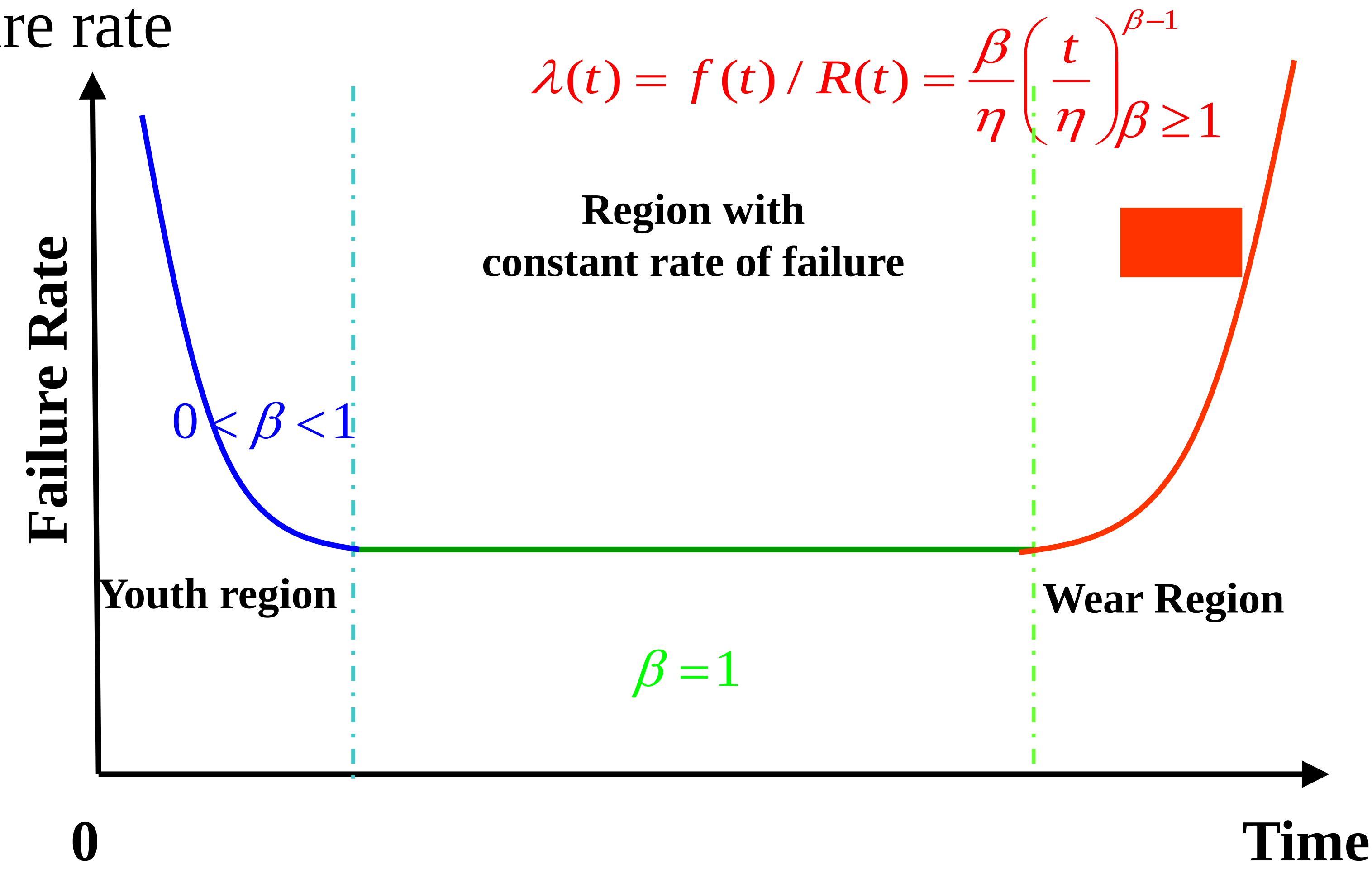
(to manage Operations)



institutCurie

The reliability Weibull Model

Failure rate



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	$.4199 \times 10^{-5}$

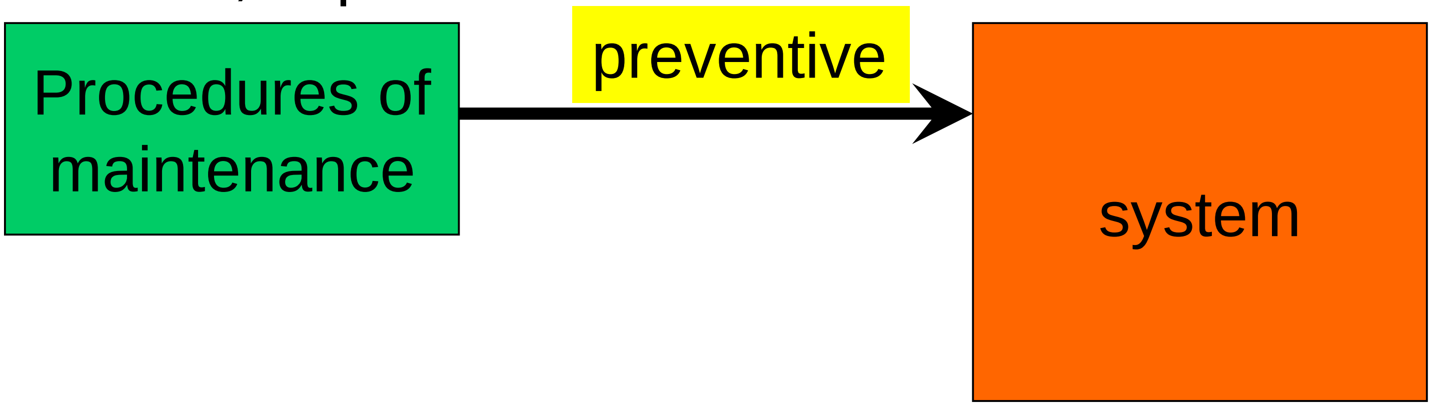
$$R_{system}(t) = e^{-\sum_{i=1}^{n} \lambda_i t} = e^{-0.000004199t}$$

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

institutCurie

Maintenances

Modelisation, experience

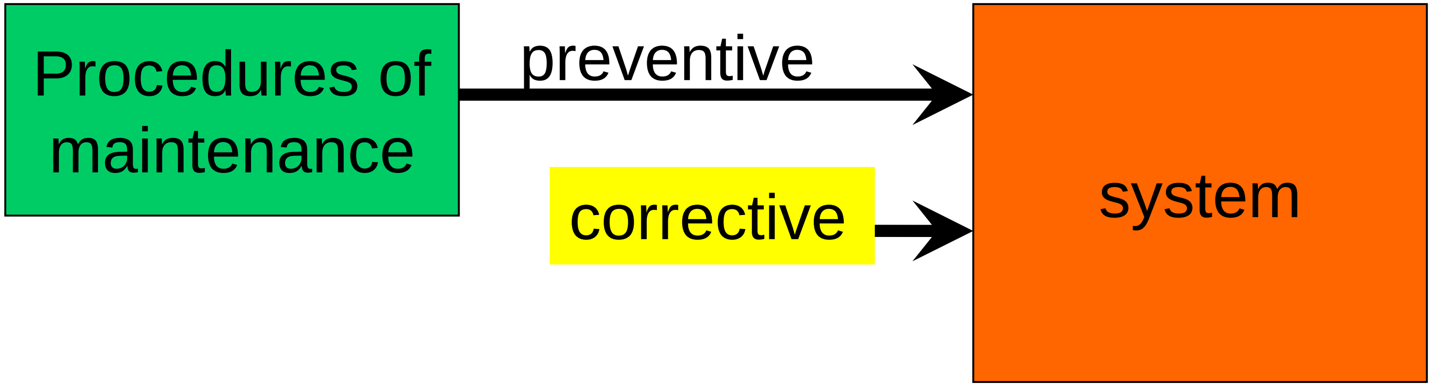


Inspect, clean, check, lubrify, calibrate, read, replace, test ,…

< 20% with high periodicity
Ex: Ions Sources

Maintenances

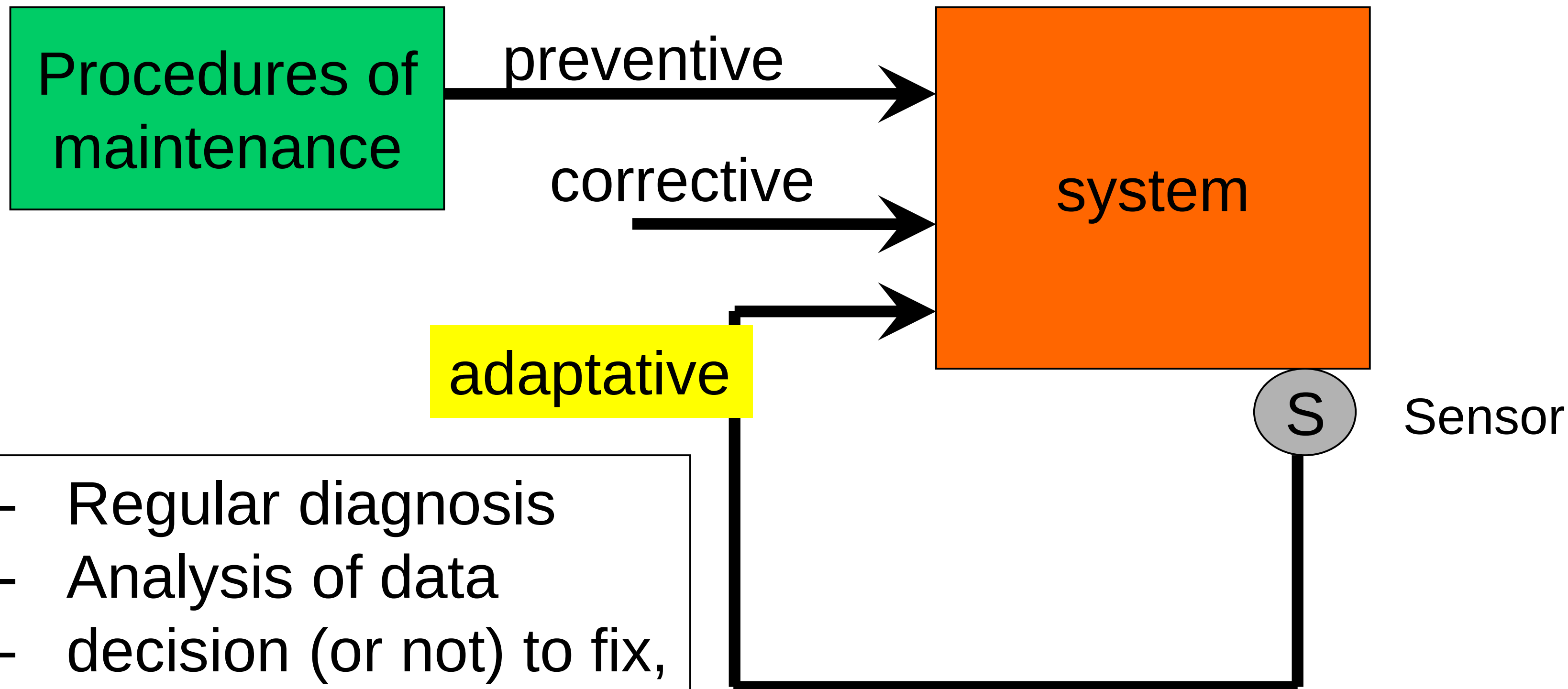
Modelisation, experience



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

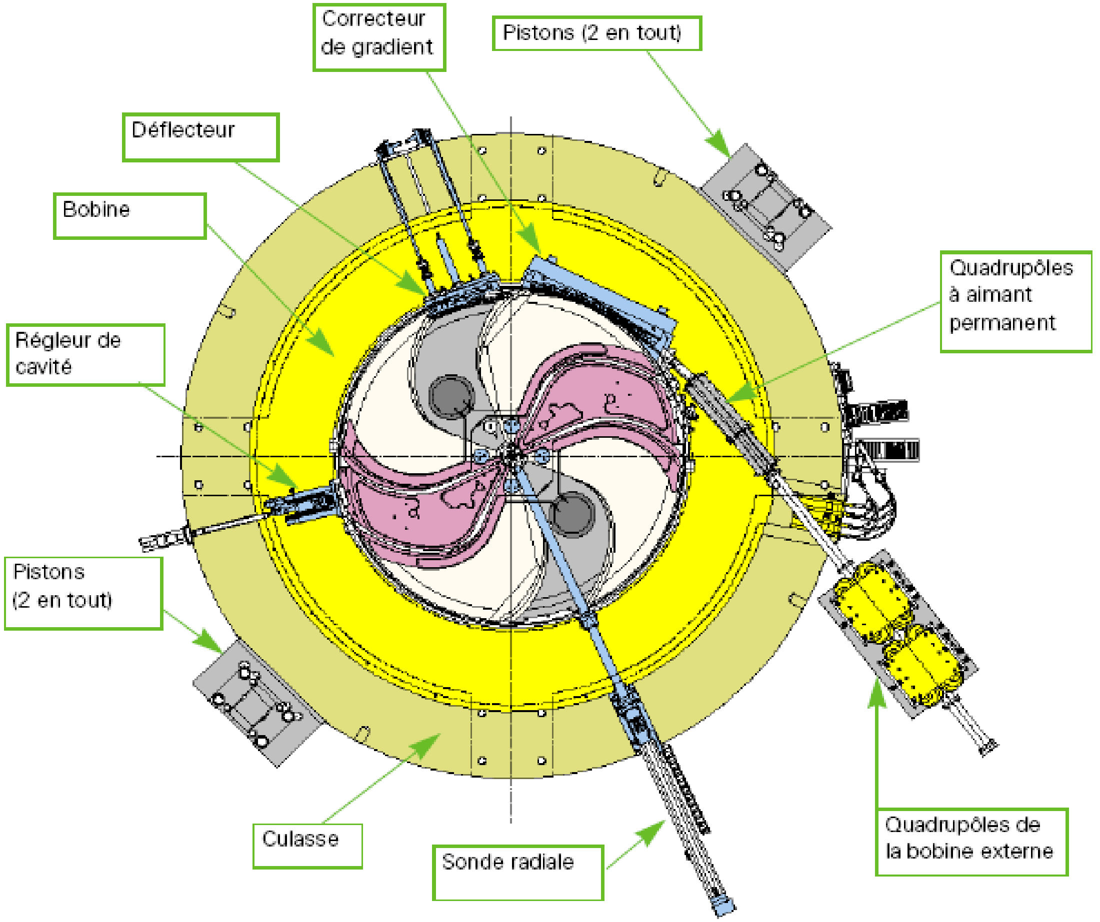
Maintenances

Modelisation, experience

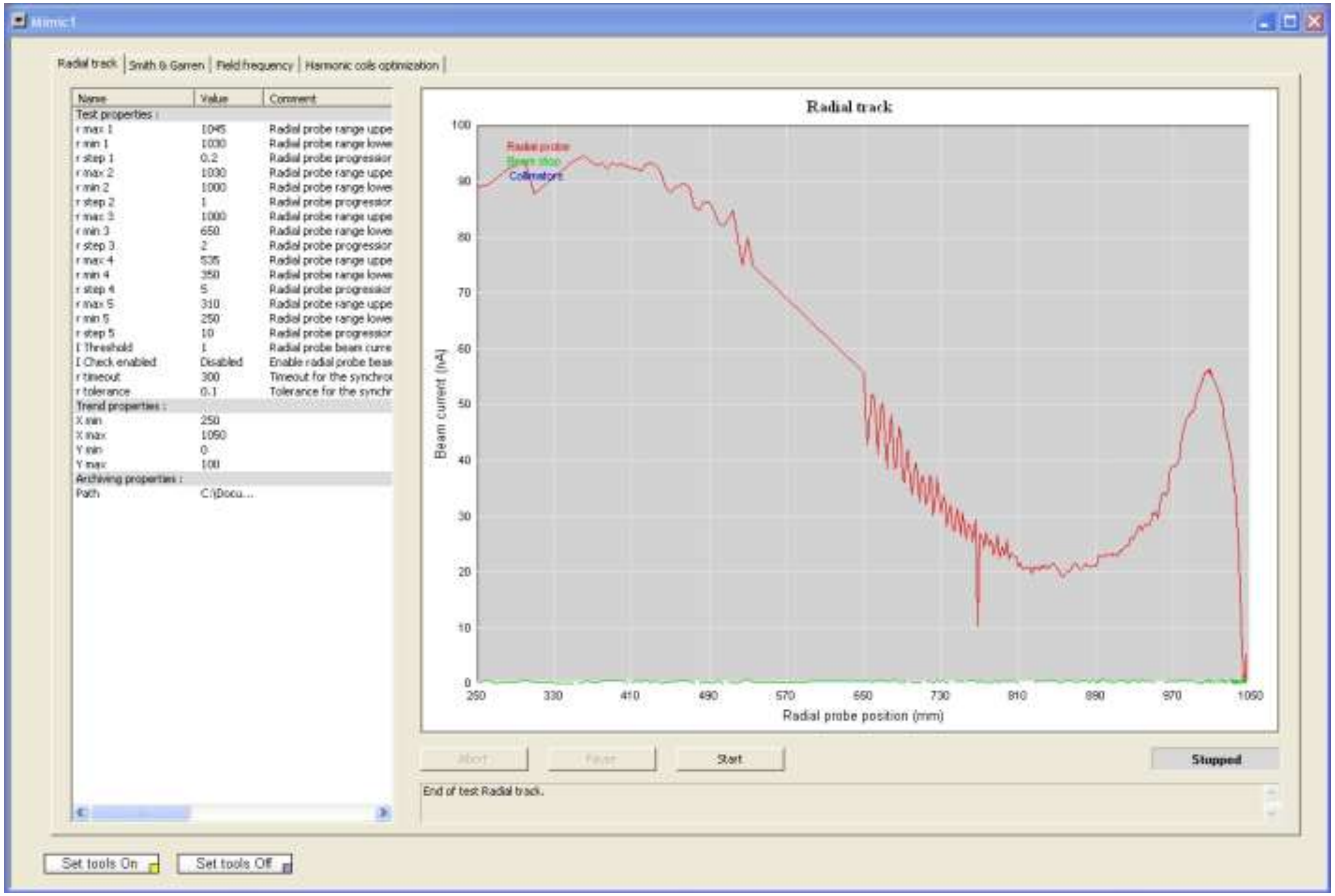


- Regular diagnosis
- Analysis of data
- decision (or not) to fix, inspect, more analysis

Diagnostic of beam inside cyclotron: the radial probe



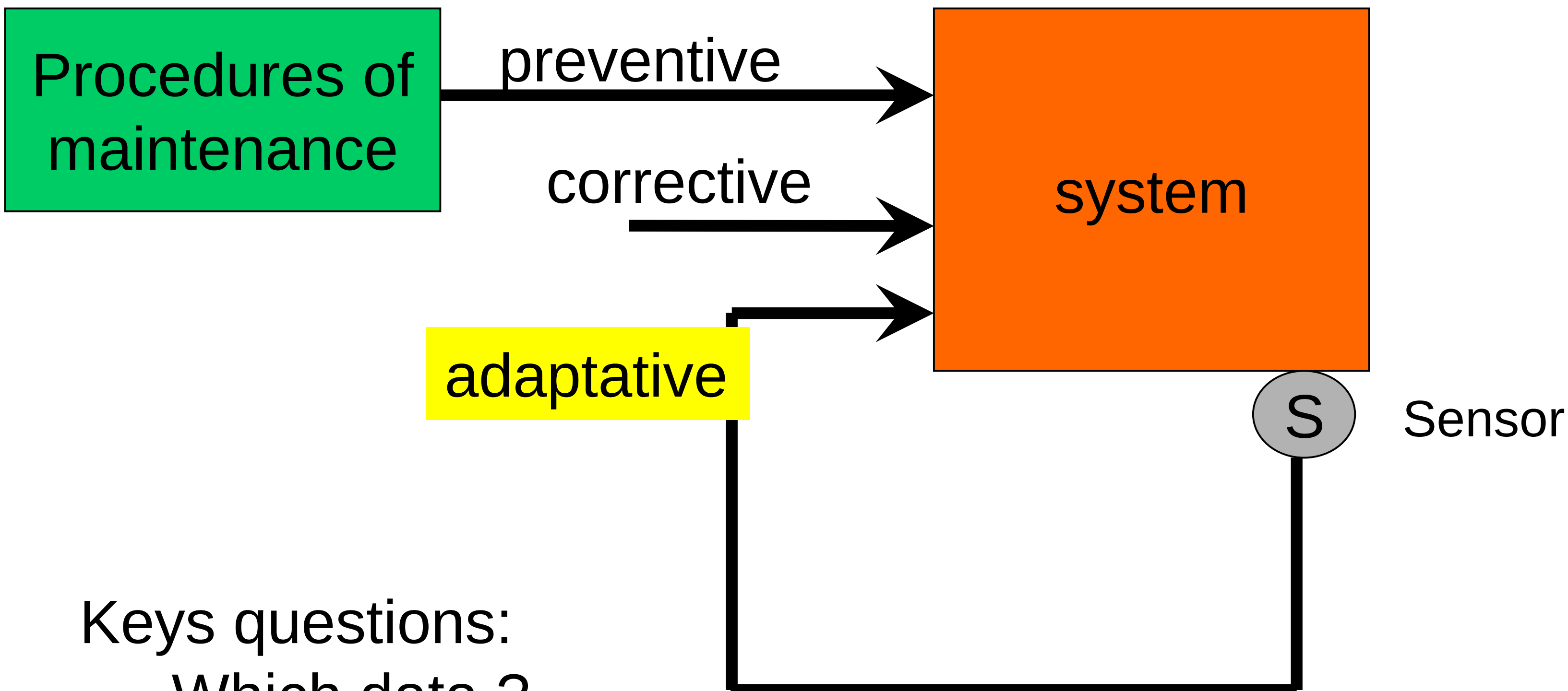
Example of result of radial track (C230IBA@CPO)



institutCurie

Maintenances

Modelisation, experience



Keys questions:

- Which data ?
- Which sensors ?

Thermography inspection C230 @ CPO

Cyclotron thermographie du 13 octobre 2011

	°C
70°C	
s	
	0.95
	20 °C

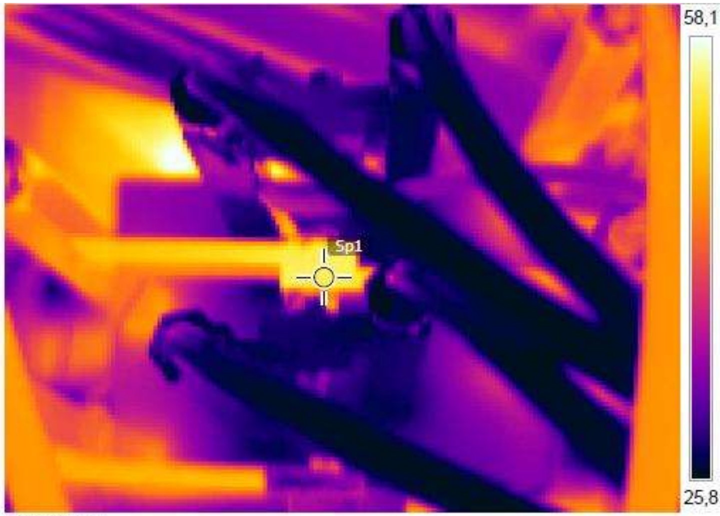
nter bobines 3 et 4
rieures. Point chaud
n sp1 A surveiller

13/10/2011 06:32:34

IR_0069.jpg

Sp1	54°C
Paramètres	
Emissivité	0.95
Temp. réfl.	20 °C

Bobines inferieurs 3 et 4

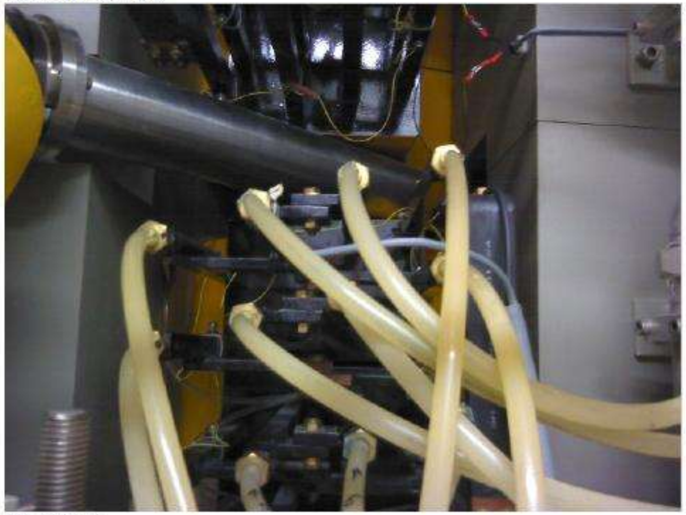


IR_0219.jpg

13/10/2011 06:32:34

DC_0070.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**

Comparing Maintenance Strategies

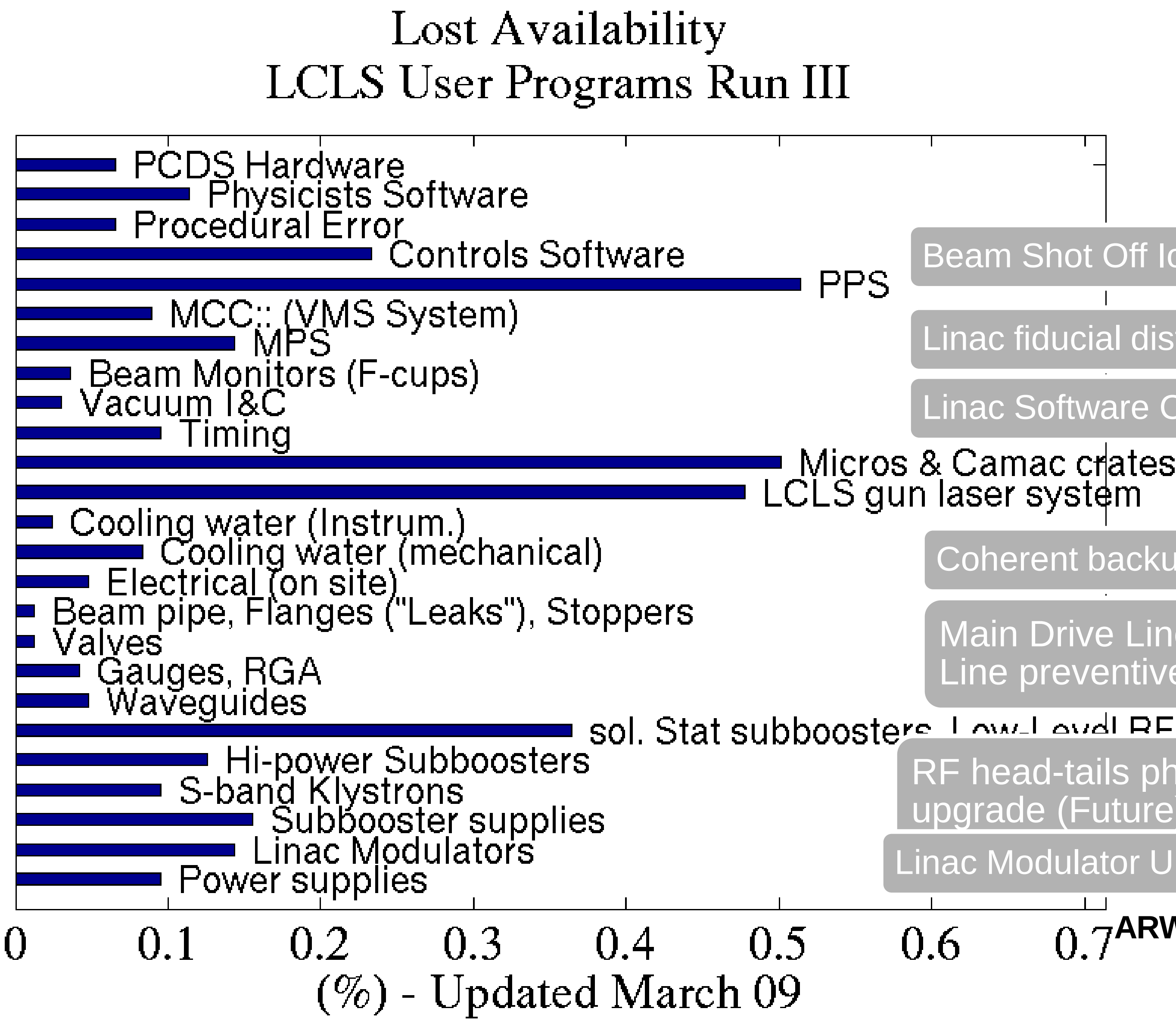
Comparison of the availability analysis

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

Provided by RelaSoft corp.

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

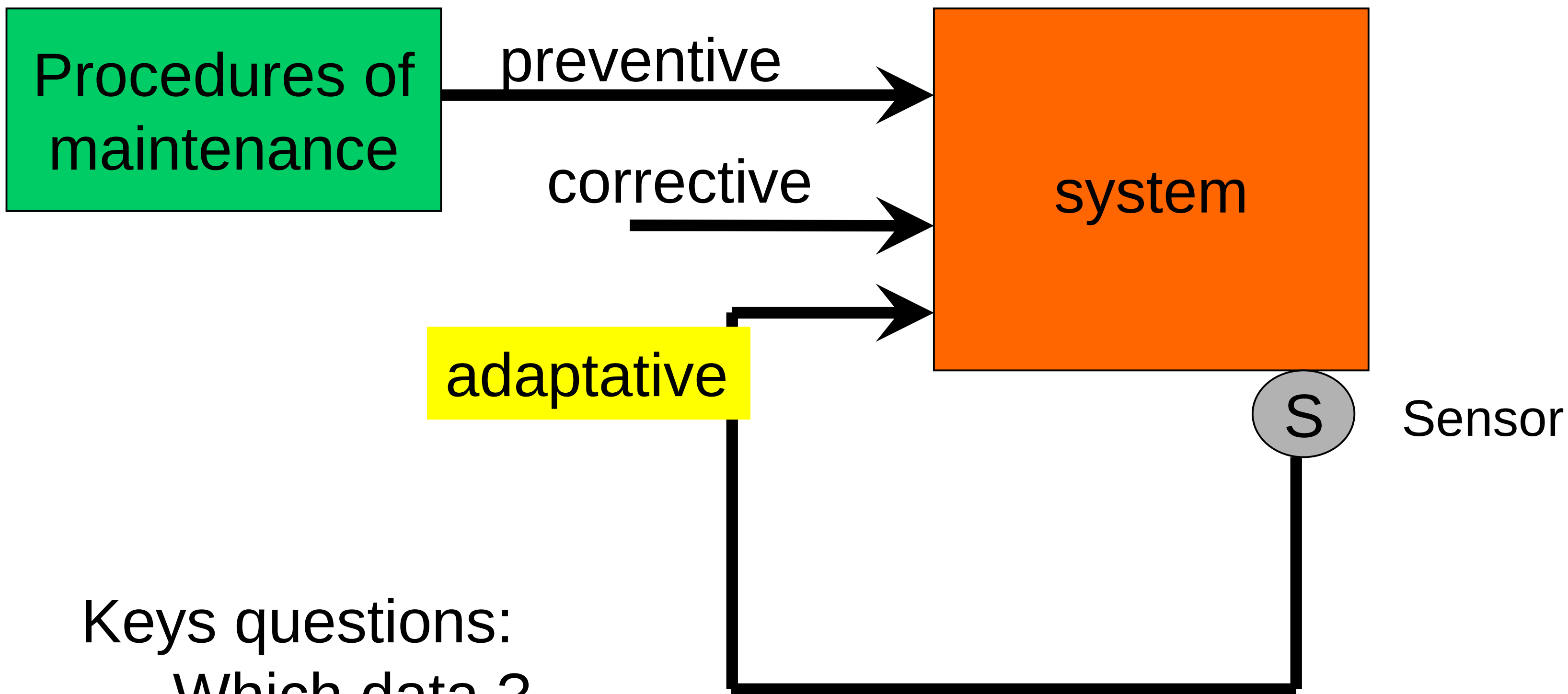
Downtime Statistics and future upgrades



- 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

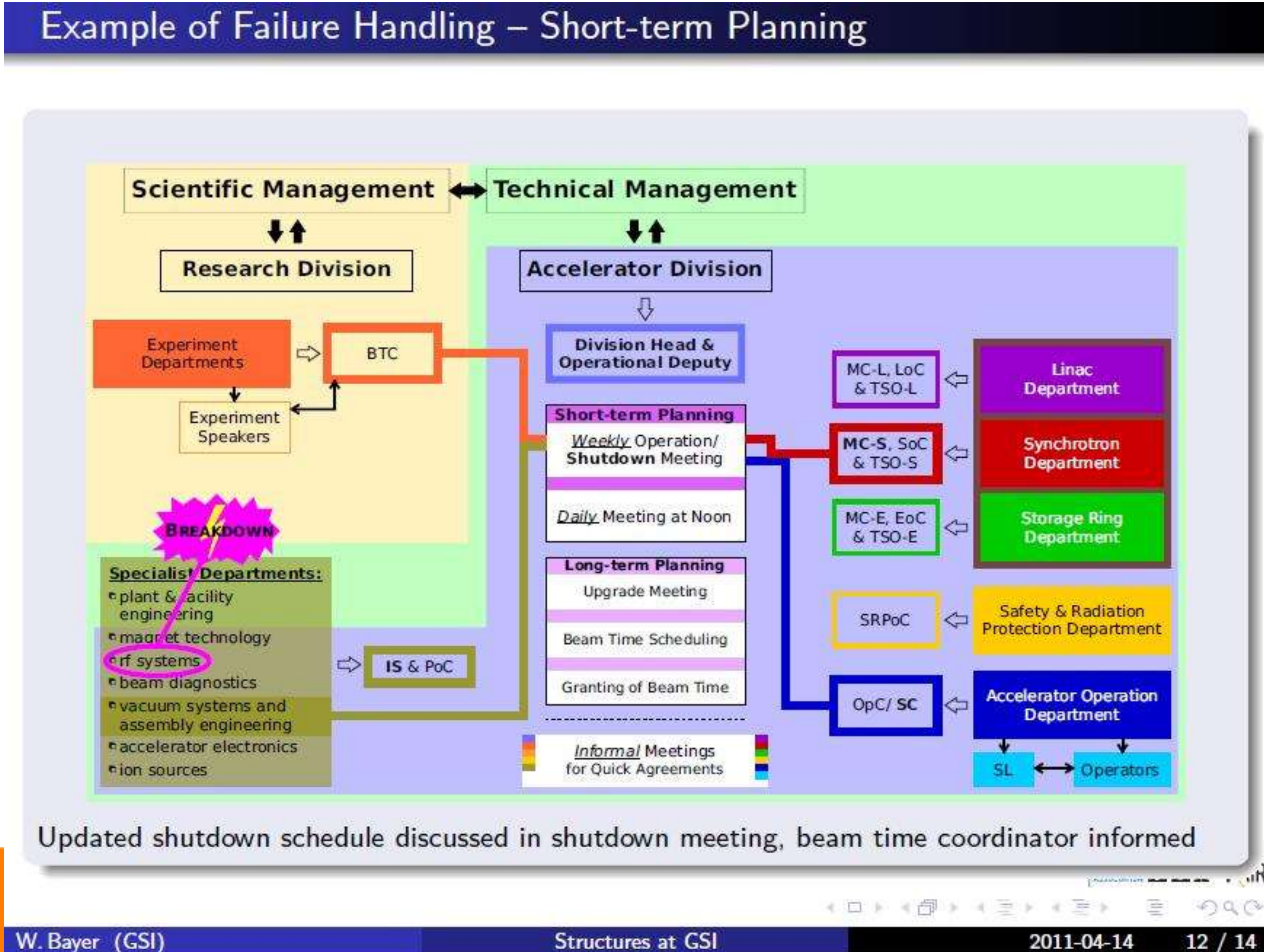
Modelisation, experience



Keys questions:

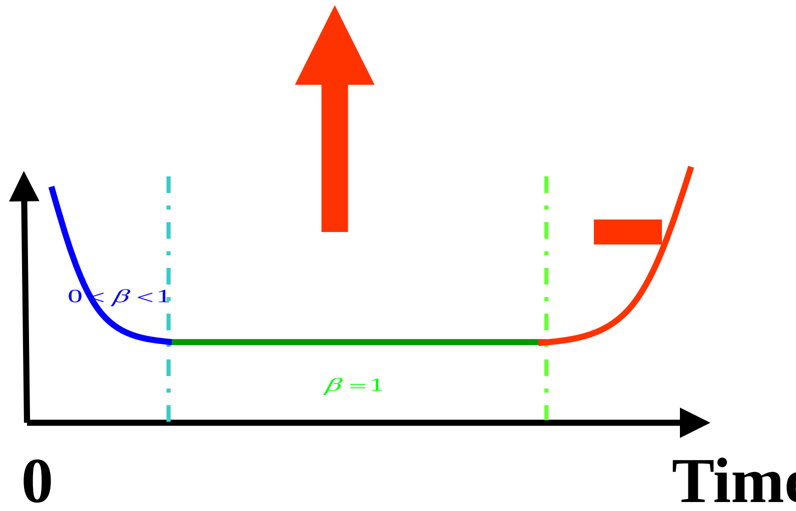
- Which data ?
- Which sensors ?

Reactivity of organisation–transmission of information



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)

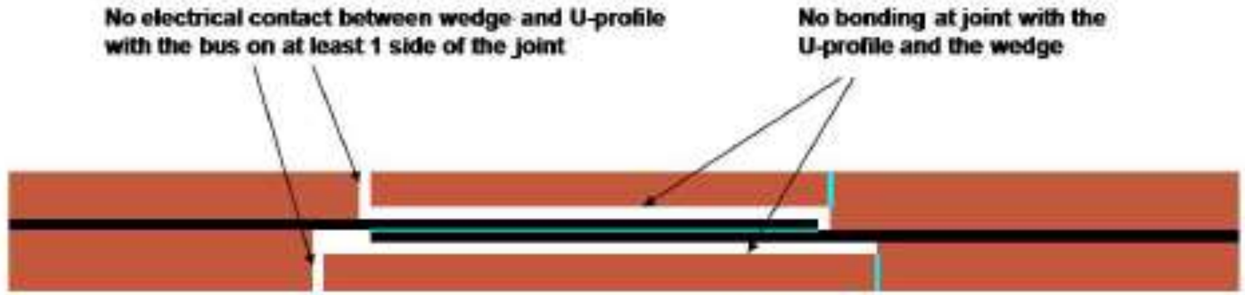


Figure 7: Model of resistive joint in bus bar
with bad electrical and thermal contact with the stabilizer

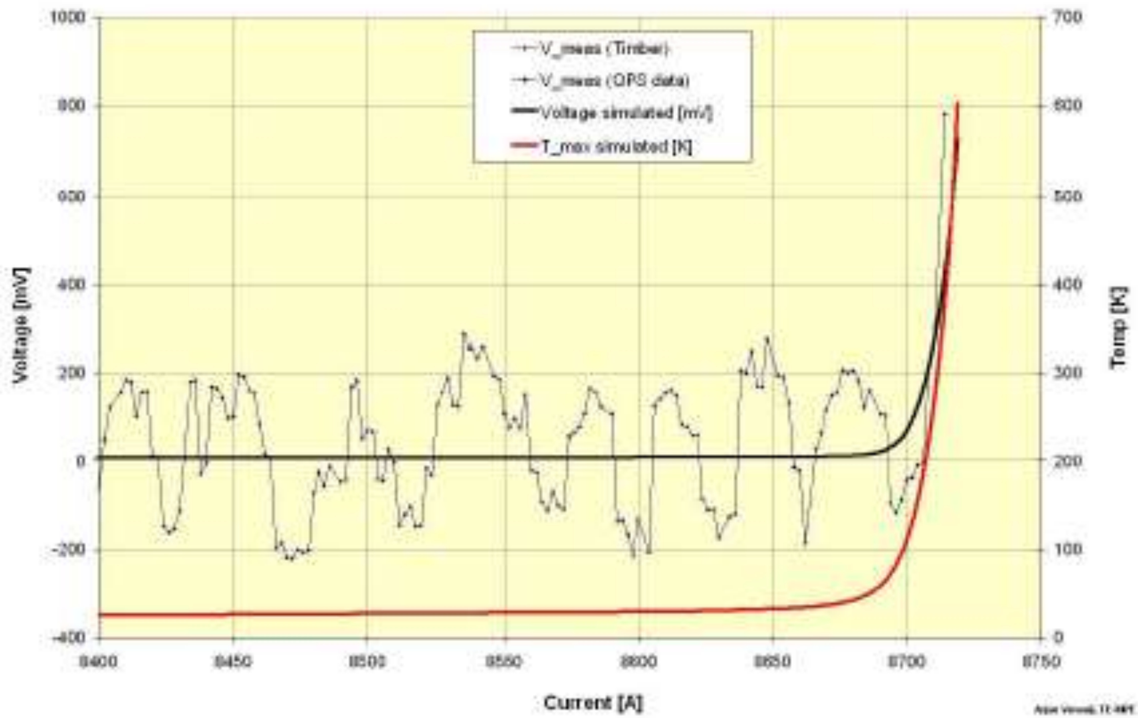


Figure 8: Measured and simulated parameters of the incident

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

institutCurie

Why transition « project » to « operation » 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

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

institutCurie

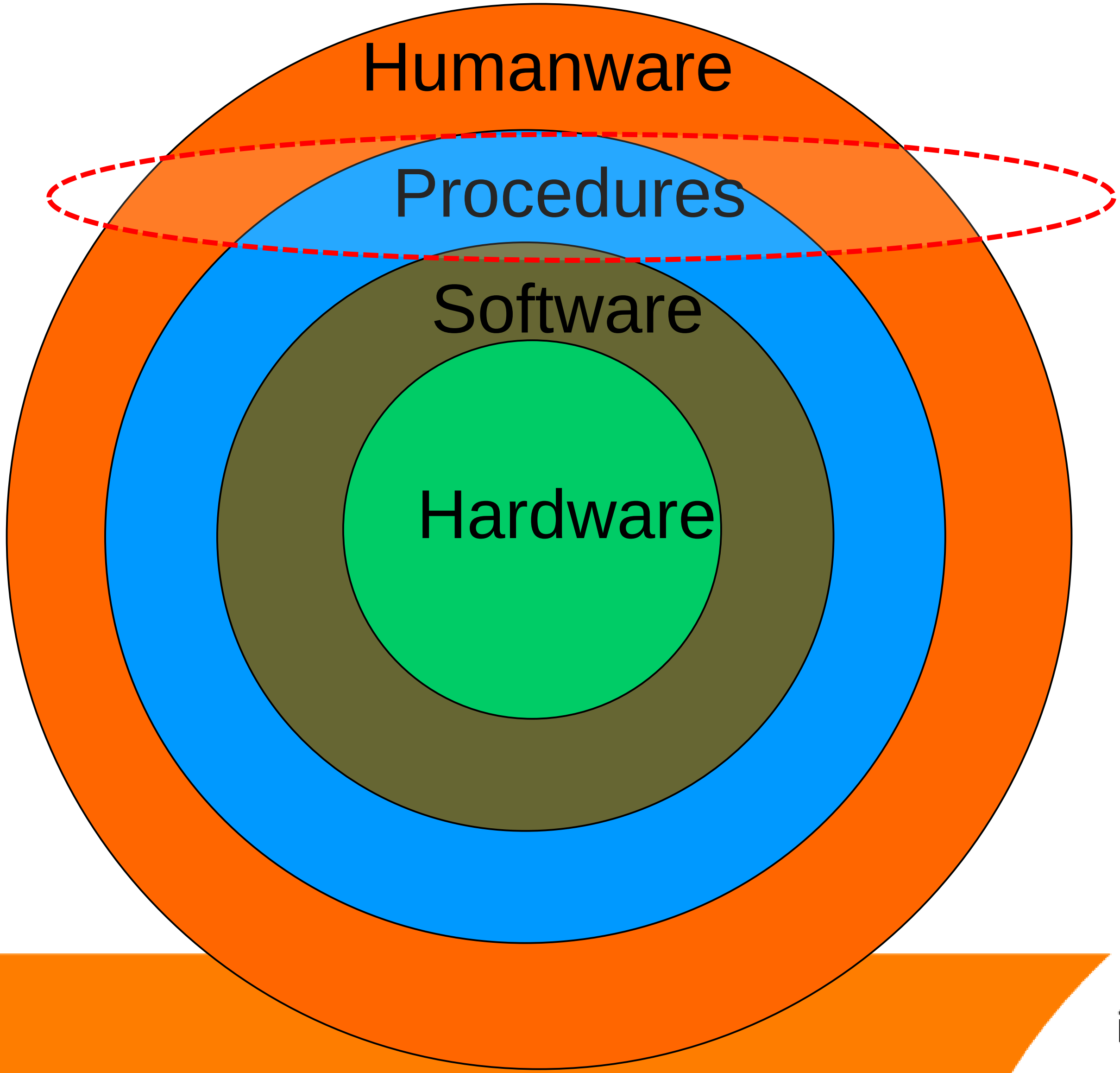
Event @CPO: july 2010, Cyclotron C230

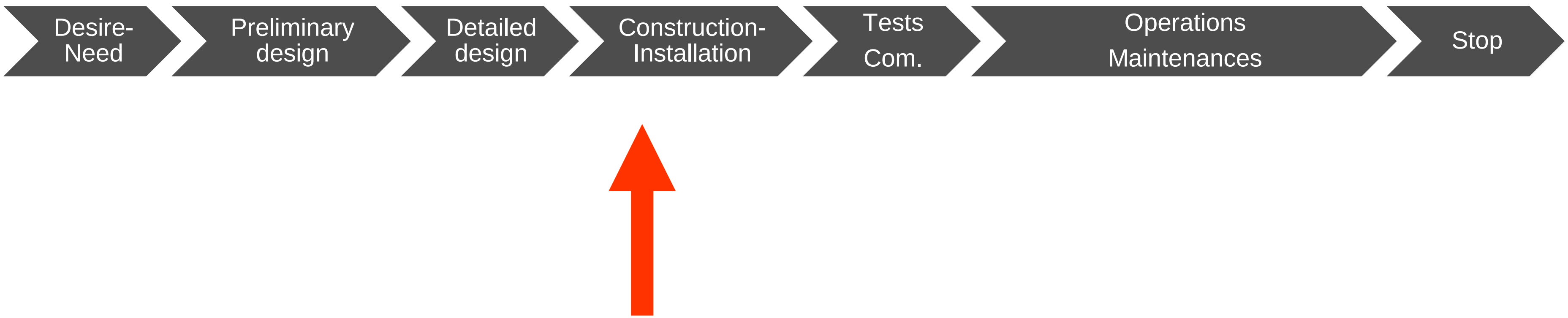
Ion Source pollution
+ RF event
+ deflector pollution
+ RF tube + PS RF …

5 days OFF

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

The 4 layers for reliability



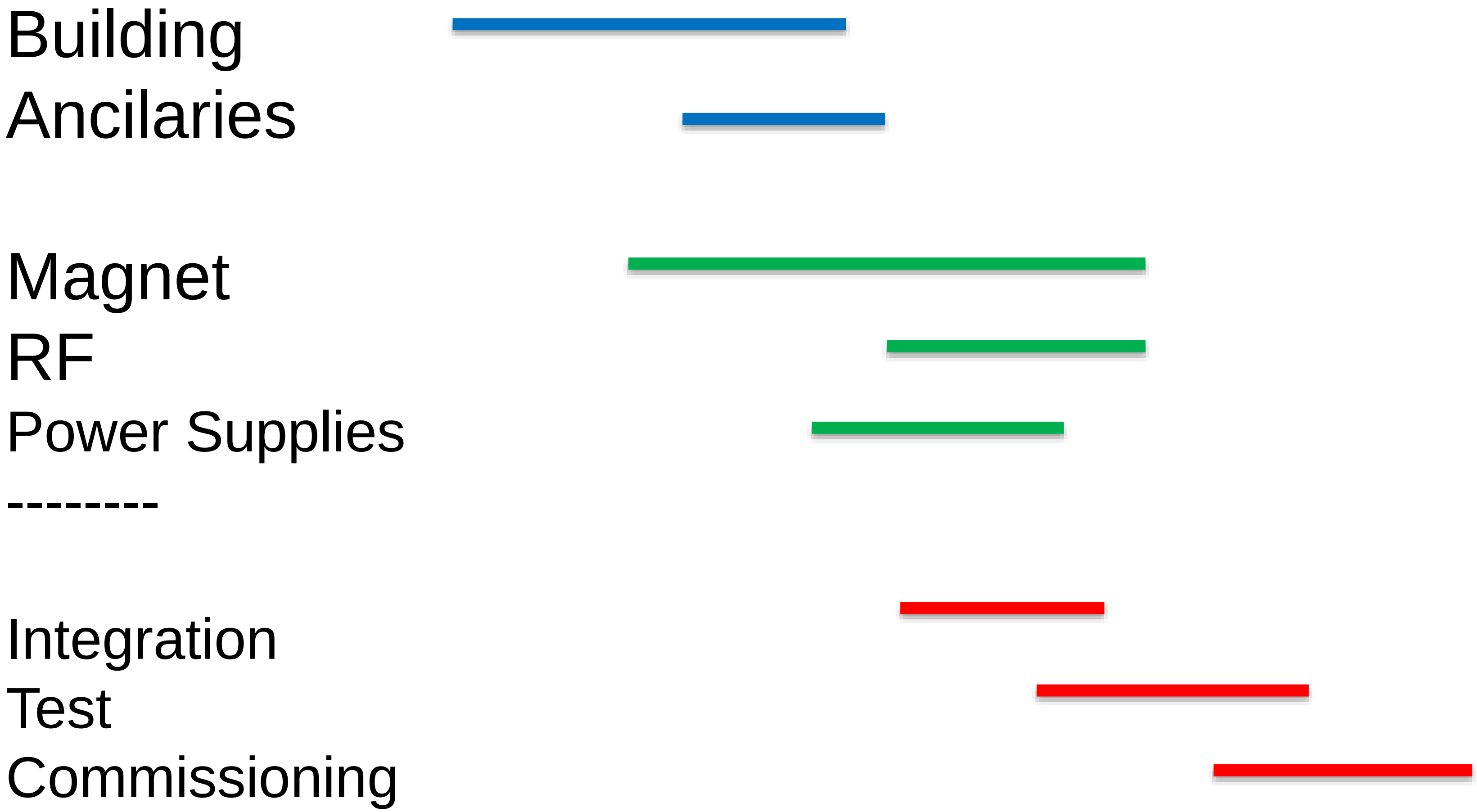

Desire-
Need
Preliminary
design
Detailed
design
Construction-
Installation
Tests
Com.
Operations
Maintenances
Stop

planning

Magnet
RF
Power Supplies

Integration
Test
Commissioning

planning



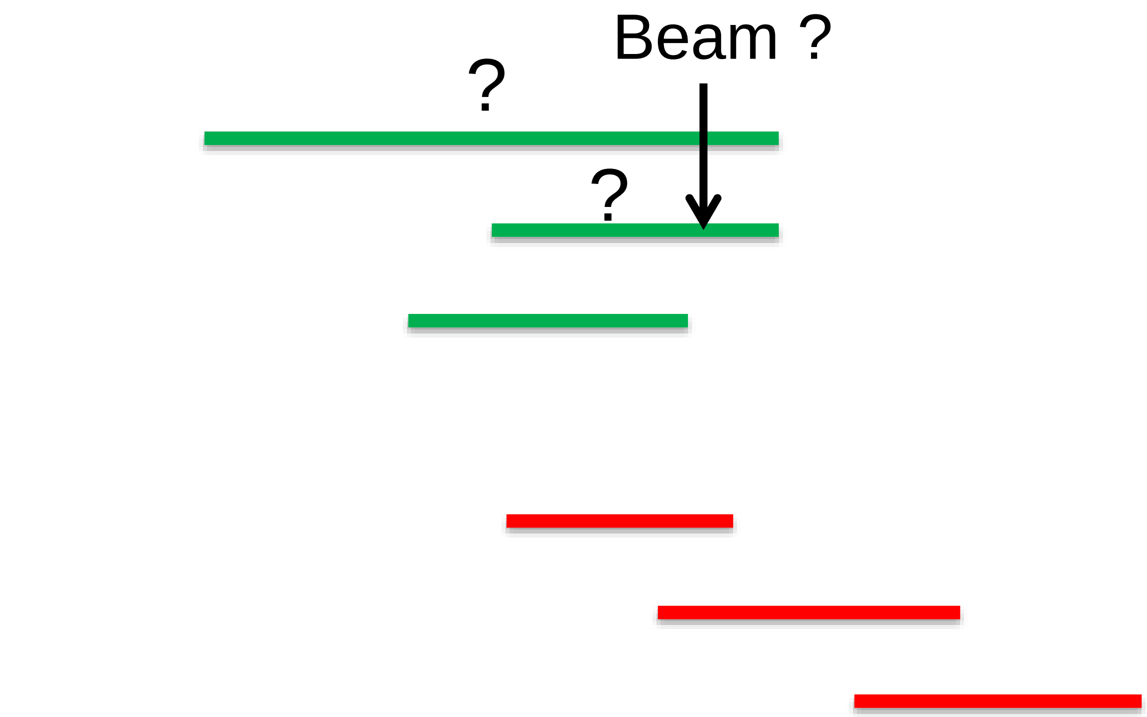
institut Curie

planning

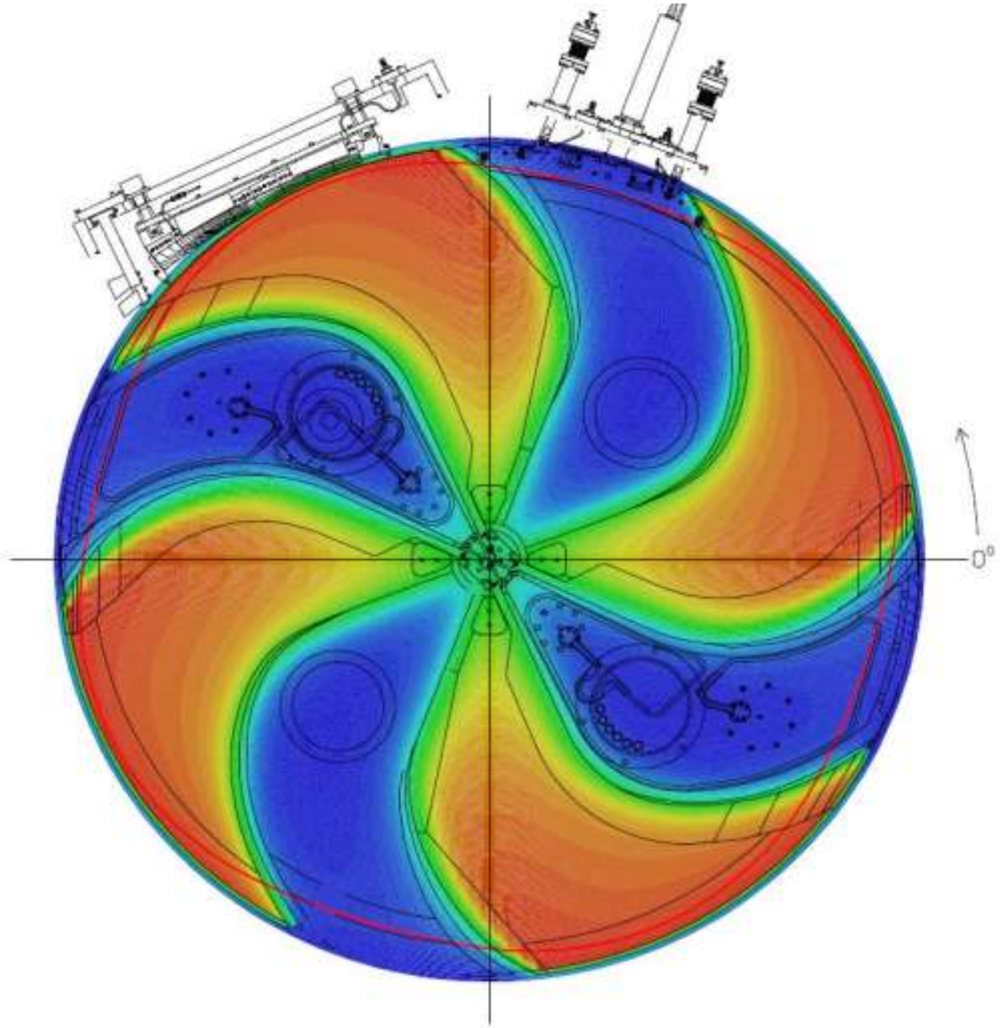
Building
Ancilaries

Magnet
RF
Power Supplies

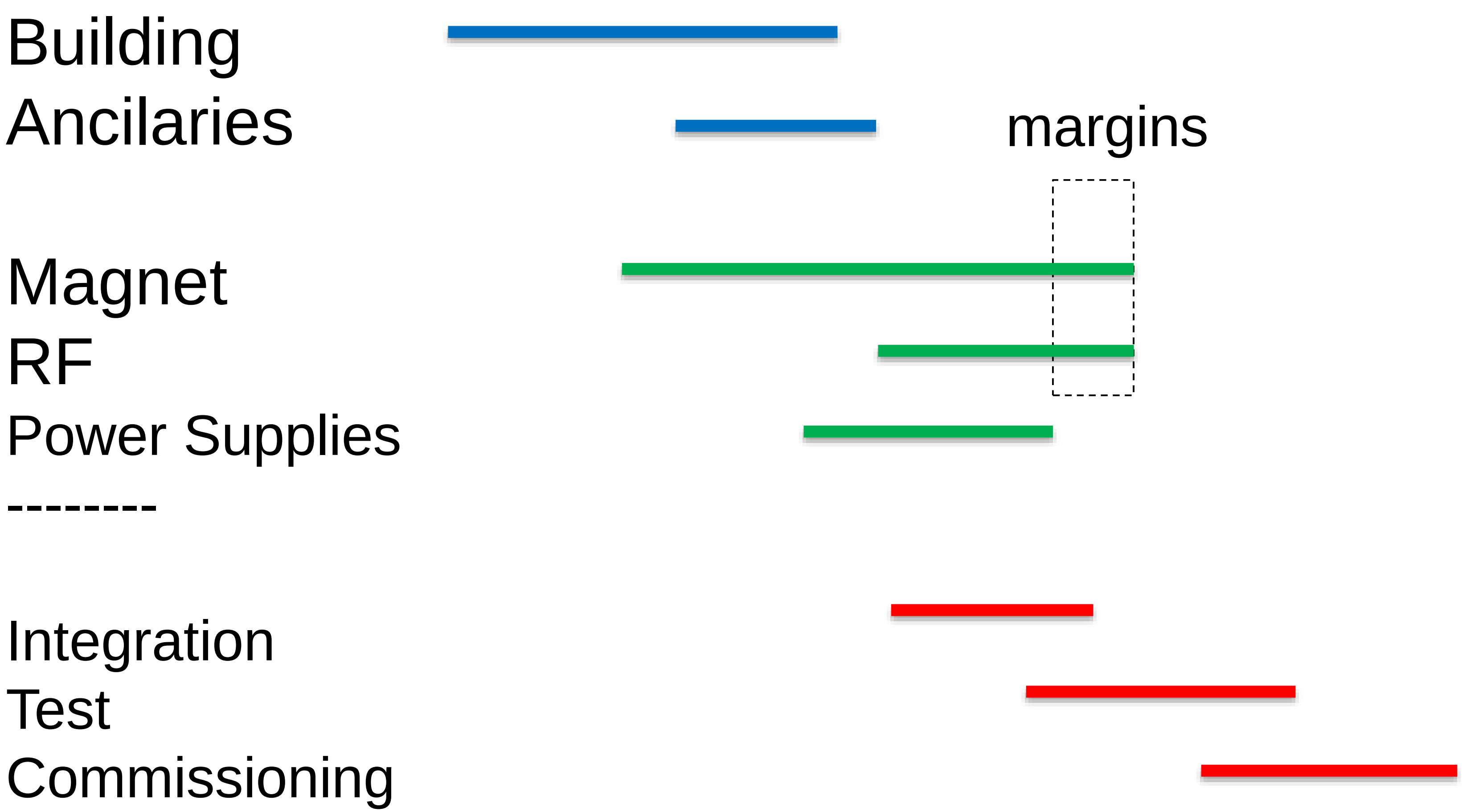
Integration
Test
Commissioning



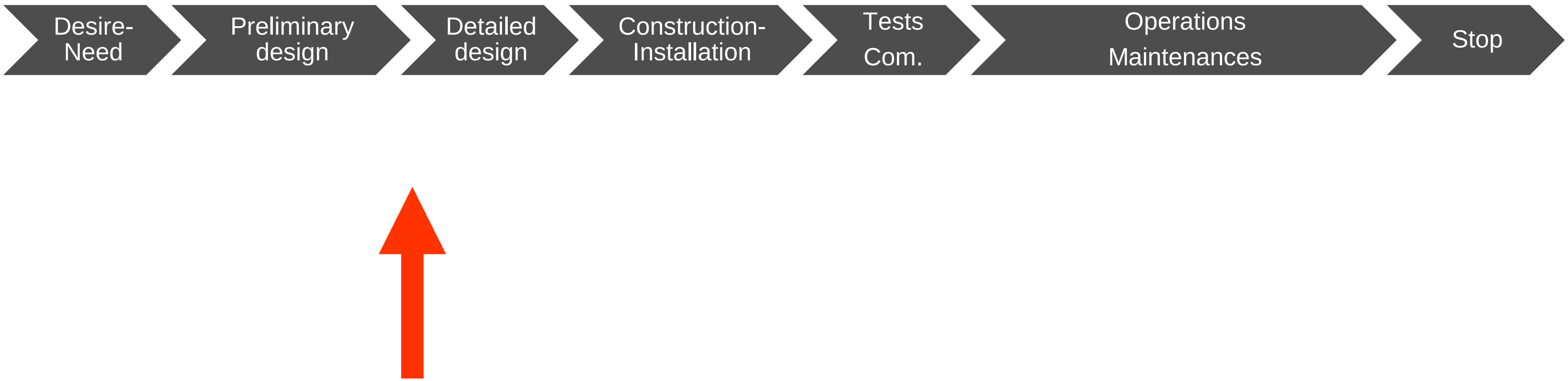
Mapping C230



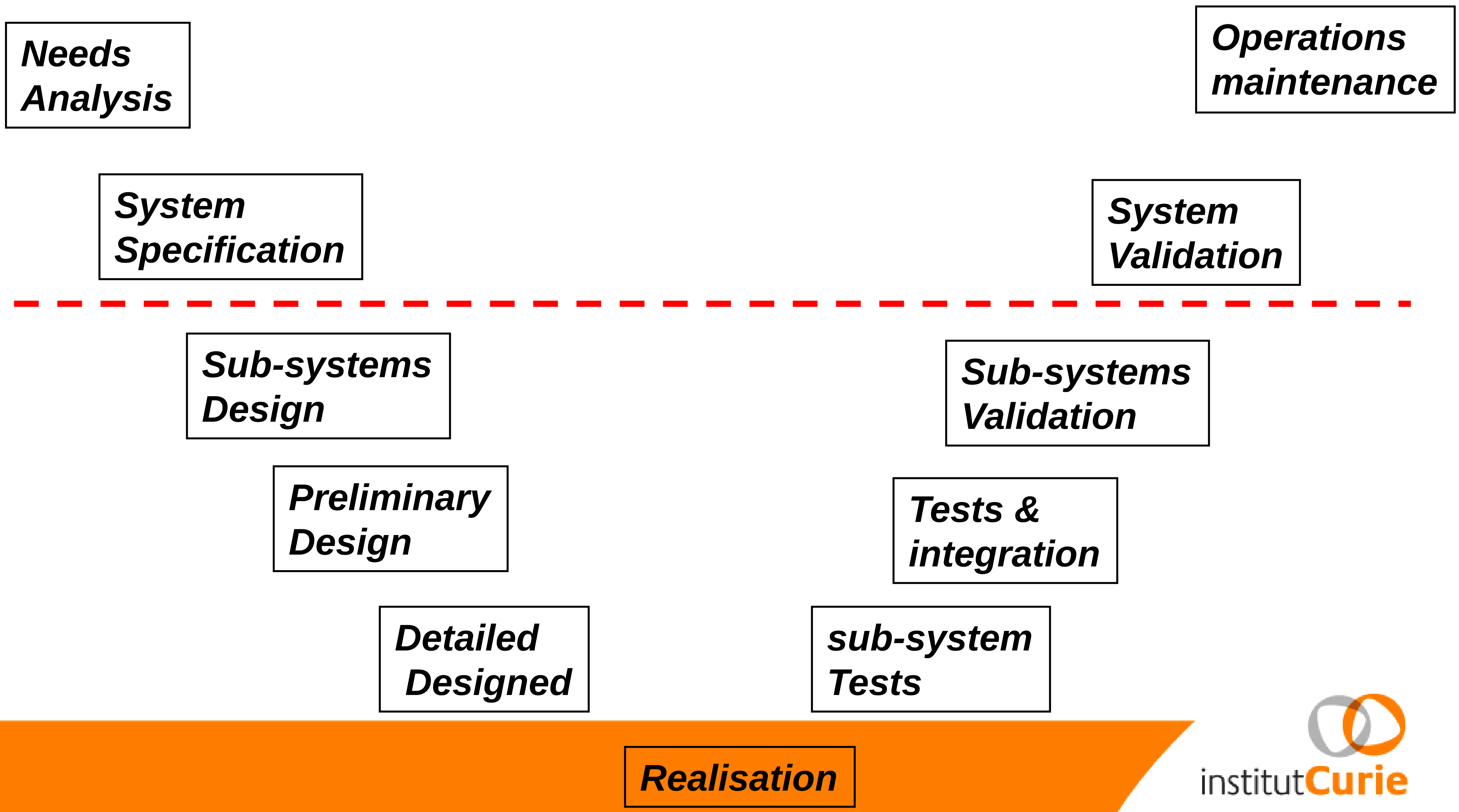
planning



institutCurie


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

Development – the V cycle



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

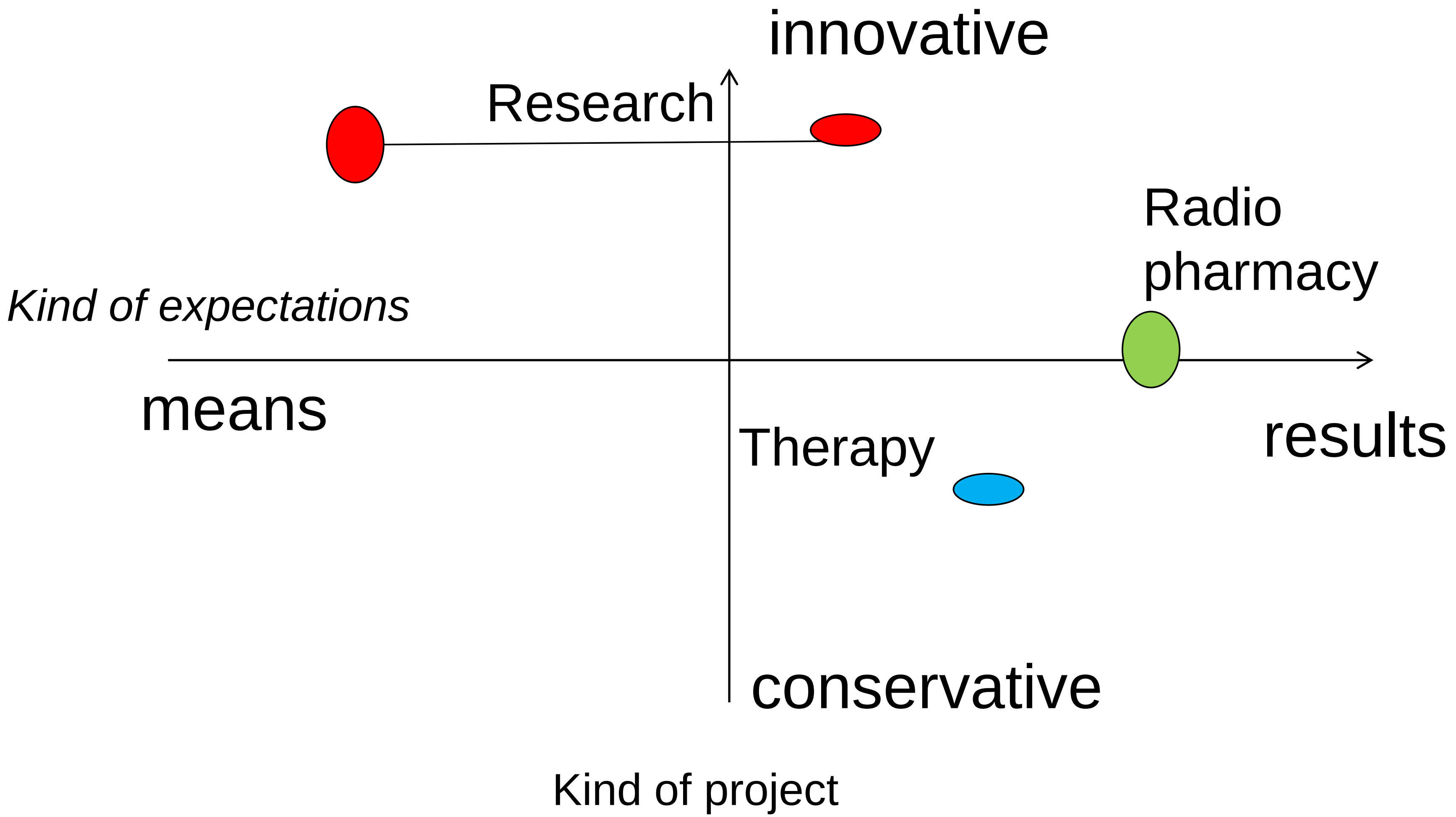
- for investment
- for ramp-up and contengencies
- for operations, maintenance, …

institutCurie

Science of Organisations

Henry Mintzberg: different kinds of coordination

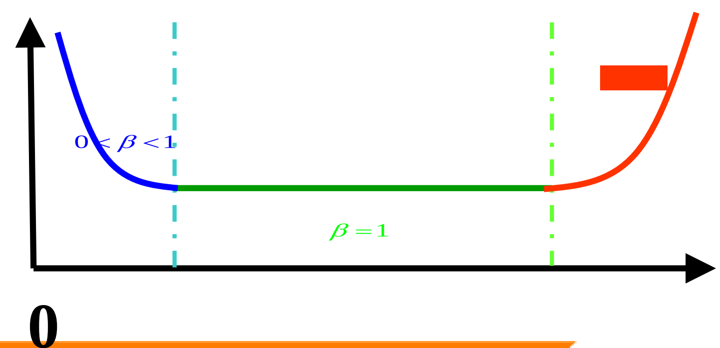
- **Mutual adjustment**
- **Direct supervision**
- **Standardization of work processes**
- **Standardization of outputs**
- **Standardization of skills**
- **Standardization of norms**


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



institutCurie

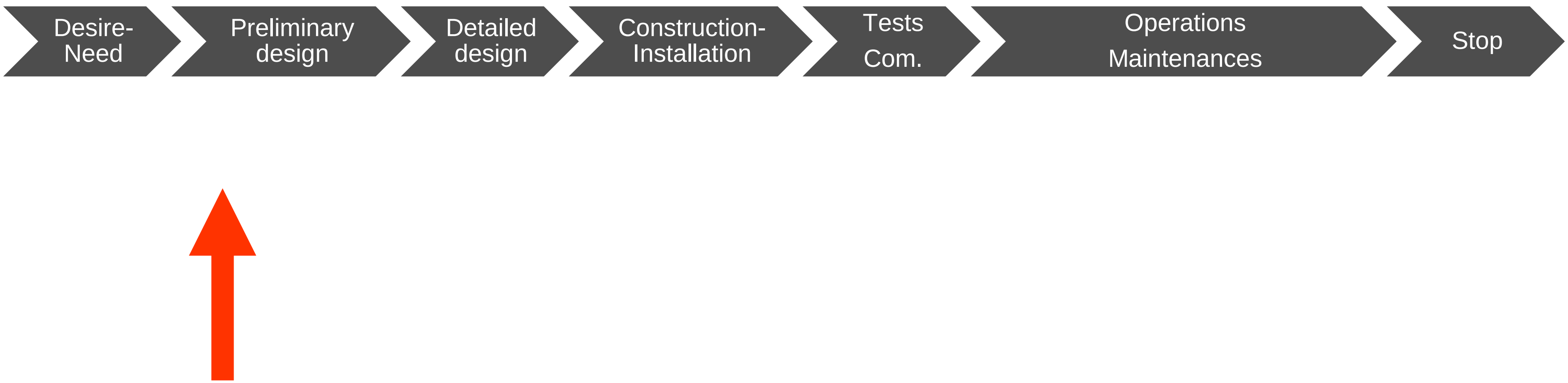
SSC: The Super Superconducting Collider

South of Dallas - 89 km – 80 TeV protons

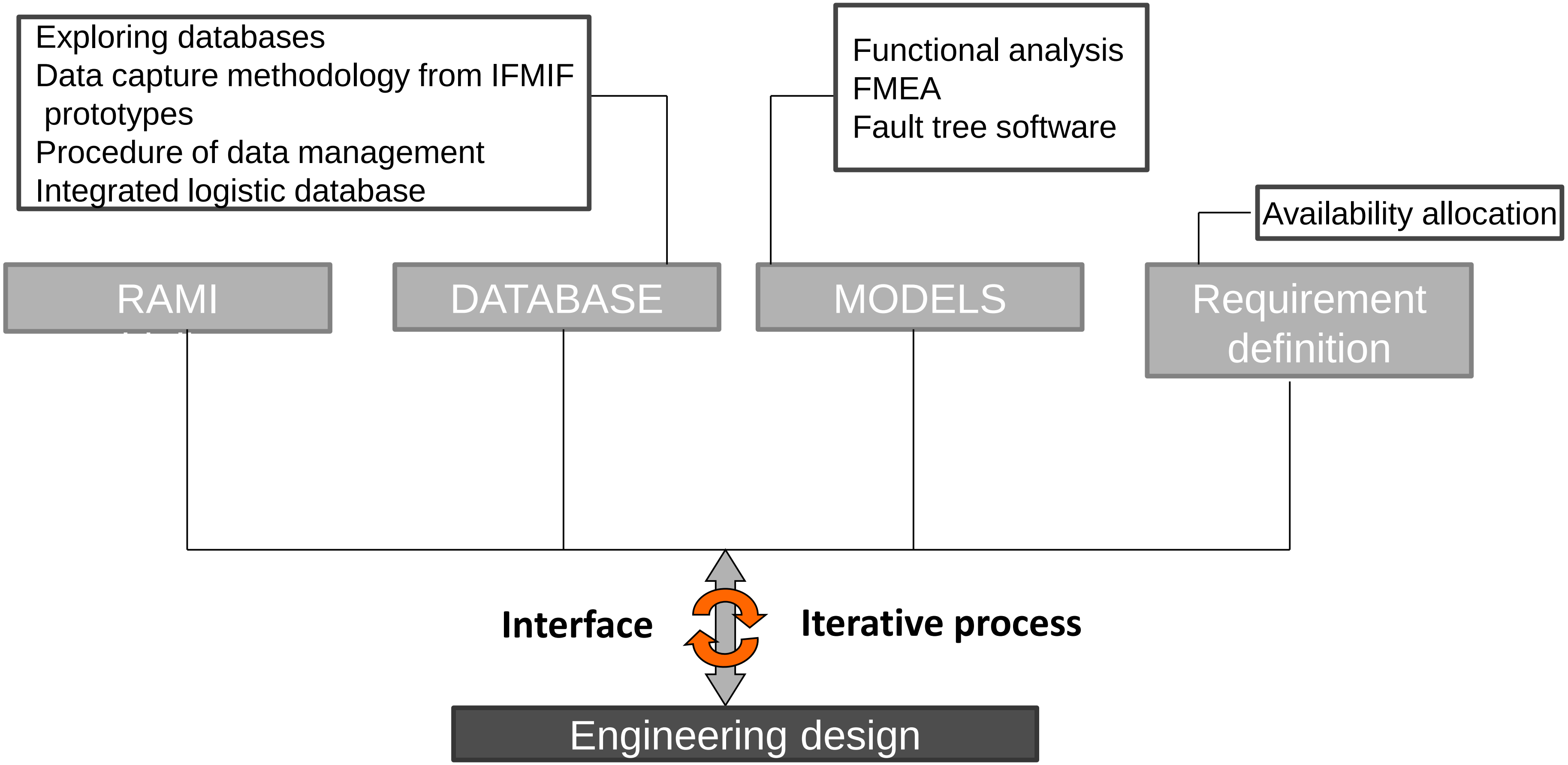
Starts 1991-1993
Then cancelled

institut Curie

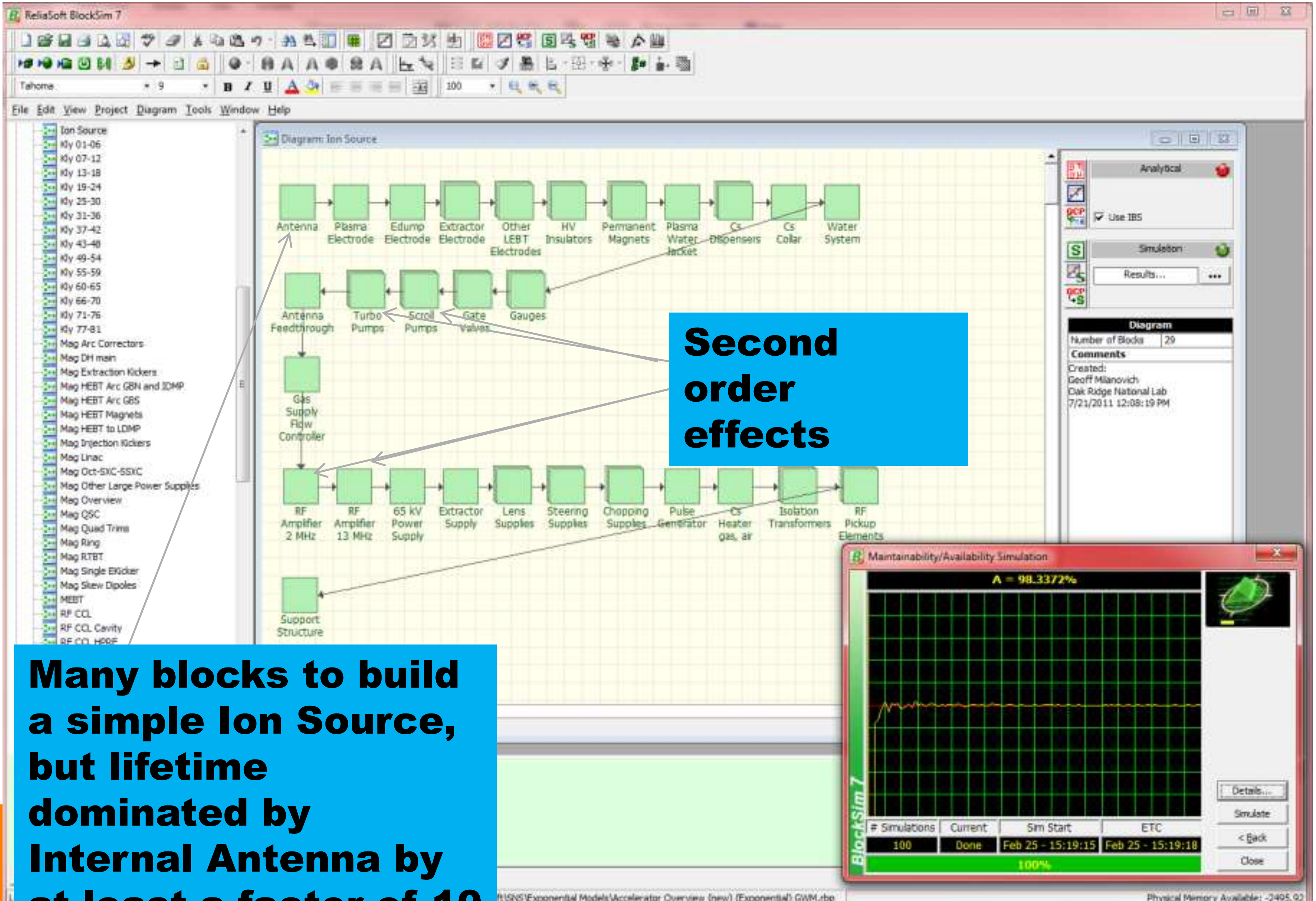
Life-cycle of an accelerator



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**
- **…**

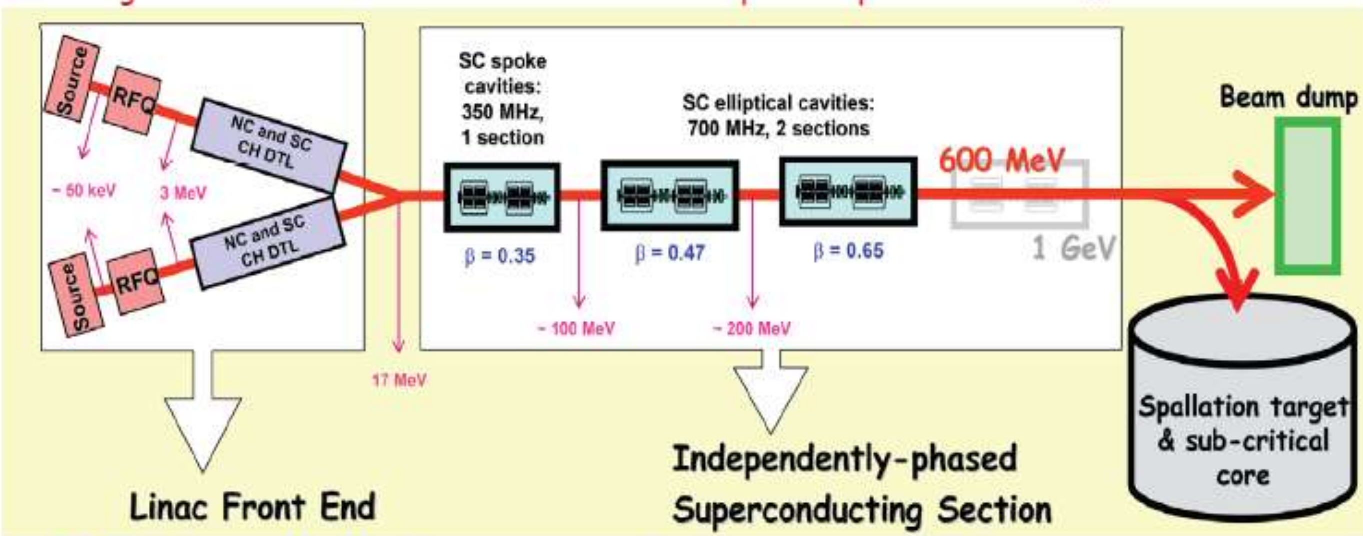
Parameters increasing risks on reliability

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

institutCurie

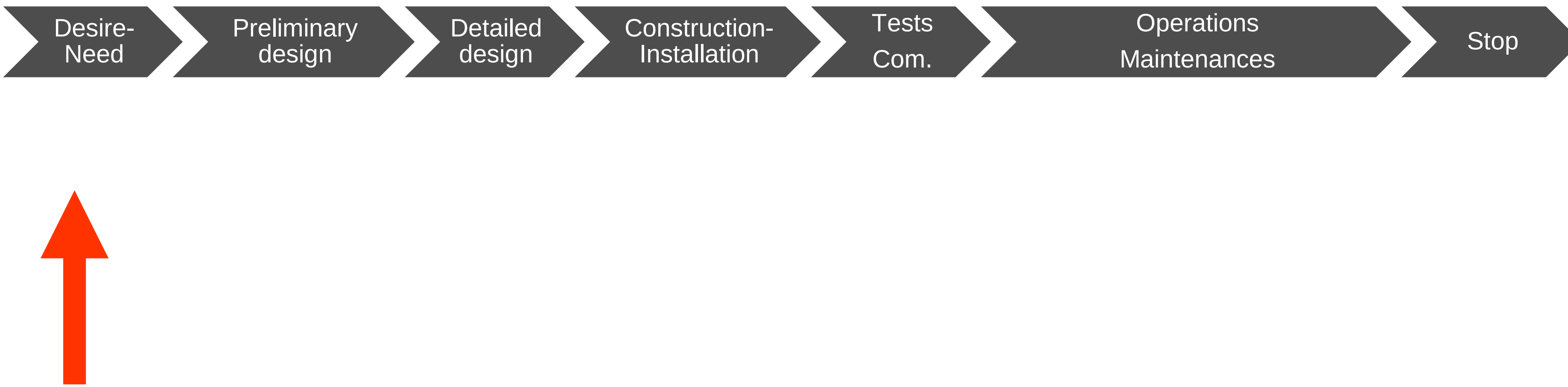
MYRRHA

- 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



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

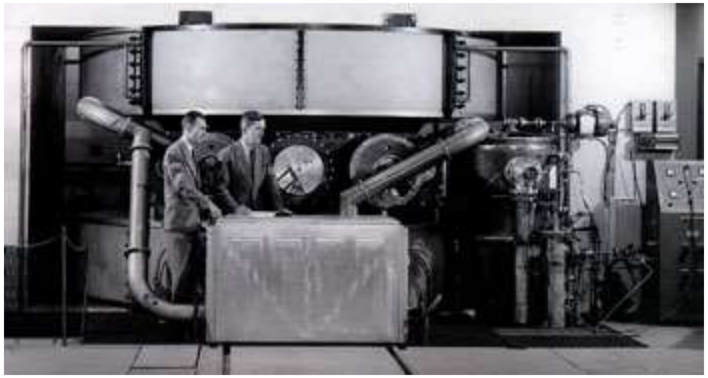
Human resources and good organization
- people trained, skilled, enough, here when required
- efficient and clean organization, data-base, Knowledge Management

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

Accelerators champions of lifetime

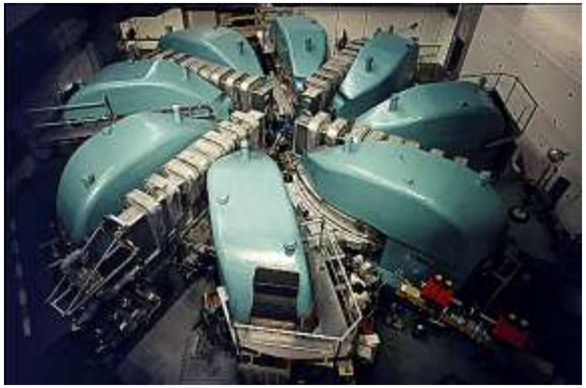
institutCurie

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)



institutCurie

Summary

institutCurie

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.