IFMIF availability oriented design

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IFMIF team

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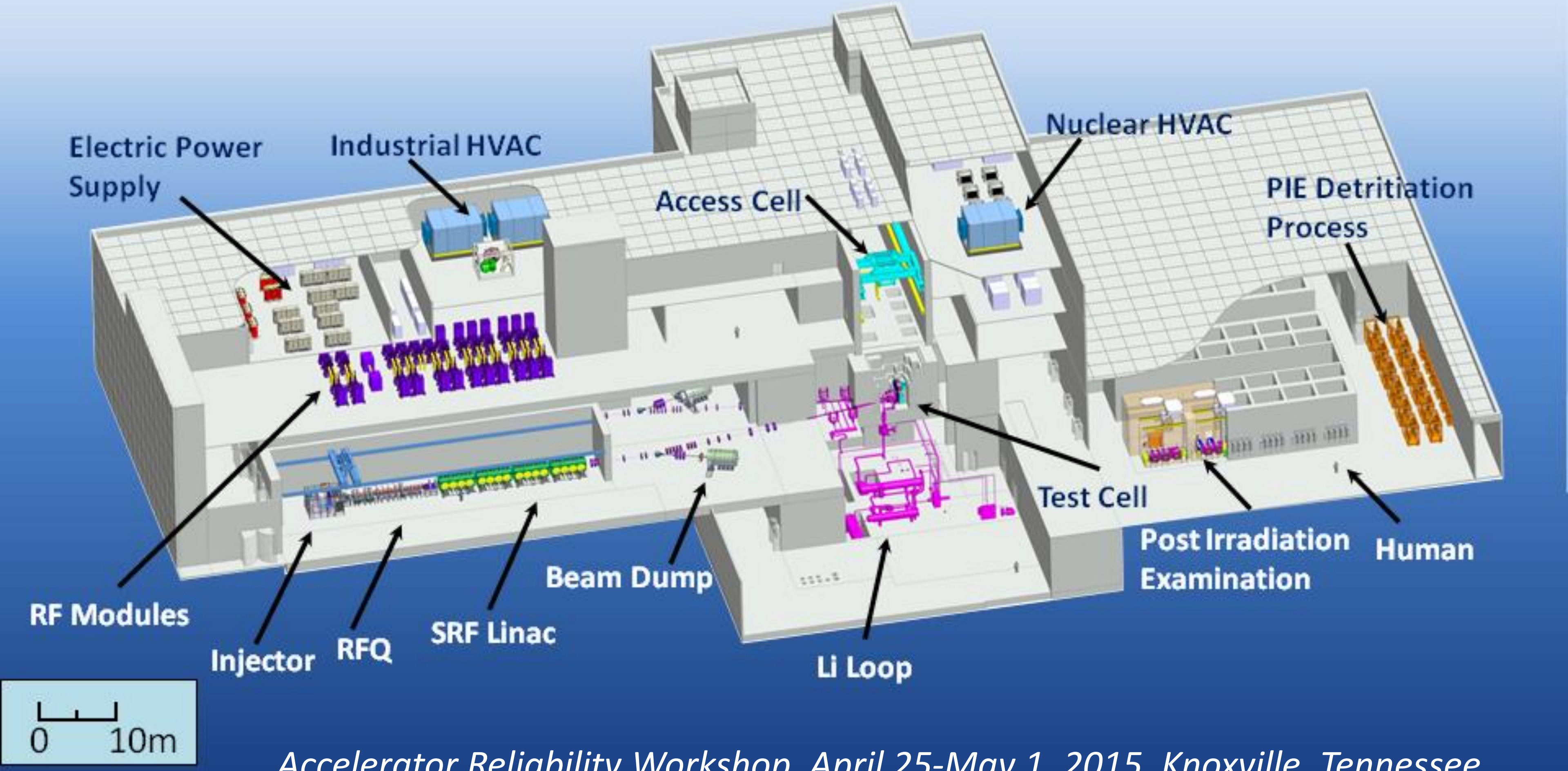


Accelerator Reliability Workshop, April 25-May 1, 2015, Knoxville, Tennessee

Outline

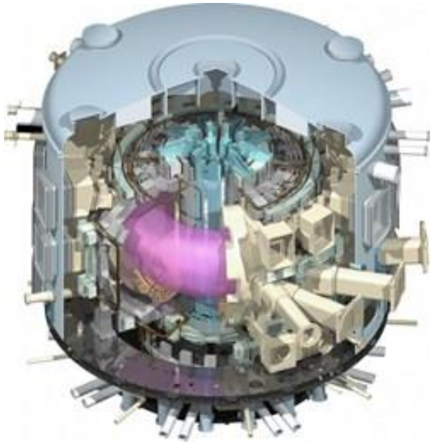
- Introduction
- Availability in IFMIF
- RAMI process and methodology
- Experience in the implementation
- Future challenges

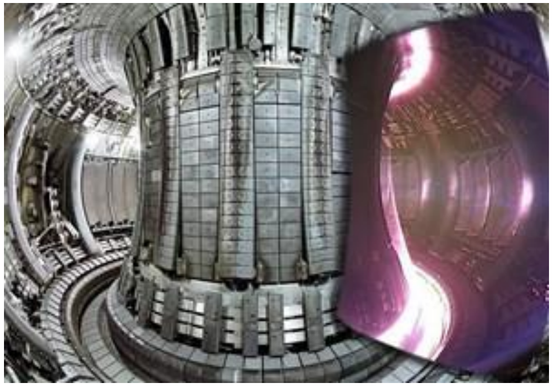
Introduction

Introduction

Framework

IFMIF project is framed in the development of Fusion Energy by magnetic confinement.



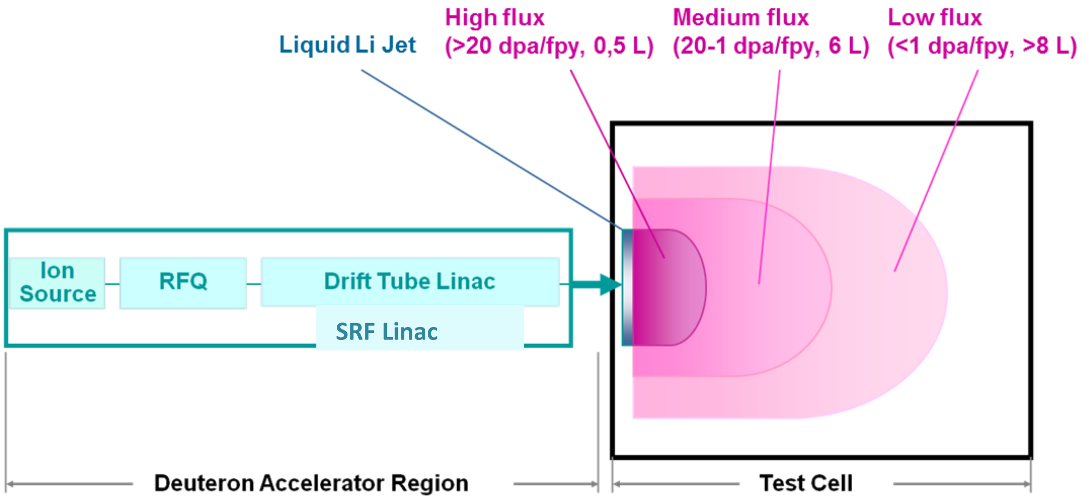


In this development, one of the key problems is the test and qualification of materials under fusion radiation environment.

IFMIF (International Fusion Materials Irradiation Facility) is a neutron source aimed at qualifying the materials necessary for the design and licensing of a DEMOstration plant and a Fusion Power Plant. It has to generate a fusion reactor relevant radiation environment.

IFMIF principles

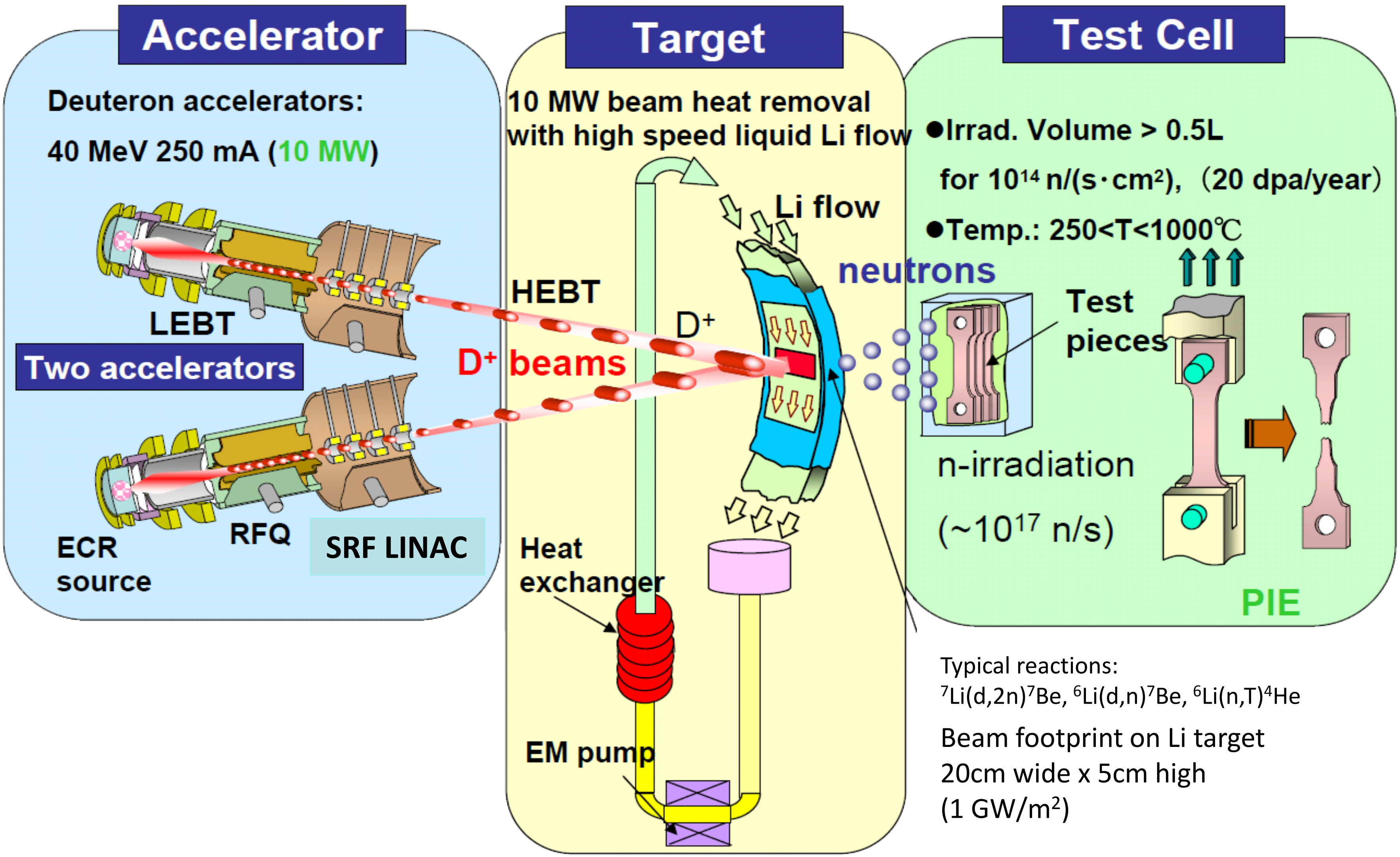
Accelerator based neutron source using the D-Li stripping reaction ⇒ intense neutron flux with the appropriate energy spectrum



Deuteron accelerators Li target Test facility

Introduction

IFMIF principles



Typical reactions:
$^{7}Li(d,2n)^{7}Be$, $^{6}Li(d,n)^{7}Be$, $^{6}Li(n,T)^{4}He$

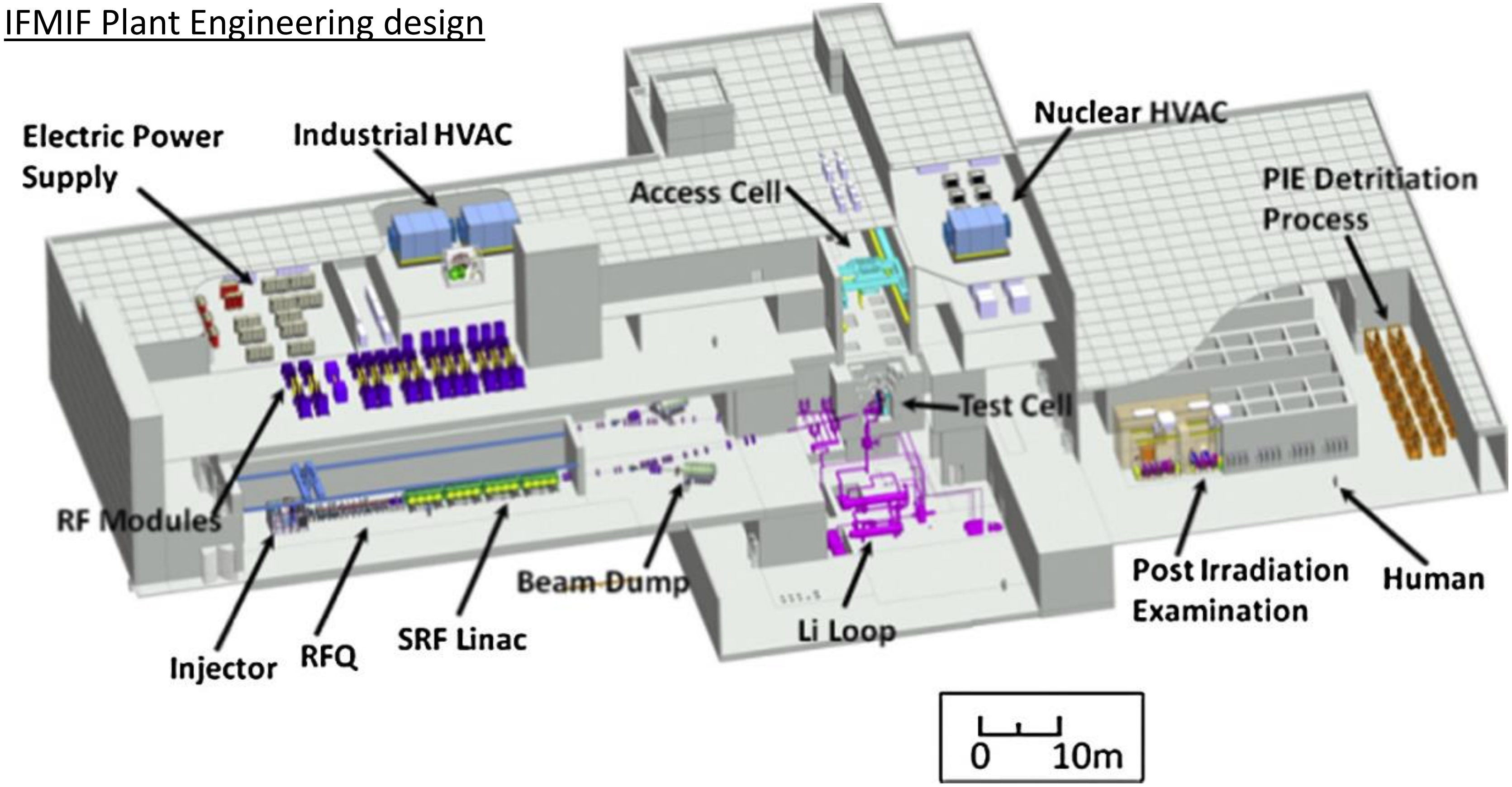
Beam footprint on Li target
20cm wide x 5cm high
($1\ GW/m^2$)

IFMIF project

IFMIF project is currently in the Engineering Validation and Engineering Design phase:

- ➢ An Intermediate Engineering Design of IFMIF plant has been accomplished

IFMIF Plant Engineering design



Introduction

IFMIF project

- Validation activities and prototypes for mitigation of risks associated to challenging technologies are on-going.

IFMIF Validation Activities. Prototypes:

- Accelerator prototype (LIPAc) scale 1:1 up to 9 MeV (Rokkasho), to be completed in June 2017.
- Li Test Loop (ELTL) integrating all elements of Li Target Facility (Oarai), commissioned in February 2011.
- High Flux Test Module with a prototype of the capsules housing the small specimens to be irradiated in the BR2 fission reactor of SCK/CEN Mol.

Availability in IFMIF

Availability in IFMIF

Why is availability so important in IFMIF?

As an irradiation facility, IFMIF is essentially a plant for the production of dpa (displacement per atom) in the corresponding materials at certain conditions. Therefore, availability metrics within IFMIF will be directly linked to the production of radiation damage.

A minimum level of such damage has to be accumulated in the materials timely for providing the data which are essential for the development of a demonstration fusion power reactor. Hence, achieving a minimum level of availability is key for IFMIF mission.

Design nominal damage rate: 20-30 dpa_{NRT}/full power year
Operational plant availability: 70% for that design damage rate. } → *IFMIF mission*

IFMIF plays an essential role in the fusion energy development roadmap

Availability plays an essential role in IFMIF mission

Availability in IFMIF

How do we define availability in IFMIF?

Availability should be directly linked to the production of damage in the test samples at certain conditions.

But this is a physical complex magnitude that will depend on many parameters.

To develop a high availability oriented design, first, we need to establish what we consider availability is and how we quantify it. We need to be able to assess the design from availability point of view.

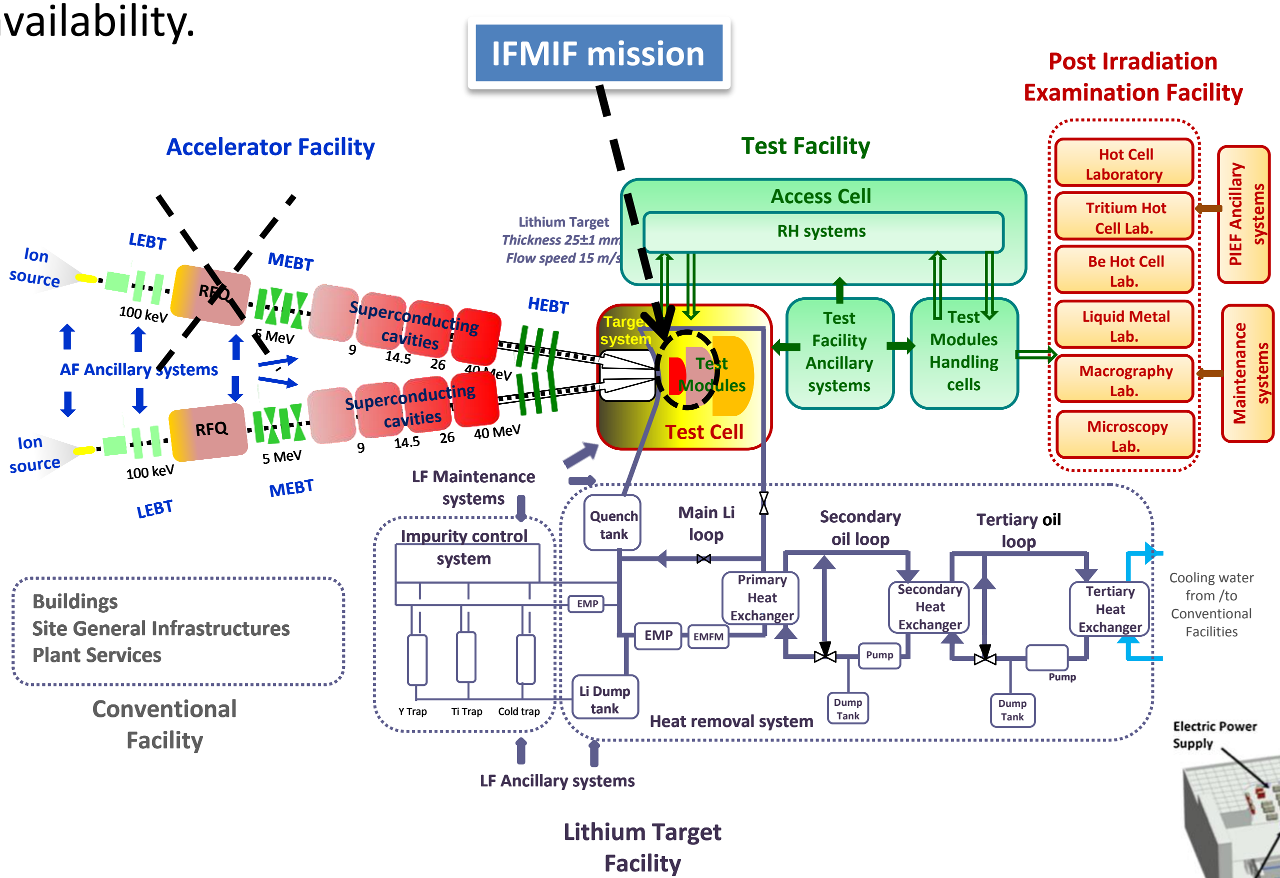
Before, we need to understand:

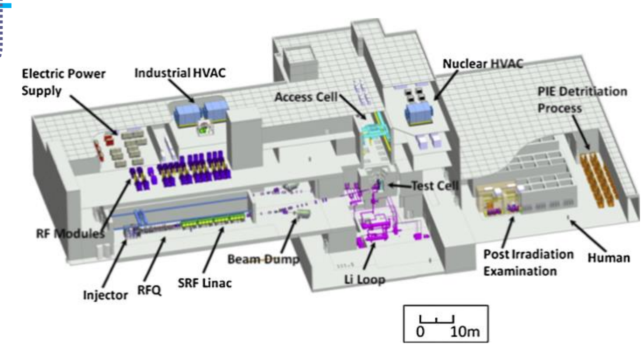
- IFMIF operation,
- all the systems that make possible to have the specified neutron source and the test modules under determined conditions,
- and the impact of failures or mal-functions of those system.

Availability in IFMIF

How do we define availability in IFMIF?

Understanding facilities and systems operation and their impact on damage production availability.





Availability in IFMIF

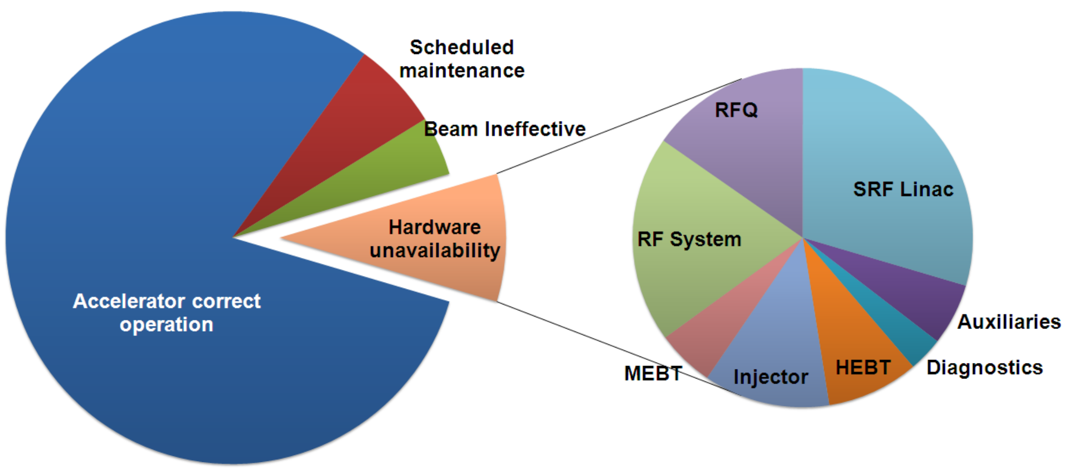
How do we define availability in IFMIF?. Accelerator Facility

Availability definitions for AF:

Hardware Availability (HA): fraction of time that the machine is available to produce beam over the scheduled operation time.

Beam Effectiveness (BE): is the effective fraction of beam time actually delivering to the target the specified parameters. Beam inefficiencies: beam trips and beam degradation.

Beam Availability (BA): BA = HA*BE



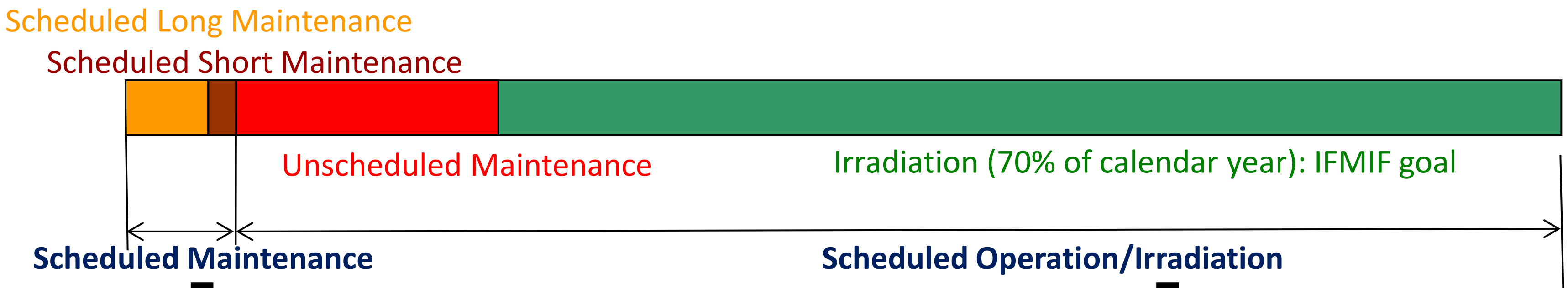
Availability in IFMIF

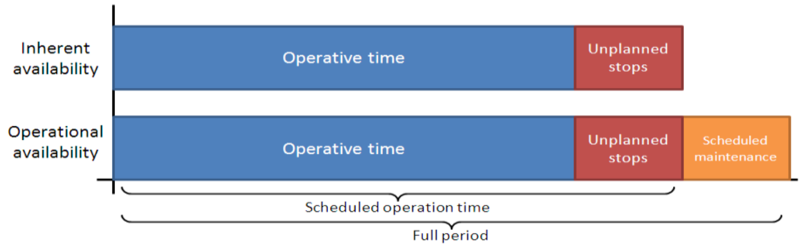
How do we define availability in IFMIF?. Accelerator Facility

Degraded operation is considered. Failure acceptance and beam degradation criteria were defined to be able to quantify it.

System	Component and kind of failure	Maximum intensity	Energy reduction	Beam shape degradation
SRF Linac	Cavity failure	Depending on the position	- E of the failed cavity	No
	Tuning system	Depending on the positions	- E of the failed cavity/2	No
	Solenoid	100 mA	- E of the switched off cavity	No
	Steerer	115 mA	No	No
MEBT	Quadrupole	87.5 mA	No	No
	Steerer	115 mA	No	No
HEBT	Quadrupole in a triplet	87.5 mA	No	Yes
	Steerers	115 mA	No	No
	Multipoles	125 mA	No	Yes

How do we define availability in IFMIF?. O&M.





Requirement: perform needed task in allocated times with reasonable resources:

Some studies/evaluations:

- Ex: logistic study RF system
- RAMI analysis of RH operations during long maintenance period

Inherent Availability requirements

IFMIF facilities.	Availability Requirement
Tests Facility	96 %
Target Facility	94 %
Accelerator Facility	**87 %**
Conventional Facilities	98 %
Central Control System and Common Instrumentation	98 %
TOTAL (product)	**75 %**

MTTF
MDT (MTTR)

Availability in IFMIF

How do we define availability in IFMIF?. Conclusions

In IFMIF, availability is directly linked to the production of damage into the samples, which is the main mission of IFMIF plant.

It is important to define how we quantify availability in order to be able to allocate the requirements among the systems and subsystems. For that, we need to understand the effect of every failure on the main function of the plant.

In that way, we can implement the RAMI process into a complex project, and orient the design towards availability, being availability a suitable measure of IFMIF mission accomplishment.

RAMI process and methodology

RAMI process and methodology

RAMI process

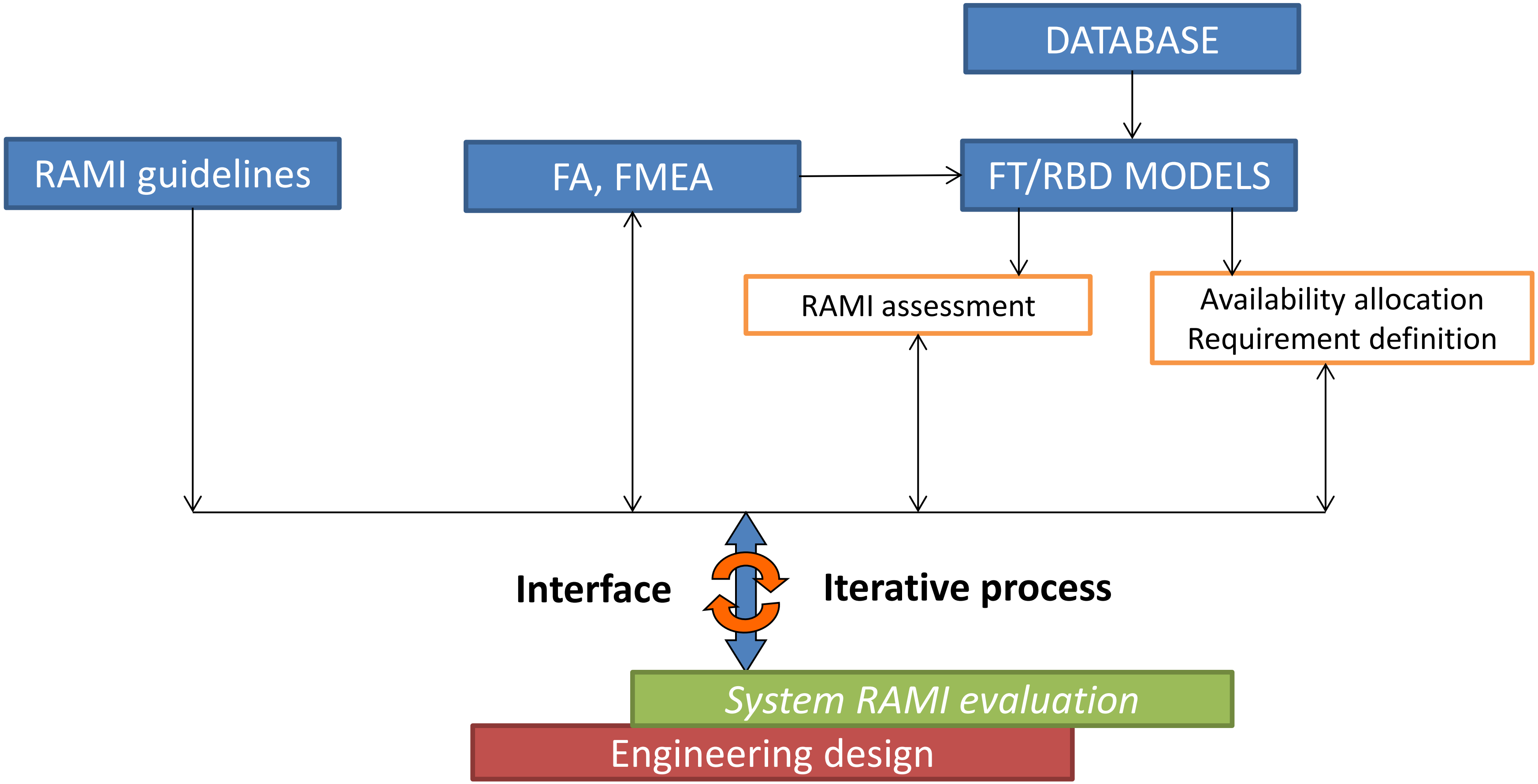
RAMI (Reliability, Availability, Maintainability, Inspectability) engineering process has been implemented through iterative analysis of the design at different stages including:

- Requirement analysis and allocation
- Reliability and availability assessments
- Design revisions and recommendations

RAMI methodology and tools

- RAMI guidelines
- Functional Analysis
- Failure Mode and Effect Analysis
- Reliability database
- Fault Tree and Reliability Block Diagram analysis (Risk Spectrum, Relisoft Blocksim)
- Availsim simulation
- Logistic and maintenance studies

RAMI process and methodology



Experience in the implementation

Experience in the implementation

Main outcomes

The main outcomes of RAMI analysis during Engineering Design have been:

- Allocation of RAMI requirements among the systems and components
- Assessment of the different systems from availability point of view
- Focus critical systems and components
- Development of strategies to increase reliability and reduce downtimes
- High reliability and availability design evolution
- Bringing up design alternatives that have been demonstrated as a way to reach IFMIF goal

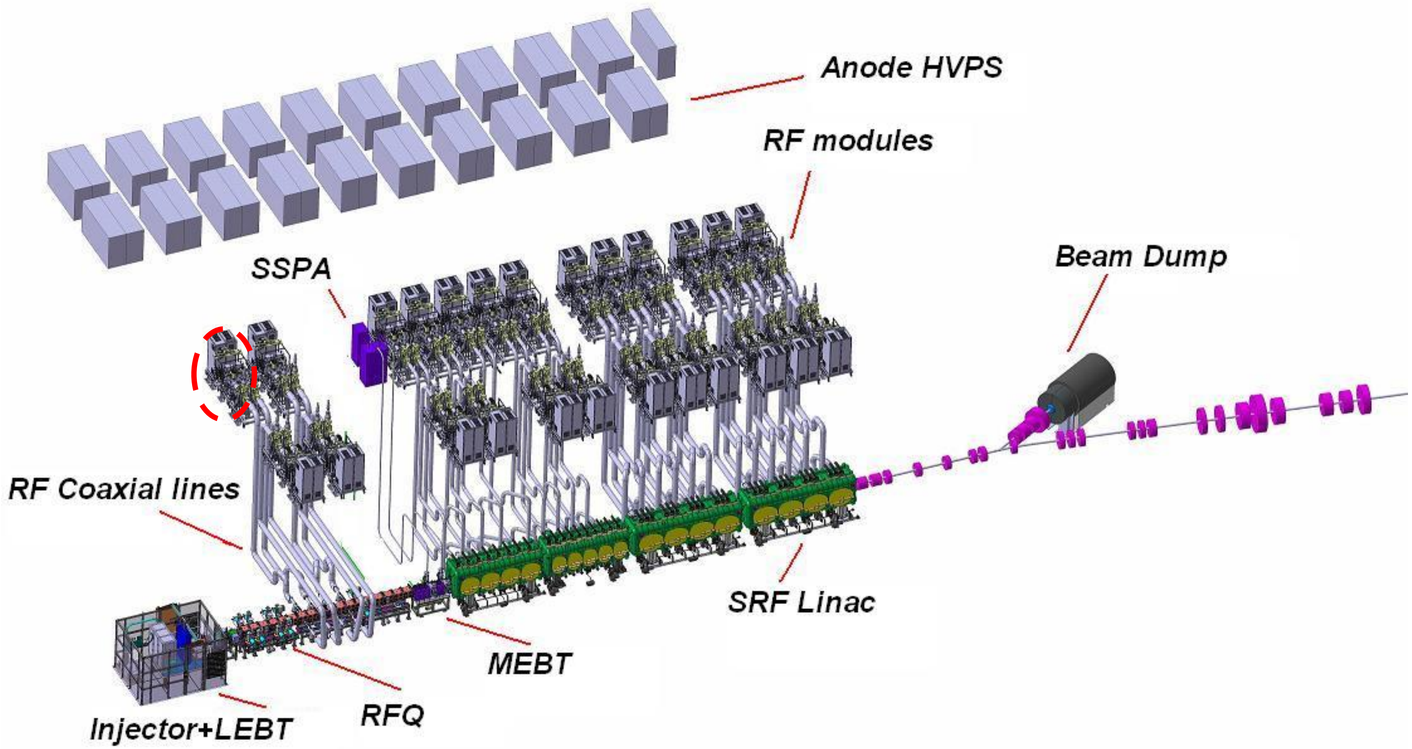
Experience in the implementation

Availability oriented design evolution. Example: RF system.

RF system is in charge of powering RFQ and SRF Linac structures, and it is based on high power RF amplifiers, and high voltage power supplies.

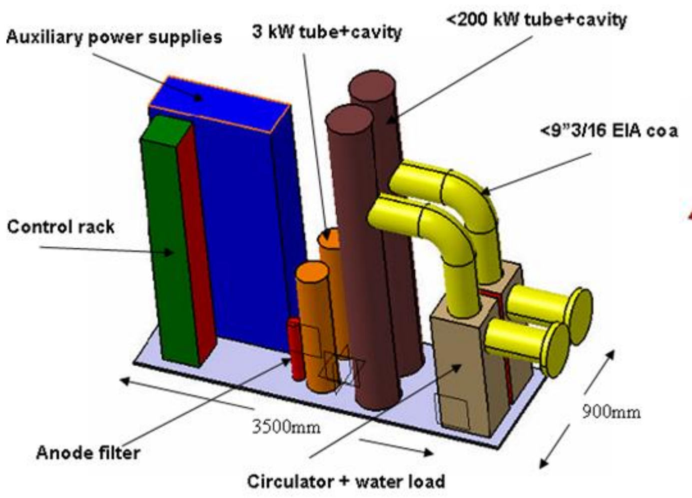
In "Classic" RF system with amplifiers and lines, due to the arrangement, to exchange or repair a failed part, frequently you need to remove not-failed parts.

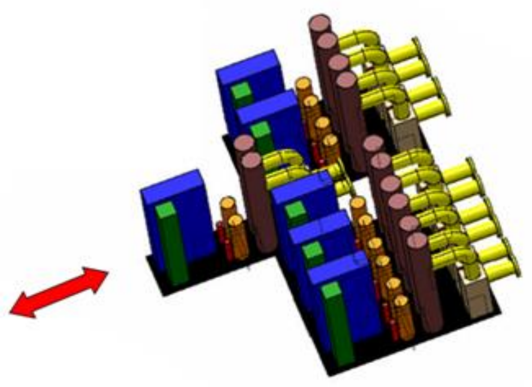
To avoid that, IFMIF RF system has been designed in exchangeable independent modules.



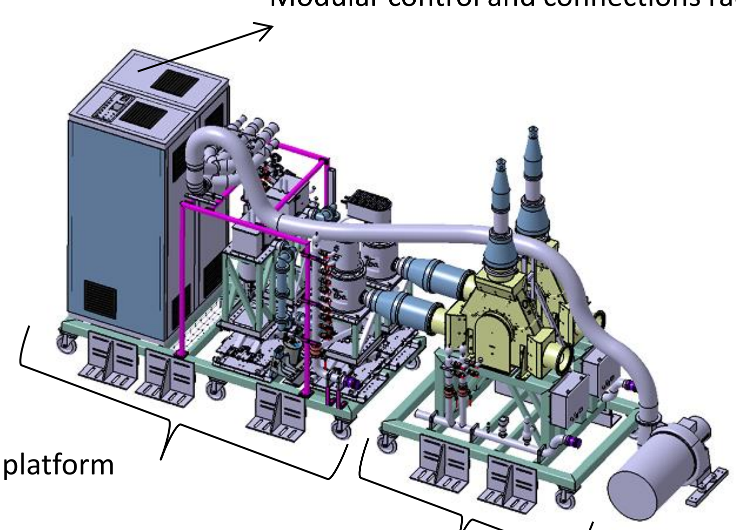
Availability oriented design evolution. Example: RF system

RF removable module





Concept



Detailed engineering design

Experience in the implementation

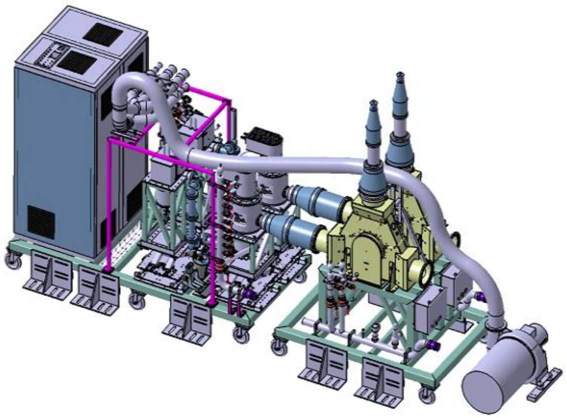
Availability oriented design evolution. Example: RF system

Experience in the implementation

Availability oriented design evolution. Example: RF system

Availability improvements:

- **Exchangeable module + diagnosis procedure**: allows to limit the MDT due to RF system failure to a maximum of 4 hours.
- **Modularity inside the module**: allows lower MDT for fast detected failures (MDT for failures without module extraction limited to 2 hours).
- **PSYS: Advanced tetrodes protection system**. "Intelligent", flexible, programmable system with FPGA that reduces the failure rate of tetrodes.
- **SMART SPARE**: allows a reduction of MDT.
- **Tetrodes management system**: allows the optimization of the resources and the schedule maintenance time.

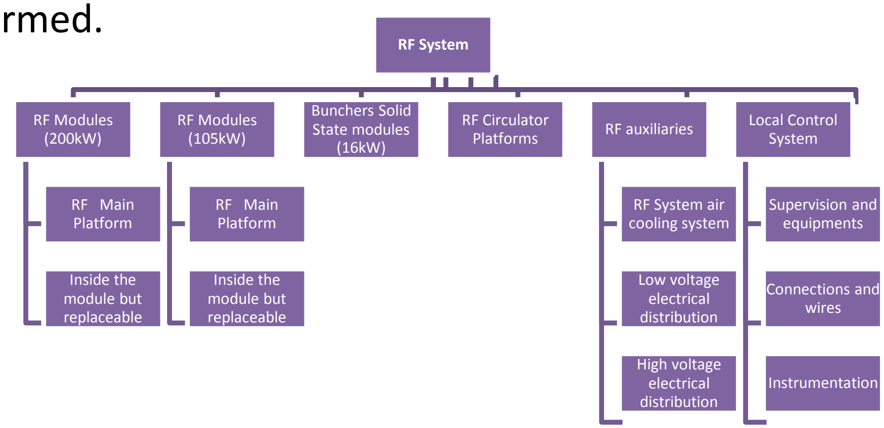


Experience in the implementation

Availability oriented design evolution. Example: RF system

A Reliability and availability analysis has been performed.

- Detailed model (7,772 basic events and 620 gates) to evaluate the availability of the whole RF system
- Simplified model to analyze the RF module design alternatives



Main results

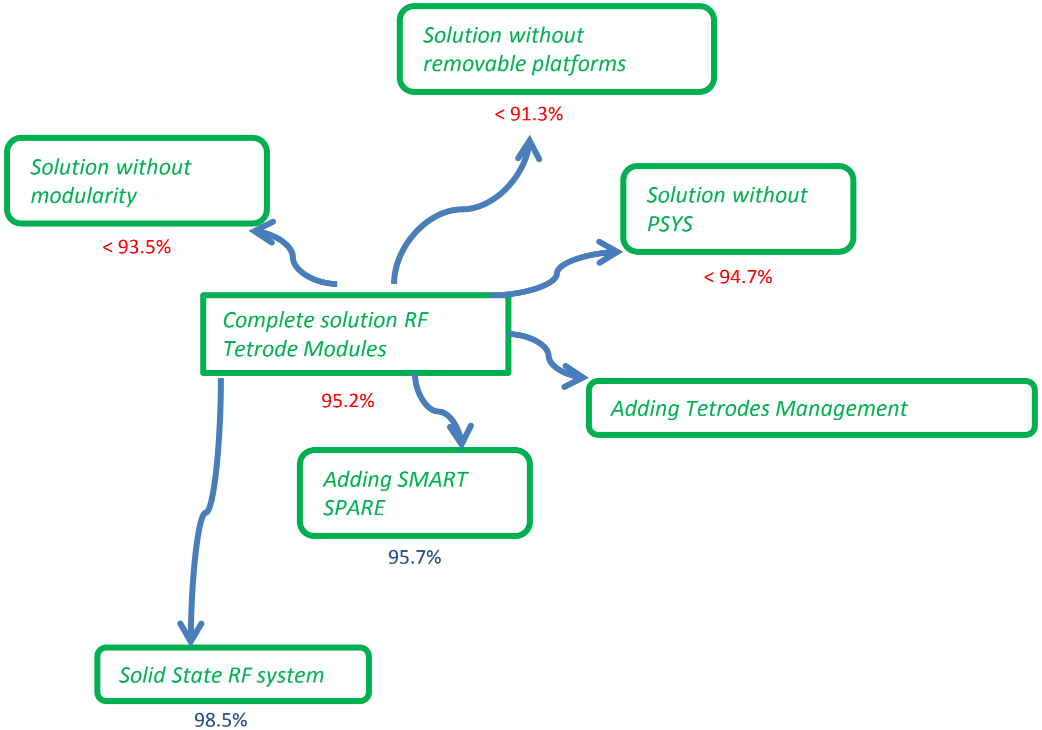
Failure	Failures per year	Mean time without beam
Failure in the main platform: extraction needed	59	4
Failure in the main platform but not extraction is needed	78	2
Failure in the circulator platform	3.4	5

Inherent Availability of about 94% for the whole RF system (main contributors to unavailability are tetrodes)

Experience in the implementation

Availability oriented design evolution. Example: RF system

Assessment of the availability improvement for each design characteristic



IFMIF RF system availability requirement (98.2%) is very demanding.
A Solid State (SS) alternative is being studied. The design is based on combining solid-state power amplifiers of about 1 KW to supply the desired power to each cavity.
Reliability and availability analysis has proven that the availability requirement can be reached with SS design implementing a redundancy of about 10% in the number of SS chains.

Experience in the implementation

Difficulties

At early stages, no detailed design information was available

→ Provide Design Guidelines
→ Implementing techniques like FMEA or FFMEA

Scarcity of available reliability data

→ Big effort to collect data: IFMIF Reliability Database integrated in Fusion Component Reliability Database

Uncertainties in MDT estimations, specially for cooling time, start-up time, etc

→ Assumptions and specific studies or analyses

Involve the "designers". Create consciousness of the importance of design for reliability and maintainability since the early stages

→ Quality System: requirement allocation, design revision, RAMI chapter included in System Design Documents…

Future challenges

Future challenges

- Finalizing Engineering Design to launch the construction of IFMIF.

- Implement a program to collect relevant data from the validation activities in order to reduce uncertainties about:
  - Knowledge failures (first part of the bath-tube curve)
  - Operation procedures and times
  - Maintenance procedures and times

  Accelerator prototype will be a perfect test bench for this

- Specific reliability test for critical components.

- Specific maintainability test for critical components.

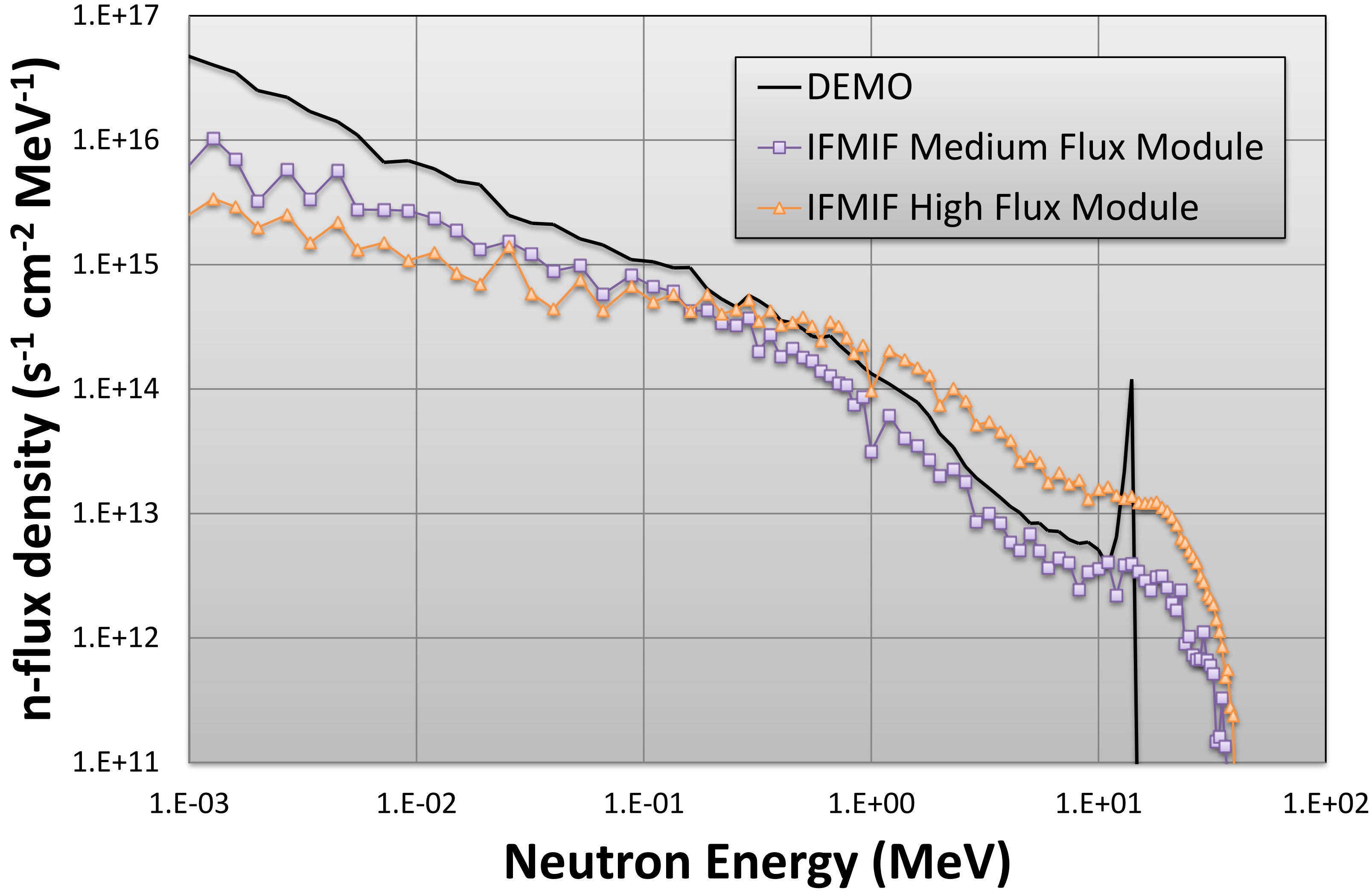
- Develop an overall logistic approach.

- Clarify specific reliability requirements.

- Adapt availability analysis to the irradiation program (optimization of irradiation program and availability) (future).

Thank you!

Extra slides


1.E+17
1.E+16
1.E+15
1.E+14
1.E+13
1.E+12
1.E+11
n-flux density (s-1 cm-2 MeV-1)
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Neutron Energy (MeV)
DEMO
IFMIF Medium Flux Module
IFMIF High Flux Module

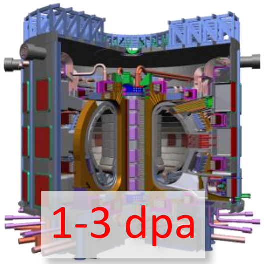
ITER

DEMO

IFMIF

Deuterium-Tritium

Test Blanket Modules



Design | Const. | Operation

~50 dpa

100-150 dpa

Const. | Operation | ...

~10 years

20-40 dpa/year

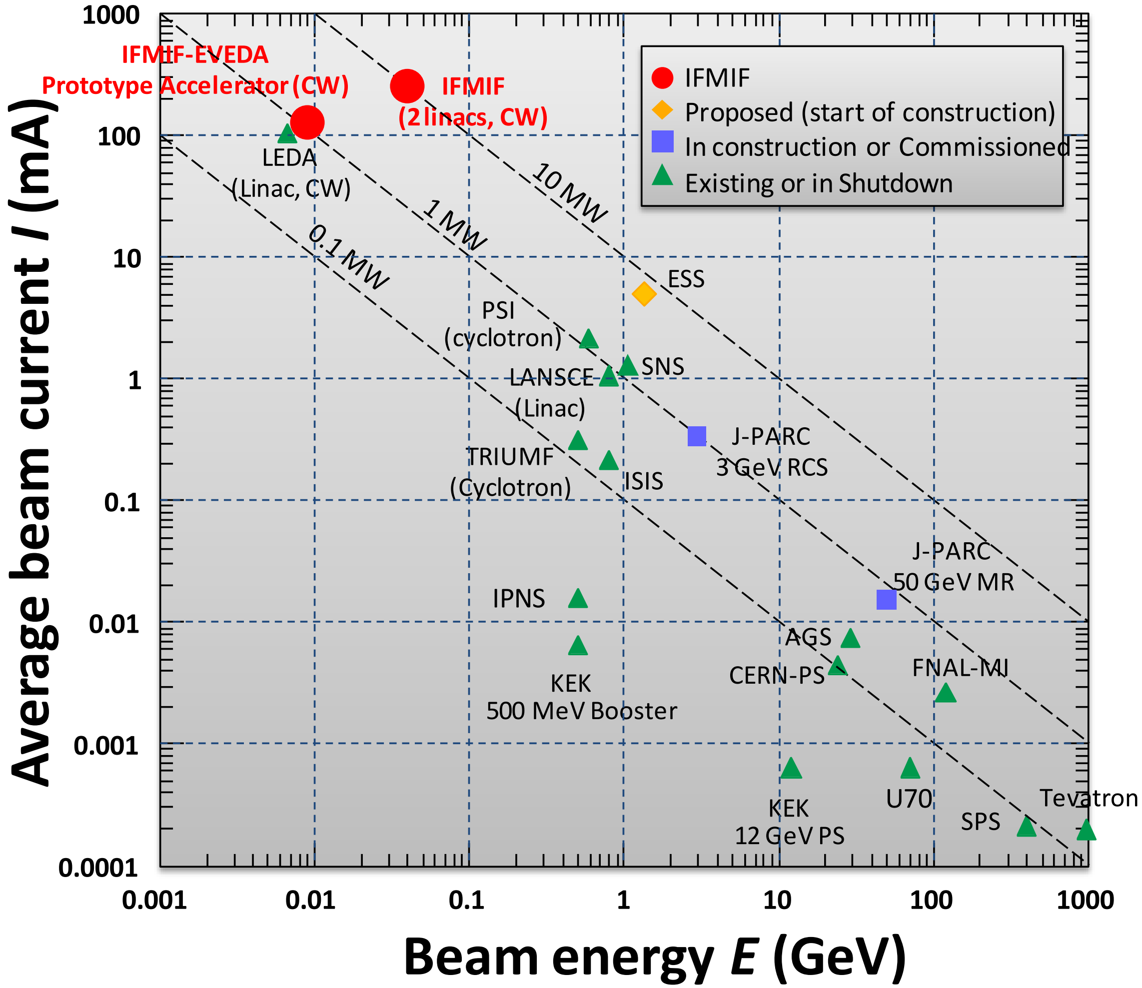
Fission Reactor and
Charged Particle Irradiation

Development of Blanket and Materials

RAF/M, Low Temperature Blanket

Advanced materials (V Alloys, SiC/SiC)
Advanced High Temperature Blankets
(Liquid LiPb, Li, Flibe, High T Gas)

Source: Y. le Tonqueze. *IFMIF EVEDA project*. RAMI workshop in LMJ’11


IFMIF-EVEDA
Prototype Accelerator (CW)
IFMIF
(2 linacs, CW)
IFMIF
Proposed (start of construction)
In construction or Commissioned
Existing or in Shutdown
10 MW
1 MW
0.1 MW
LEDA
(Linac, CW)
ESS
PSI
(cyclotron)
SNS
LANSCE
(Linac)
J-PARC
3 GeV RCS
TRIUMF
(Cyclotron)
ISIS
J-PARC
50 GeV MR
IPNS
AGS
CERN-PS
FNAL-MI
KEK
500 MeV Booster
KEK
12 GeV PS
U70
SPS
Tevatron
Average beam current I (mA)
Beam energy E (GeV)
1000
100
10
1
0.1
0.01
0.001
0.0001
0.001
0.01
0.1
1
10
100
1000