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Accelerator Reliability requirements for ADS: the MYRRHA project goals

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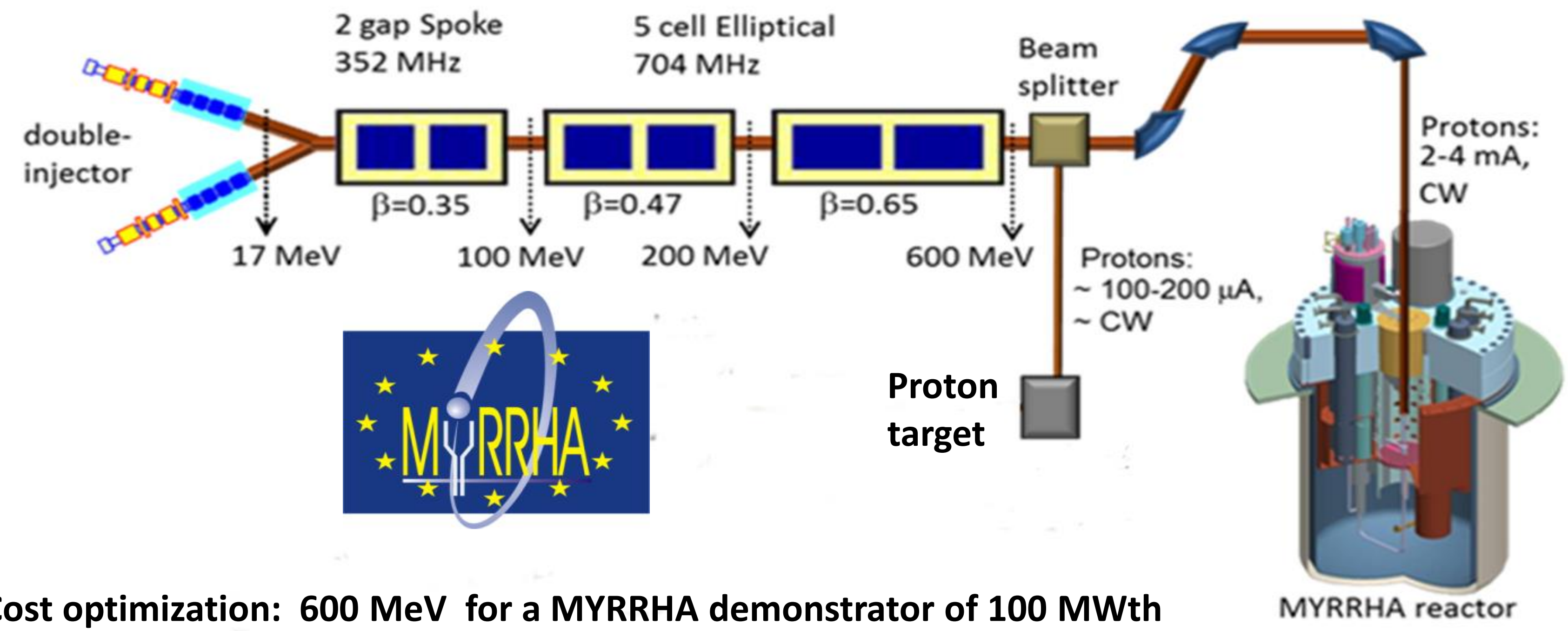
MYRRHA

The Reference Conceptual Design of the MYRRHA accelerator was progressively introduced and developed within several Euratom projects :

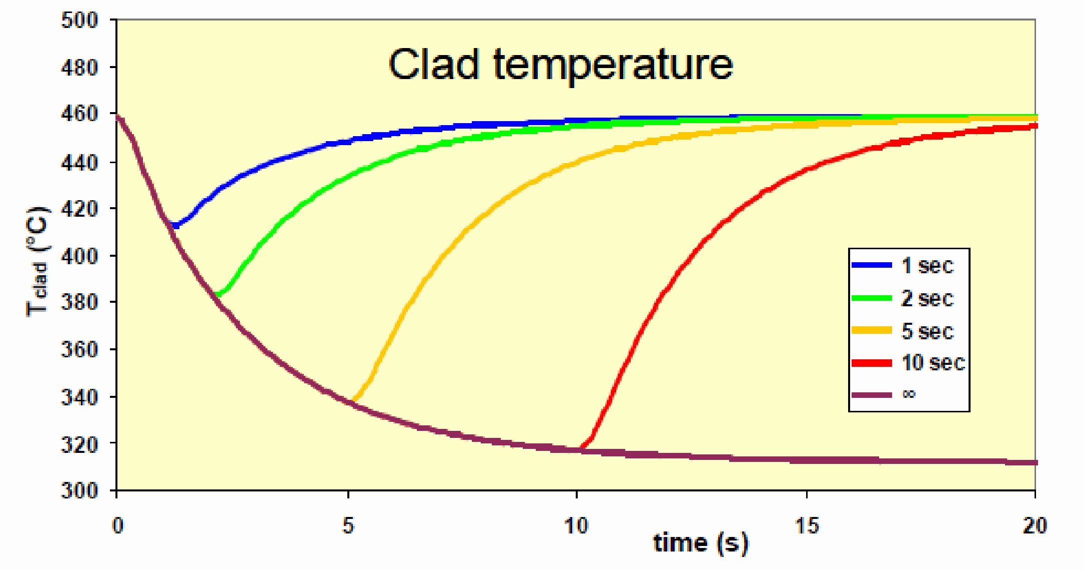
- **PDS-XADS (2002 – 2004)**
- **EUROTRANS (2005 – 2010)**
- **MAX (2011 – 2014)**



- **Cost optimization: 600 MeV for a MYRRHA demonstrator of 100 MWth**
- **Beam current to control the reactor is determined by the thermal power and the level of sub-criticality of the core. For MYRRHA (keff = 0.95) the nominal average current is 2.5 mA corresponding to a mean beam power of 1.5 MW**

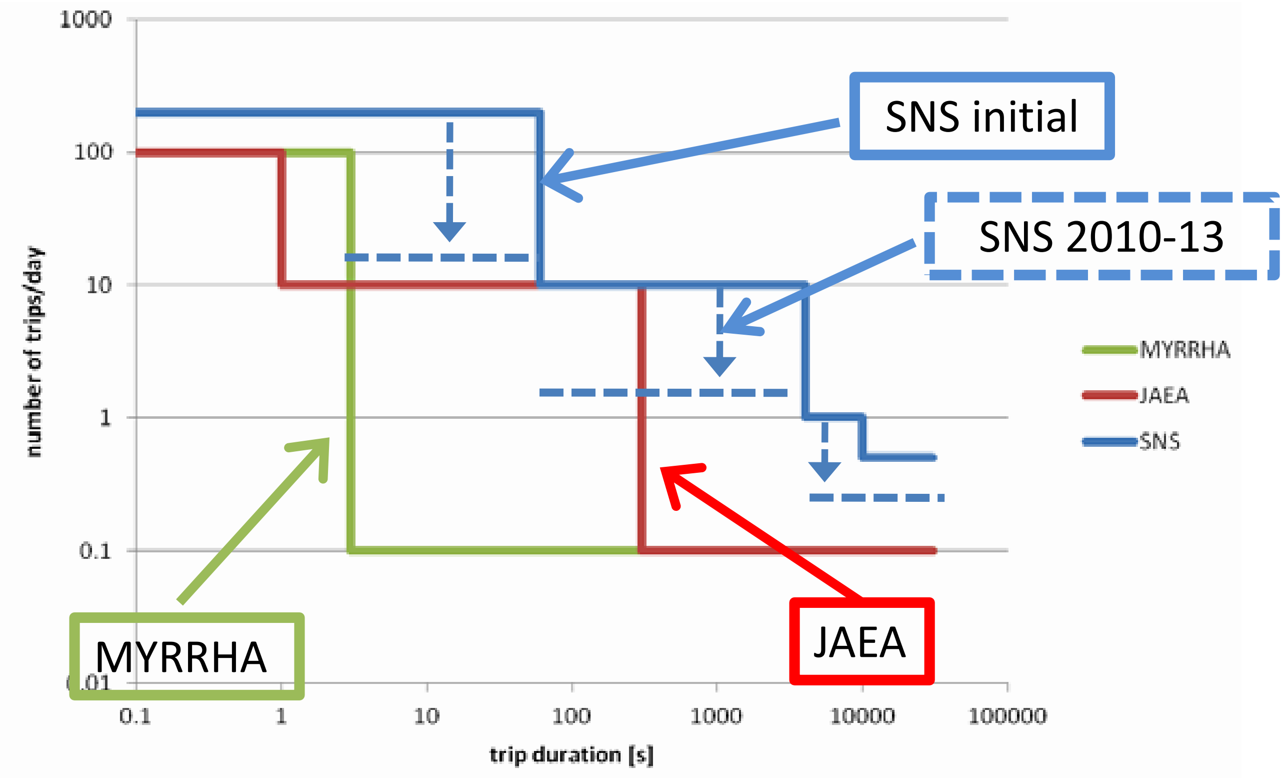
MYRRHA Accelerator Reliability requirements:

- **the number of beam interruptions should be limited to extremely low values** the limit was set to **10 beam interruptions per 3-month operating cycle, only interruptions of more than 3 seconds** being counted, leading to a global accelerator MTBF of about 250 hours.
- beam interruptions longer than a few seconds could lead, if repeated frequently, to unacceptably **high thermal stresses on the highly irradiated materials of the target window, the fuel claddings and more generally on all the reactor structures**
- **long beam interruptions will be associated with reactor shutdowns, affecting the availability of the system** (restart procedures could last between 20 and 40 hours)



According to recent findings the allowable number of beam trips will be dominated by the material characteristics of the oxide layer protecting the fuel clads under LBE

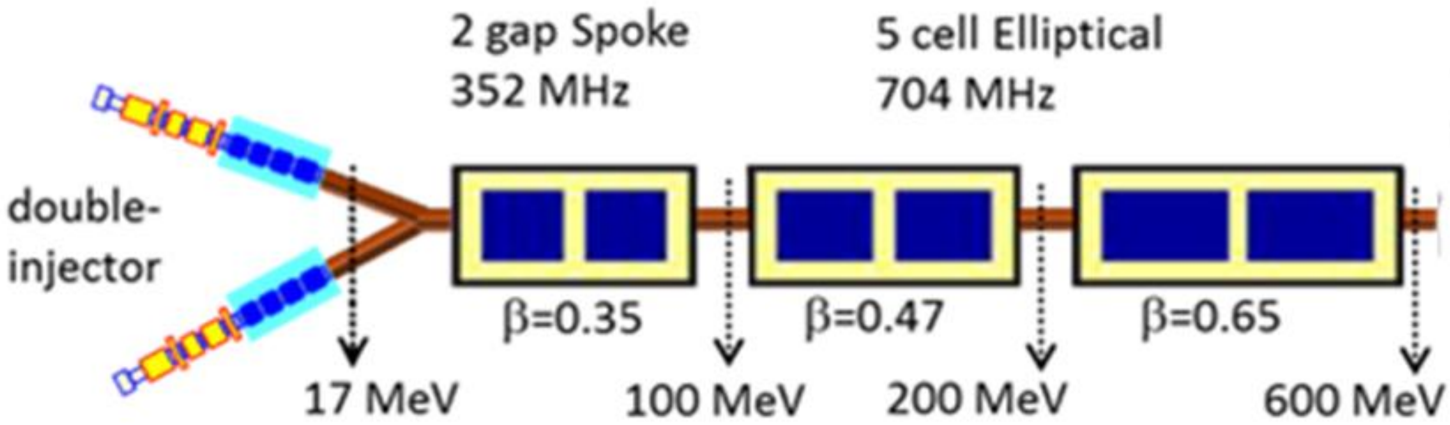
The reliability target for the MYRRHA ADS accelerator **will need to be significantly higher than the actual reliability recorded worldwide on comparable accelerators** in operation today, like the SNS which presently exhibits a MTBF of a few hours



⇨ **beam interruptions shorter than 3 seconds** can be theoretically unlimited. In practice, it is proposed to limit the number of interruptions of duration inside the range 0.1ms – 3s to less than 100 per day,

MYRRHA proposals:

To reach the reliability goal, the linac scheme will consist of 2 clearly distinct sections



1. **A low energy section** (injector or **linac front end**), where redundancy is applied in its parallel form, and so two similar compact injectors with fast switching capabilities are foreseen.
2. **A medium and high energy section** (main linac or independently-phased superconducting section), highly modular, based on individual, independently controlled accelerating cavities. **Fault tolerance** concepts (serial redundancy) can be applied to yield a strong tolerance to faults.

The Reliability Issue: developments within the Euratom projects

FP5: PDS-XADS activities

Initial reliability studies INFN 2003

- Qualitative **FMEA (**Failure mode and effects analysis)
- **RBD (**Reliability Block Diagram) **analysis**
- Assessment of (lack of) existing **MTBF database**
- Identification of **redundant and fault tolerant linac configurations**

FP6: EUROTRANS activities

Linac design and R&D: modular fault-tolerant concept (2010)
Reliability analysis , MonteCarlo approach with Matlab

FP7: MAX project

- **Global fault tolerant beam dynamics design (2013)**
- **Reliability model of an existing accelerator (SNS Linac) (2012)**
- **Reliability model of the Myrrha Linac (2014)**

Present activities

H2020: MYRTE **→ work initiated in 2015**

- **Reliability analysis of LINAC4 (CERN)**
  Commissioning results analysis
- ***R&D on components for reliability enhancement***

Recent Reliability studies for Myrrha

- Modelling of SNS reliability and comparison with operation results (MAX Nov. 2012)
- Reliability model for Myrrha: first estimations (MAX June 2014)

These works were developed within FP7 MAX and presently pursued in H2020-MYRTEprojects

The Work Packages were coordinated by Empresarios Agrupados (Spain), with the participation of SCK, IPNO, ACS, Thales and, more recently, with CERN

1. SNS reliability model
(developed within the MAX project by E.A. Nov. 2012)

Goal: develop an accurate reliability model of the MYRRHA accelerator using the methodology applied for nuclear power plants. A reliability model of an existing accelerator (SNS) has been developed.

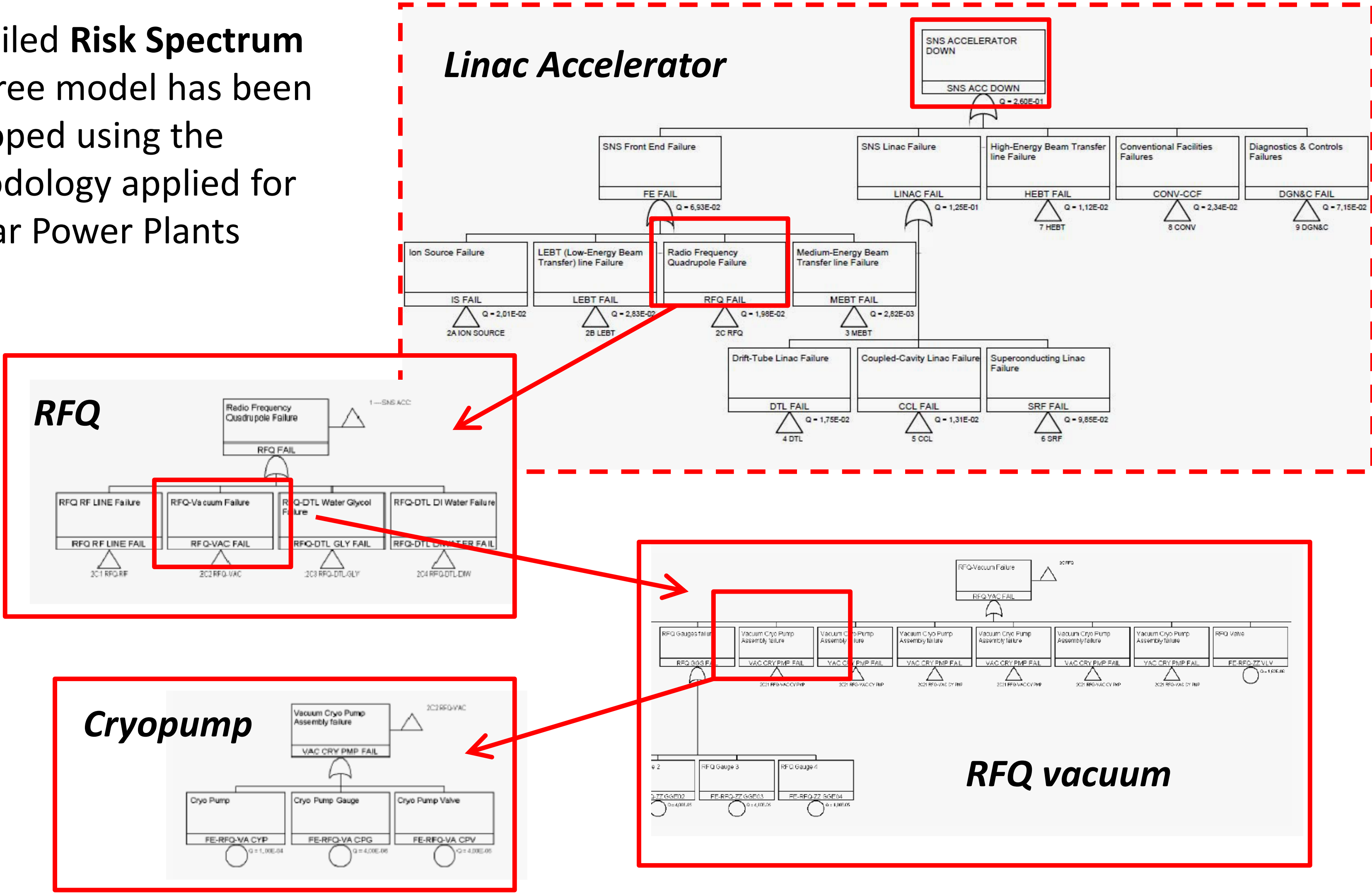
SNS Logbook operational data was recorded during the period October 2011 – June 2012, and is available on the SNS website

The **detailed reliability model of the SNS has been developed using Risk Spectrum,** based on the fault tree built in consideration of the above-mentioned input data

Theoretical results from the model and the operational data records (real operation data) were then compared, and it was concluded that the RS model can be considered a trustworthy tool to further build the model for evaluation of the Myrrha linac reliability

SNS fault tree

A detailed **Risk Spectrum** fault tree model has been developed using the methodology applied for Nuclear Power Plants



Component failures : basic events were modeled using the RS Repairable Model – RS model Type1

<u>Inputs</u> : Parameters necessary to quantify the repairable model

- *Failure rate, $\lambda=1/MTBF$*
- *Mean time to repair, MTTR*

<u>Results</u>

- *failure probability Q(t)*
- ***m**ean Unavailability (Qmean)*

SNS Linac analysis results

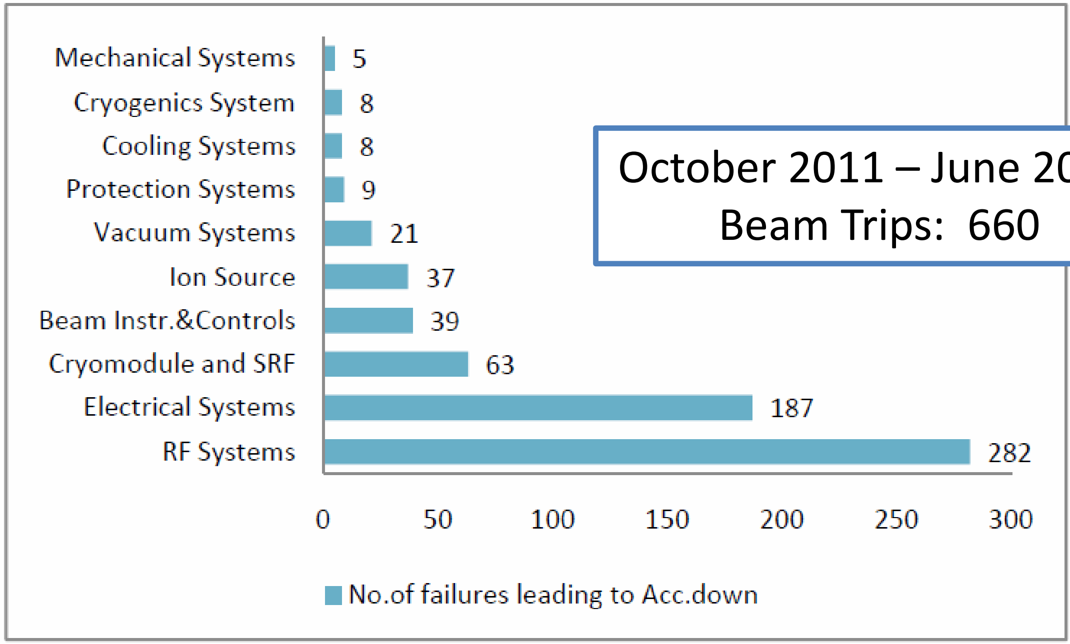
Global Mean Availability **A = 1 - Q = 73 %**
with details for all system s and components

The Linac components (DTL-CCL-SCL) represents the system most affected by failures, in terms of unavailability (Q=1.25E-01; A=87.5%)

The highest values of Unavailability have been found (in this order) for:

- SCL (Q=9.85E-02; A=90%)
- DGN&C (Q=7.15E-02; A=93%)
- Front-End (Q=6.93E-02; A=93%)

SNS LogBook



October 2011 – June 2012, Beam Trips: 660

Model: 73 % in agreement with results from 2008

Year	Availability Commitment	Availability Actual
FY2007	68.0%	65.7%
FY2008	74.0%	72.0%
FY2009	80.0%	80.7%
FY2010	85.0%	85.6%
FY2011	88.0%	91%YTD
FY2012	90.0%	TBD

Better results in last years

- MTTF and MTTR values used for model quantification may be too conservative
- improved operational reliability and improvements of the maintenance program

2. MYRRHA model (July 2014)

Based on the development of the SNS reliability model , a preliminary reliability model of the MYRRHA linac was developed

The MYRRHA reliability constraint (no more than 10 beam trips longer than 3 seconds per 3-month operation cycle), may be reformulated as following: the Mean Time Between Failures (MTBF) of the beam delivery must be > 250 h, a failure being defined as a beam trip > 3 s.

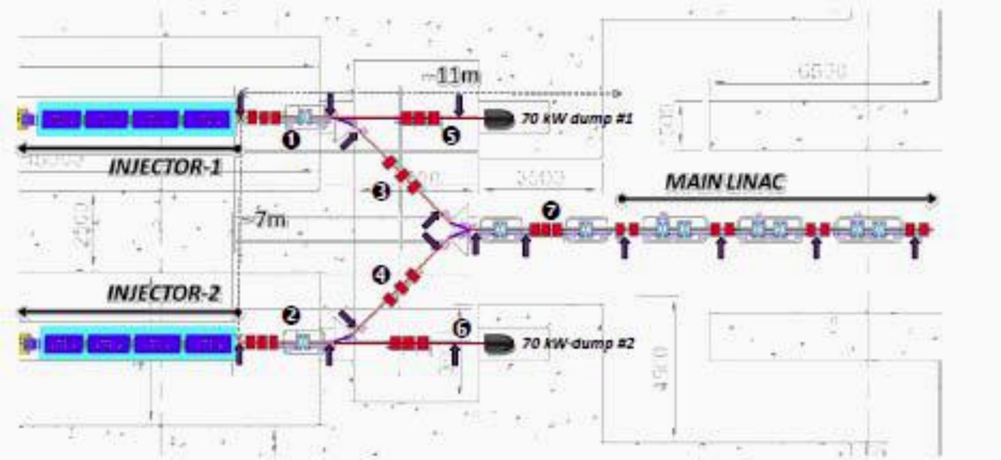
. For the MYRRHA accelerator, the following 3 principles have been adopted regarding the reliability goal:

- **Use of components far from their limits (margins)**
- **Fault-tolerance (serial redundancy)**
- **Redundancy/ Repairability**

Input Data: The Myrrha linac Risk Spectrum model has been developed from studies in precedent Myrrha programs activity
Quantified in most part using the reliability data from SNS in terms of failure data (MTTF) and repair time data (MTTR), when high grade of similitude between SNS and Myrrha linac components and systems was observed.

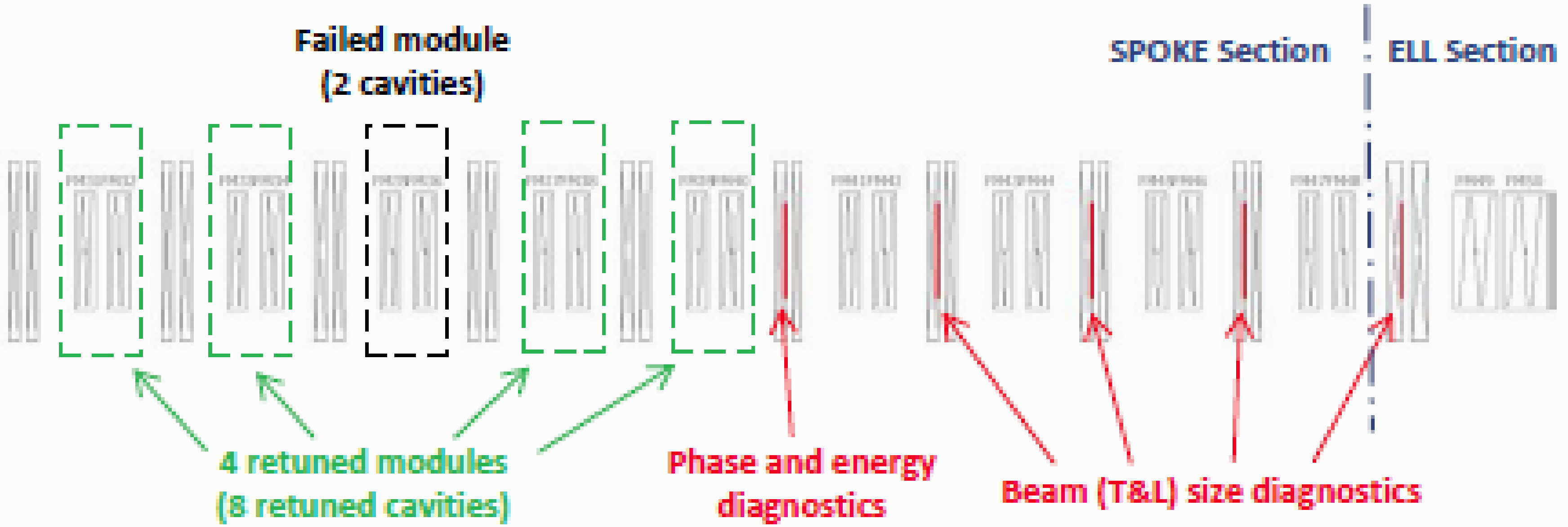
Two major design improvements for the MYRRHA Linac

1. Parallel beam redundancy at the injector In order to increase the reliability in the low energy section of the MYRRHA accelerator, the philosophy followed consists in doubling the whole 17 MeV linac, providing a hot stand-by spare injector able to quickly resume beam operation in case of any failure in the main one.



The fault-recovery procedure is based on the use of a switching dipole magnet with laminated steel yoke connecting the two injectors through a 'double-branch' Medium Energy Beam Transport line.The reference scenario of injector reconfiguration, which should take not more than 3 seconds was defined

2. SC Linac Serial Redundancy: a missing element's functionality can be replaced by retuning other elements with nearly identical functionalities.



The fault tolerance can be effective if accompanied by a realistic switching time and an MTTR much shorter than the MTBF of the failing element. A switching time of three (3) s, which is the sum of the fault detection time and the reconfiguration time, could be a realistic goal in view of the performances of present day digital electronics.

Such a fault-tolerance scheme applied to RF systems or focusing element failures was already experimentally confirmed in the SNS linac.

Modelling Data

Table 4.2 - INJECTOR (ECR source + LEBT) modeling data

Model code	Part/System	No.	MTBF	MTTR	Manufacturer/ Ref. Design	Model/ Type	Details; Obs.
ECR IS (YYY-UUUvv)	**ECR**	1/line	**1000**	**10**	Pantechnik (Bayeux, France)	Monogan M-1000	Overall: MTBF 1000h, MTTR 10h **Assumed values**
ECR-PLH	Plasma chamber	1	**1000**	**10**		-	**Assumed values**
ECR-PLE	Plasma Electrode	1	50000	8	SNS (IS plasma electrode)	SNS	
ECR-PMG	Permanent magnets	2	100000	8	SNS Ion Source	SNS	ECR magnetic system
ECR-HVI	HV insulators	2	50000	8	SNS Ion Source	SNS	
ECR-PSP	Power supply	1	50000	1	SNS (65 kV supply)	SNS	30 kV
ECR-AMP	RF Amplifier	1	50000	8	SNS (13 MHz amp.)	SNS	2.45GHz, 1.2kW (SSA)
ECR-CIR	RF circulator	1	50000	10	SNS (DTL, CCL, SCL circulator)	SNS	

Reliability data inputs for 155 types of components/systems

Number of components considered in the reliability model simulations (examples):

- 150 accelerating cavities (RT and SC)
- 60 cryostats
- 150 RF amplifiers,
- 148 Q-poles with 148 power supplies

MYRRHA Linac reliability model results

Events: combination of events which causes the top event to occur.

⇨ Initial MYRRHA Linac Model running has been performed **without considering redundancy of the front end or any failure compensation in the superconducting part.**

Mean availability A = 70% (the limit availability), which is slightly worse than in the SNS case (A = 73%), due to the increased number of cavities in the SCL part with correspondingly increased capacity and number of components of the auxiliary support systems

The initial frequency result was 550 trips/year (137 trips/3months)

Introduction of redundancy (injector and cavities fault tolerance)
Strongly reduces the beam trips number: 100 trips /year

Further optimizations on other components, and **identifying all failures that could be considered compensable by parallel redundancy**, lead to :
A = 97.7% and the frequency result was 38 trips/year (~ 10 trips/3 months)

Present activities

MYRTE program: Reliability related Work Packages

R&D activities are strongly focused on the injector reliability:

- Ion Source - LEBT (existing) & RFQ (in construction) & developments on operation control systems (Platform for low energy proton beam dynamics)
- Dedicated to reliability studies (collecting failure datas, long run tests …)

Improvements of the Fault compensation procedure:

- Improvements on cavity set points , possibility to use more cavities to compensate one failure

- **RF systems: solid state amplifier and digital low-level RF control system**

- **Reliability modelling : Beam commissioning Tests with the Linac 4 at CERN**

- **Smart and Reliable Control**

Recent decisions

→ **November 2015 : SCK proposal for a phased approach**

1. 100 MeV linac / prep. 600 MeV / reactor R&D **2024**
2. 600 MeV **2030**
3. ADS **(2032)**

→ **100 MeV + useful proton target(s)**

goal: relevant fault tolerance check
layout: modified MAX, 1 injector + single spoke
applications: 1 HP target + 1 ISOL target

1st milestone: September 2017
Technical Design Report
Decision to launch construction

milestone	date
ground breaking	2018
very first beam	2021
hold point	2024
nominal beam	2025