Availability studies for MYRRHA

- RAMI studies overview -
(CERN, 07 July 2016)

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Introduction

- **MYRRHA** - long term supporting research facility for Accelerator Dri Spallation system (ADS).
- **MAX** - (MYRRHA Accelerator eXperiment research and development programme)

EUROPEAN COMMISSION
Community research

MAX
(Contract Number 269565)

DELIVERABLE Number 4.2

Reliability model of an existing accelerator (SNS Linac)

EUROPEAN COMMISSION
Community research

MAX
(Contract Number 269565)

DELIVERABLE Number 4.4

Reliability model of the MYRRHA Linac

- **MYRTE** - research activities to demonstrate the feasibility of transmutation of high-level nuclear waste at industrial scale (MYRRHA research facility)
- MYRTE **WP2** – continues MAX activities aimed to demonstrate high reliability of the Myrrha Linac is achievable

1. SNS & Myrrha linac – Risk Spectrum Reliability models (MAX project)

2. Linac 4 & Myrte (linac for Myrrha) – Reliability Modelling

SNS Linac Modeling (MAX Task 4.2)

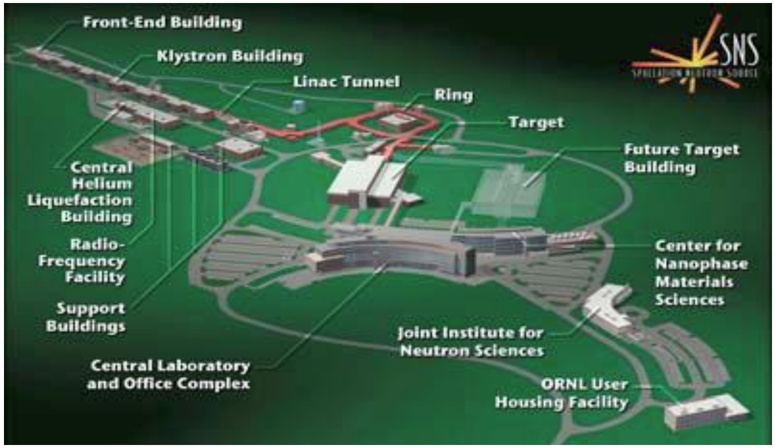
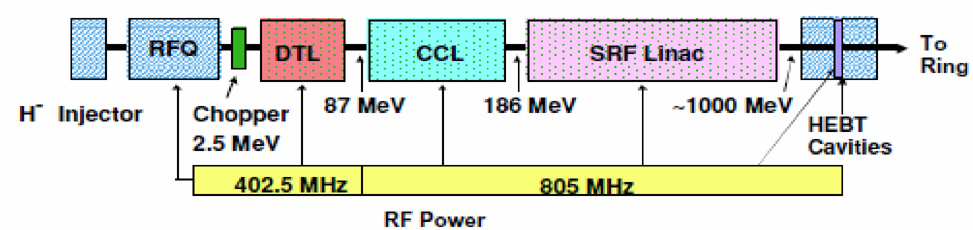


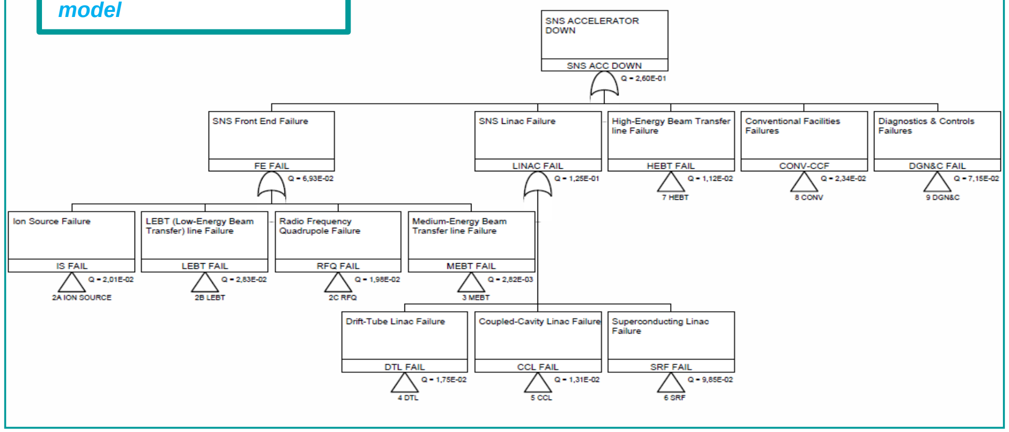
Figure 2-2. a) The 1,000-foot SNS linear accelerator is made up of three different types of accelerators. It is the first of its kind used to generate a pulsed energy beam.
b) The SNS ring intensifies the high-speed ion beam and shoots it at the mercury target 60 times a second (60 Hz).

- **<u>MAX Task 4.2</u>** - **<u>SNS (ORNL)</u> Linac - Reliability modeling** (methodology currently applied for NPPs –with **Risk Spectrum (RS-PSA)**)
  - **<u>SNS Linac reliability analysis</u>**
    - **feedback on SNS Linac reliability performance**
    - **modeling tool for Task 4.4**
  - **<u>Draft preliminary conclusions and recommendations:</u>**
    - **Maximize the reliability/availability/safety** of MYRRHA Acc.
    - **Guidance for designing the MYRRHA Accelerator.**



SNS Linac Modeling – Results & evaluation vs. SNS Logbook data (Accelerator trip failures)

SNS Linac Risk Spectrum model



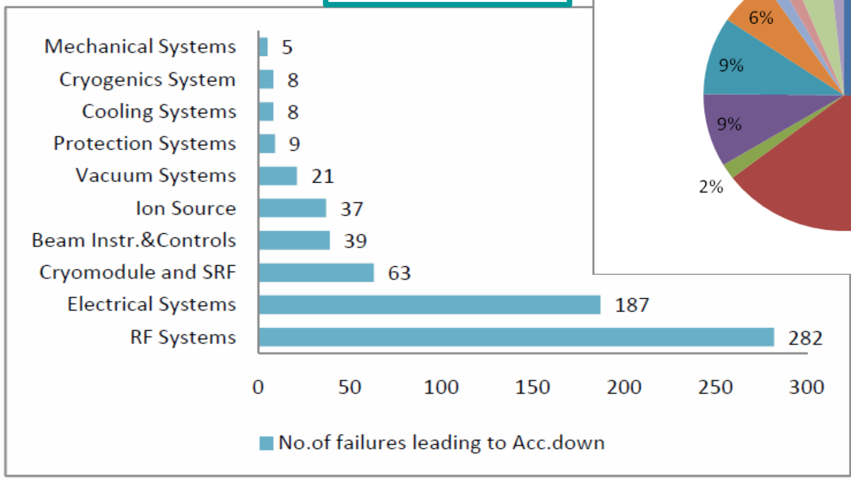
SNS Reliability Analysis results:

- **Most affected SNS Linac parts/systems** :
  - **SCL systems**
  - **Front-End** systems **(IS, LEBT, MEBT)**
  - **Diagnostics & Controls**

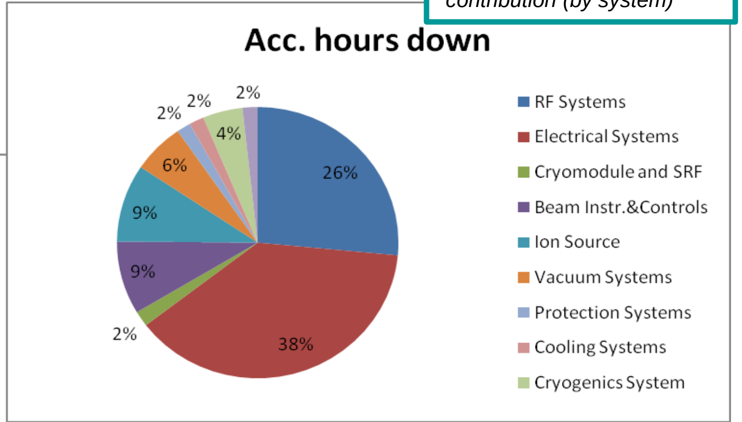
  - **SCL RF system**
  - **SCL Power Supplies and PS Controllers**

- **SNS RS Model results - in line with the SNS Logbook data statistics:**
  - **RF system and electrical system failures - most frequent**
  - **Electrical systems failures - most contributing to accelerator downtime**

*Accelerator trip failures **frequency** (by system)*



*Accelerator **downtime** contribution (by system)*



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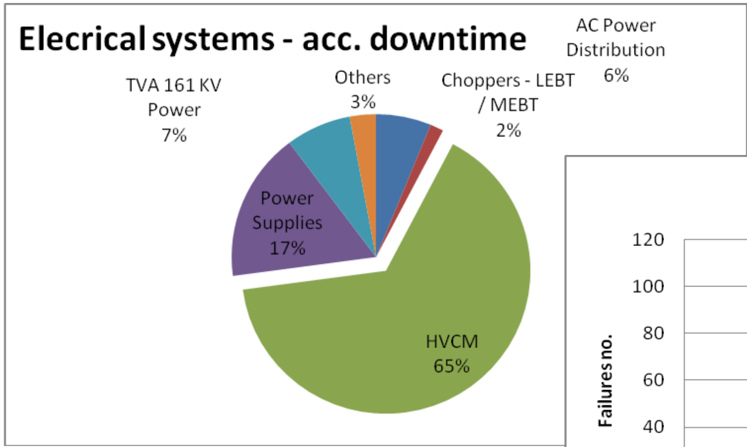
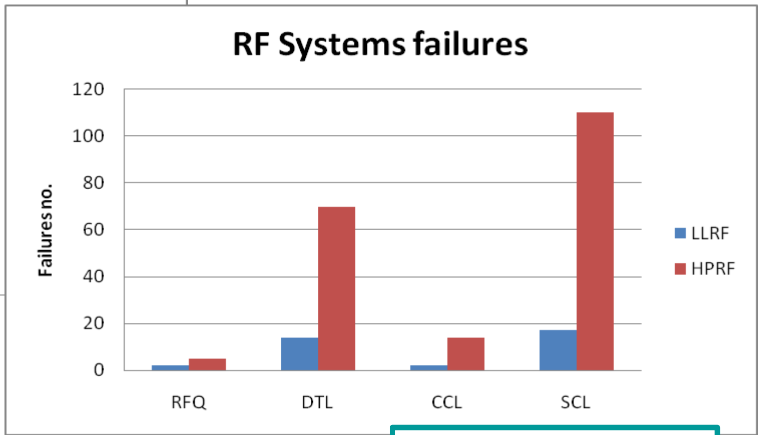
SNS Linac Modeling – Results vs. SNS Logbook data





RF System failures (no. & duration-hours)

Status

Overview Beam Target Logbook Shift Experiments Availability

Availability For The Past Week

Date	Production Beam Requested	Production Beam Delivered	Accel Physics Requested	Accel Physics Delivered	Startup Requested	Startup Delivered	Planned Shutdown Requested	Planned Shutdown Delivered	Availability Percentage
2012-03-13	8.5 h	8.5 h	-	-	7.5 h	7.5 h	8.0 h	8.0 h	100.0%
2012-03-12	-	-	24.0 h	23.4 h	-	-	-	-	97.5%
2012-03-11	2.0 h	2.0 h	22.0 h	22.0 h	-	-	-	-	100.0%
2012-03-10	24.0 h	20.7 h	-	-	-	-	-	-	86.25%
2012-03-09	24.0 h	18.1 h	-	-	-	-	-	-	75.42%
2012-03-08	24.0 h	23.6 h	-	-	-	-	-	-	98.33%
2012-03-07	24.0 h	23.5 h	-	-	-	-	-	-	97.92%
2012-03-06	16.0 h	15.1 h	7.5 h	7.5 h	-	-	0.5 h	0.5 h	96.17%

The current run started on 2012-03-13. Availability has been 100.0% over the past day.

Most Recent Downtime: 2 Days Ago (Monday, March 12, 2012)

Category	SubCategory	Hours Down	Notes	Date (Shift)
RF Systems	HPRF	0.3	SCL xmtr 7 trips x3 on cathode 4 overcurrent	2012-03-12 (D)
RF Systems	HPRF	0.3	SCL xmtr 9 Cathode 1 & 3 overcurrent trips	2012-03-12 (D)

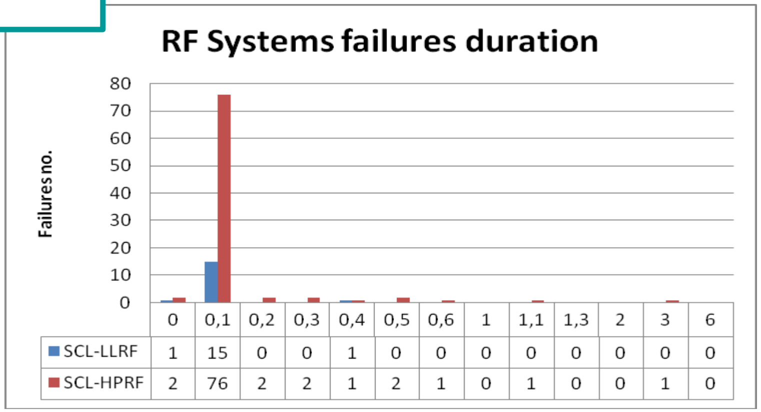
Downtime For The Past Week Including Last Wednesday

Category	SubCategory	Hours Down	Notes
Accelerator Physics	Beam Loss	0.1	Injection dump power limit trip & 5 SCL errant beam trips
Accelerator Physics	Beam Loss	0.1	SCL Cavity 02B trip on Cavity Field.
Controls	Accelerator	2.4	HEBT MPS IOC crate fan failure & crate replacement
Electrical Systems	Power Supplies	0.2	EKick 11 showing no current; resets failed. Swapped to EKick 6.
Electrical Systems	Power Supplies	0.2	DTL Mag OS DCV239 PSI Swap

- ❑ **In accordance with the SNS Logbook, SCL RS analysis →**

  SNS Linac most affected subsystems (failures leading to accelerator trips):

  - ➢ **SCL-HPRF** - short failures frequency
  - ➢ **HVCM** - duration of trips (High Voltage Converter Modulator)



	0	0,1	0,2	0,3	0,4	0,5	0,6	1	1,1	1,3	2	3	6
SCL-LLRF	1	15	0	0	1	0	0	0	0	0	0	0	0
SCL-HPRF	2	76	2	2	1	2	1	0	1	0	0	1	0

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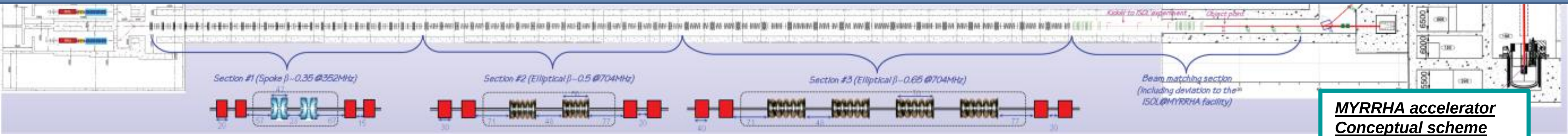


MYRRHA accelerator Conceptual scheme

SNS Linac Modeling (MAX Task 4.4

Myrrha Linac design:

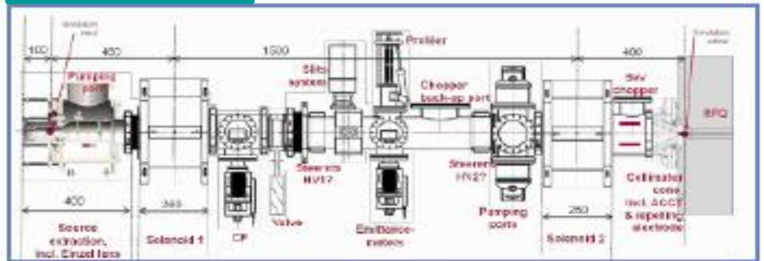
Low energy section – Injector/Linac front end: Multicell cavities – Modularity & fault tolerance not applicable

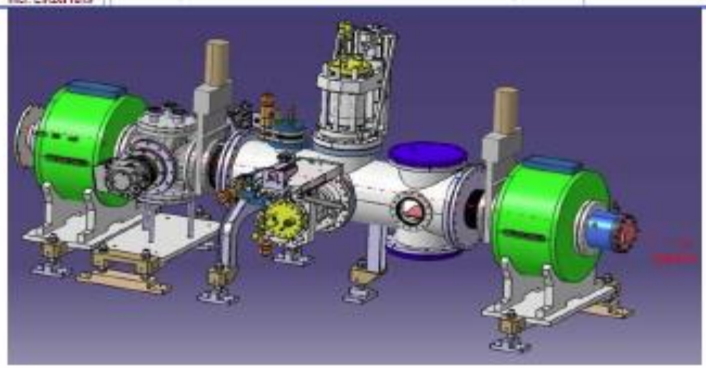
→ **Parallel Redundancy** - 2 Injectors with fast switching

Medium and High energy section – Independently-phased superconducting section - Highly modular (individual, independently controlled accelerating cavities).

→ **Serial redundancy** - strong tolerance to faults.

LEBT Conceptual scheme



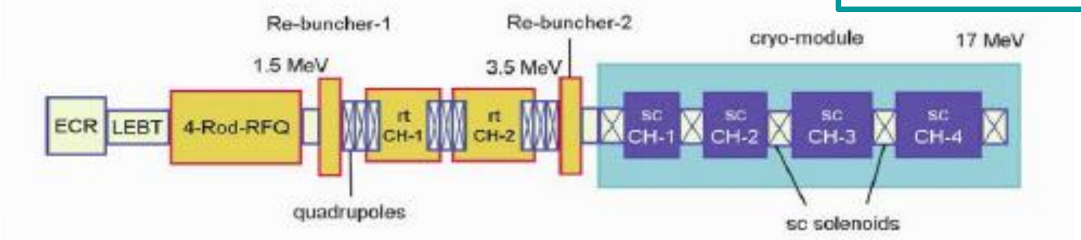


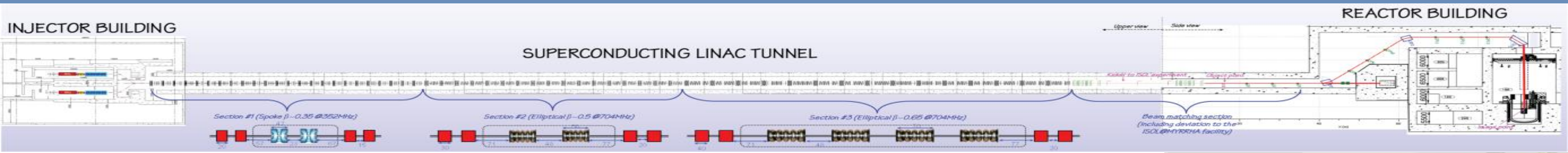
MYRRHA reference injector:

ECR proton source, LEBT, RFQ, CH-Booster , MEBT

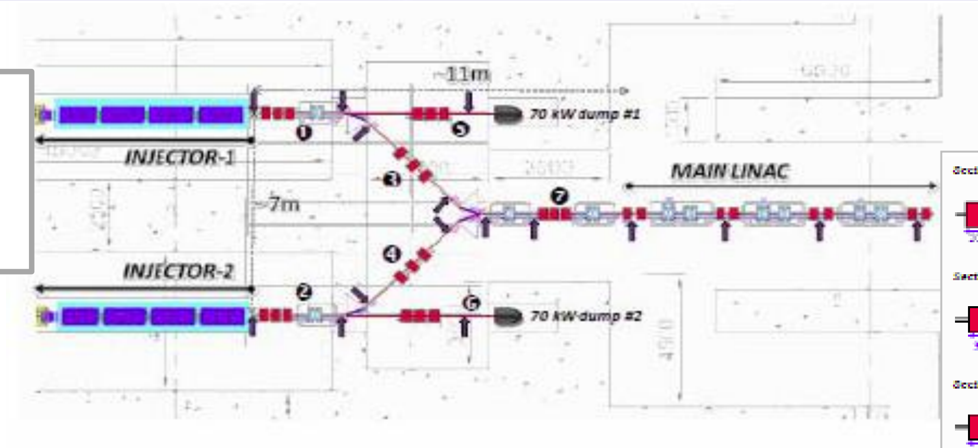
Reference injector; CH-DTL cavity with two triplets

MYRRHA 17 MeV Injector - reference layout

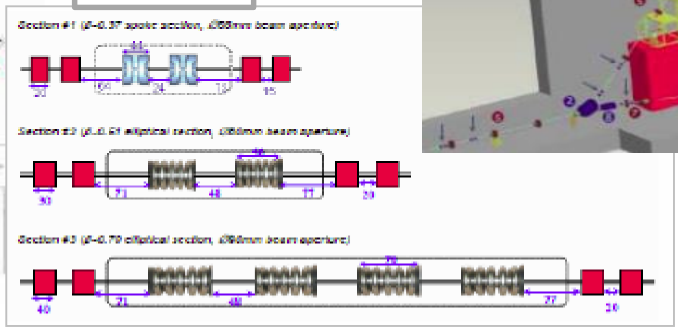




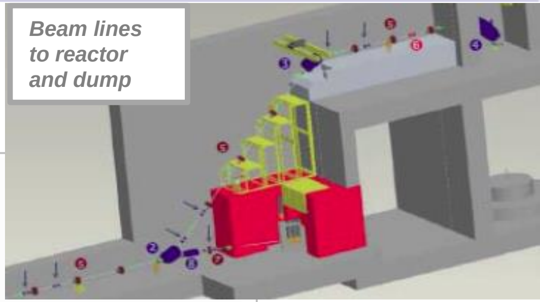
MEBT general layout (red squares: quads, blue elements: Spoke SRF cavities, purple arrows: BPMs)



Reference lattices of the SCL



Beam lines to reactor and dump



The ADS reliability requirement

J.L. Biarrotte

- **Beam trips longer than 3 sec** must be very rare:
  - To limit thermal stress & fatigue on the target window, reactor structures & fuel assemblies
  - To ensure a 80% availability – given the foreseen reactor start-up procedures
- **Present MYRRHA spécifications:** <10 beam trips per 3-month operation period (i.e. MTBF > 250h) – derived from the PHENIX reactor operation analysis
  - Far above present HPPA accelerator performance – MTBF is a few hours at PSI or SNS
  - Far above present ADS specifications in US or Japan – based on simulations
- **In any case, reliability guidelines are needed for the ADS accelerator design:**
  - **Strong design** i.e. robust optics, simplicity, low thermal stress, operation margins…
  - **Redundancy** (serial where possible, or parallel) to be able to tolerate failures
  - **Repairability** (on-line where possible) and efficient maintenance schemes

Reliability challenges:

- **Injector Switch Magnet**
- **Fault tolerance**/compensation function
- **Reliability of SSAs** (Solid State Amplifiers)

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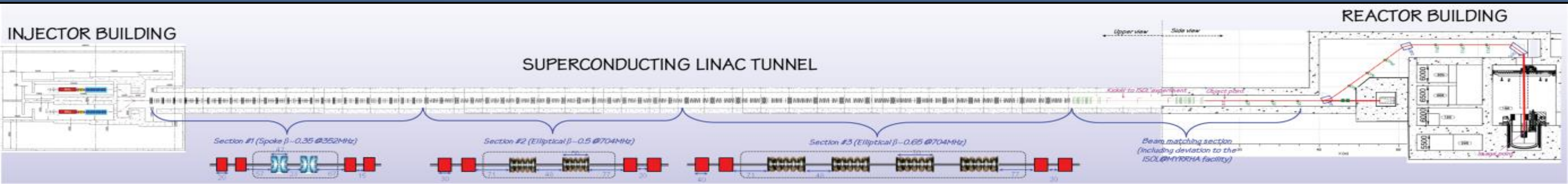
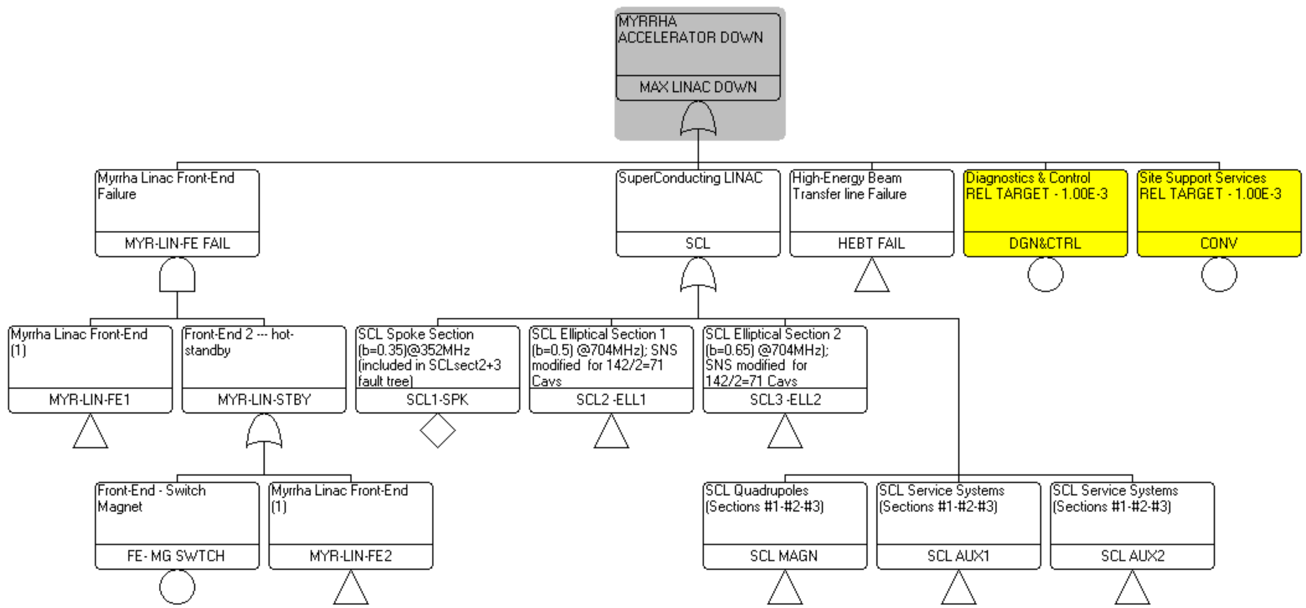


MYRRHA reliability model

- **Failure database** – developed from SNS/Myrrha, other; system of failure coding defined, e.g. failure IDs (basic events in Fault Tree)
- Myrrha **Linac Reliability model** (Risk Spectrum fault tree) - based on SNS design&rel. data and MAX project design
- Different Linac **configurations** /extension of failures compensation were investigated.
- Calculation of **Availability** + Linac Fault **Frequency** - for optimized configuration/design



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Input Data; General assumptions

Model code	Part/System	No.	MTBF	MTTR	Manufacturer/ Ref. Design	Model/ Type	Details; Obs.
	Faraday Cup		no data	no data	IPHC	-	Not considered; beam diagnostics (not normal beam operation)
	Allison scanner		no data	no data	Emittance-meter	-	Not considered; beam diagnostics (not normal beam operation)
	Vacuum chamber		no data	no data	UCL/CRC	-	Not considered; Experimental vacuum chamber (not normal beam operation)
	Beam dump	1	5000	8	SNS IS Edump electrode	up to 1200W	Not considered; Designed, under construction
LE (XX-UUUvv)	**LEBT**				**LPSC**	-	Reference layout (D1.2)
ECR EXT	**Source Extraction system**				**SNS IS**	**SNS**	
LE-EXE	Extraction electrodes	6	5000	8	SNS IS (2 extractor electrodes)	SNS	Multi-electrode system
LE-RPL	Electron repeller	1	50000	8	SNS IS (other LEBT	SNS	Intermediate electrode
LE-ESP	Extrac						
	Pum						
	Ein						
	Vacuu						
LE-SLP	Scre						
LE-TBP	Turb						
LE-QMA	**Sol**						
LE-STR	**H,V stee**						
	Fara						

Table 4.3 - INJECTOR (RFQ + CH-Booster) modeling data

Model code	Part/System	No.	MTBF	MTTR	Manufacturer/Ref. Design	Model/Type	Details; Obs.
RFQ (YYY-UUUvv)	**RFQ**						
RFQ-CAV	RFQ Cavity	1	1000000	4380	SNS RFQ	SNS	SNS RFQ Structure
RFQ-WIN	Window	1	100000	12	SNS RFQ windows	SNS	
	RF System						
RFQ-AMP	SS Amplifier		50000	4	Soleil technology	-	Power RF for RFQ: 176.1 MHz, 160 kW CW
	Transmitters & Aux	*1*			***Transmitters & Aux***	*SNS*	***Transmitters & Aux***
SNS tree	LLRF	1	100000	2	SNS DTL-LLRF	SNS	
SNS tree	AC distribution	1	77700	4	SNS DTL-HPRF	SNS	RF power-line
RFQ-WCL	Water-cooling	1	30000	3	SNS DTL	SNS	RFQ stems, SSA water-cooling (deionised water)
	—				—		—
SNS tree	**Vacuum System**	1	SNS tree	SNS tree	SNS RFQ Vacuum syst.	SNS	SNS tree
SNS tree	Scroll Pumps	2	20000	2	SNS RFQ Vacuum syst.	SNS	2 pumps considered instead of 4-in SNS
SNS tree	Gauges	2	100000	4	SNS RFQ Vacuum syst.	SNS	2 gauges considered instead of 4-in SNS
SNS tree	Cryo Pump	3	35714	1	SNS RFQ Vacuum syst.	SNS	3 pumps considered instead of 6-in SNS
IJB (YYY-UUUvv)	**CH-Booster**						
SNS tree	**CH-Booster support**	1	5000000	504	SNS DTL support	SNS	Support structure
SNS tree	magsl (Solenoid)	1	10000000	4	SNS quads -Magnet Assembly	SNS	Assumed- similar to the SNS quadrupole (MYRRHA Linac-solenoid)
IJB-RBC1	**RB-1**	1	100000	4	SNS MEBT rb-cav	SNS	Rebuncher cavity 1

Linac design - General hypotheses & assumptions

(A1) Radiofrequency (RF) System - similar to SNS (excepting Klystron and Modulator subsystems and related). All MYRRHA Linac amplifiers are solid-state type.

(A2) ¨Transmitter¨subsyst. (SNS model) - equipment to run the SSA for RF cavity control. Generally, the transmitters consist of a low level RF system, amplifier water-cooling, AC distribution, etc.

(A3) Auxiliary systems (AUX) -based on SNS (reference), modified to MYRRHA Acc. Design, adjusted to a lower level of detail. No glycol cooling -not applicable to the MYRRHA Linac case.

(A4) Relevant Beam Diagnostics -those related to possible beam failures and/or linked to the Machine Protection System (MPS).

Diagnostics for monitoring and tuning - not relevant to normal operation.

(A5) MTBF=10e5h (SNS) SC Cavs -cavity failures due connected systems failures (other than cav. Mechanical failure)

(A6-7)

Comps. Missing data – SNS similitude, assumptions

Impact on global reliability:

- Injector Switch magnet
- Fault tolerance and compensation system/function -high reliability objectives for detection and control systems.

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Input Data; Detailed assumptions

➢ MAIN SUPERCONDUCTING LINAC modeling data

Model code	Part/System	No.	MTBF	MTTR	Manufacturer/Ref. Design	Model/Type	Details; Obs.
SCL (YYY-UUUvv)	**SCL**						
	Section 1						
	Spoke CAVs	48	100000	3	SNS RF SCL cavity	SNS	Spoke 2-gap (β=0.37); (included in SCLsect2+3 fault tree)
	Section 2						
SNS tree	**Elliptical-1 CAVs**	34	100000	3	SNS RF SCL cavity	SNS	Elliptical1-5cell (β=0.51); SNS modified for 142/2=71 Cavs
	Section 3						
SNS tree	**Elliptical-2 CAVs**	60	100000	3	SNS RF SCL cavity	SNS	Elliptical2-5cell (β=0.7)); SNS modified for 142/2=71 Cavs
SNS tree	**SCL cavities-total** (spoke+ellipt.)	**142 (2x71)**	SNS SCL: 81 cavities (33mb + 48 hb) => 1.75 -2 multiplication factor for SCL AUX systems capacity				
SNS tree	**Cryostats (cryomodules)**	**56 (2x28)**				MAX	**24+17+15 (configuration in Figure 2.10)**
SCL-SSAS	**SS Amplifier**	2x71	50000	4	Soleil technology	-	
SNS tree	**RF Feedthroughs**	2x71	100000	24	SNS SCL-RF	SNS	
SNS tree	**SCL Cavity**	**142**			**SNS RF SCL Cavity**	**SNS**	
	SCL Circulator	2x71	50000	3	SNS scl	SNS	
	SCL Load	2x71	75019	3	SNS scl	SNS	
	SCL Waveguide	2x71	100000	3	SNS scl	SNS	
	SCL Window	2x71	100000	3	SNS scl	SNS	
	SCL Cavity	2x71	100000	3	SNS scl	SNS	

Modeling Assumptions (Risk Spectrum)

- ¨Continuously monitored repairable component¨ - Risk Spectrum Type 1 reliability model – Linac components
- ¨Constant Frequency¨ - Risk Spectrum Type 5 reliability model – accelerator trip frequency
- ¨Mean Unavailability¨ and ¨Frequency¨ types of calculation - unavailability/frequency values (basic events). The long-term average unavailability (Q) and frequency (F), the expected number of failures per unit time) were calculated

RS Modeling - methodology

❑ RS Reliability model - Availability

- **Risk Spectrum Type 1 – Repairable components** (continuously monitored) –modeling the SNS Linac components

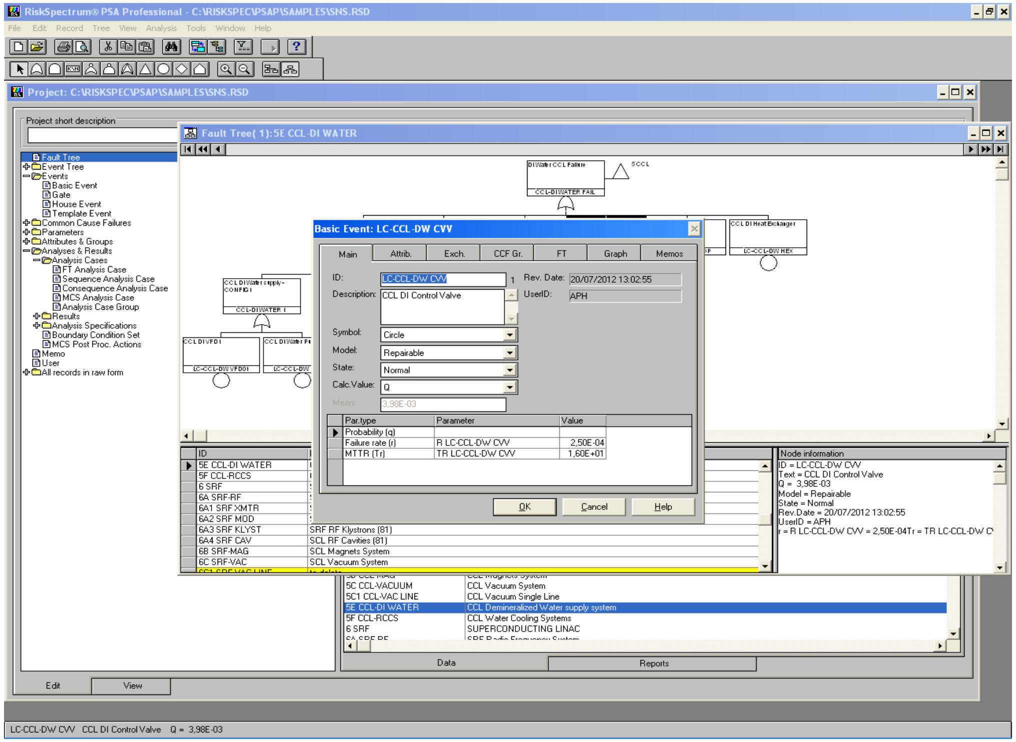
  - Failure/Repair processes – exponential distributions; failure/repair rates -ct.
  - It is assumed q=0

$$Q(t) = q e^{-\mu t} + \left(\frac{\lambda}{\lambda+\mu}\right)\left(1 - e^{-(\lambda+\mu)t}\right) \qquad Q_{mean} = \frac{\lambda}{\lambda + \mu}$$

λ=1/MTTF -failure rate); μ=1/MTTR -repair rate

- ¨**Mean Unavailability**¨ type of calculation used to obtain the unavailability values for the basic events:

Q=λ/(λ+μ) (the **long-term average unavailability - Q** calculated for each basic event)



❑ other RS Reliability models

- Type 2 – Periodically Tested Component (most complex)
- Type 3 – Constant Unavailability
- Type 4 – Component with Fixed Mission Time
- Type 5 – Constant Frequency
- Type 6 – Non-Repairable Component

RS Modeling - methodology

❑ RS Reliability model - Frequency

- **Risk Spectrum Type 5 – Type 5 - ¨Constant Frequency¨ ,** used for accelerator trip frequency

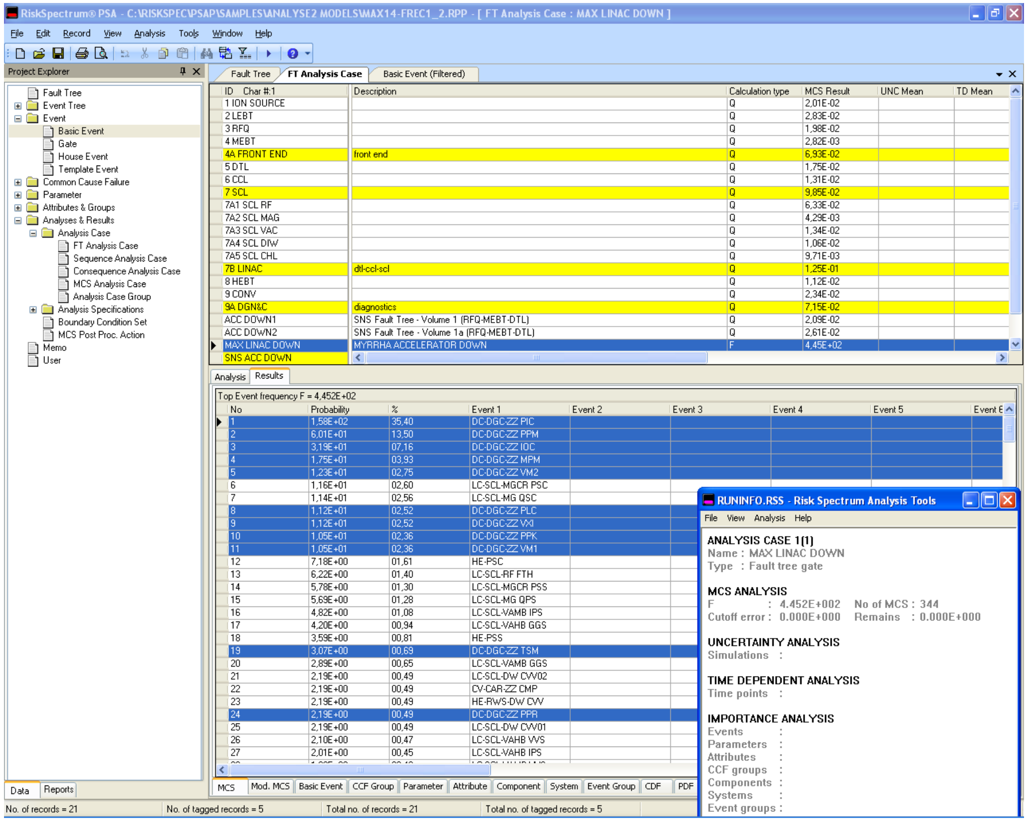
$$Q(t) = 0$$

$$Q = 0$$

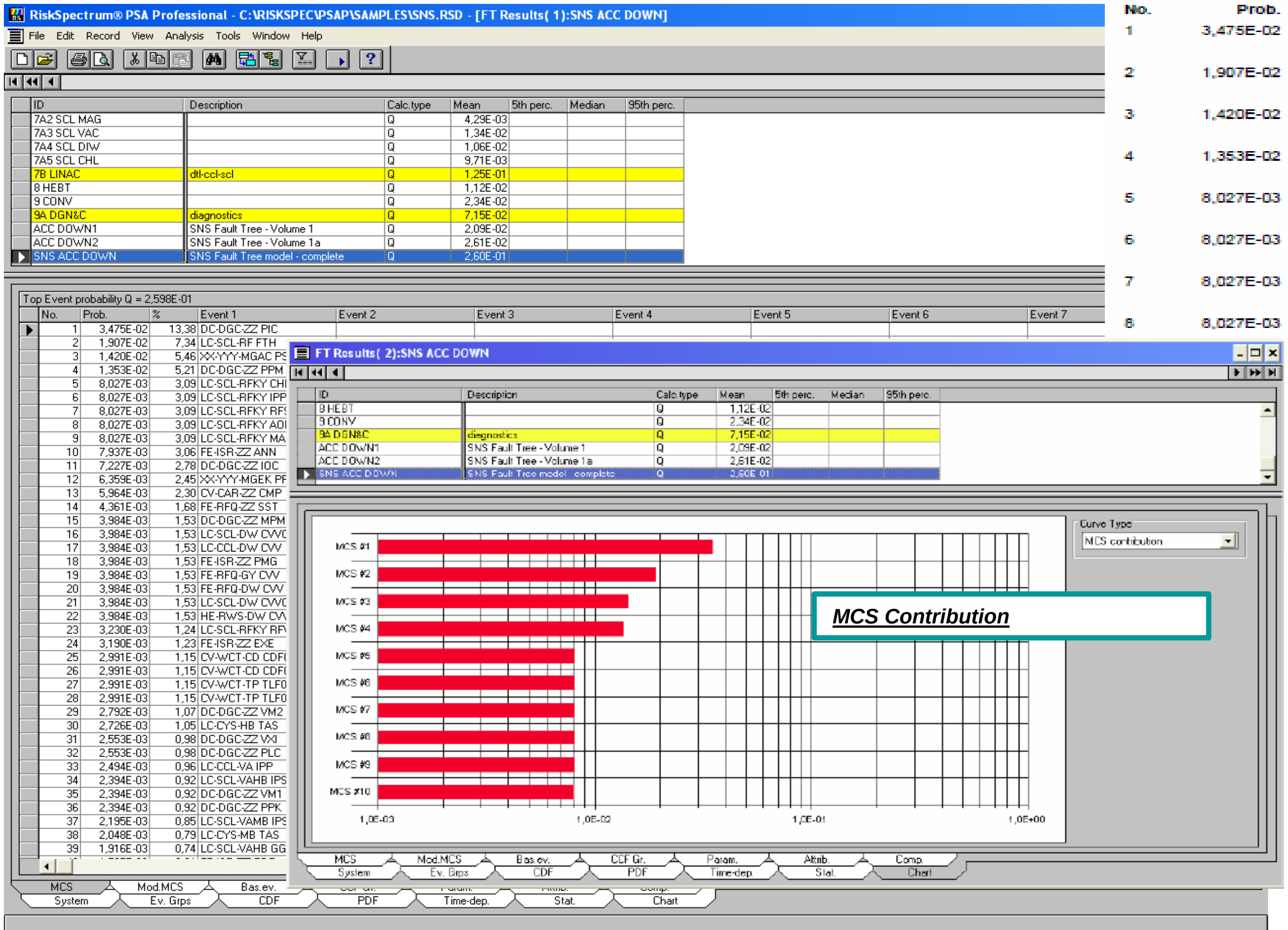
(eve $W(t) = f$ scribed by a Poisson process).

- ¨**Frequency**¨ type of calculation, used to obtain the frequency values for basic events.

➢ Frequency results for case 1.5.1 (Redundant FE/INJ + Compensation)



SNS Systems - MCS Analysis



Minimal Cutsets

Top Event probability Q = 2,598E-01

No.	Prob.	%	Q	Event	Description
1	3,475E-02	13,38	3,475E-02	DC-DGC-ZZ PIC	EPIC Modules -900series
2	1,907E-02	7,34	1,907E-02	LC-SCL-RF FTH	SCL RF Feedthroughs (81):(12+12+12+6+6+
3	1,420E-02	5,46	1,420E-02	XX-YYY-MGAC PSC	Arc PSC - 36 series
4	1,353E-02	5,21	1,353E-02	DC-DGC-ZZ PPM	PPS Modules -343series
5	8,027E-03	3,09	8,027E-03	LC-SCL-RFKY CHD	SCL Cathode (x81)
6	8,027E-03	3,09	8,027E-03	LC-SCL-RFKY IPP	SCL Ion Pump (x81)
7	8,027E-03	3,09	8,027E-03	LC-SCL-RFKY RFS	SCL RF Structure (x81)
8	8,027E-03	3,09	8,027E-03	LC-SCL-RFKY AOD	SCL Anode (x81)
		3,09	8,027E-03	LC-SCL-RFKY MAG	SCL Magnet (x81)
		3,06	7,937E-03	FE-ISR-ZZ ANN	ISR Antenna
		2,78	7,227E-03	DC-DGC-ZZ IOC	IOCs -182series
		2,45	6,359E-03	XX-YYY-MGEK PFN	PFN - 10 series
		2,30	5,964E-03	CV-CAR-ZZ CMP	CAR Compressor

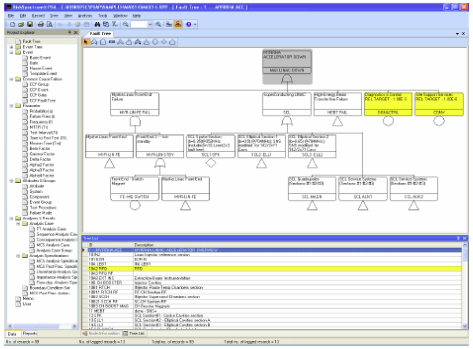
❑ MCS analysis

- **Minimal cut-set (MCS) - combination of events which causes the top event to occur**
- **"minimal" - if any of events is removed from the set, the top event no longer occurs.**

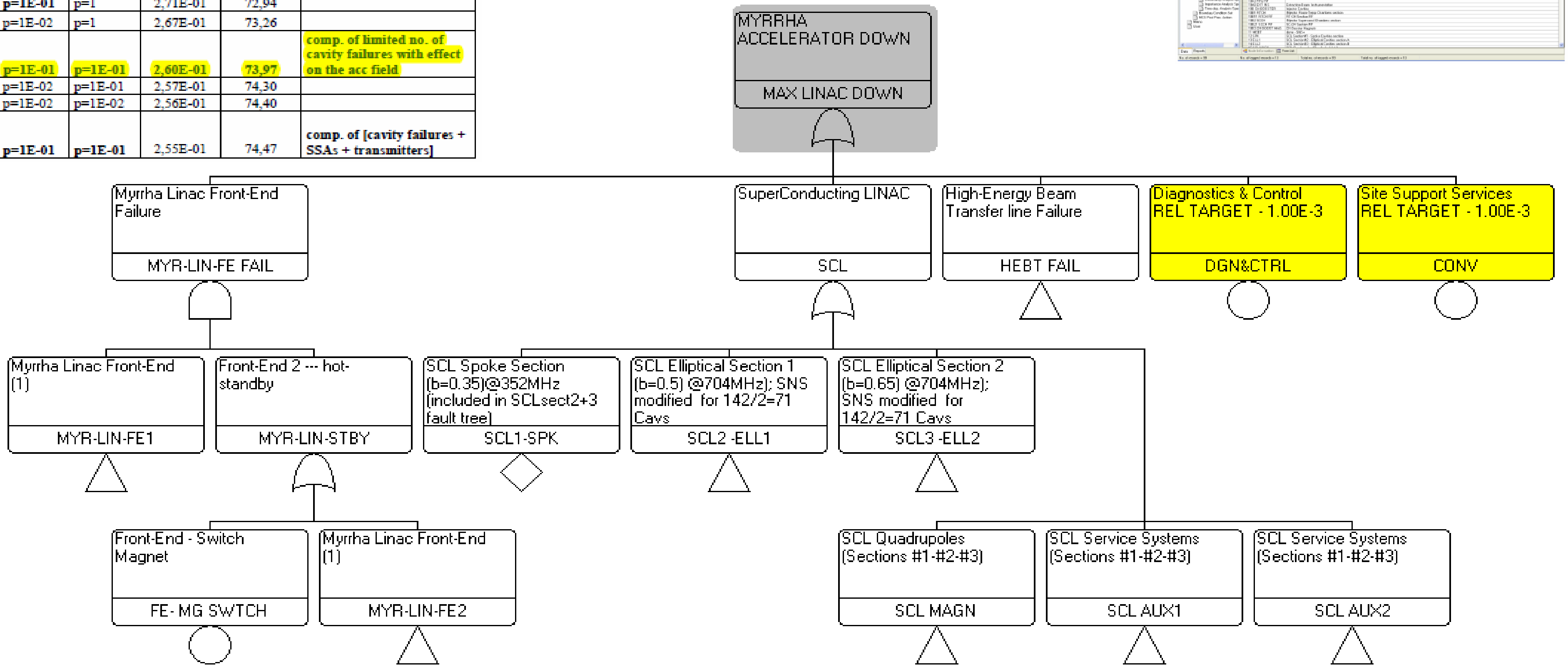
Myrrha Linac Modeling – Fault Tree

Table 6.1 Linac conceptual options – Initial Availability results

Case	Conditions	INJ switch	Comp.	Q	A (%)	Obs.
1.1	no Redundant FE/INJ + no Comp.	p=1	p=1	3,02E-01	69,76	
1.2	no Redundant FE/INJ + Comp.	p=1	p=1E-01	2,93E-01	70,75	comp. of limited no. of cavity failures with effect on the acc. field
1.2.1		p=1	p=1E-02	2,92E-01	70,84	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp.	p=1E-01	p=1	2,71E-01	72,94	
1.3.1		p=1E-02	p=1	2,67E-01	73,26	
1.4	Redundant FE/INJ + Comp	p=1E-01	p=1E-01	2,60E-01	73,97	comp. of limited no. of cavity failures with effect on the acc field
1.4.1		p=1E-02	p=1E-01	2,57E-01	74,30	
1.4.2		p=1E-02	p=1E-02	2,56E-01	74,40	
1.5	Redundant FE/INJ + Comp(ext.)	p=1E-01	p=1E-01	2,55E-01	74,47	comp. of [cavity failures + SSAs + transmitters]

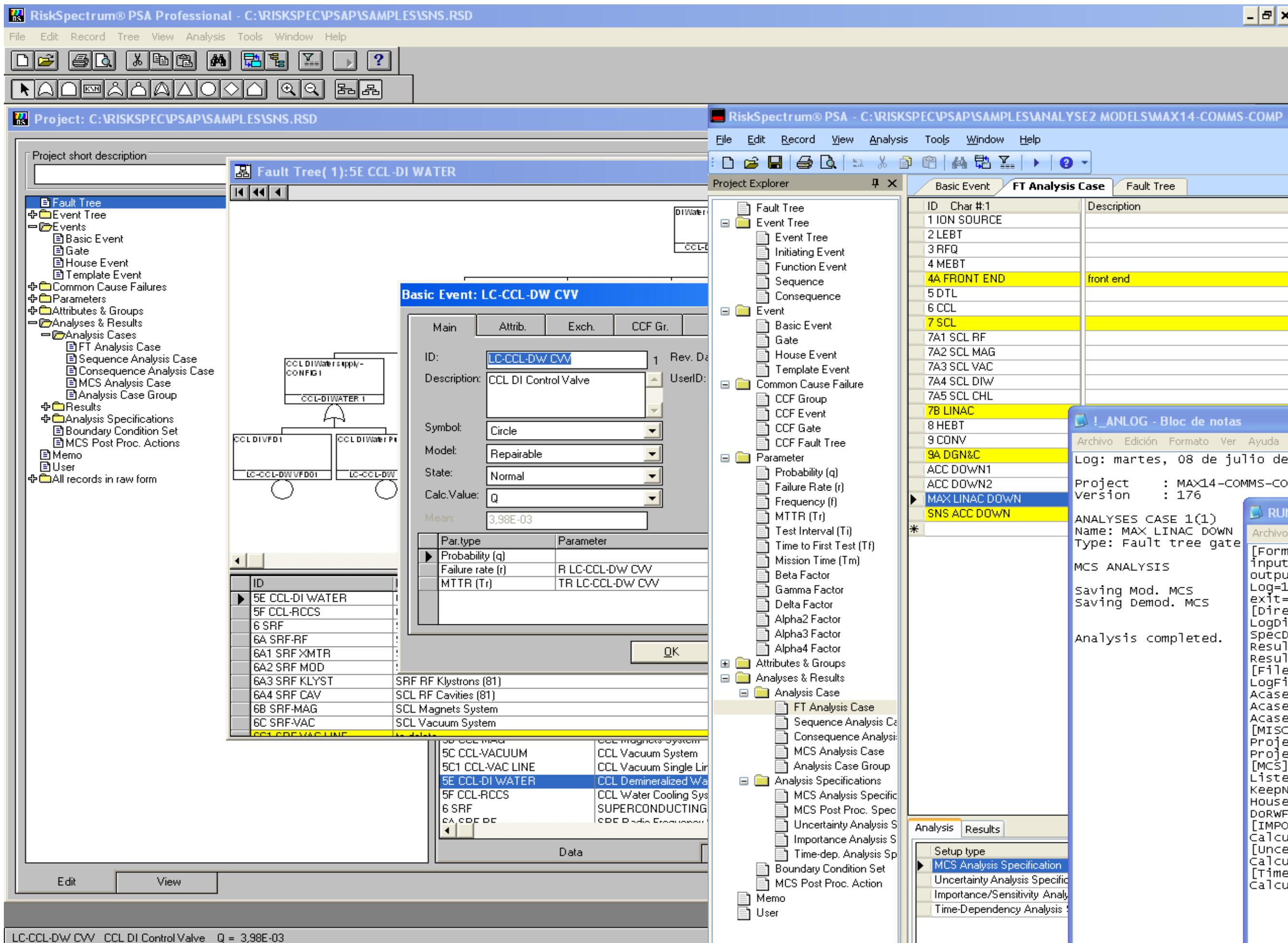


- **Myrrha Linac Fault Tree – main level**

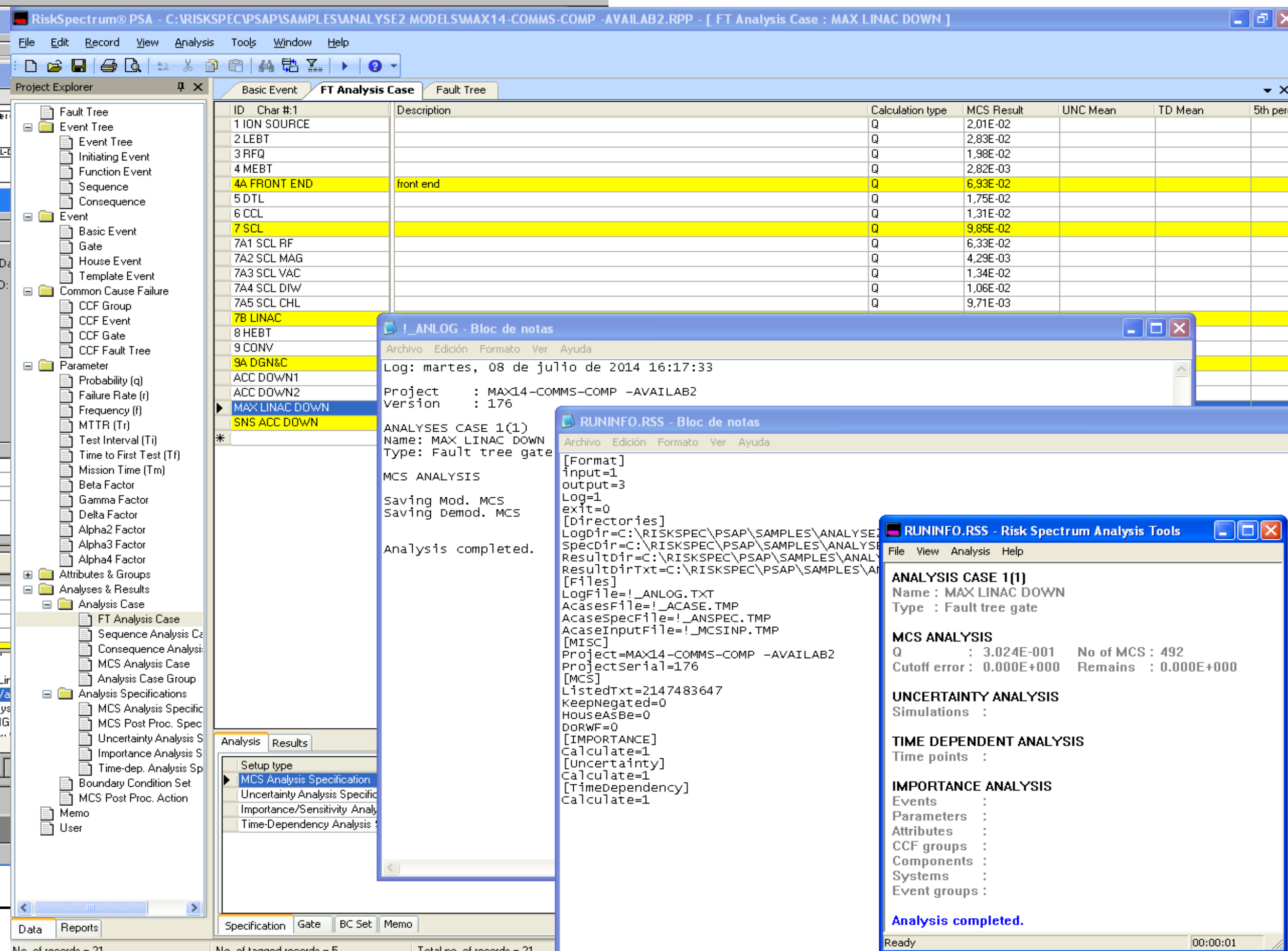


Myrrha Linac Modeling – Quantification & Analysis

➢ Risk Spectrum basic events quantification window



➢ MCS analysis – Initial point-estimate (case 1.1) quantification of the top event (MYRRHA ACC DOWN)



MAX
MYRRHA ACCELERATOR EXPERIMENT
RESEARCH & DEVELOPMENT PROGRAMME

SEVENTH FRAMEWORK PROGRAMME

Myrrha Linac Modeling –optimization (Availability)

➢ Myrrha Linac Design optimization - Availability

Table 6.1 Linac conceptual options – Initial Availability results

Case	Conditions	INJ switch	Comp.	Q	A (%)	Obs.
1.1	no Redundant FE/INJ + no Comp.	p=1	p=1	3,02E-01	69,76	
1.2	no Redundant FE/INJ + Comp.	p=1	p=1E-01	2,93E-01	70,75	comp. of limited no. of cavity failures with effect on the acc .field
1.2.1		p=1	p=1E-02	2,92E-01	70,84	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp.	p=1E-01	p=1	2,71E-01	72,94	
1.3.1		p=1E-02	p=1	2,67E-01	73,26	
1.4	Redundant FE/INJ + Comp	p=1E-01	p=1E-01	2,60E-01	73,97	comp. of limited no. of cavity failures with effect on the acc field
1.4.1		p=1E-02	p=1E-01	2,57E-01	74,30	
1.4.2		p=1E-02	p=1E-02	2,56E-01	74,40	
1.5	Redundant FE/INJ + Comp(ext.)	p=1E-01	p=1E-01	2,55E-01	74,47	comp. of [cavity failures + SSAs + transmitters]

Table 6.5 Linac conceptual options – Optimized Availability results

Case	Conditions	INJ switch	Comp	Q	A (%)	Obs.
2.1	no Redundant FE/INJ + no Comp	p=1	p=1	8,385E-02	91,61	
2.2	no Redundant FE/INJ + Comp	p=1	p=1E-01	7,085E-02	92,91	comp. of limited no. of cavity failures with effect on the acc field
2.2.1		p=1	p=1E-02	6,955E-02	93,04	comp. of limited no. of cavity failures with effect on the acc field
2.3	Redundant FE/INJ + no Comp	p=1E-01	p=1	4,204E-02	95,79	
2.3.1		p=1E-02	p=1	3,786E-02	96,21	
2.4	Redundant FE/INJ + Comp	p=1E-01	p=1E-01	2,845E-02	97,15	comp. of limited no. of cavity failures with effect on the acc field

EMPRESARIOS AGRUPADOS

➢ MYRRHA Linac analysis Case 1.4 (DG&C systems – SNS fault tree); DG&C failures

A - C:\RISKSPEC\PSAP\Samples\Analyse2 models\MAX14-comms-comp -Availab2+Optimiz.RPP - [FT Analysis Case : MAX LINAC DOWN]

Fault Tree | FT Analysis Case

ID	Char #:1	Description	Calculation type	MCS Result	UNC Mean	TD Mean
1	ION SOURCE		Q	2,01E-02		
2	LEBT		Q	2,83E-02		
3	RFQ		Q	1,98E-02		
4	MEBT		Q	2,82E-03		
4A	FRONT END	front end	Q	6,93E-02		
5	DTL		Q	1,75E-02		
6	CCL		Q	1,31E-02		
7	SCL		Q	9,85E-02		
7A1	SCL RF		Q	6,33E-02		
7A2	SCL MAG		Q	4,29E-03		
7A3	SCL VAC		Q	1,34E-02		
7A4	SCL DIW		Q	1,06E-02		
7A5	SCL CHL		Q	9,71E-03		
7B	LINAC	dtl-ccl-scl	Q	1,25E-01		
8	HEBT		Q	1,12E-02		
9	CONV		Q	2,34E-02		
9A	DGN&C	diagnostics	Q	7,15E-02		
ACC DOWN1		SNS Fault Tree - Volume 1 (RFQ-MEBT-DTL)	Q	2,09E-02		
ACC DOWN2		SNS Fault Tree - Volume 1a (RFQ-MEBT-DTL)	Q	2,61E-02		
MAX LINAC DOWN		MYRRHA ACCELERATOR DOWN	Q	2,60E-01		
SNS ACC DOWN						

obability Q = 2,603E-01

Probability	%	Event 1	Event 2
6,02E-02	23,10	LC-SCL-DW CVV01	
6,02E-02	23,10	LC-SCL-DW CVV02	
3,47E-02	13,40	DC-DGC-ZZ PIC	
1,68E-02	06,44	LC-SCL-RF FTH	
1,35E-02	05,20	DC-DGC-ZZ PPM	
7,23E-03	02,78	DC-DGC-ZZ IOC	
5,96E-03	02,29	CV-CAR-ZZ CMP	
5,65E-03	02,17	SCL SSAS COMP	SCL-AMP
3,98E-03	01,53	LC-SCL-DW VLV01	
3,98E-03	01,53	DC-DGC-ZZ MPM	
3,98E-03	01,53	HE-RWS-DW CVV	
3,98E-03	01,53	LC-SCL-DW VLV02	
2,99E-03	01,15	CV-WCT-CD CDF02	
2,99E-03	01,15	CV-WCT-TP TLF02	
2,99E-03	01,15	CV-WCT-TP TLF01	
2,99E-03	01,15	CV-WCT-CD CDF01	
2,79E-03	01,07	DC-DGC-ZZ VM2	
2,73E-03	01,05	LC-CYS-HB TAS	
2,73E-03	01,05	LC-CYS-MB TAS	
2,63E-03	01,01	LC-SCL-MGCR PSC	
2,59E-03	01,00	LC-SCL-MG QSC	
2,55E-03	00,98	DC-DGC-ZZ PLC	
2,55E-03	00,98	DC-DGC-ZZ VXI	
2,39E-03	00,92	DC-DGC-ZZ PPK	
2,39E-03	00,92	DC-DGC-ZZ VM1	
2,20E-03	00,84	LC-SCL-VAMB IPS	
1,92E-03	00,74	LC-SCL-VAHB GGS	

RUNINFO.RSS - Risk Spectrum Analysis Tools

ANALYSIS CASE 1(1)
Name : MAX LINAC DOWN
Type : Fault tree gate

MCS ANALYSIS
Q : 2.603E-001 No of MCS : 492
Cutoff error : 0.000E+000 Remains : 0.000E+000

UNCERTAINTY ANALYSIS
Simulations :

TIME DEPENDENT ANALYSIS
Time points :

IMPORTANCE ANALYSIS
Events :
Parameters :
Attributes :
CCF groups :
Components :
Systems :
Event groups :

Analysis completed.

MCS | Mod. MCS | Basic Event | CCF Group | Parameter | Attribute | Component | System | Event Group | CDF | PDF | Time-dep. | STAT | Graph

No. of records = 21 | No. of tagged records = 5 | Total no. of records = 21 | Total no. of tagged records = 5

Myrrha Linac Modeling –optimization (Frequency)

➢ **Myrrha Linac Design optimization - Frequency**

Table 6.6 Linac conceptual options – Initial Frequency results

Case	Conditions	INJ switch	Comp	F(/yr)	A (/3mth)	Obs.
1.1	no Redundant FE/INJ + no Comp	p=1	p=1	550	137,50	
1.2	no Redundant FE/INJ + Comp	p=1	**p=1E-01**	509	127,25	comp. of limited no. of cavity failures with effect on the acc field
1.2.1		p=1	p=1E-02	505	126,25	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp	**p=1E-01**	p=1	499	124,75	
1.3.1		p=1E-02	p=1			
1.4	**Redundant FE/INJ + Comp**	**p=1E-01**	**p=1E-01**			
1.4.1		p=1E-02	p=1E-01			
1.4.2		p=1E-02	p=1E-02			
1.5	Redundant FE/INJ + **Comp(ext.)**	p=1E-01	p=1E-01			
1.5.1		**p=1E-02**	**p=1E-02**			

➢ **Frequency results for case 1.5.1 (Redundant FE/INJ + Compensation)**

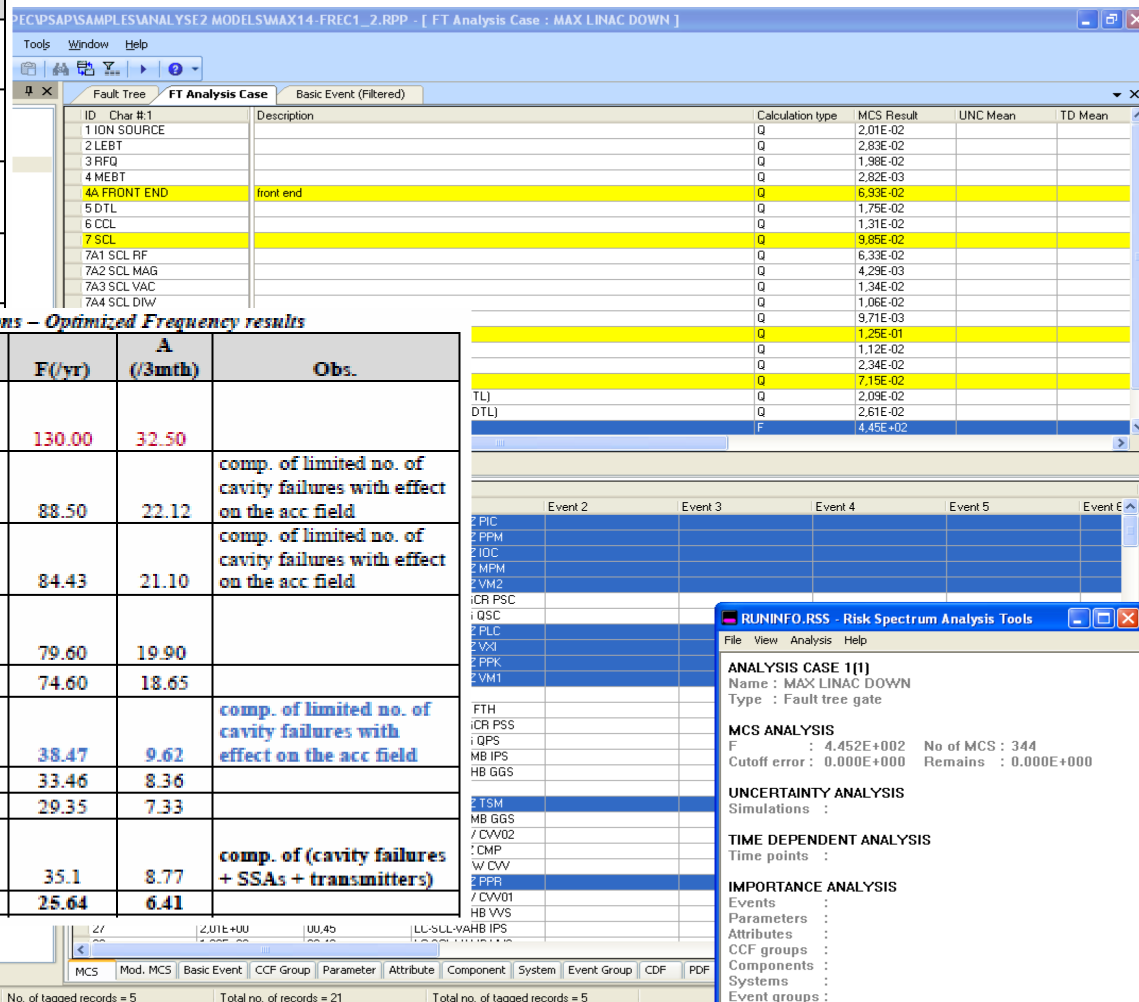


Table 6.8 Linac conceptual options – Optimized Frequency results

Case	Conditions	INJ switch	Comp	F(/yr)	A (/3mth)	Obs.
1.1	no Redundant FE/INJ + no Comp	p=1	p=1	130.00	32.50	
1.2	no Redundant FE/INJ + Comp	p=1	**p=1E-01**	88.50	22.12	comp. of limited no. of cavity failures with effect on the acc field
1.2.1		p=1	p=1E-02	84.43	21.10	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp	**p=1E-01**	p=1	79.60	19.90	
1.3.1		p=1E-02	p=1	74.60	18.65	
1.4	**Redundant FE/INJ + Comp**	**p=1E-01**	**p=1E-01**	**38.47**	**9.62**	**comp. of limited no. of cavity failures with effect on the acc field**
1.4.1		p=1E-02	p=1E-01	33.46	8.36	
1.4.2		p=1E-02	p=1E-02	29.35	7.33	
1.5	Redundant FE/INJ + **Comp(ext.)**	p=1E-01	p=1E-01	35.1	8.77	**comp. of (cavity failures + SSAs + transmitters)**
1.5.1		**p=1E-02**	**p=1E-02**	**25.64**	**6.41**	

➢ **Optimized -Frequency results**

MYRRHA reliability model - Results

➢ Outcomes of the study:

➢ Without/With injector redundancy: Availability from 70% to 75%

➢ If MTBFs of diagnostics replaced by reliability target value (not from SNS experience) + target value for compensation function reliability: Availability to 80%.

➢ Improve superconducting part and assume larger MTBF for components (better comps. Reliability): improvement of the availability to 97%.

➢ Generally, Linac Fault Frequency could evolve from 100/3mths to less than10/3mths

Table 6.6 Linac conceptual options – Initial Frequency results

Case	Conditions	INJ switch	Comp	F(/yr)	A (/3mth)	Obs.
1.1	no Redundant FE/INJ + no Comp	p=1	p=1	550	137,50	
1.2	no Redundant FE/INJ + Comp	p=1	**p=1E-01**	509	127,25	comp. of limited no. of cavity failures with effect on the acc field
1.2.1		p=1	p=1E-02	505	126,25	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp	**p=1E-01**	p=1	499	124,75	

Table 6.8 Linac conceptual options – Optimized Frequency results

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1.1	no Redundant FE/INJ + no Comp	p=1	p=1	130.00	32.50	
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1.2.1		p=1	p=1E-02	84.43	21.10	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp	**p=1E-01**	p=1	79.60	19.90	
1.3.1		p=1E-02	p=1	74.60	18.65	
1.4	**Redundant FE/INJ + Comp**	**p=1E-01**	**p=1E-01**	**38.47**	**9.62**	**comp. of limited no. of cavity failures with effect on the acc field**
1.4.1		p=1E-02	p=1E-01	33.46	8.36	
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1.5	Redundant FE/INJ + **Comp(ext.)**	p=1E-01	p=1E-01	35.1	8.77	**comp. of (cavity failures + SSAs + transmitters)**
1.5.1		**p=1E-02**	**p=1E-02**	**25.64**	**6.41**	

Table 6.6 Linac conceptual options – Initial Frequency results

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1.2.1		p=1	p=1E-02	505	126,25	comp. of limited no. of cavity failures with effect on the acc field
1.3	Redundant FE/INJ + no Comp	**p=1E-01**	p=1	499	124,75	
1.3.1		p=1E-02	p=1	494	123,50	

Table 6.8 Linac conceptual options – Optimized Frequency results

Case	Conditions	INJ switch	Comp	F(/yr)	A (/3mth)	Obs.
1.1	no Redundant FE/INJ + no Comp	p=1	p=1	130.00	32.50	
1.2	no Redundant FE/INJ + Comp	p=1	**p=1E-01**	88.50	22.12	comp. of limited no. of cavity failures with effect on the acc field
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1.5.1		**p=1E-02**	**p=1E-02**	**25.64**	**6.41**	

➢ Conclusions:

➢ **High-reliability for MYRRHA Linac - achieved if anticipated in the design** of the machine.

➢ **Compensation (fault-tolerance) -** solution to minimize the effect of RF/magnets failures.

➢ **Double injector definitely improves the overall reliability** (avoid trips caused by components in the front-end), assuming a reliable switching magnet can be provided.

➢ **Critical failures leading directly to Acc. trip** (i.e. cooling control valves, common cause failures, etc.) should be prevented by classical **parallel redundancy**

➢ **Parallel redundancy** should also be implemented **for power supplies and their controllers** and other components in the SCL and HEBT.

EMPRESARIOS AGRUPADOS

Myrte WP2 – Task 2.9, To be developed:

- **LINAC4 reliability model**
- **AFT for LINAC4**

	2015, October 1 (Milestone #1)	2016, April 1	2016, October 1 (Milestone #2)	2017, April 1	2017, October 1 (Milestone #3)	2018, April 1	2018, October 1	2019, April 1 (Milestone #4)
Task 2.9 CERN (R.Schmidt)	A detailed work programme should have been defined and agreed between EA and CERN.	The development of the LINAC4 reliability model should have started. The requirements for the modification of the LHC accelerator fault tracking tool (AFT) for LINAC4 should have been defined, in collaboration between CERN and EA.	The first AFT version for LINAC4 should be operational. The LINAC4 reliability model should be complete.	The reliability run of the LINAC4 should have started. The operational data from the reliability run (e.g. faults and their characteristics) should be entered in the AFT.	The validation of the reliability model should be carried out, using operational data available in AFT for a period of at least 6 month from the reliability run for LINAC4.	Recommendations for LINAC4 reliability enhancement should be derived. Applicability of these recommendation to MYRRHA reliability model developed in MAX should be defined	MYRRHA linac reliability results and conclusions from MAX D4.4 should be reviewed in the light of LINAC4 reliability work performed. Draft recommendations for the Myrrha linac design should be defined.	Final conclusions & recommendations towards the MYRRHA linac reliability enhancement should be gathered into Deliverable 2.9.

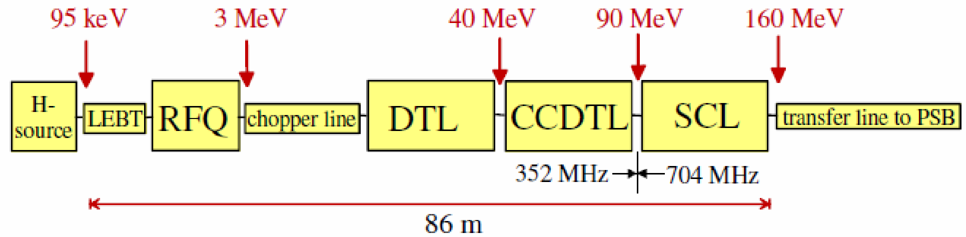
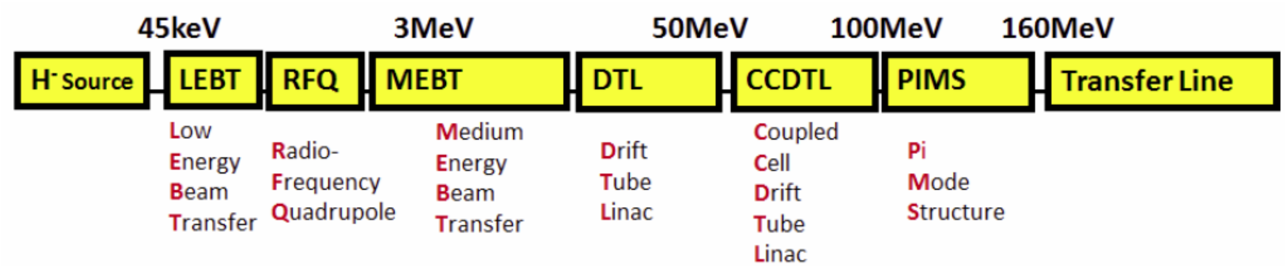


Figure 1.1: Scheme of Linac4

➢ **LINAC4 Reliability modeling conclusions – to be extended to Myrrha Linac: LINAC injector + accelerator up to 100 MeV)**

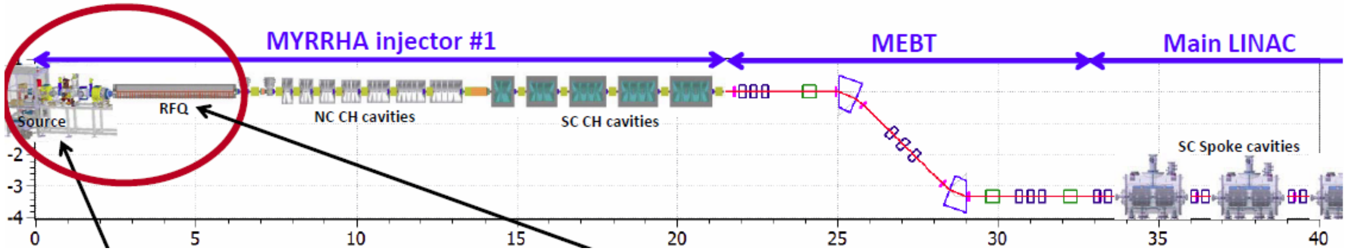


➢ **Recommendations for Myrrha Linac high-Reliability**

WP2 objectives

➢ **Pursue the research, design and development of the MYRRHA accelerator**

➢ **W/ special focus on the first section of the INJECTOR part (building from previous work)**



Data for Linac Reliability Modelling

- Development of a common database for reliability analyses for MYRRHA (CERN + EA)
- All figures currently being reviewed at CERN in view of the Linac4 reliability run (2017)

CERN

Availability studies for MYRRHA EDIT LINKS

Linac 4 Failure Catalogue

Failure Catalogues
LINAC 4
MYRRHA
SNS
Documents
Notebook
Site Contents
EDIT LINKS

Excel Web Access - FC_Linac4
FILE OPEN IN EXCEL DATA FIND

FAILURE

SECTION: **Linac4**	BEAM CONDITION	FAILURE MODE
1) SOURCE	80mA H-, 45keV, 0.25 mm*mrad	H- source not available (source short stop)
	80mA H-, 45keV, 0.25 mm*mrad	H- source not available (source long-stop)
2) LEBT	80mA H-, 45keV	
2.1) SOLENOIDS		Powering Failure
		Wrong Magnetic Field
2.2) BEAM STOPPER		Mechanical Failure
		Electronic Failure
		Incorrect Position
2.3) PRE-CHOPPER		Powering Failure
		Wrong Electric Field
		PSB Synchrnization
3) RFQ	70mA H-, 3MeV	Powering Failure
		Wrong Field

Empresarios Agrupados

Availability studies for MYRRHA EDIT LINKS

SNS Failure Catalogue

Failure Catalogues
LINAC 4
MYRRHA
SNS
Documents
Notebook
Site Contents
EDIT LINKS

FILE OPEN IN EXCEL DATA FIND

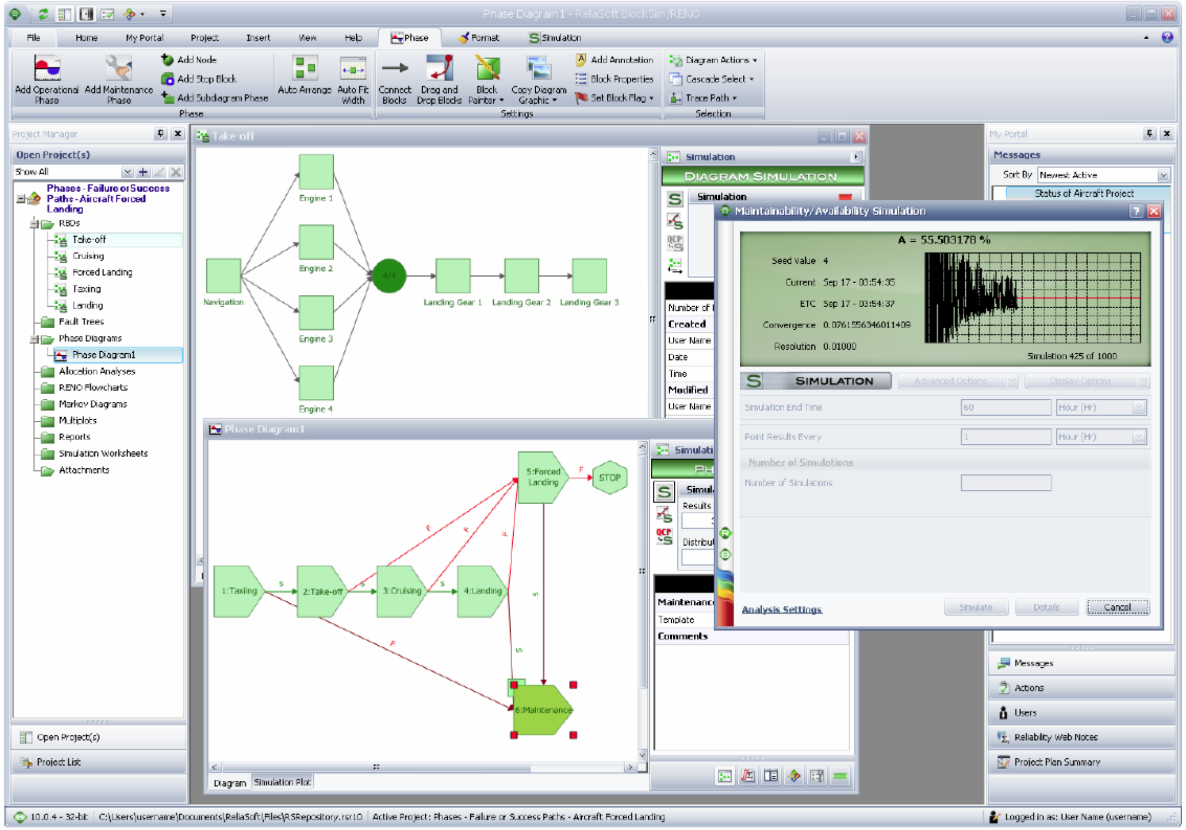
FAILURE CATALOGUE

SECTION: SNS	BEAM CONDITION	FAILURE MODE	LOCATION	MTTR	FAILURE RATE (per component, 1/h)	SEVERITY
ION SOURCE						
Plasma Electrode			Ion Source	8	2.00E-05	
Permanent Magnets			Ion Source	8	1.00E-05	
HV Insulators			Ion Source	8	2.00E-05	
Power Supply			Ion Source	1	2.00E-05	
RF Amplifier			Ion Source	0.8	2.00E-05	
RF Circulator			Ion Source	3	2.00E-05	
Gas Supply			Ion Source	4	2.00E-05	
Pumping			Ion Source	1	5.00E-05	
Valves			Ion Source	4	1.00E-05	
Gauges			Ion Source	4	5.00E-06	
Support			Ion Source	0.8	8.00E-05	
Beam Dump			Ion Source	8	2.00E-04	
LEBT						
Extraction Electrodes			LEBT	8	2.00E-04	
Electron Repeller			LEBT	8	2.00E-05	
Extractor Supply			LEBT	0.8	2.00E-05	
Scroll pump			LEBT - Vacuum System	1	5.00E-05	
Turbo pump			LEBT - Vacuum System	1	1.00E-05	
Turbo pump Gauge			LEBT - Vacuum System	4	1.00E-05	
Turbo pump Valve			LEBT - Vacuum System	4	1.00E-05	
Solenoid 1			LEBT	2	1.00E-06	
H,V Steerers (dipoles)			LEBT	2	1.00E-06	
Valve			LEBT	4	1.00E-05	
Slits System (collimator)			LEBT	4	1.11E-05	
Solenoid 2			LEBT	2	1.00E-06	
H,V Steerers (dipoles)			LEBT	2	1.00E-06	
Inj. Cone Cooling			LEBT	8	2.00E-05	

Merging relevant information to build a MYRRHA failure catalogue

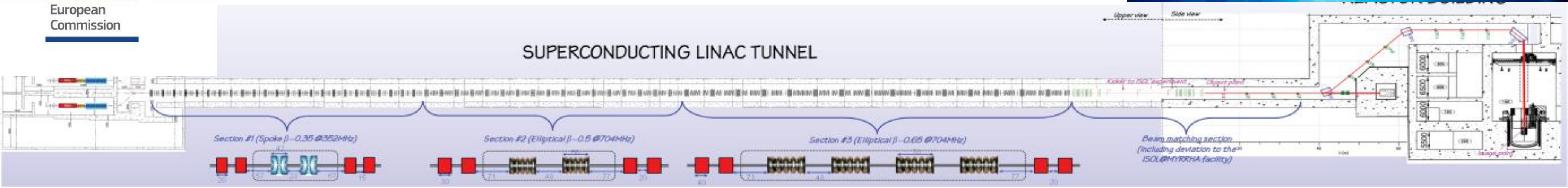
Linac4 Reliability Model – software

- ReliaSoft's BlockSim software tool - comprehensive platform for system reliability, availability, maintainability and related analyses.
- Sophisticated graphical interface, modeling the simplest/most complex systems and processes using reliability block diagrams (RBDs) or fault tree analysis (FTA)



MYRTE

MYRRHA Research and Transmutation Endeavour



Thank you

A.E. PITIGOI – EA aph@empre.es

P. FERNANDEZ RAMOS – EA pfr@empre.es

EMPRESARIOS AGRUPADOS