
CERN

Linac4

Failure catalogue and Availability model

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Workshop follow-up meeting II

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- Availability model
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FAILURE CATALOGUE I

SECTION: **Linac4**	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)	COMMENTS	SEVERITY (**mitigation)
1) SOURCE	1	80mA H-, 45keV, 0.25 umrad	H- source not availableor below nominal intensity	Source/LEBT					Low
1.1) HYDROGEN			Hydrogen delivery system	Plasma generator	3	3h*	26000		
			Hydrogen pulser	Plasma generator	3	3h*	8760		
1.2) RF-SOURCE			LLRF controller	Plasma generator	2	2 h	17000		
			RF-amplifier	Plasma generator	2	6h	8.76E03		
			Matching network connection	Plasma generator	1	1 h*	26000		
			RF-antenna - air ionization	Source	24	24 h*	26000		** New PG
1.3) PLASMA GENERATOR			Plasma generator leak	Plasma generator	24	24 h*	17000		** short circuit Bias
			Plasma electrode Bias power supply		1	1 h*	17000		
			Permanent magnets		24	24 h*	26000		
			Vis ceramique		24	24 h*	26000		
1.4) SOURCE HIGH VOLTAGE			10 kV Puller-dump transformer	Source	3	3 h*	26000		
			45 kV HV transformer	Source	3	3 h*	26000		
			25/45 kV Einzel Lens transformer	Source	3	3 h*	26000		
			Fron-end insulator	Source	72	72 h*	26000		
			10/25/45 kV converter	Source	3	3 h	8.76E03		
1.5) CESIATION SOURCE			CS-heating system		1	1 h*	17000		
			Air cooling system		1	1 h*	17000		
			Cs-valve motorization		1	1 h*	8.76E03		
1.6) SOURCE VESSELS			Flange leak	Source	24	24 h*	26000		
			Front-end leak	Source	72	72 h*	26000		
1.7) SOURCE VACUUM			TM pump		3	3 h*	17000		
			Roughing pump		3	3 h*	26000		
			Vacuum gauge		1	1 h*	8.76E+03		** use a different gauge
			Vacuum valve		24	24 h*	26000		
			Vac-Interlock	Source	3	3 h*	8.76E+03		** use a different gauge
1.8) SOURCE CONTROLS			BCT-LEBT		3	3 h*	8.76E03		
			PLC-Hardware / software		8	8 h	8.76E03		
			FESA-software		8	8 h	8.76E03		
			Autopilot software		8	8 h	8.76E03		** Manual operation
1.9.) FC ACCESS SYSTEM			PLC	Source	3	3 h*	26000		
			Doors Micro-switches	Source	3	3 h*	17000		** Manual operation

FAILURE CATALOGUE II

SECTION: **Linac4**	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)	COMMENTS	SEVERITY (**mitigation)
2) LEBT		80mA H-, 45keV							
2.1) SOLENOIDS	2								
2.1.1) Power Electronics			Powering Failure	Solenoids	0.4	23min	100000		Low
2.1.2) Controls				Solenoids	0.4	23min	200000		Low
2.1.3) Measurement part				Solenoids	0.4	23min	200000		Low
2.1.3) Water Cooling				Solenoids					
2.2) BEAM STOPPER			Mechanical Failure	TL, PSB Injection		few hours	130000		Low
			Electronic Failure	TL, PSB Injection	1.5	1-2h	43000		Low
			Incorrect Position				43000		Low
2.3) PRE-CHOPPER			Powering Failure	PSB Injection (BIS)	0.4	23 min	270000		Low
			Wrong Electric Field	PSB Injection (BIS)					Low
			PSB Synchonization	PSB Injection (BIS)					
3) RFQ	1	70mA H-, 3MeV	Cooling			few hrs		few years	
			Wrong Field	RFQ, Chopper					Low
4) MEBT		70mA H-, 3MeV							
4.1) BUNCHER	1		Powering Failure	MEBT, DTL	0.4	23min	26700		Low
			Wrong EM Field	MEBT, DTL					Low
			Wrong Phase	MEBT, DTL					Low
			Movable Tuner not working	MEBT, DTL	1	1 hr (unless the vacuum has to be broken)	26000		Low/Marginal
			Vacuum leak in the cavity	MEBT, DTL		hrs/days	8760		Marginal
4.2) CHOPPER	1		Powering Failure	PSB Injection (DIS)	0.4	23min	26700		Low
			Wrong Electric Field	PSB Injection (DIS)					Low
			Synchronization	PSB Injection (DIS)					
5) DTL		40mA H-, 50MeV							
5.1) CAVITIES	3		Wrong EM Field	DTL	0.5	15-30 min for reset	168	<168	Low
			Wrong Phase	DTL	0.5	15-30 min for reset	168	<168	Low
			Movable Tuners (2 per cavity) not working	DTL	1	1 h (unless the vacuum has to be broken)	26000		Low/Marginal
			Vacuum leak in the cavity	DTL		h/days	8760		Marginal

FAILURE CATALOGUE III

SECTION: **Linac4**	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)	COMMENTS	SEVERITY (**mitigation)
6) CCDTL		40mA H-, 100MeV							
6.1) CAVITIES	7		Wrong EM Field	CCDTL,TL	0.5	15-30 min for reset	168	<168	Low
			Wrong phase	CCDTL,TL	0.5	15-30 min for reset	168	<168	Low
			Movable Tuners not working (1 per cavity for the first 5 modules, otherwise 2)	CCDTL	1	1 h (unless the vacuum has to be broken)	26000		Low/Marginal
			Vacuum leak in the cavity	CCDTL		h/days	8760		Marginal
7) PIMS	12	40mA H-, 160MeV							
7.1) MODULES 1-10	10		Wrong EM Field	TL	0.5	15-30 min for reset	168	<168	Low
			Wrong phase	TL	0.5	15-30 min for reset	168	<168	Low
			Movable Tuners not working (2 per cavitys)	PIMS	1	1 h (unless the vacuum has to be broken)	26000		Low/Marginal
			Vacuum leak in the cavity	PIMS		h/days	8760		Marginal
7.2) MODULES 11-12	2		Wrong EM Field	BHZ.21	0.5	15-30 min for reset	168	<169	Low
			Wrong Voltage for Energy Painting	PSB Injection					Low
			Movable Tuners not working (2 per cavitys)	PIMS	1	1 h (unless the vacuum has to be broken)	26000		Low/Marginal
			Vacuum leak in the cavity	PIMS		h/days	8760		Marginal
8) ION PUMPS	**49**		Powering failure (1oo2 Redundancy)	Linac	2	2h	4392	1/[6m] (checked every 24h)	
9) VACUUM VALVES	**9**		Vacuum Leak	Linac					Marginal
			Mechanical Failure (Compressed Air System) + Vacuum Leak		24	>24h	130000	< 1.3E+05 (RELIAB: 50000 cycles)	Marginal
			Electronics Failure	Linac	1.5	1-2h	43000		Low
			Sensor/Powering Failure (Valve closes when not asked)		2	2h	4350	4.35E+03 (checked every 24h)	Low
			Sensor/Powering Failure (Valve not closed when asked)	Linac	2	2h	4350	4.35E+03 (checked every 24h)	Low

FAILURE CATALOGUE IV

SECTION: **Linac4**	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)	COMMENTS	SEVERITY (**mitigation)
10) LINAC 4 DUMP **LBE DUMP** **LBS DUMP**			Vacuum Leak reaching the Peak Temperature Area, several pulses hitting the dump	DUMP	168	1w	8760		Marginal
			Cooling Failure	DUMP		few h		few years	Low
			Core Failure	DUMP	168	1w	8760		Marginal
			Sufficient Air Leak						
11) QUADRUPOLES	**49**			BHZ.30, Linac, TL					
11.1) Powering									
11.1.1) Power Electronics			Powering Failure	Quadrupoles	0.4	23min ?	1000000		Low
11.1.2) Controls				Quadrupoles			200000		
11.1.3) Measurement part				Quadrupoles			200000		
12) STEERING MAGNETS	**50**								
12.1) Powering									
12.1.1) Power Electronics			Powering Failure	Steering magnets	0.4	23min ?	100000		Low
12.1.2) Controls				Steering magnets			200000		
12.1.3) Measurement part				Steering magnets			200000		
13) BENDING MAGNETS	**2**								
13.1) Powering									
13.1.1) Power Electronics			Powering Failure	Bending magnets	0.4	23min ?	100000		Low
13.1.2) Controls				Bending magnets			200000		
13.1.3) Measurement part				Bending magnets			200000		
13.2) Water Cooling				Bending magnets					
14) MODULATORS	**14**			RFQ, Chooper, CCDTL,TL, DTL, BHZ.20					
14.1) Powering									
14.1.1) Power Electronics			Powering Failure		0.4	23min ?	100000		Low
14.1.2) Controls					0.4	23min ?	200000		
14.1.3) Measurement part					0.4	23min ?	200000		
15) KLYSTRONS	**14**			RFQ, DTL, CCDTL, PIMS			50000		

AVAILABILITY MODEL: Assumptions

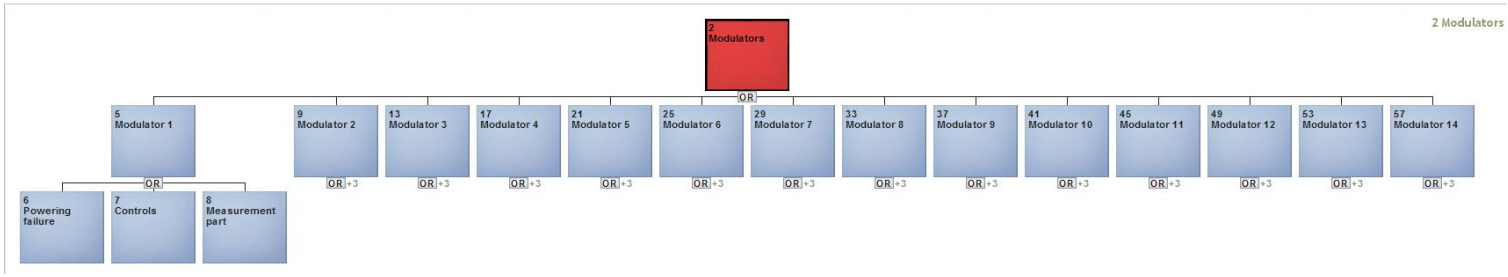
- Data from Failure Catalogue
- Lifetime: 1 year
- Maintenance: Only corrective!
- No operational phases are defined
- One reliability block per failure mode of:
  - 49 Ion pumps
  - 9 Vacuum Valves
  - 49 Quadrupoles
  - 50 Steering magnets
  - 14 Modulators
  - 14 Klystrons

Impact on the results?? 14 Modulators Example

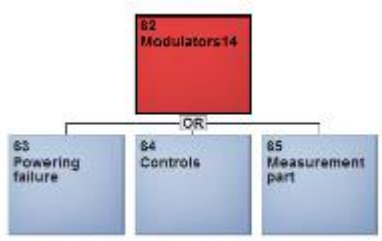
AVAILABILITY MODEL: 14 Modulators example

SECTION: **Linac4**	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)	COMMENTS	SEVERITY (**mitigation)
14) MODULATORS	**14**			RFQ, Chooper, CCDTL,TL, DTL, BHZ.20					
14.1) Powering									
14.1.1) Power Electronics			Powering Failure		0.4	23min ?	100000		Low
14.1.2) Controls					0.4	23min ?	200000		
14.1.3) Measurement part					0.4	23min ?	200000		

1) One reliability box per modulator and failure mode (14 x 3)



2) One reliability block per failure mode of 14 modulator (3)



$MTTF_{14} = MTTF/14$

Approach	Availability	Down time
1	98.889	40d 14h
2	98.867	41d 9h
Difference	**0.022**	**19h**

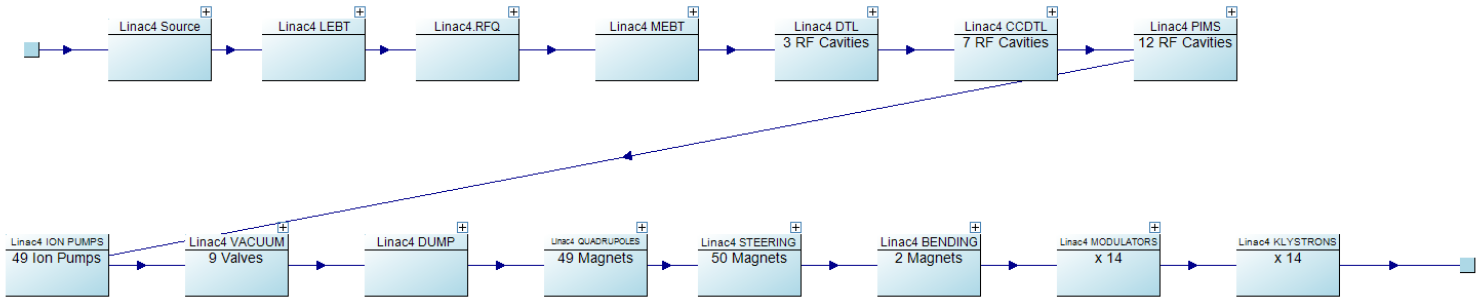
Simulation time: 10 years

AVAILABILITY MODEL: ISOGRAPH

AvSim

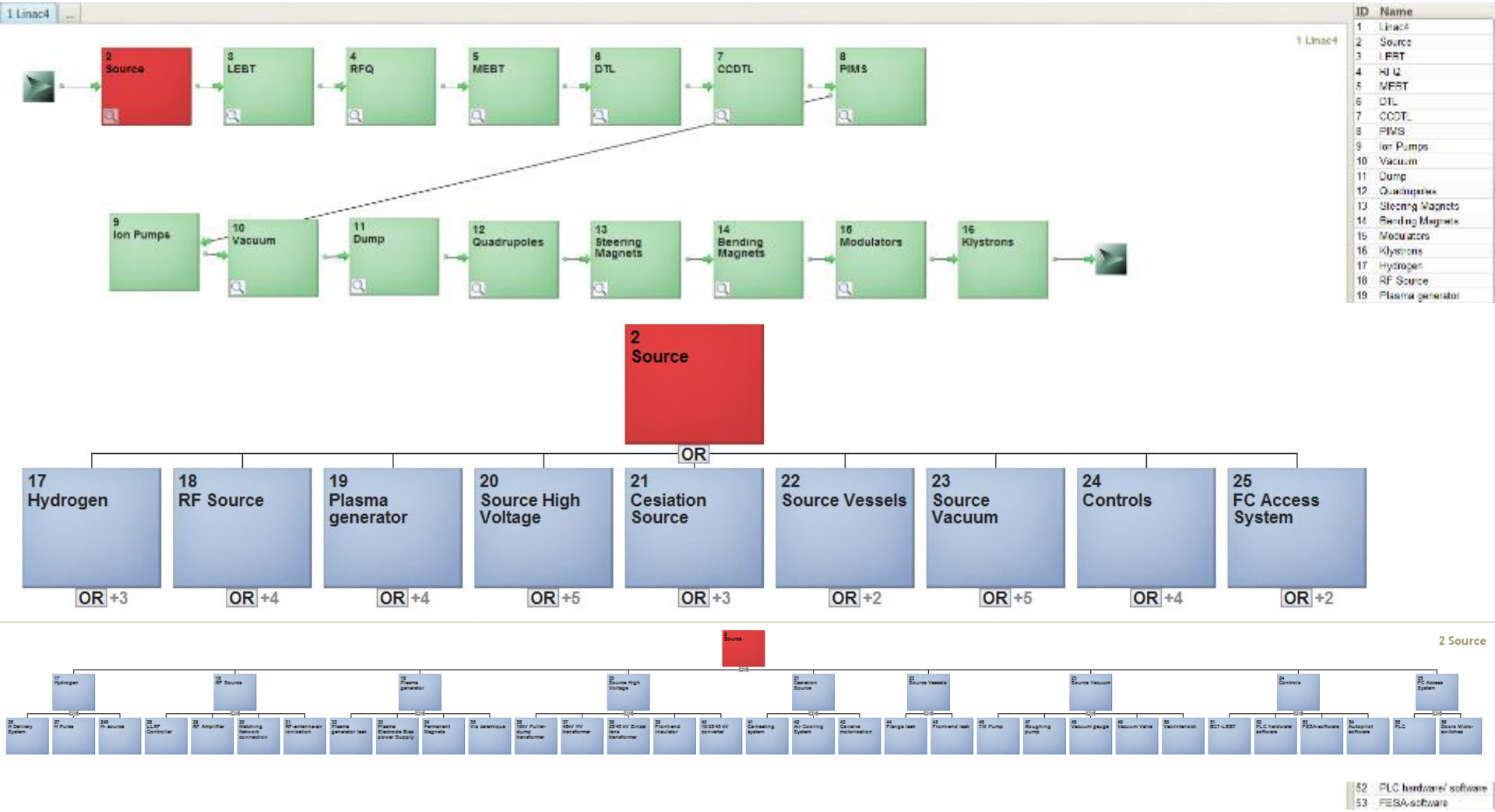
- <ProjectID>
  - RBD Pages
    - Linac4
      - Linac4 Source
        - Hydrogen
        - RF Source
        - Plasma generator
        - Source High Voltage
        - Cesiation Source
        - Source Vessels
        - Source Vacuum
        - Source Controls
        - FC Access system
      - Linac4 LEBT
        - Solenoids:x 2
        - Beam Stopper
        - Pre-Chopper
      - Linac4.RFQ
      - Linac4 MEBT
        - Buncher
        - Chopper
      - Linac4 DTL:3 RF Cavities
        - Linac4 DTL.1.3:Movable tuner
        - Linac4 DTL.2.3:Movable tuner
        - Linac4 DTL.3.3:Movable tuner
      - Linac4 CCDTL:7 RF Cavities
        - Linac4 CCDTL.6.3:Movable tu
        - Linac4 CCDTL.7.3:Movable tu
      - Linac4 PIMS:12 RF Cavities
        - Linac4 PIMS.1.3:Movable tune
        - Linac4 PIMS.2.3:Movable tune
        - Linac4 PIMS.3.3:Movable tune
        - Linac4 PIMS.4.3:Movable tune
        - Linac4 PIMS.5.3:Movable tune
        - Linac4 PIMS.6.3:Movable tune
        - Linac4 PIMS.7.3:Movable tune
        - Linac4 PIMS.8.3:Movable tune
        - Linac4 PIMS.9.3:Movable tune
        - Linac4 PIMS.10.3:Movable tun
      - Linac4 VACUUM:9 Valves
        - Vacuum.4:Sensor
      - Linac4 DUMP
      - Linac4 QUADRUPOLES:49 Magn
      - Linac4 STEERING:50 Magnets
      - Linac4 BENDING:2 Magnets
      - Linac4 MODULATORS:x 14
  - Fault Tree Pages
  - Failure Models
    - LEBT
    - Source
    - RFQ
    - MEBT
    - RF Cavities Failures
    - Ion Pumps:49
    - Vacuum Valves:9
    - DUMP
    - QD Magnets:49
      - QD Powering failure

Diagram | Grid | Plot | Diagram & Grid | Plot & Grid | Libraries | Reports | RBD | Linac4



- Failure Models
  - LEBT
    - Solenoids
      - Powering failure
      - Controls
      - Measurement part
    - BeamStopper
      - BS Mechanical Failure
      - BS Electronic Failure
      - BS Incorrect position
    - Pre-chopper
      - PC Powering Failure
      - PC Wrong Electric Field
      - PC PSB Synchonization
  - Source
    - Hydrogen
      - Hydrogen delivery system
      - Hydrogen pulser
    - RF-source
      - LLRF controller
      - RF-amplifier
      - Network connection
      - RF-antenna-air ionization
    - Plasma generator
      - Generator leak
      - Bias power supply
      - Permanent Magnets
      - Vis ceramique
    - Source High Voltage
      - Puller down transformer:10 kV
      - HV transformer:45 kV
      - Einzel Lens Transformer:25/45 kV
      - Frond-end insulator
      - Converter:10/25/45 kV converter
    - Cesiation source
      - Cs Heating system
      - Air cooling system
      - Cs-valve motorization
    - Source Vessels
      - Flange leak
      - Front-end leak
    - Source Vacuum
      - Tm Pump
      - Roughing pump
      - Vacuum Gauge
      - Vacuum Valve
      - Vac-Interlock
    - Source Controls
      - BCT-LEBT
      - Source controls failure:- PLC Hardware/software- FESA-software- Autopilot
  - FC Access System
    - Doors Micro-switches
    - PLC
  - RFQ
    - RFQ Wrong Field
  - MEBT
    - Buncher
      - Powering Failure in Buncher
      - Wrong EM Field in Buncher
      - Wrong Phase in Buncher
      - Movable tuner not working
      - Vacuum Leak
    - Chopper
      - Powering Failure in Chopper
      - Wrong EM Field in Chopper
      - Synchronization
  - RF Cavities Failures
    - MovableTuner not working
    - Wrong Phase
    - Wrong EM field
    - Vacuum leak in the cavity
    - Wrong voltage for energy painting:PIMS Modules 11-12
  - Ion Pumps:49
    - Ion Pumps Powering failure
  - Vacuum Valves:9
    - Valves Vacuum Leak
    - Mechanical failure:Compressed air system + Vacuum Leak
    - Electronics failure
    - Valve closes (not asked)
    - Valve not closed (when asked)
  - DUMP
    - Dump Vacuum Leak
    - Core Failure
    - Dump Air Leak
  - QD Magnets:49
    - QD Powering failure
    - QD Controls failure
    - QD Measurement failure
  - Steering Magnets:50
    - ST Powering failure
    - ST Controls failure
    - ST Measurement failure
  - Bending Magnets:2
    - BD Powering failure
    - BD Controls failure
    - BD Measurement failure
  - Modulators:14
    - MO Powering failure
    - MO Controls failure
    - MO Measurement failure
  - Klystrons: 14
    - Klystron Failure
  - Water Cooling
    - Water Cooling Failure

AVAILABILITY MODEL: ELMAS



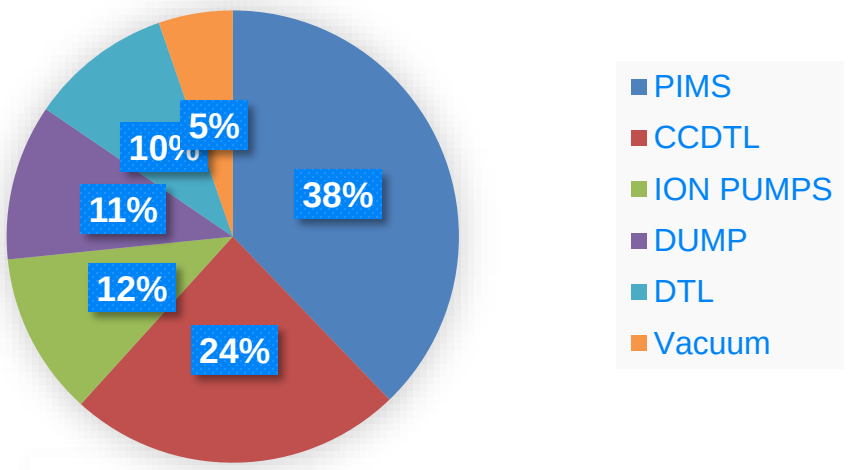
- Component data input text files for Isograph and ELMAS
- Changes in the failure catalogue automatically done in input files

AVAILABILITY MODEL: FIRST RESULTS

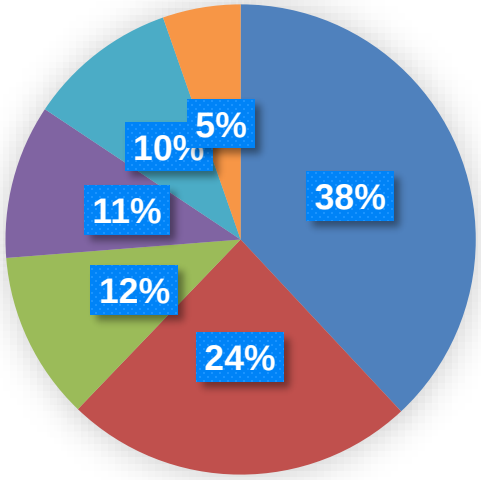
Linac4	Isograph	ELMAS
Availability	%80.53	% 80.62
No. of system failures	1923	1918
Mean Down time	1706 h	1698 h
MTTR	0.8868 h	0.8845 h
Simulation time	~ 35 min	2.1 s

CONTRIBUTORS TO Linac4 DOWNTIME

Isograph



ELMAS



NEXT STEPS

- Complete Linac4 failure catalogue
- Update Availability models in Isograph and ELMAS
- Build Availability model in AvailSim 3.0 (waiting for first version)
- Run Simulations. Compare results.
- Proposal for a common input format of models.

Thanks a lot for your attention!

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