GANIL:
FROM THE BEGINNING 40 YEARS AGO TO RECENT RESULTS AND PROSPECTIVE

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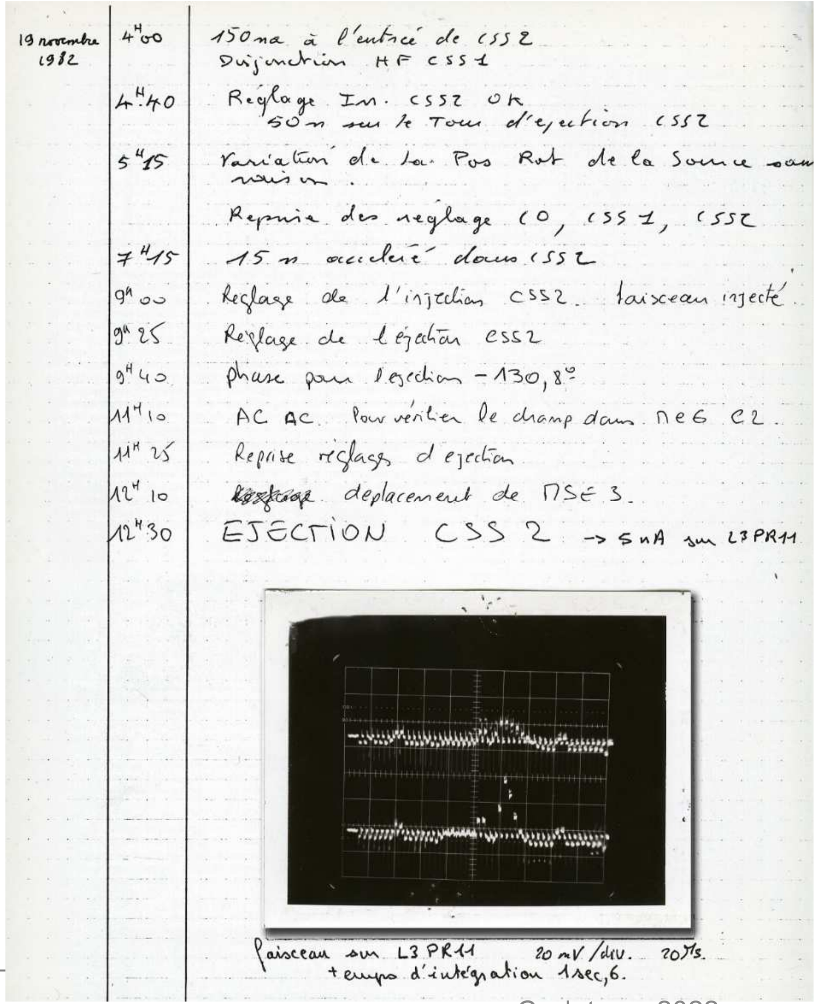
And the GANIL staff

A few days (and 40 years) ago : First beam from SSC2

November 19th, 1982 :
Output C02 : 2 µA
200 nA ejected from CSS1

Ar^{4+} stripped into Ar^{16+}

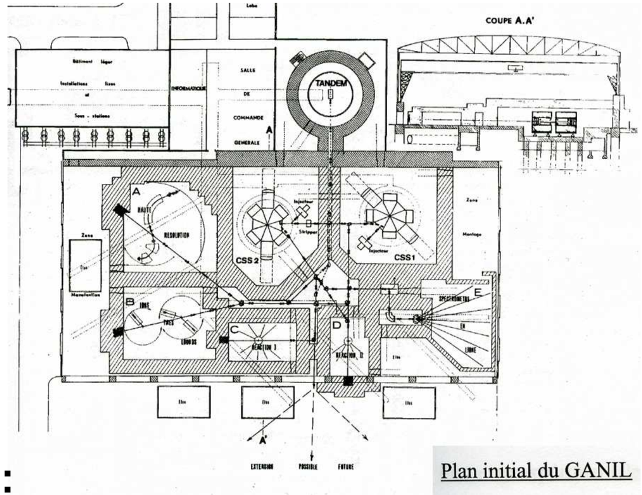
4h : 150 nA entrance SSC2
7h15 : 15 nA accelerated
12h30 : 5 nA <u>ejected from CSS2</u>



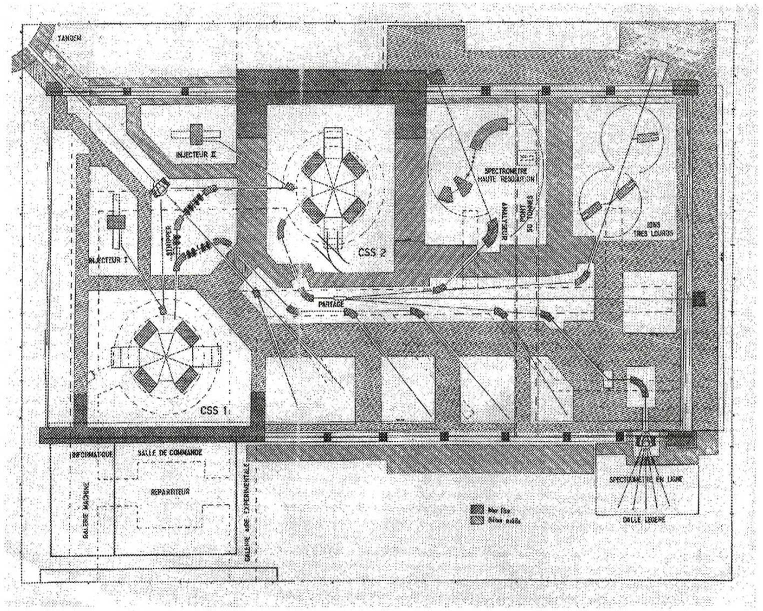
Design

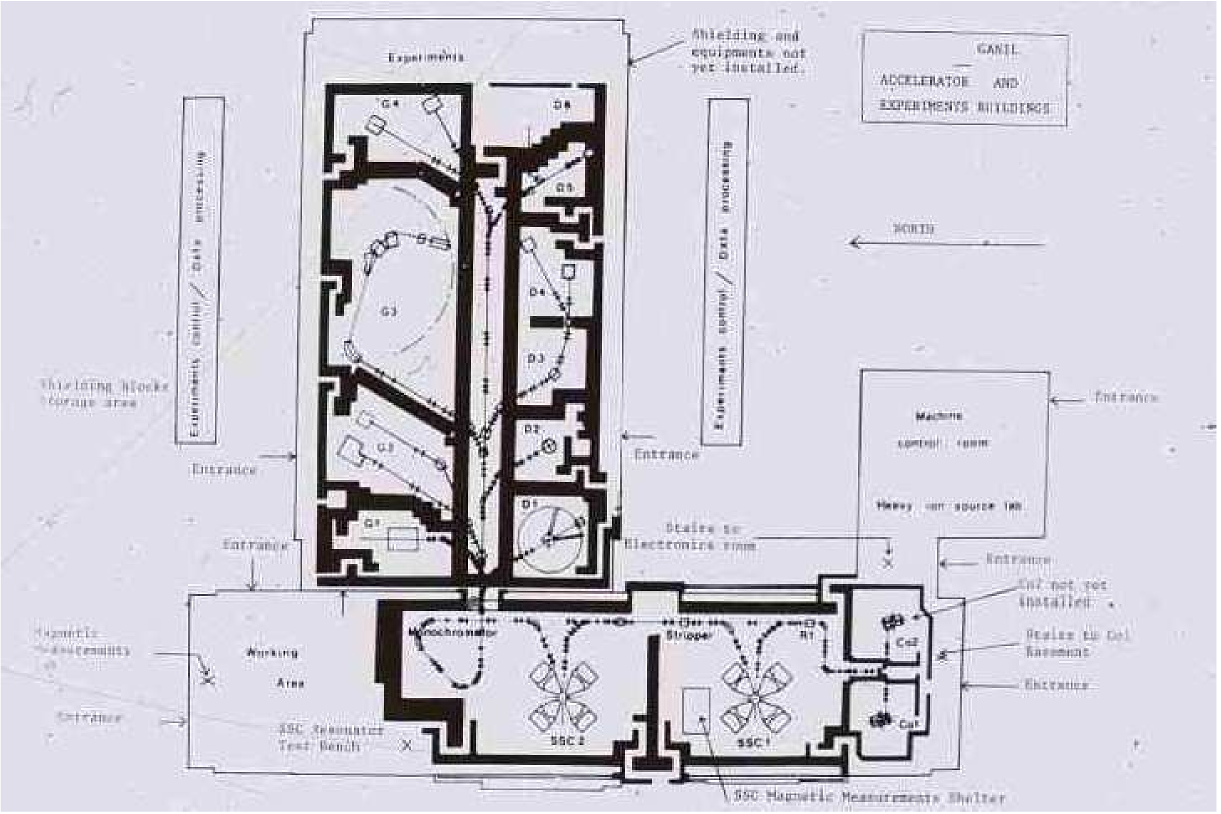
laboratoire commun CEA/DRF CNRS/IN2P3

1973 :



1975 :

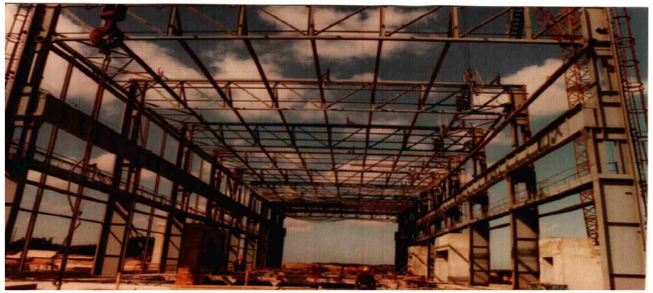


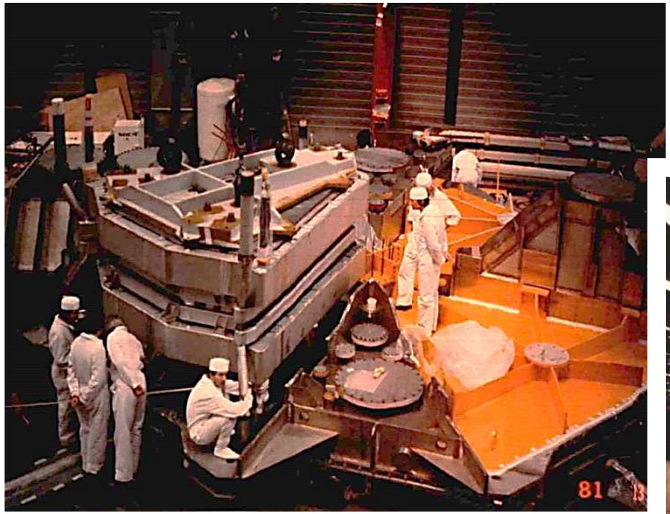


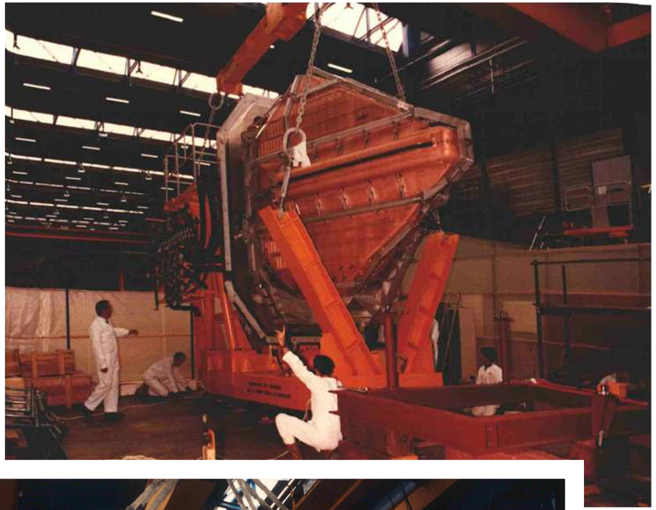
1977

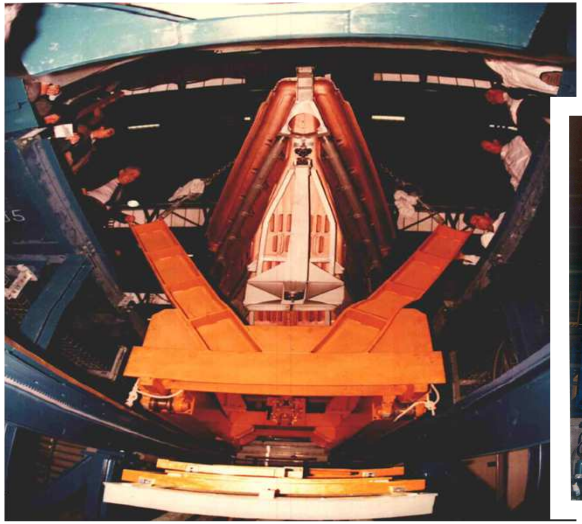
Final design

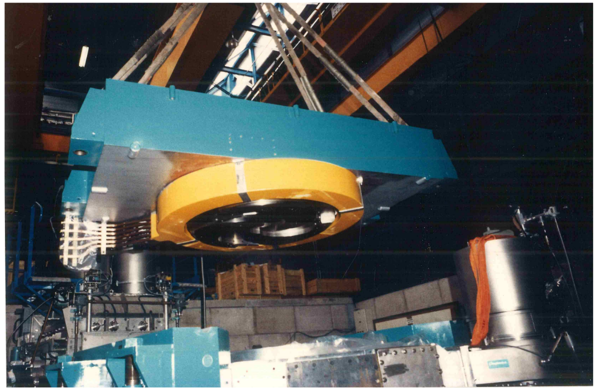
The building of the facility (1978 – 1982)



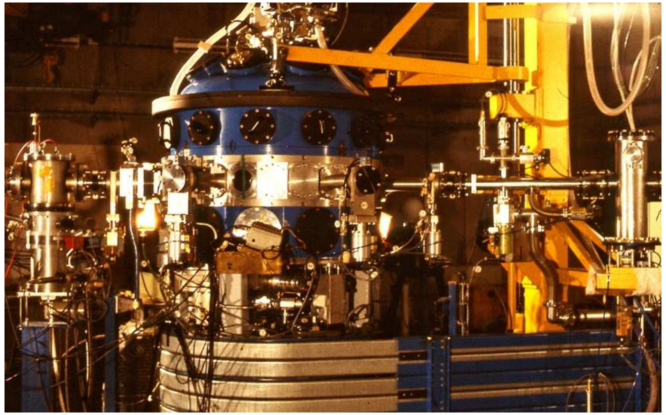






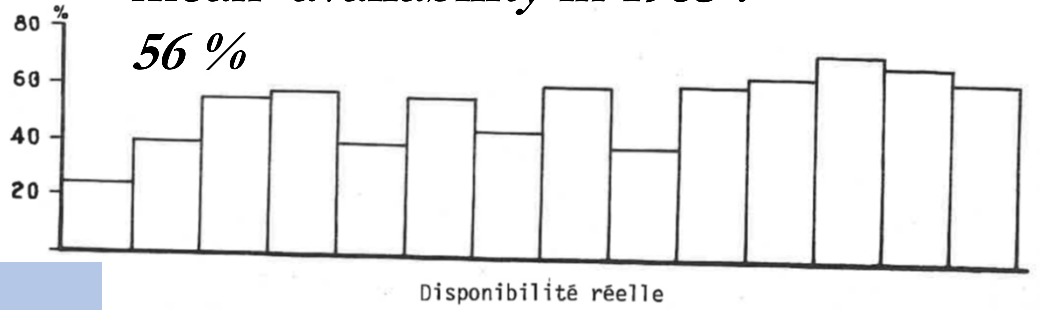


Beginning of operation

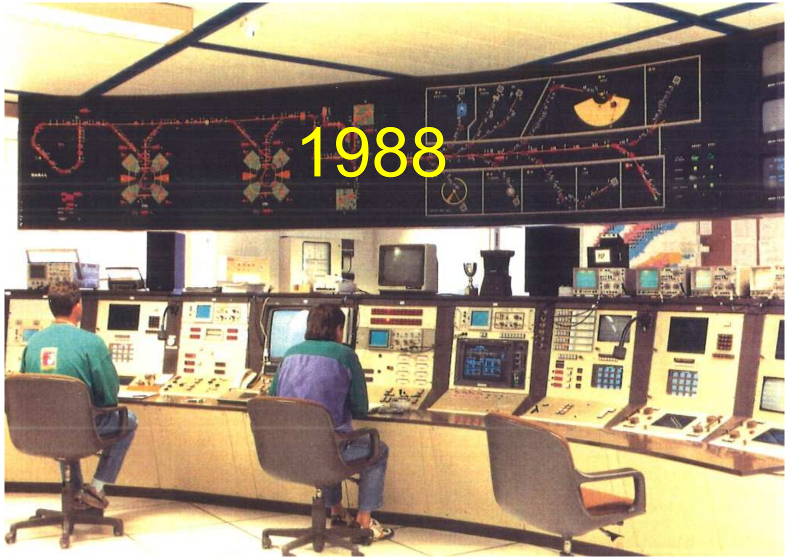


January 1983 :
1st experiment

mean availability in 1983 :
56 %



1st beams :
^{16}O @ 95 MeV/A
^{20}Ne @ 44 MeV/A
^{40}Ar @ 27, 44 and 60 MeV/A
^{84}Kr @ 35 MeV/A



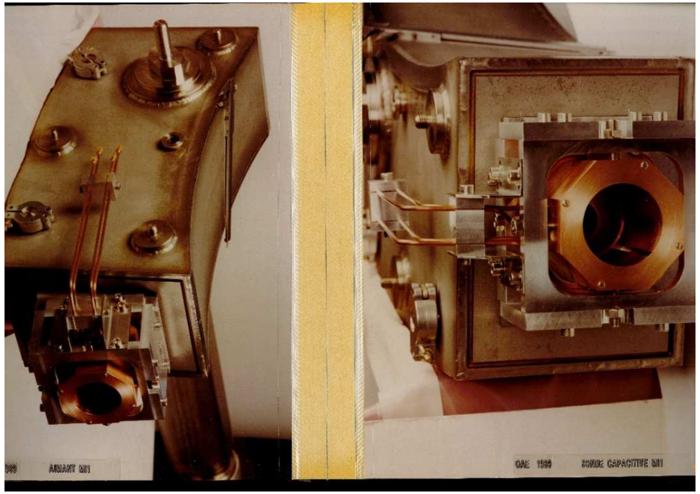
1989: Opération Augmentation de l'Energie (OAE project)

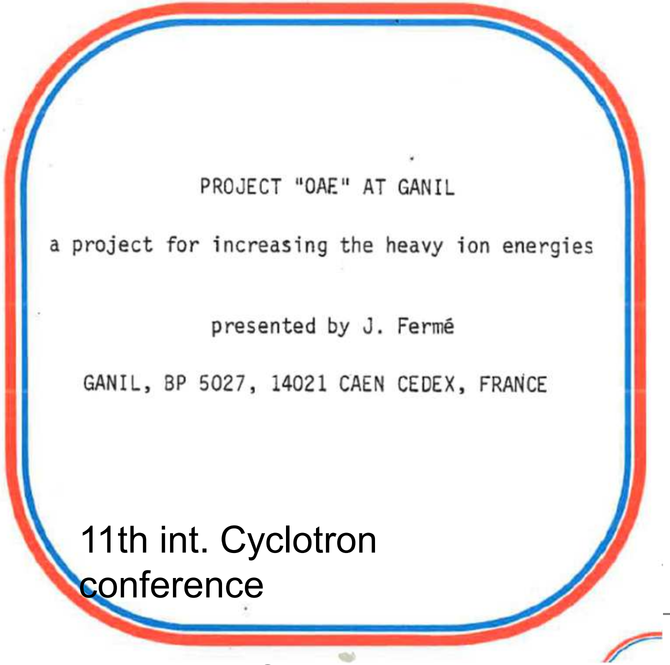
The stripping efficiency was very bad at the beginning :

- Maximal energy 45 MeV/A for Kr, 25 for Xe (heavier beam accelerated)
- increase of the injection radius of SSC2 => increase of SSC1 energy
- New harmonics : SSC1 5 (previously : 7), SSC2 2

After OAE : Kr @ 60 MeV/A, Xe @ 50 MeV/A, U @ 24 MeV/A

New injection elements in SSC2





PROJECT "OAE" AT GANIL

a project for increasing the heavy ion energies

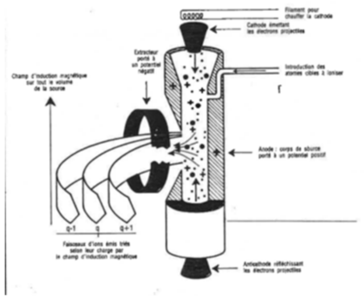
presented by J. Fermé

GANIL, BP 5027, 14021 CAEN CEDEX, FRANCE

11th int. Cyclotron conference

Jacques Fermé (left)

Ion sources Evolutions



PIG

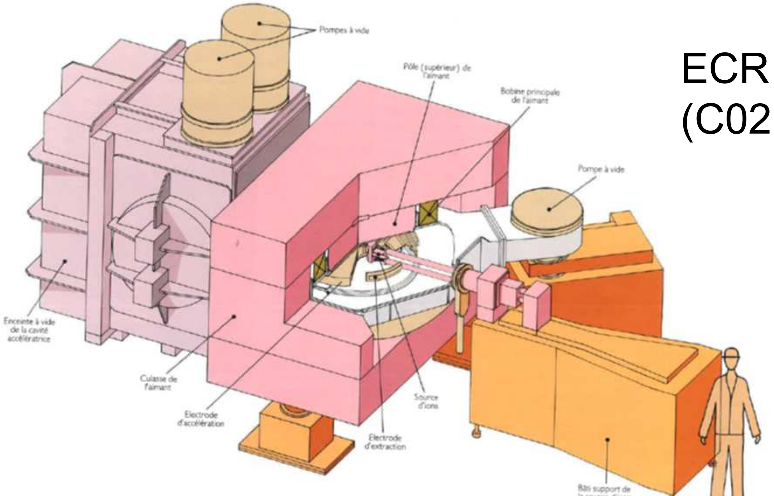
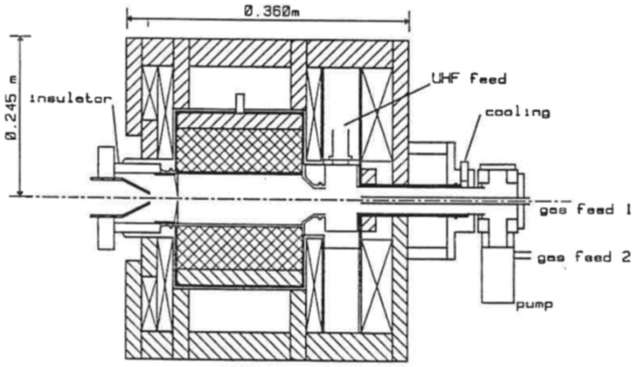
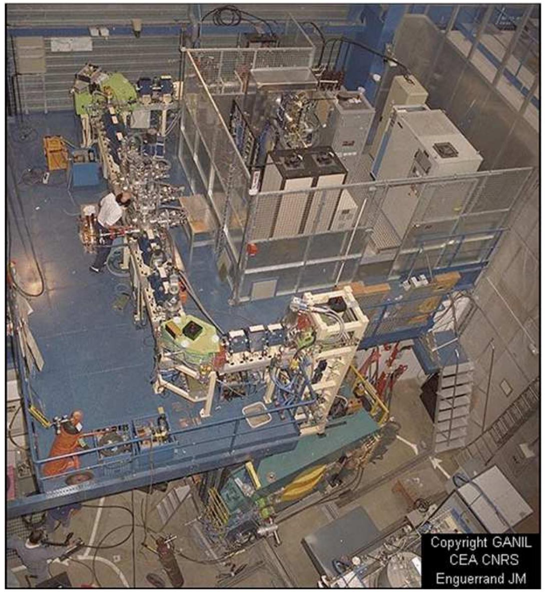


Schéma montrant les principaux éléments d'un injecteur Co

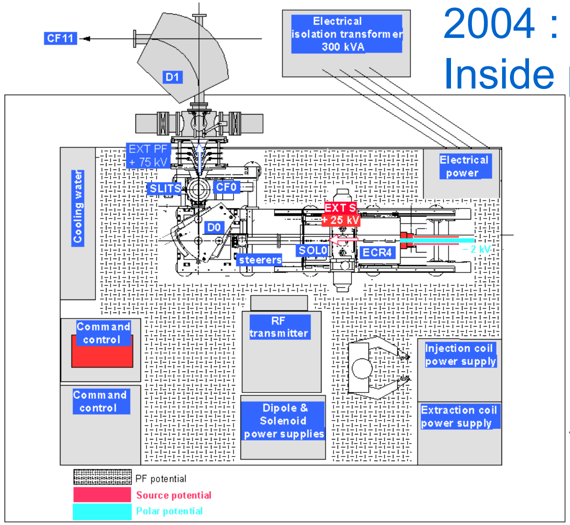


ECR on injector 2 (C02) : 1985



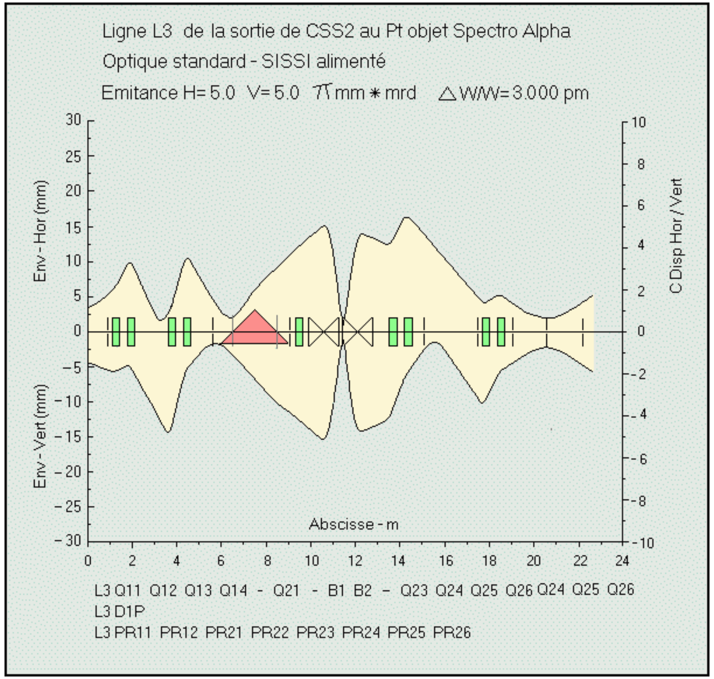
100 kV platform on injector 1 (C01) : 1992

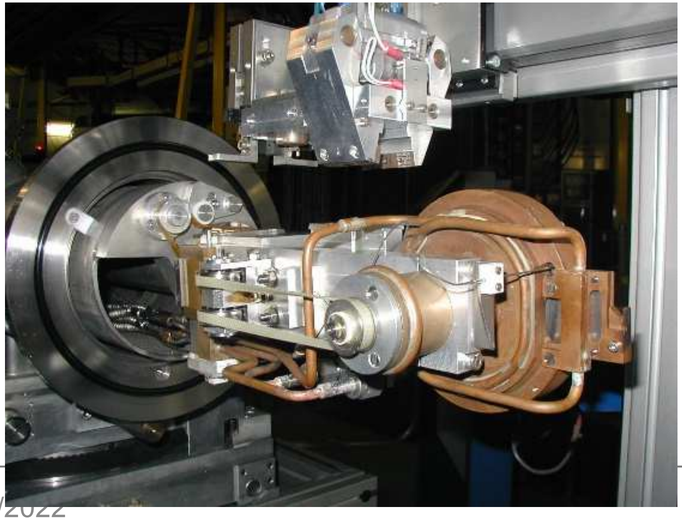
2004 : beam pre-selection Inside platform



The first radioactive beams : SISSI

Two superconducting solenoids

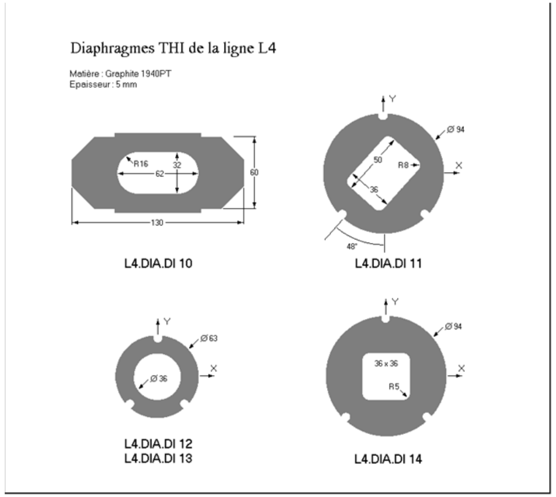




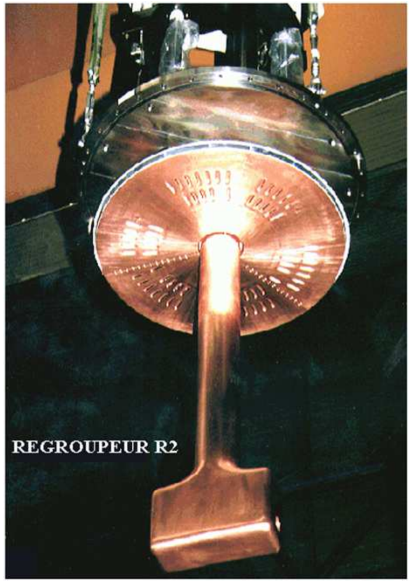
cooled, rotated target (1 KW deposited power)

To high intensity : the THI project : 6 kW

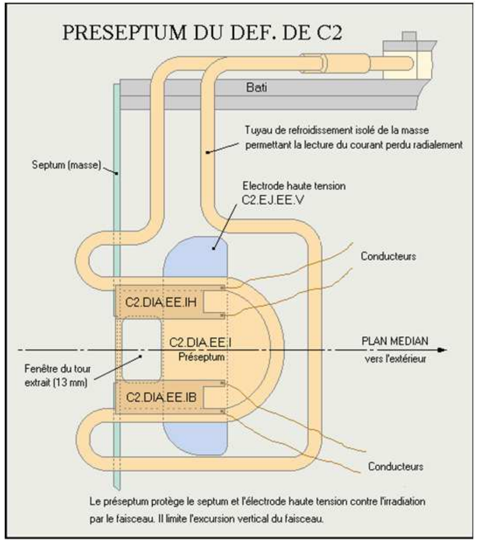
Beam loss monitors

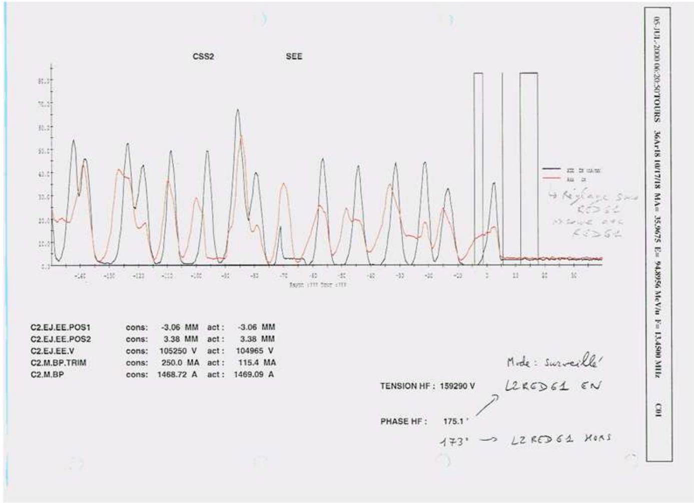


Second Rebuncher



New SSC2 deflector





December 2001 :
36Ar 95 MeVA,
26 µA (5 kW)

1995 – 1998 : SPIRAL 1

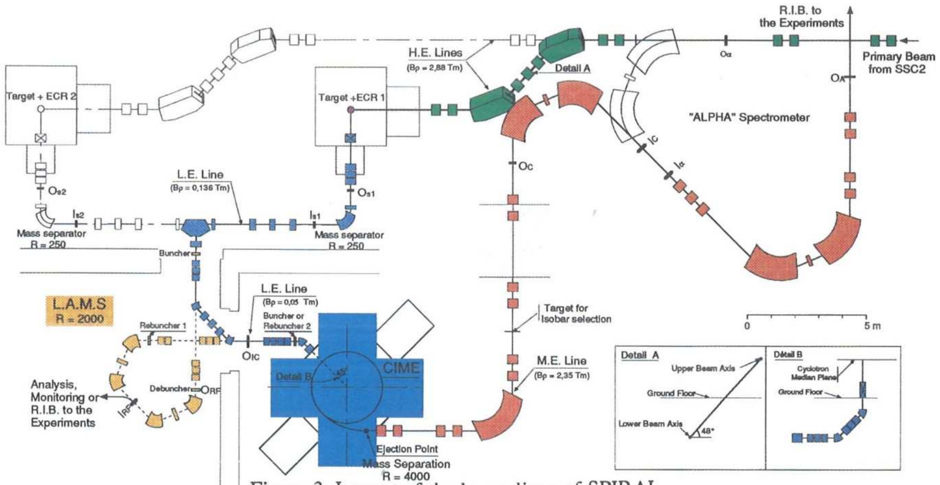
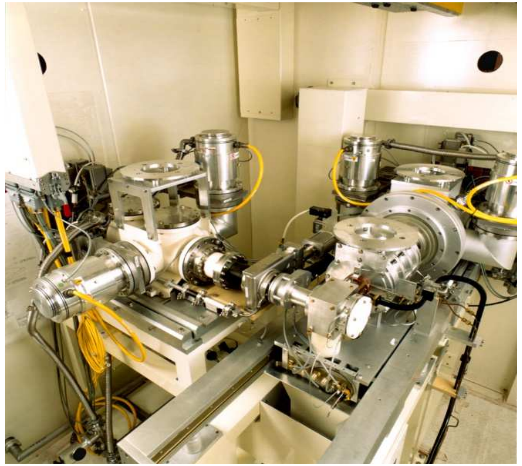
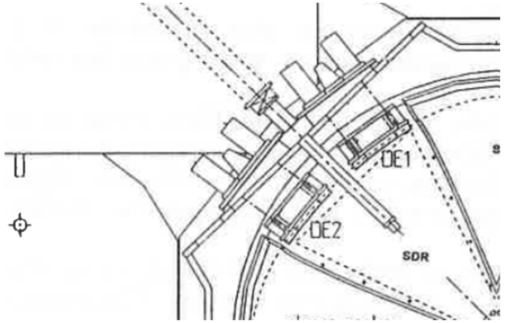


Figure 3. Layout of the beam lines of SPIRAL.

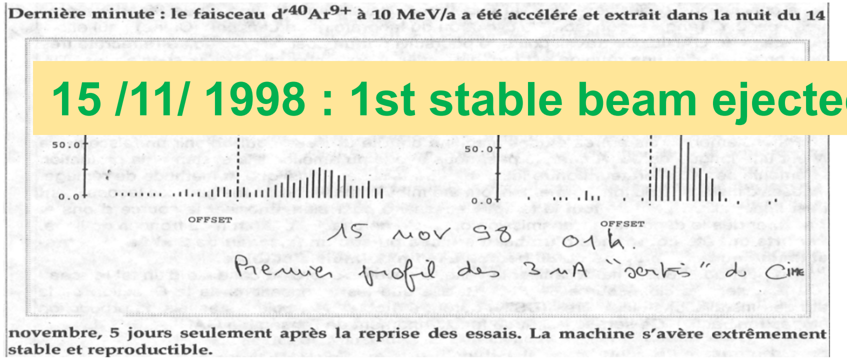


1997 - 1998 : 1st beam tests in CIME

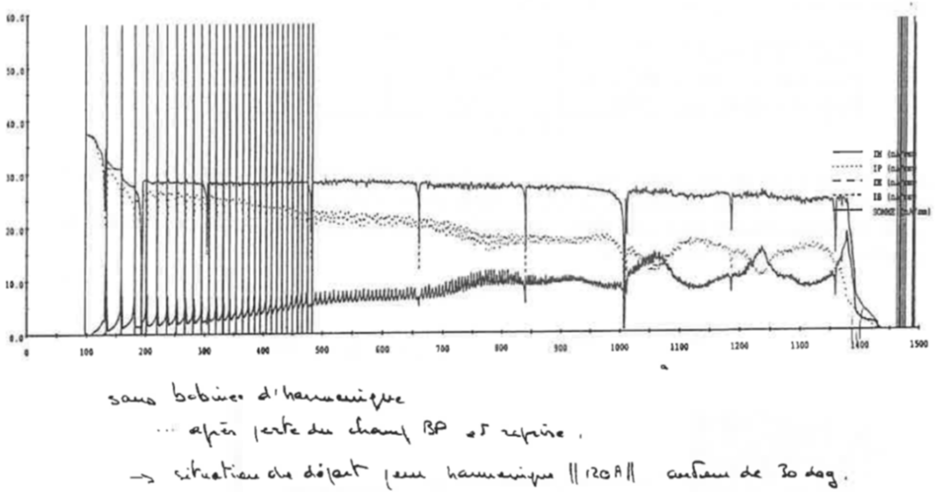


December 22th, 1997 :
1st beam accelerated
Very low intensity measured on the radial probe between the two parts of the deflector

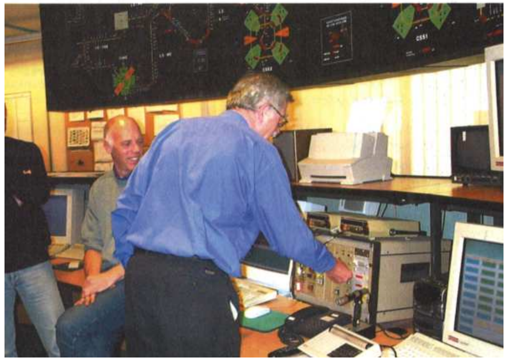
It was understood that the magnetic field was not equilibrated in the 4 sectors :
Installation of magnetic coils to compensate this effect

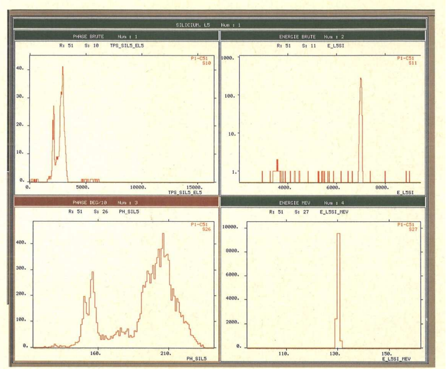

Dernière minute : le faisceau d'$^{40}Ar^{9+}$ à 10 MeV/a a été accéléré et extrait dans la nuit du 14 novembre, 5 jours seulement après la reprise des essais. La machine s'avère extrêmement stable et reproductible.

But it was not the beam ! (the radial probe moving through the electric field measures a current without beam)

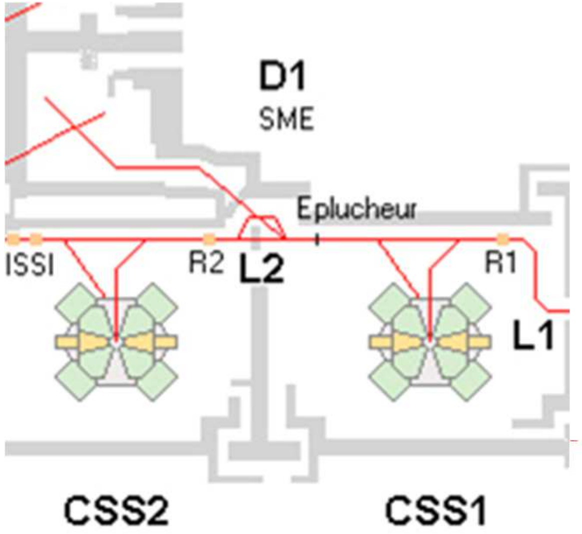


sept 27th, 2001 : 1st radioactive beam

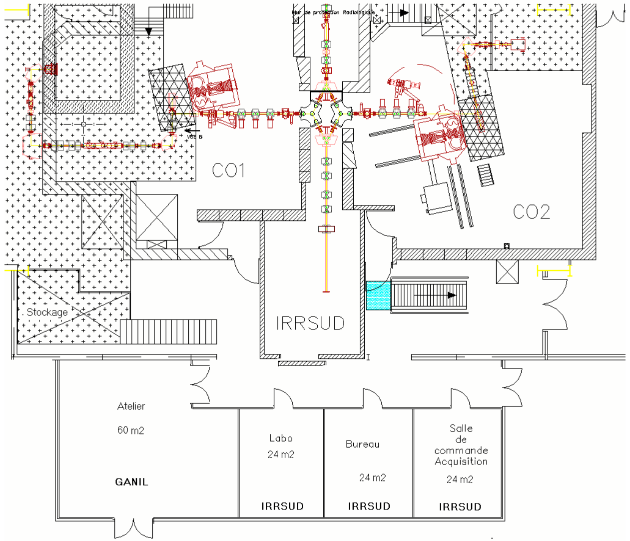




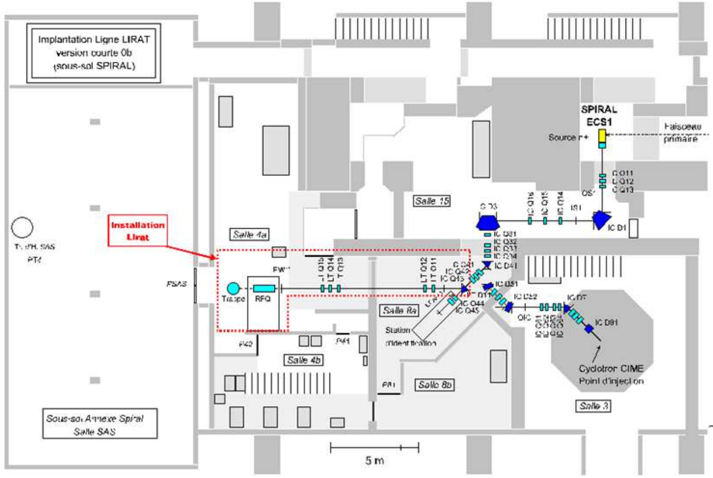
1989 : SME



2002 : IRRSUD

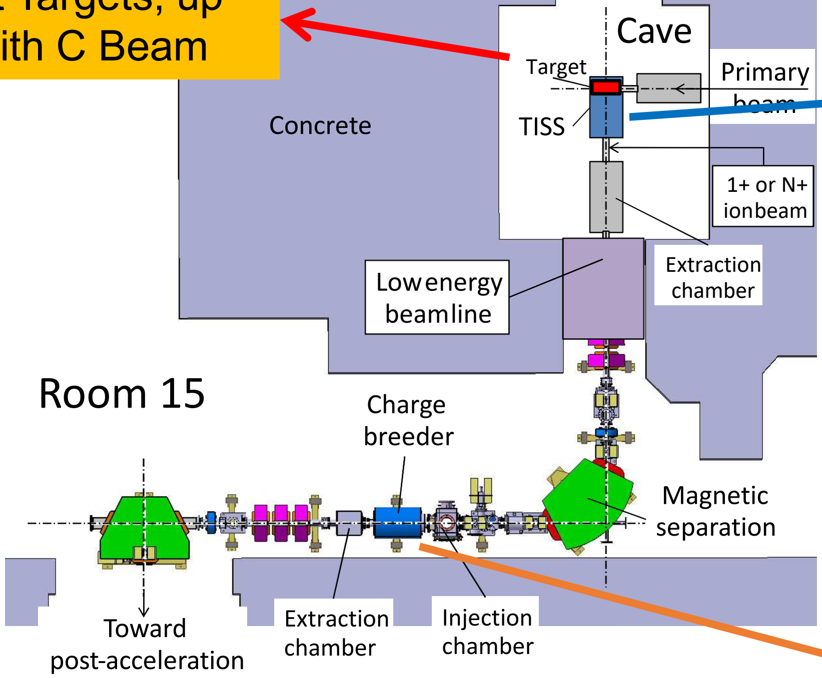


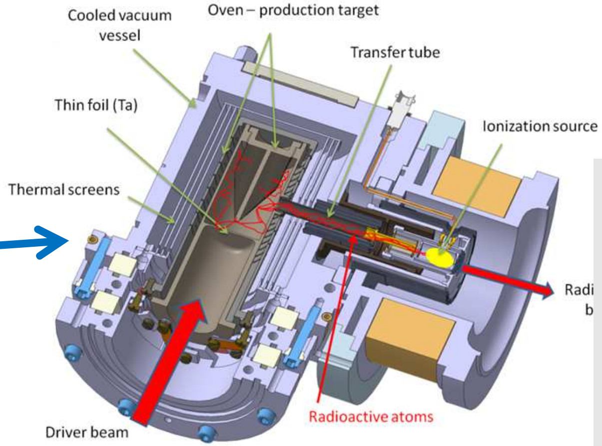
2005 : LIRAT



2018 : New SPIRAL1

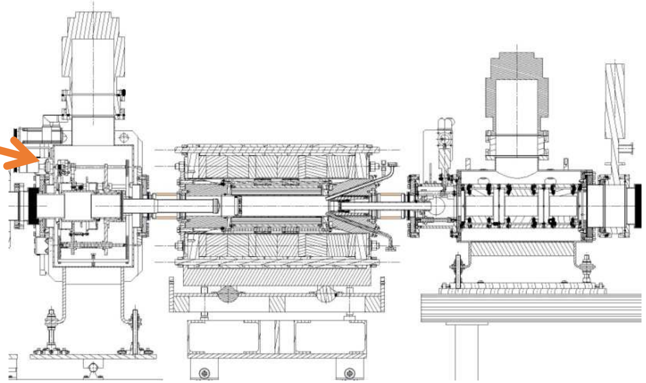
Different Targets, up to Nb, with C Beam

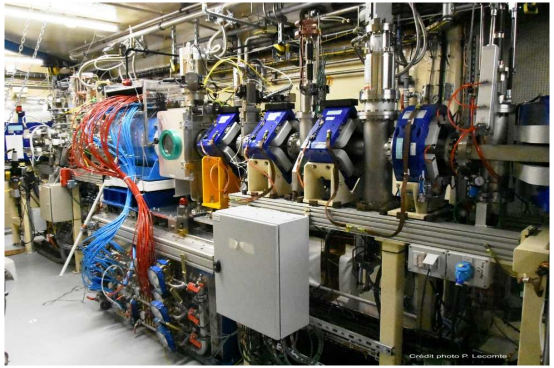




FEBIAD 1+ Source

- Non selective source : Mg, Ca, Sc, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ce, As, Se, Al
- But no acceleration by CIME (Q/A too low)



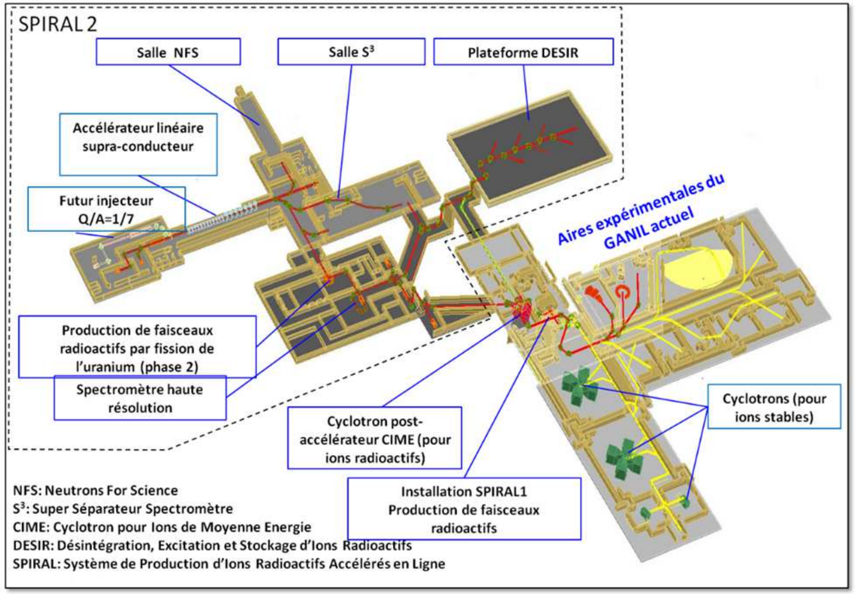


Further requirement : Still possible to use ECR N+ source, beam passing through the booster

Charge breeder

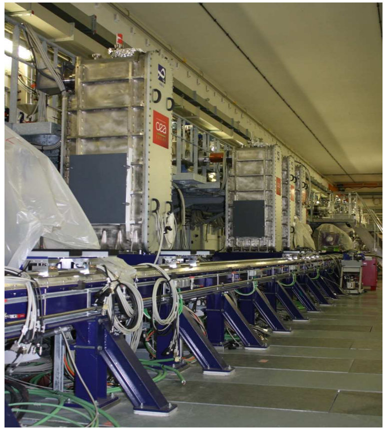
SPIRAL2 Project

2005 : Project launched

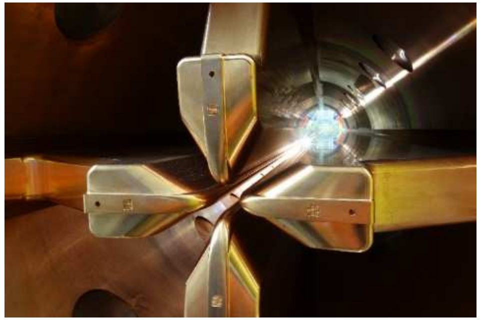


Original project, including post-acceleration of fission products in CIME

2011 : excavation

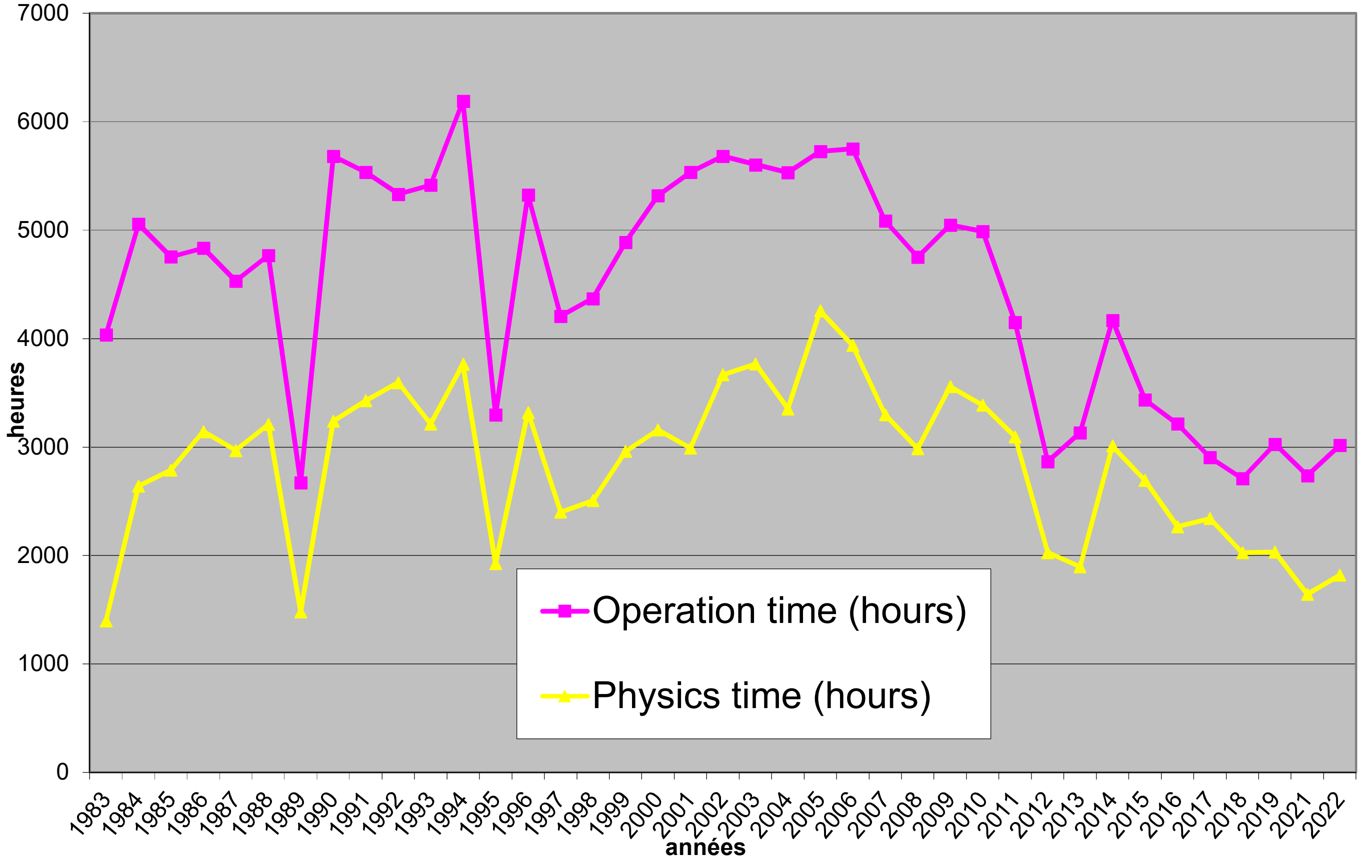


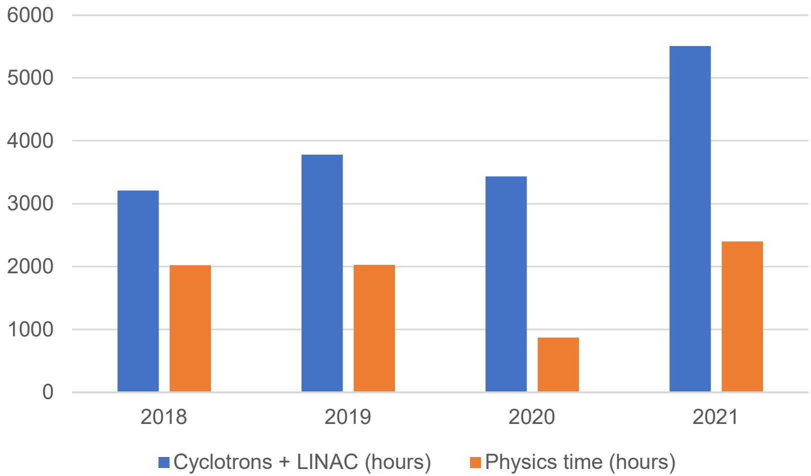
2015: 1st beam in RFQ



October 28th, 2019 : 1st beam in the LINAC

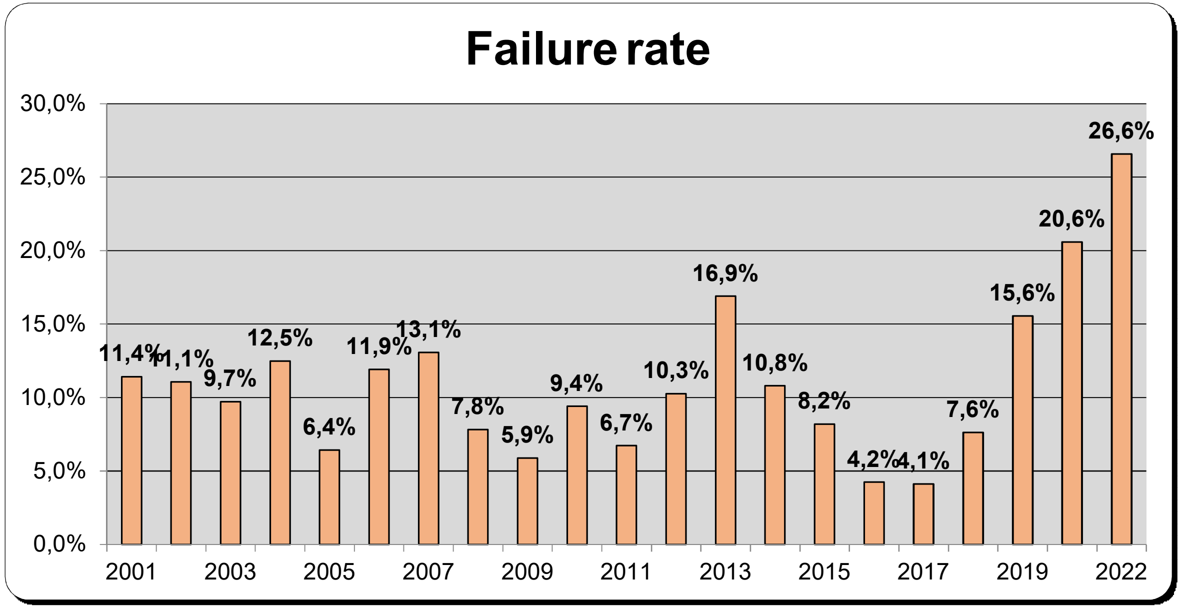
OPERATION 1983 – 2022 (cyclotrons)





LINAC + CYCLOTRONS 2019 - 2021

Failures (cyclotrons)



Mainly due to Water leak Inside the machine (cavity, injection elements, beam line – slits, diagnostics, …)

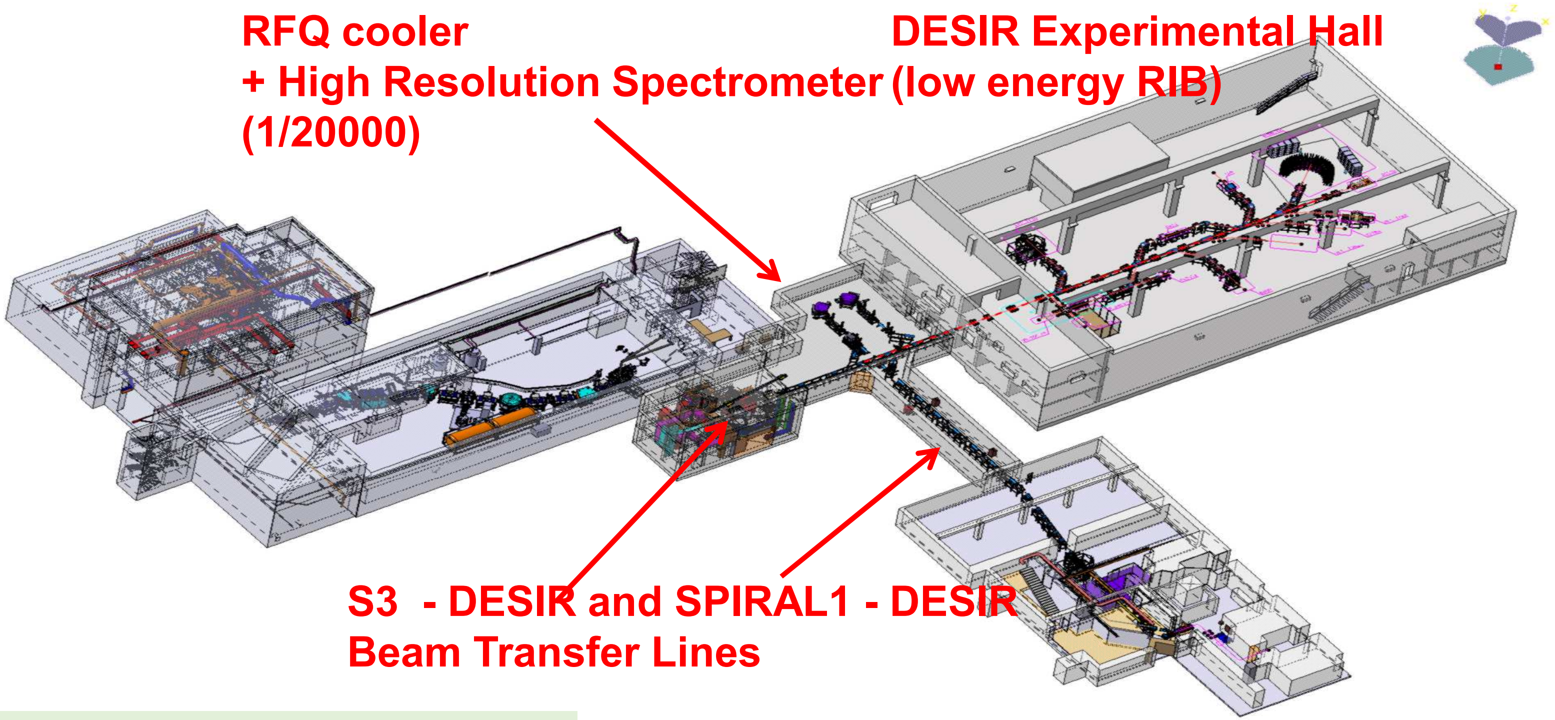
And for the future ?

DESIR (Decay, Excitation, Storage of Radioactive Ions) Facility

The French Safety Authority has authorized the construction

Public Enquiry in March-April 2023

Construction should begin in June 2023



Beam lines are ready, waiting to be installed

And for the future ?

- Next years : Still more demand than time available for cyclotrons

- LISE spectrometer with SSC2 beams
- Post-accelerated SPIRAL1 new beams
- Fusion reactions (SSC1 beams)
- Industrial applications

- Tomorrow : DESIR with SPIRAL1 (^{21}Na, ^{23}Mg, ^{33}Cl, ^{37}K, ^{39}Ca, ^{41}Sc …)

=> Cyclotrons to be still operated in 15 – 20 years

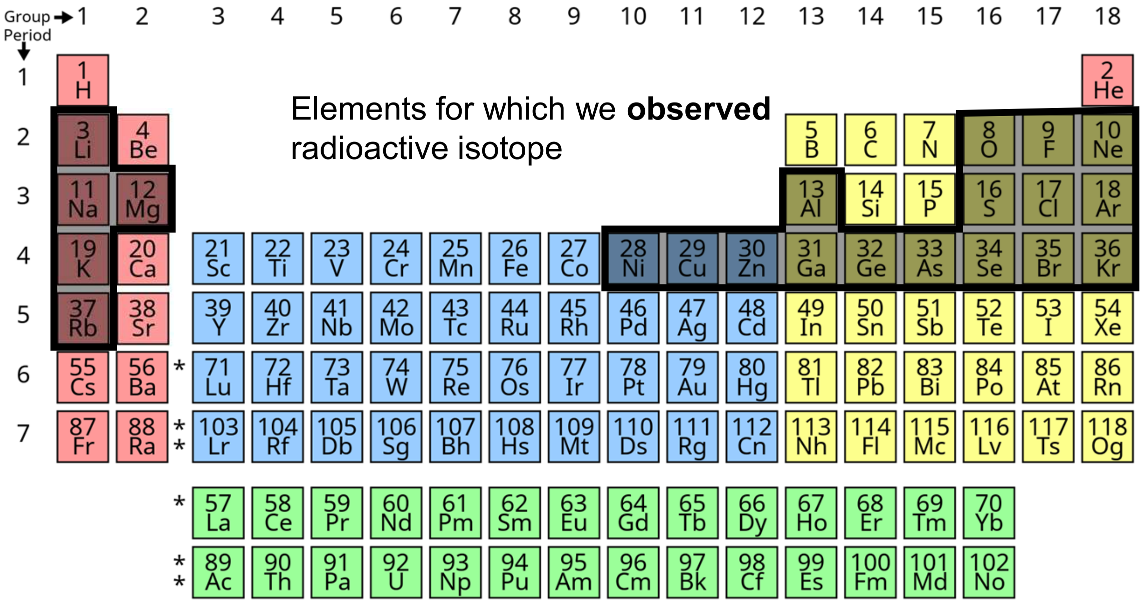
Developments of secondary beams
1 : FEBIAD 1+ source

Phase	Objectives Project	2019 $^{38m}K^{9+}$ 9MeV/A	2021 $^{47}K^{10+}$ 7MeV/A
1+ ionization	10%	**> 5%**	**>15%**
1+ to N+ transport	80%	>80%	>80%

FEBIAD has been used in line in alkali mode : post accelerated beams : ^{38m}K (2019), ^{47}K (2021)

It has been fiabilized (cooling of the insulators) and many tests have been made

- ≈80 radioactive isotopes/isomers **seen**, including 50+ at post-accelerable intensities (>10^5pps).



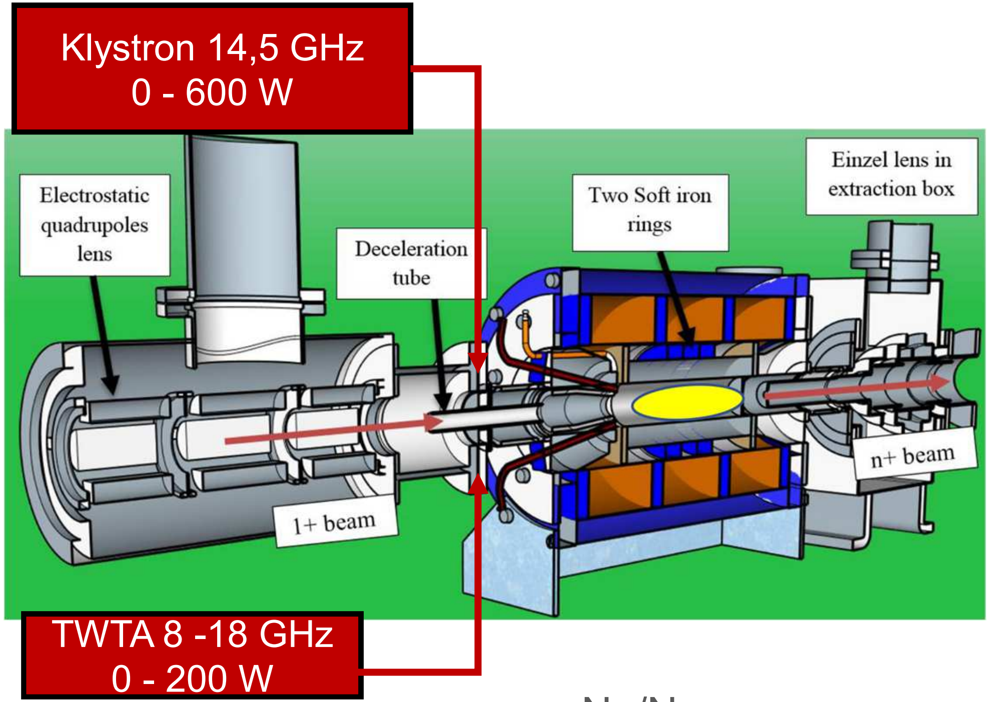
36Ar@74MeV/A 850W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@1200W
8	8Li	0.84	1.00E+05
20	20Na	0.4479	1.38E+06
21	21Na	22.49	1.13E+07
	1H20F	11	3.90E+04
23	23Ne	37.25	1.43E+06
	23Mg	11.3046	4.27E+06
24	24Ne	202.8	2.18E+05
	24Na	53989.2	9.29E+07
	24Na_m	0.0202	2.87E+05
	24Al	2.053	9.47E+02
25	25Al	7.183	3.80E+04
	25Na	59.1	8.67E+06
	25Ne	0.602	6.52E+03
	25Na 100V	59.1	8.00E+06
26	26Na	1.07128	2.21E+05
	26Al_m	6.346	9.22E+04
27	27Mg	567.5	2.62E+06
28	28Al	134.7	3.27E+06
29	29Al	394	1.14E+06
	29Mg	1.3	2.27E+03
30	30Al	3.62	1.30E+03
31	31Cl	0.19	8.05E+02
	C19O	26.91	1.92E+03
32	32Ar	0.098	1.16E+03
	32Cl	0.298	8.52E+04
33	33Ar	0.173	9.81E+04
	33Cl	2.511	2.21E+06
34	34Ar	0.8438	7.02E+06
	34Cl	1.5266	2.39E+07
	34mCl	1919.4	7.90E+07
35	35Ar	1.7756	1.54E+08
	H34mCl	1919.4	1.89E+07

84Kr@67MeV/A 10W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@500W
80	80Rb	34	7.13E+07
79	79mKr	50	3.28E+07
	79Kr	126144	6.39E+07
	79Rb	1374	1.14E+07
	79mBr	4.85	8.17E+06
78	78mRb	344.4	1.98E+06
	78Rb	1059.6	3.89E+05
	78Br	387	4.69E+07
77	77Rb	226.8	5.20E+05
	77Kr	4275	2.81E+07
	77mBr	256.8	5.29E+07
	77Br	205344	7.59E+07
	77mSe	17.36	3.08E+04
76	76Rb	36.5	2.37E+04
	76Kr	53280	7.21E+06
	76Br	58320	6.00E+07
	76mBr	1.31	1.53E+06
75	75Kr	276	8.03E+05
	75Br	5802	4.26E+07
	75Ga	126	1.22E+04
	75Ge	4966.8	1.98E+05
71	71Se	284.4	2.63E+04
	71As	235080	2.26E+07
	71Zn	147	1.96E+04
	71mZn	14256	1.67E+05
69	69As	912	1.86E+05
	69Ge	140580	1.39E+07
	69mZn	49521.6	2.66E+06
	69Cu	171	4.22E+04
68	68mCu	225	7.03E+04
	68Ga	4062.6	1.42E+07
67	67Ge	1134	1.74E+05
	67Ga	281810.88	4.42E+07
65	65Ga	912	6.92E+06
	65Ni	9061.884	4.53E+04

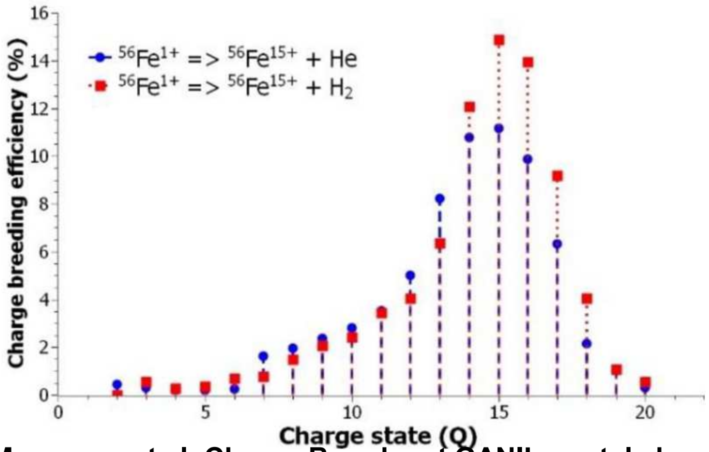
48Ca@60MeV/A 200W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@700W
37	37S	303	9.27E+04
42	H41Cl	38.4	3.50E+05
	42Cl	6.8	3.23E+05
	42K	44496	6.24E+08
43	43Cl	3.3	6.84E+04
	43Ar	322.2	3.92E+07
45	45Ar	21.48	5.68E+06
	45K	1038	4.95E+08
47	47K	17.5	2.67E+08

Developments of secondary beams
2 : SPIRAL1 Charge breeder

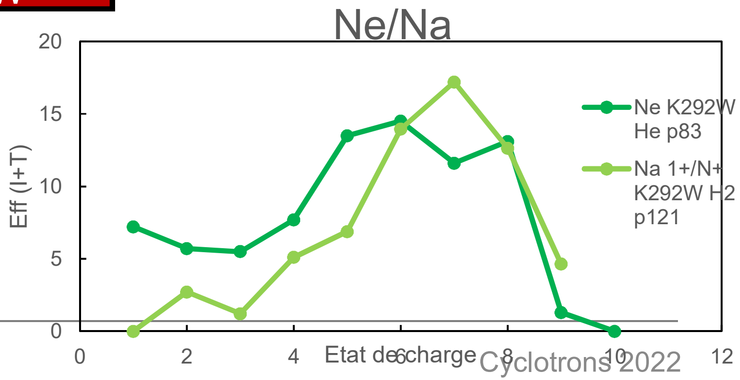
Phase	Objectives Project	2019 $^{38m}K^{9+}$ 9MeV/A	2021 $^{47}K^{10+}$ 7MeV/A
Charge Breeding	5-10%	**1.5%**	**8%**
Extraction N+	50%	80%	80%



Plasma in the Charge breeder heated by:
- The historic fixed frequency Klystron
- A variable frequency Travelling-Wave Tube Amplifier



L. Maunoury et al, Charge Breeder at GANIL: metal charge-bred elements, Journal of Physics: Conference Series 2244 (2022) 012066



Renovation program

Pre project
CYclotrons REN ovation

➢ ***Objectives of the project***

to keep the facility in operational conditions for at least 20 years

Cyclotrons and experimental caves

Power Supplies and Magnets
RF cavities and systems
Remote control
PLCs
Vacuum systems
Diagnostics
Production targets
Ions Sources

Infrastructures and utilities

Electricity Distribution
Cooling systems
HVAC
Buildings
Various networks (water, air, gas)
Computer Infrastructures

Safety / Security / Radioprotection Systems

Radioprotection devices *(radiation detectors, active dosimeters, gamma spectrometers, …)*
Access Management System
Fire Safety System

WHAT IS TO BE DONE ?

THE MAIN TOPIC : RF CAVITIES

Risk : cooling circuit leak, unreachable for repairing

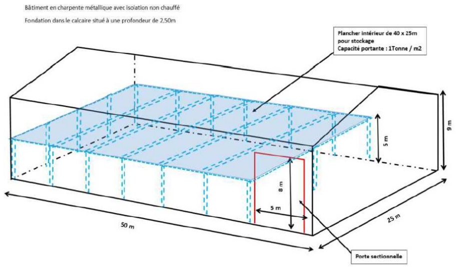
➔ **At least, manufacturing of a new cavity and keeping an old one as a spare : Reference scenario**

➔ **Replace the 4 SSC RF cavities : HIGH scenario**

40 years ago

Issues to be assessed

- ***Sourcing***
  - ✓ At least one company able to manufacture a SSC RF cavity
  - ✓ Evaluated cost : **5,7 M€** first cavity, 4 M€ each other
  - ✓ Manufacturing delay : **2 years** first cavity then 1 cavity per year
- ***RF characterization*** of the new cavity
  - ✓ **8 months**
  - ✓ No test stand available => qualification in a SSC cave
- ***Storage conditions*** of the spare cavity
- ***Handling issue :*** How to take a cavity out of a cyclotron cave and out of the building



New 2200 m² storage building
(not only for spare cavity)

assembly area

OTHER MAJOR TOPICS

Power Supplies

REF scenario

~4 M€ 11,5 FTE

360 PS over 30 years old to refurbish or replace

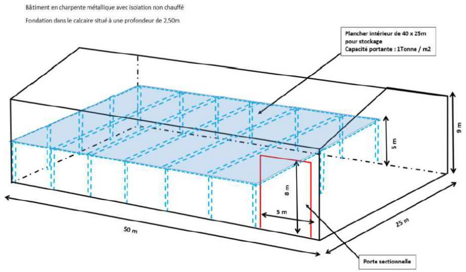
Radiation detectors

REF scenario

~2 M€ 0,8 FTE

60 detectors to replace

Storage building



REF scenario

~2 M€ 0,5 FTE

2200 m²

Cooling Systems

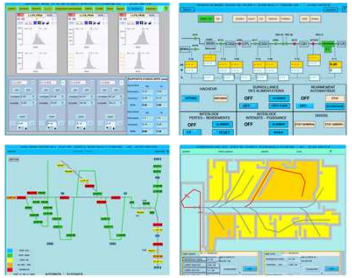
REF scenario

~1,5 M€ 1,2 FTE

6 months of unavailability in 2026

Project Management Contract

Remote control



REF scenario

~1,5 M€ 5 FTE

Code refactoring

VME crates virtualisation

Software engineering contract

HIGH scenario

Not evaluated yet

Conclusion

After 40 years, GANIL cyclotrons are still demanded and it should be true for 20 years more

SPIRAL1 development is still active after the upgrade

DESIR : start of building construction in 2023

A large renovation plan is to be launched

In addition to the LINAC part (SPIRAL2) of the facility : operation, new experimental room, new injector to come

Thank you for your attention