ADS based on Linear Accelerators

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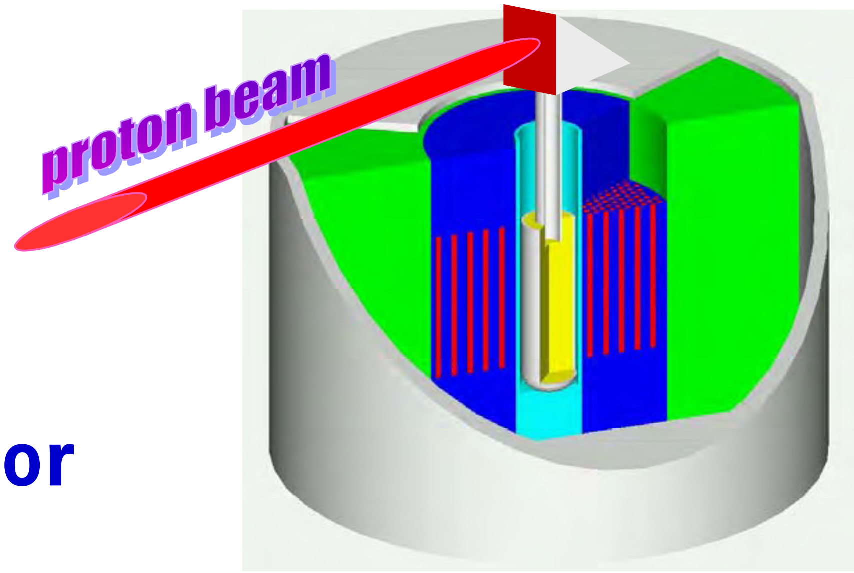
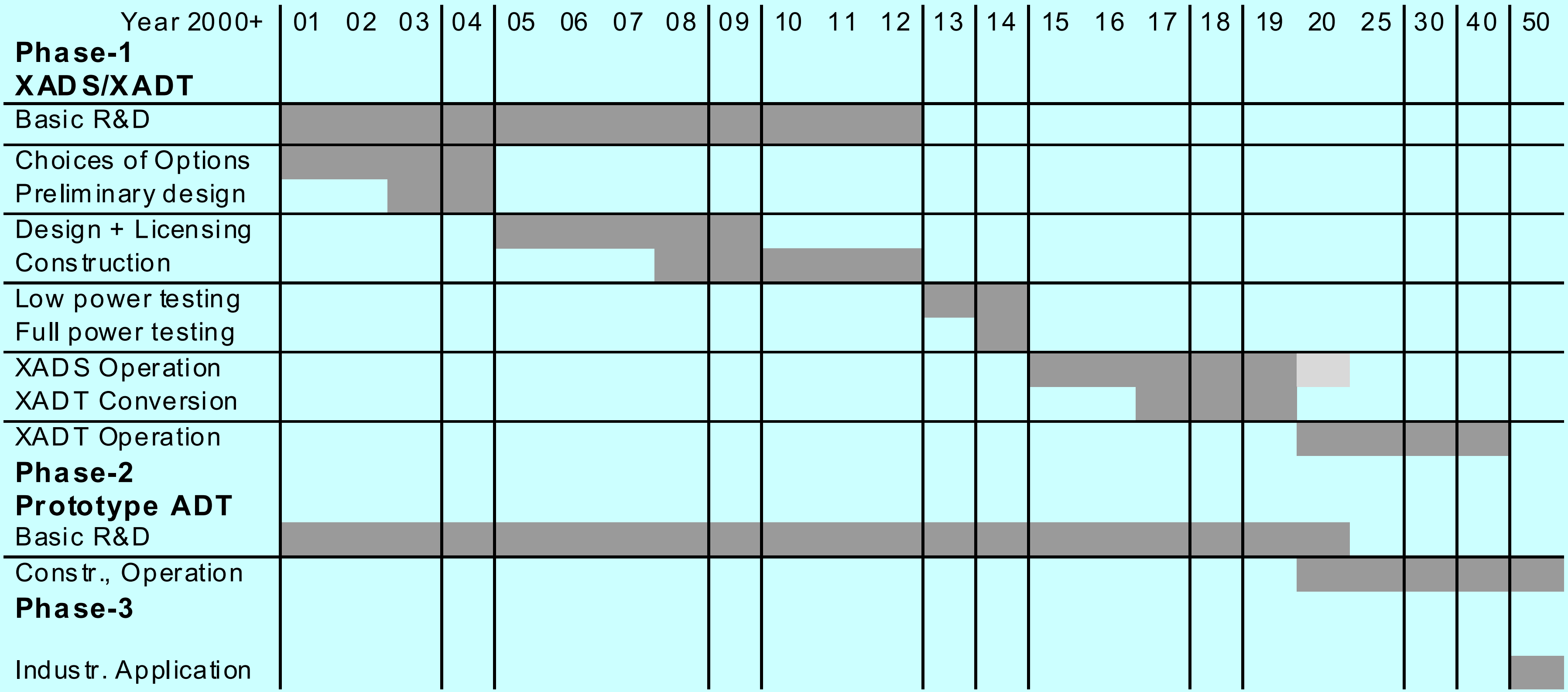


- **Introduction**
- **Main Specifications**
- **A Solution as Baseline for Evaluation**
- **Specific Aspects**

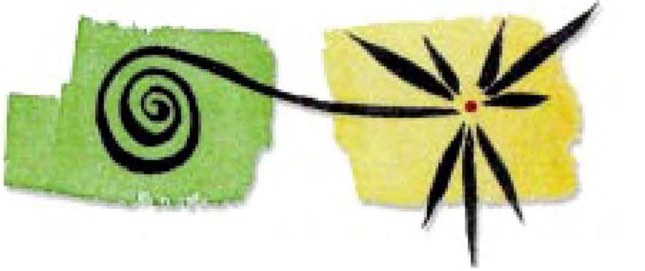
The TWG European Roadmap towards Nuclear Waste Incineration by ADS

Table 2.3. Time schedule and milestones for the development of ADS technology in Europe



XADS (technology demonstrator)

Roadmap as proposed by the TWG



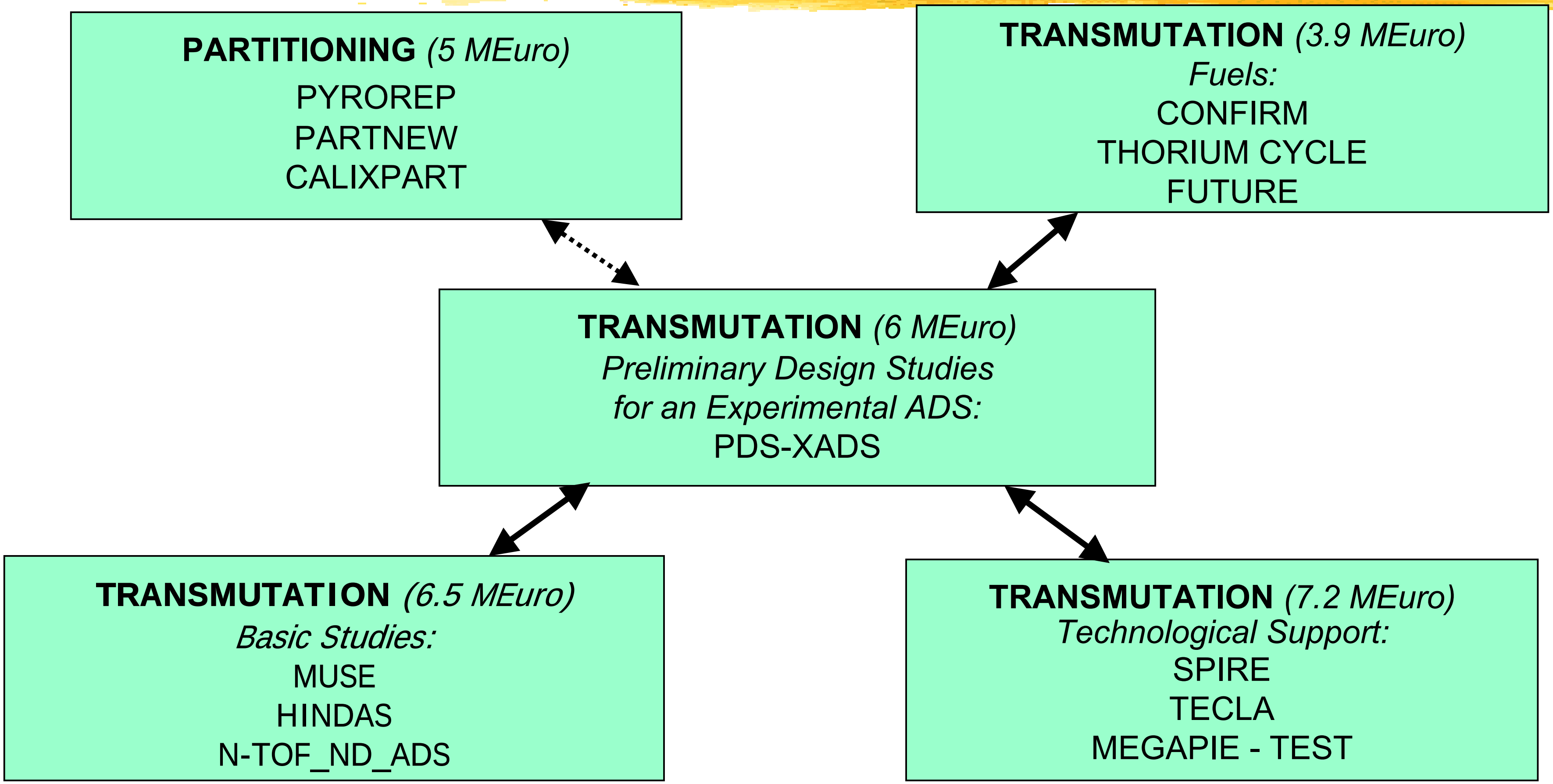
Year 2000 +	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
ACCELERATOR															
- R&D	■	■	■	■											
- Design			■	■	■	■									
- Construction						■	■	■	■						
XADS Site and Infrastructures Preparation					(1)	■	■								
SPALLATION MODULE															
Prototypical Target - connection to accelerator						■	■	■	■						
Operation of accelerator & target combined										(2)	■	■			
SUBCRITICAL SYSTEM															
- Choice of Options (coolant and fuel)		(3)	■	■											
- Detailed Design and Licensing					■	■	■	■	■						
- Construction								■	■	■	■	■			
- Commissioning and operations													■	■	■

(1) Nuclear island foundations and infrastructures for accelerator complex

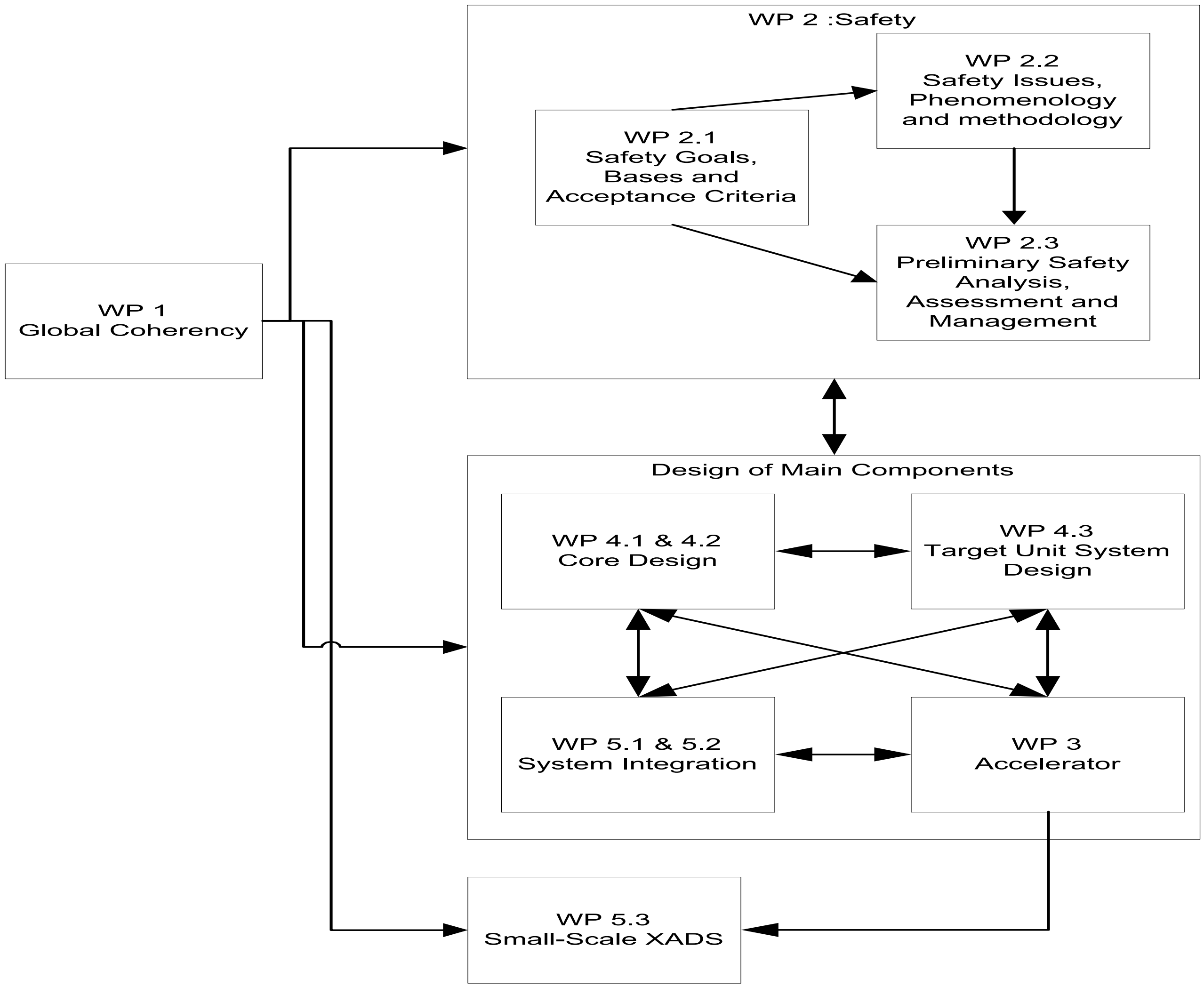
(2) Refer to figure 3.1 for plant configuration

(3) PDS-XADS activities within 5th FP

Projects on ADvanced Options for Partitioning and Transmutation (ADOPT)



PDS - XADS
Work organisation



PDS-XADS WP1 (Global Coherency)

preliminary requirements (status 01/2002)

	Reference XADS requirements
Accelerator requirements	
Max. Beam Intensity	5 to 10 mA
Proton Energy	600 to 800 MeV
Beam focalisation stability	± 5 to 10 %
Intensity Beam stability	± 2 to 4 %
Beam entry	To be defined
Beam trip number	Less than 10 per year
Beam type	CW, Pulsed
Target requirements	
Target Life time	1 year of operation
Target Material	LBE
Target Diameter	30 to 40 cm
Target Power	2 to 5 MW
Sub critical core requirements	
Power	60 to 100 MWTh
Min. Core volume	500 liters
Max. Core volume	1500 liters
Vol. Power	80 à 200 W/cm3
Pu	Less than 30 %
$\Delta\rho/\rho$ BU	between -10 and –15 pcm/efpd
Cycle length	Larger than 100 efpd
DPA max	0.15 dpa/efpd
Max Flux	$3\ 10^{15}$ n $cm^{-3}s^{-1}$
H.N. Inventory	≈ 1000 / 2500 kg

- **600 - 800 MeV**
- **10 mA**
- **less than 10 trips per year**
- **stability +/- 2%**
- **CW (with pulsing capability)**

Arguments for LINAC-based ADS from the roadmap

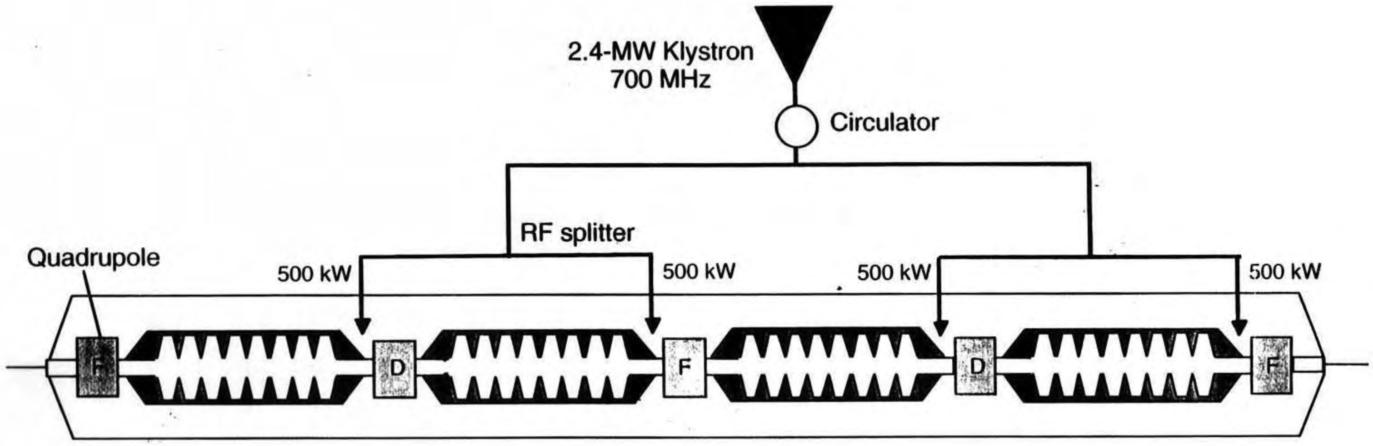
- The "Front end"
  - impressive R&D efforts (LEDA, IPHI, TRASCO, SNS, ISIS, ESS)
  - sophisticated beam dynamics simulations
  - first experimental demonstration by LEDA 7 MeV, 100mA
  - the halo problem and hence activation are under control
  - designs integrate reliability aspects from the intitial phase on (important safety margins), specific tests and improvements (e.g. SILHI)

- The high-energy linac
  - beam losses below 1nA/m for hands-on maintenance
  - impressive R&D efforts for SC cavities
    - important potential for cost reduction réduction/decrease of accelerator length and/or reliability (franco-italien strategy)
  - decision SC/nSC at the 2MW frontier (cf. SNS)

Linac "design philosophy" aspects

(Transparency G. Lawrence 1999 HPPA-Workshop, Aix en Provence)

Cost-Optimized Cryomodule for ATW High-Beta SC Linac ($\beta = 0.75$)

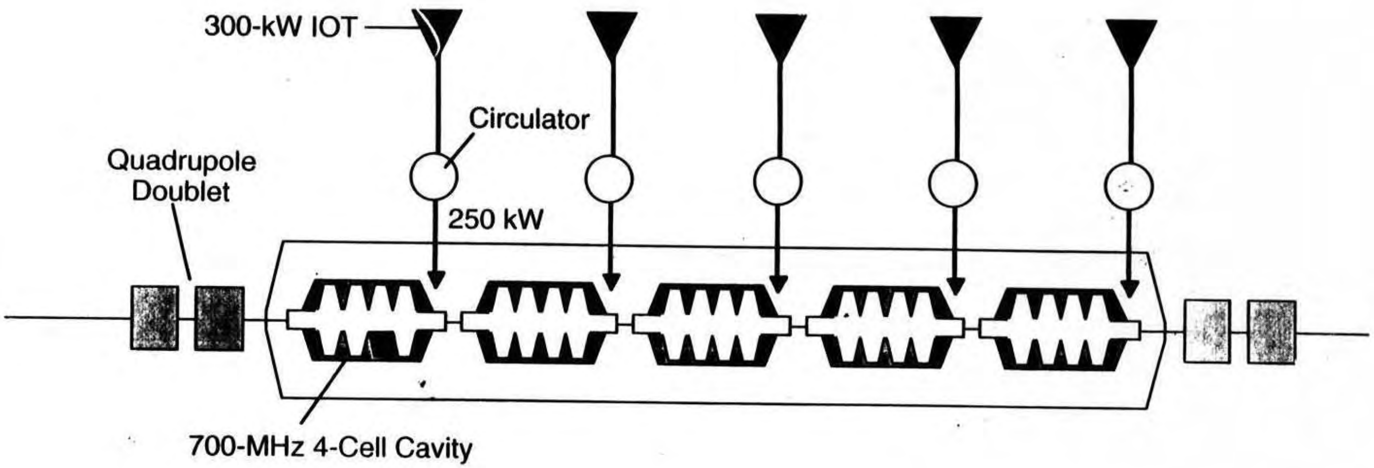


Cells per cavity	8	Cryomodule length	9.7 m
Accel gradient E_oT	10.0 MV/m	Cavity Q_o	3×10^9
Energy gain per cavity	11.1 MeV	RF loss per cavity	99
Energy span	390-1000 MeV	Operating temperature	2.1K
Cavity length	1.28 m	Number of klystrons	16

Linac "design philosophy" aspects

(Transparency G. Lawrence 1999 HPPA-Workshop, Aix en Provence)

High-Reliability Cryomodule for ATW High-Beta SC Linac ($\beta = 0.75$)



Cells per cavity	4	Cryomodule length	6.1 m
Accel gradient E_oT	10.0 MV/m	Cavity Q_o	1×10^{10}
Energy gain per cavity	5.55 MeV	RF loss per cavity	16 W
Coupler power	250 kW	Operating temperature	2.1K
Cavity length	0.64 m	Number of IOTs	128

The European projects: EURISOL & XADS

XADS

A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration

http://itumagill.fzk.de/ADS

« eXperimental Accelerator Driven System »

⇒ **Development of ADS for Nuclear Waste Transmutation**

Partners: Austria, Belgium, Finland, France, Germany, Italy, Portugal, Spain, Sweden

EURISOL

EURISOL

Radioactive Nuclear Beam Facility

http://www.ganil.fr/eurisol

« EURopean Isotope Separation On-Line »

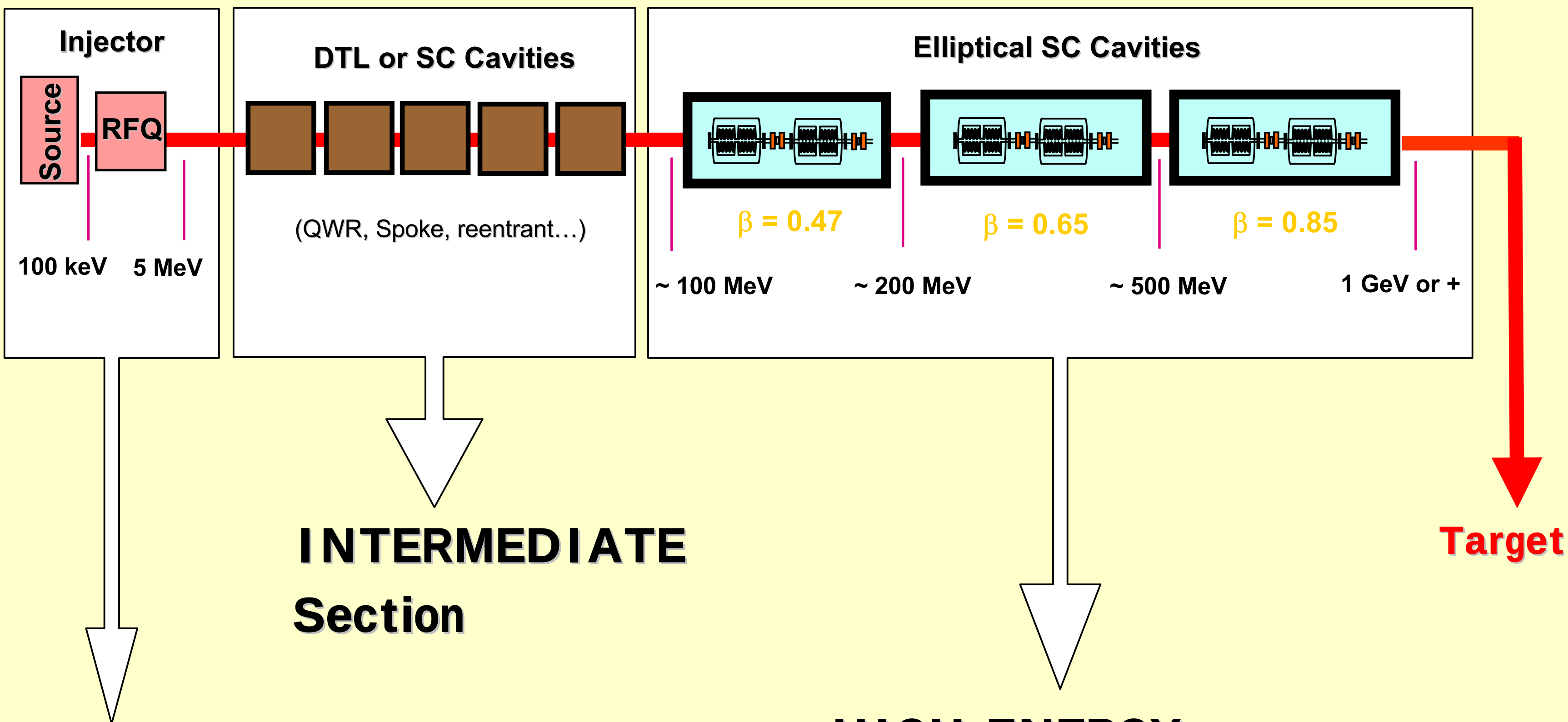
⇒ **Design study of the next-generation European ISOL RNB facility**

« Driver Accelerator Group » = CEA Saclay, CERN, GANIL, INFN LNL, IPN Orsay

PROTON BEAM REQUIRED

	Nominal current	Maximum Energy	Beam structure
EURISOL	**5 mA** (& 0.5 mA)	**1 GeV** *(→ 2 GeV)*	CW
XADS	**20 mA** *(→ 40 mA)*	**600 MeV** *(→ 1 GeV)*	CW

Lay-out of a High Power Proton Linac à la EURISOL / XADS



INTERMEDIATE Section

LOW ENERGY Section

HIGH ENERGY Section

A superconducting intermediate section ?

The « very low β SC cavity » solution compared with a DTL solution
(5 – 85 MeV, 20 mA CW)

1. Same investment cost: **20 to 25 M€** - not including infrastructures
   Same length: **60 to 80 metres**

2. Better efficiency: 8 MW AC = **3 M€/year are saved**
   Larger beam apertures (×3): **safety** ← no structure activation
   Independant RF structures: **reliability** ← low power sources
   \+ **flexibility** (power adjustments, heavy ion capability)

3. Beam matching after the RFQ (5 MeV) is **difficult** ← long focusing length

Design of a SC linac
from 12 MeV to 1 GeV
(I=20 mA CW)

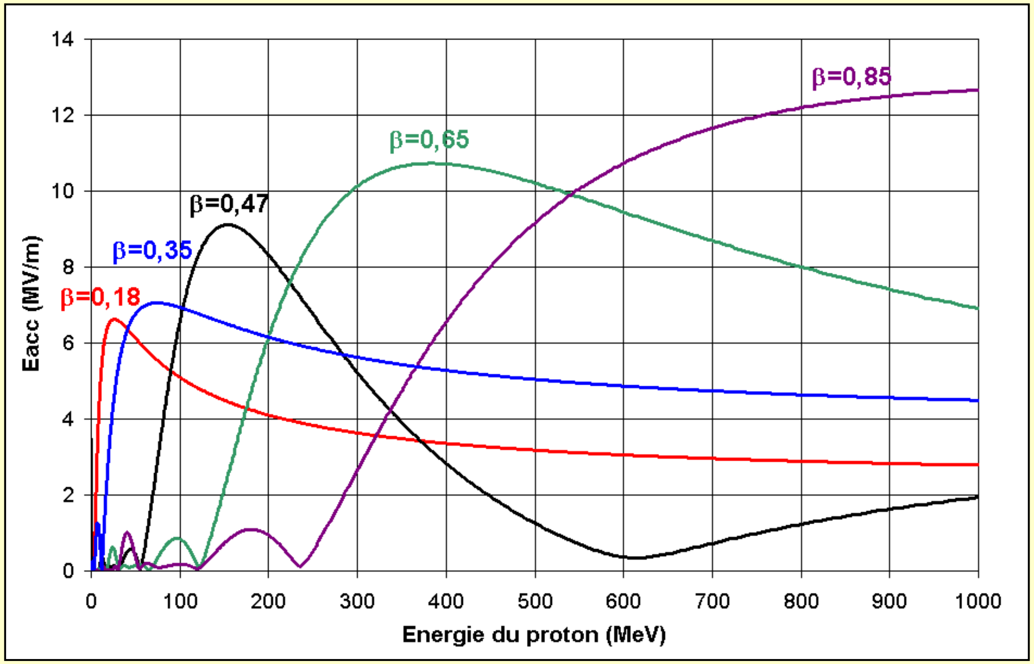
Choice of the accelerating structures

Main goals:

1. Maximize the accelerating fields ⇔ minimize the linac length
2. Keep some safety margins on peak surface fields: Bpk<50mT, Epk<25MV/m
3. Minimize the RF losses
4. Minimize the number of different structures
5. Provide acceptable beam dynamics
6. Check the mechanical feasability of the structures

2-gaps spoke cavities β=0.18 & β=0.35
@ 352.2 MHz, 2K (or 4K)

5-cells elliptical cavities β=0.47, β=0.65 & β=0.85
@ 704.4 MHz, 2K

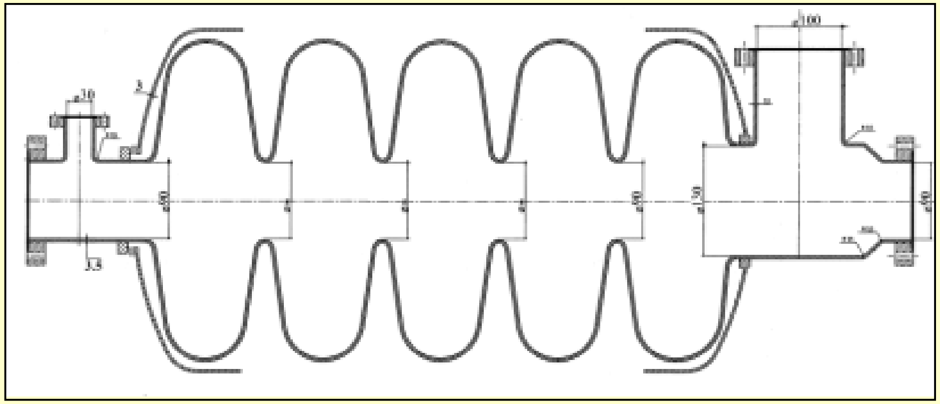


Cavity design & optimisation

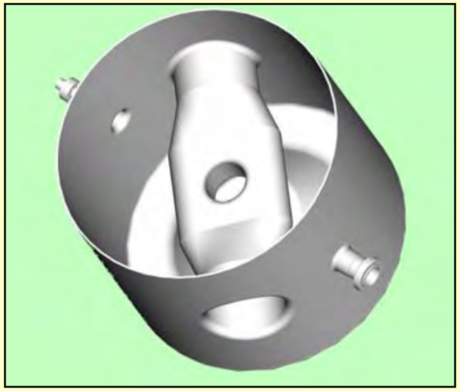
Main goals:

1. Minimize Epk/Eacc and Bpk/Eacc
2. Minimize the RF losses on the cavity walls
3. Keep large bore radius
4. Provide a good mechanical stability

Elliptical cavity, 704.4 MHz, β=0.65



Spoke cavity, 352.2 MHz, β=0.35

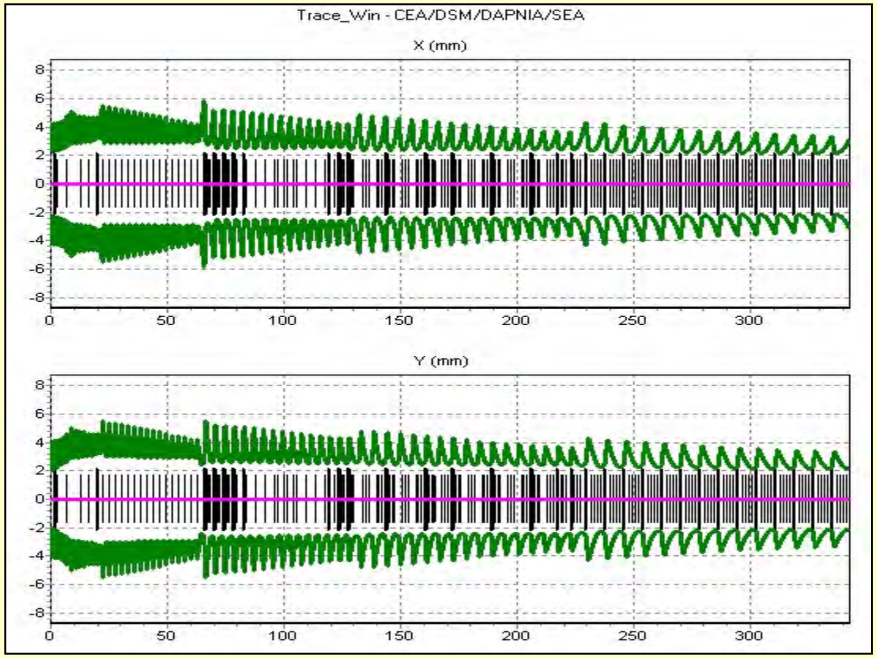


Simulations with:
- RF calculations: Superfish, BuildCav, Mafia
- Mechanical calculations: Castem, Ansys, Acord

Beam dynamics studies

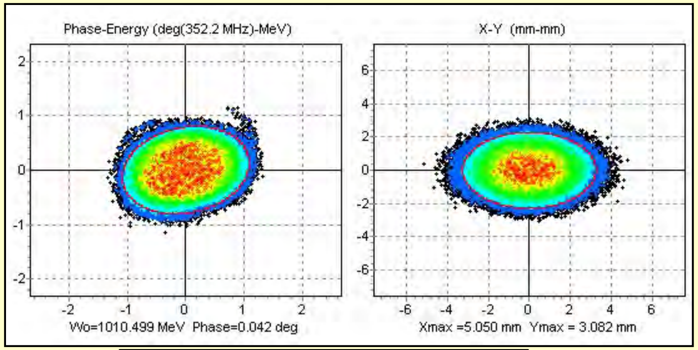
Main goal:

Provide a good longitudinal and transverse beam stability: σ_0<90°/lattice, σ_0/L as continuous as possible, $\sigma_{0T} \neq \sigma_{0L}$



Choices:

1. Focusing by quadrupole doublets
2. Smooth growth of the focusing lattice (1m to 8.1m)
3. Synchronous phase -30° & -25°
4. Beam matching at each transition



Simulations with GenLin, TraceWin, Partran, codes developed at CEA Saclay by N.Pichoff & D.Uriot

EURISOL

12 MeV – 1 GeV SC linac characteristics

	Spoke 2-gaps β=0.18	Spoke 2-gaps β=0.35	5-cells β=0.47	5-cells β=0.65	5-cells β=0.85
Energy (MeV)	12 - 26	26 - 77	77 - 185	185 - 486	486 - 1010
Number of cav.	26	48	32	51	56
Gain/cav. (MeV)	0.35 à 0.60	0.45 à 1.4	1.4 à 4.2	3.2 à 6.8	7.1 à 10.3
Cav./lattice	2	3	2	3	4
L lattice (m)	1.0 à 1.9	2.7	4.1	5.65	8.1
Length (m)	21.8	43.2	65.6	96.1	113.4
Gradient (MeV/m)	0.64	1.18	1.65	3.13	4.62

TOTAL

350 metres

213 cavities

Beam current	Beam power	AC power	Invest. cost	Elect. cost
5 mA	5 MW	13.0 MW	110 M€	5.0 M€/y
20 mA	20 MW	42.5 MW	150 M€	16.5 M€/y

EURISOL

Conclusion & Perspectives (1)

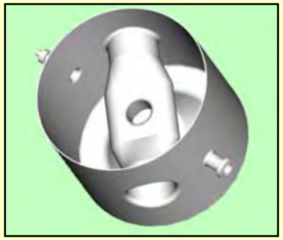
1. The use of **superconducting cavities** can be envisaged **from the injector** up to the high energy end, providing all the **advantages** inherent to superconductivity
2. A preliminary design of a **12 MeV – 1 GeV SC linac** has been achieved, showing the feasibility of such a solution
3. **Work in progress**: design of a 5 MeV – 1 GeV SC linac, detailed comparative study between « warm » and « cold » options in the intermediate part, etc..
4. Active **R&D programs** on SC linacs are going on, especially in the European context (5th & 6th PCRD)

IPN Orsay Division Accélérateurs

R&D Spoke Cavities

2002 : Cold test of the first prototypes

2005 : Fabrication of a complete cryomodule to be tested with beam



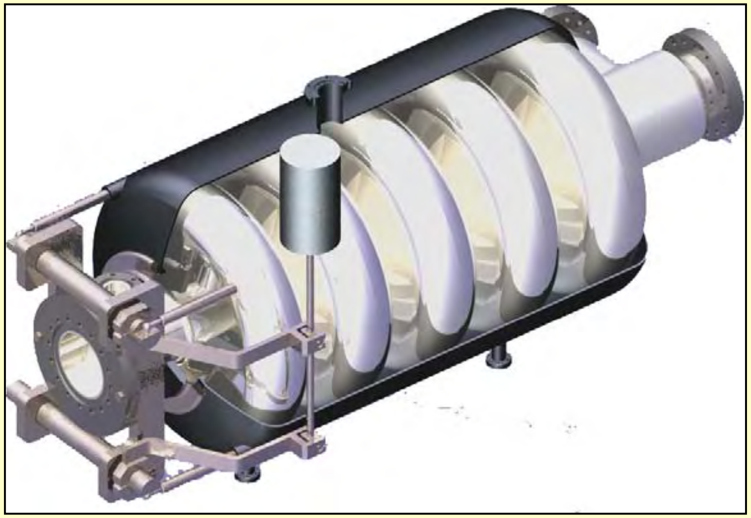
Conclusion & Perspectives (2)

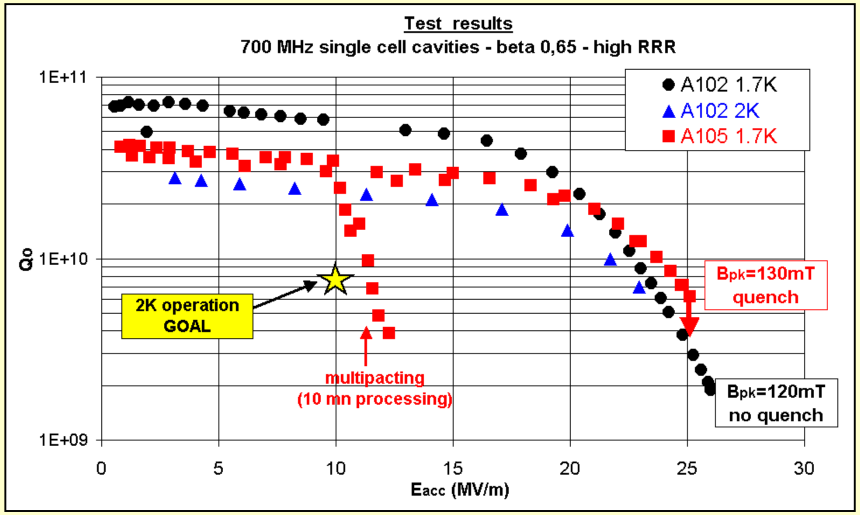
Collaboration
CEA Saclay
INFN Milano
IPN Orsay

R&D 700 MHz Cavities

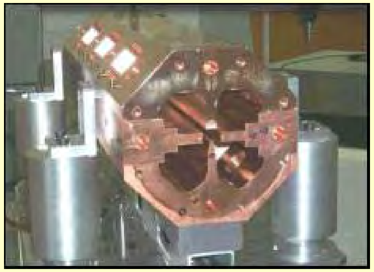
Very good test results on prototypes since 1998

2002: Test of the first 5-cells cavity in CryHoLab
(with He tank + tuning system + IOT 80 kW)

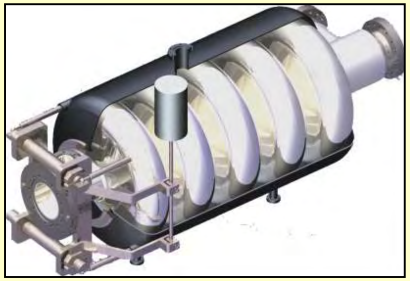




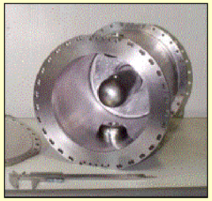
The linac base-line options for an XADS

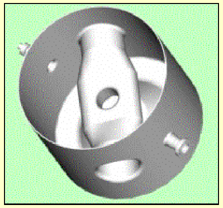


- The injector section is an easy extrapolation from projects presently under construction in Europe



- The high-energy section uses structures that are within the present main-stream developments of low-β elliptical SCRF cavities





- The intermediate section will use, a priori, independently-phased SCRF cavities

Facts & recommendations (1)
from the EURISOL study

- The EURISOL base-line driver accelerator, a 1 GeV, 5 MW CW proton facility, with a possible upgrade to 2 GeV, has remarkable synergies in components and R&D needs with other high-intensity projects. The proposed solution is thus in the mainstream of today's accelerator development.

- The demonstration of the injector accelerator, up to about 10 MeV, relies on existing projects like IPHI or the TRASCO injector. Therefore, it is important that full funding for these R&D projects is ensured.

- Two items have high R&D priority: (a) construction of complete prototype accelerator sections for low-β elliptical SCRF cavities; (b) development of prototypical spoke, quarter-wave and re-entrant cavities with associated auxiliary RF components, to be tested with beam from existing facilities.

EURISOL

Facts & recommendations (2)
from the EURISOL study

- The funding for these identified R&D needs for the EURISOL driver accelerator should be proposed, within the frame of the 6th PCRD, in a co-ordinated manner with other projects, where applicable.

- Assuming that it is possible to establish common R&D programmes with other projects, it should be investigated whether common designs could be adopted. Important cost saving can be anticipated from this action.

- Such a common and "synergistic" R&D programme should also provide the opportunity to investigate whether additional saving can be achieved by sharing the driver accelerator. From the technical point of view, pulsed driver accelerators provide a priori sufficient beam power for time-sharing the beam between two or even more users. But at present stage, it is too early to draw conclusions about the opportunities for such an approach.