STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

a Cyclotron based European Multipurpose **ADS** for **R&D (MYRRHA)**
Pre-Design Phase Completion

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Contents

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Introduction (1)

- SCK•CEN core competencies: design, realisation and operation of large nuclear research facilities (BR1, BR2, BR3, VENUS reactors, LHMA Hot cells, HADES URL for waste).
- BR2, a 100 MW MTR, is arriving to an age of 40 years, like other major MTRs in Europe (OSIRIS, HFR, R2). In 2010, Europe which relies for 35% of its electricity on nuclear energy (145 reactors) will not have any MTR anymore, except:
- the RJH (F) project a thermal spectrum MTR and **MYRRHA** natural **fast spectrum** complementary **facility**.
- This will put **Europe in a strategic position towards its energy independence**.

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Introduction (2)

- SCK•CEN and IBA have been associated to develop the ADONIS project during the 1995-97 period. A ~1.5 MW ADS with 0.1 to 0.2 MW low energy (150 MeV) proton beam for Radioisotopes production
- Ad-hoc Scientific Committee recommended to extended the fields of applications:
  - to material and fuel research,
  - to P&T studies,
  - to system integration for helping ADS demonstration
- Therefore we migrated from ADONIS to MYRRHA as a Multipurpose R&D facility able to replace BR2 and being able to be the first step for ADS demo facility.

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Introduction (3)

- Europe : 35% of electricity from nuclear energy
- produces about 2500 t/y of used fuel: 25 t (Pu), 3.5 t (MAs: Np, Am, Cm) and 3 t (LLFPs).
- social and environmental satisfactory solution is needed for the waste problem
- The P&T in association with the ADS can lead to this acceptable solution. Therefore we need the XADS demo facility in Europe.
- We are willing to fit MYRRHA to serve the development of European XADS demo facility or to be it.

Introduction (4)

- MYRRHA is intended to be:
  - An irradiation testing facility in replacement of BR2
  - A fast spectrum testing facility in Europe complementary to RJH
  - A testing facility for fusion programme
  - A medical application based facility
  - An ADS first step demo facility
  - A P&T testing facility
  - An attractive tool for education and training

R&D Applications considered in MYRRHA (1)

- ADS concept demonstration
  - Coupling of the 3 components at rather reasonable and soundfull power level **(20 to 30 MWth)**, operation feed-back, reactivity effects mitigation
- MAs transmutation studies
  - Need for high fast flux level **($\Phi_{>0.75MeV}=10^{15}$ n/cm².s)**
- LLFPs transmutation studies
  - Need for high thermal flux level **($\Phi_{th}=2$ to 3.10^{15} n/cm².s)**
- Radioisotopes for medical applications
  - Need for high thermal flux level **($\Phi_{th}=2$ to 3.10^{15} n/cm².s)**
- Material research for PWR and BWR
  - Need for **large irradiation volumes** with high constant fast flux level **($\Phi_{>1\ MeV}=1 \sim 5.10^{14}$ n/cm².s)**

R&D Applications considered in MYRRHA (2)

- Material research for Fusion
  - Need for **large irradiation volumes** with high constant fast flux level **(Φ_{fast} =1 ~ 5.10^{14} n/cm².s with a ratio appm He/dpa(Fe)=~15)**
- Fuel research
  - Need irradiation rigs with adaptable flux spectrum and level **(Φ_{tot}=10^{14} to 10^{15} n/cm².s)**
- Safety studies for ADS
  - Beam trips mitigation
  - sub-criticality monitoring and control
  - restart procedures after short or long stops
  - feedback to various reactivity injection
  - spallation products monitoring and control
  - ....

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Why a cyclotron ?

- For achieving the performances requested by the considered applications, one needs a spallation source intensity of 1.5 ~ 2 10^{17} n/s with a sub-criticality level of 0.95
- This source intensity can be achieved with a proton beam of (350 MeV x 5 mA = 1.75 MW) impinging on a Pb-Bi target
- We are still below the technology upper threshold (600 ~ 800 MeV, 10 mA)
- Volume of waste to be generated at the end life of the facility should be considered

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MYRRHA, design parameters

Proton Accelerator → **Spallation Source** → **Subcritical Neutron Multiplier**

Proton Accelerator
- Cyclotron
- 5 mA - 350 MeV
- H^+ or (H^+-H^+)
- 1 or 2 stages
- 4 (or 6) sectors

Spallation Source
- Liquid Pb-Bi
- No window

Subcritical Neutron Multiplier
- Fast zone
  - ➔ Known fuel Tech
  - ➔ triangular lattice
  - ➔ Pb-Bi pool
- Thermal zone
  - ➔ in-pile islands
  - ➔ surrounded by ZrH_2 solid matrix

➔ Safety :	$k_{eff} < 0.95$
➔ Safety :	$P_{lin} < 500$ W/cm
➔ Total core power:	$20 < P < 30$ MW
➔ LLFP transmutation :	$\Phi_{th} = 10^{15}$ n/cm^2.s
➔ MA transmutation :	$\Phi_{> 0.75\ MEV} = 10^{15}$ n/cm^2.s

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MYRRHA design constraints

- Taking into account that MYRRHA should be put into operation by 2010, :
  - the accelerator => **upgrade of existing cyclotron technology**
  - core design of fast spectrum core => make **use of existing MOX FR fuel** design with a maximum enrichment limited to 30 % of Pu_{Tot}
- We fixed maximum K_s to 0.95 (Fuel storage)

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Accelerator (1)

- Cyclotron/Linac choice driven by price consideration
- To increase beam reliability, we are looking for a one stage (0 - 350 MeV) solution
- In order to obtain the very high extraction efficiency, 2 extraction principles are studied: through an extractor with well separated turns, or by stripping of H^+-H^+ molecules
- Both routes (H^+ and H^+-H^+ molecules with stripping) are being studied for the moment
- Beam guidance by focussing and deflecting magnets, wiggling of the narrow beam profile on the windowless target to generate suitable time averaged heat deposition profile matching the hydraulic flow profile
- Beam diagnostics and interlocks - switch-off possible in < 1 Millisecond - will be important safety features

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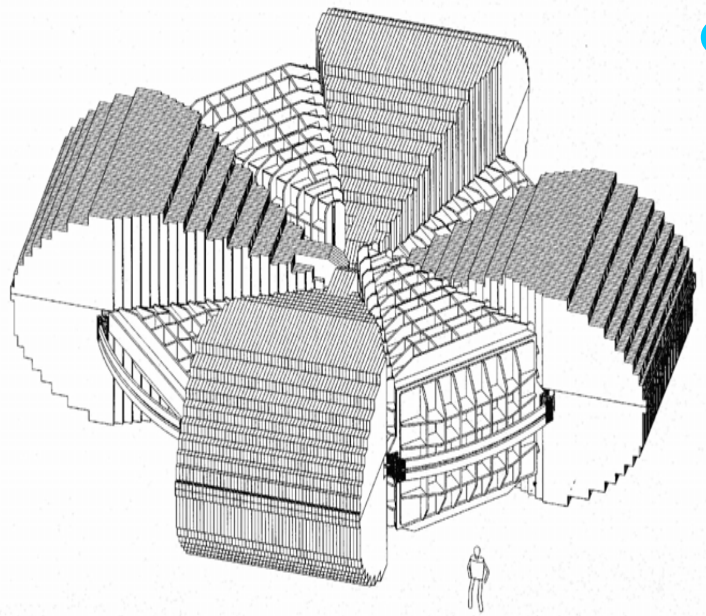
Accelerator (2)

- 4 sector machine,
- physical magnet diameter of 16m diameter,
- total weight~5000 t

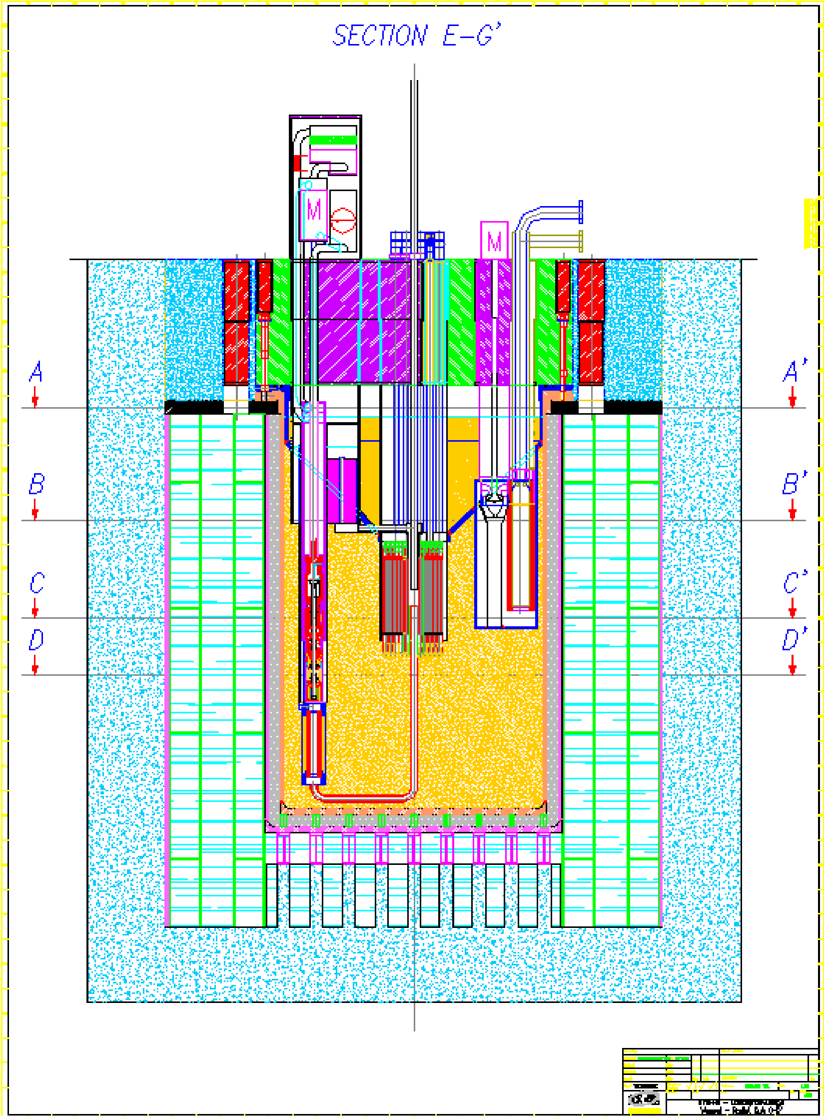


- Still considering :
  - Cyclo. supra-cond. Magnets
  - Linac

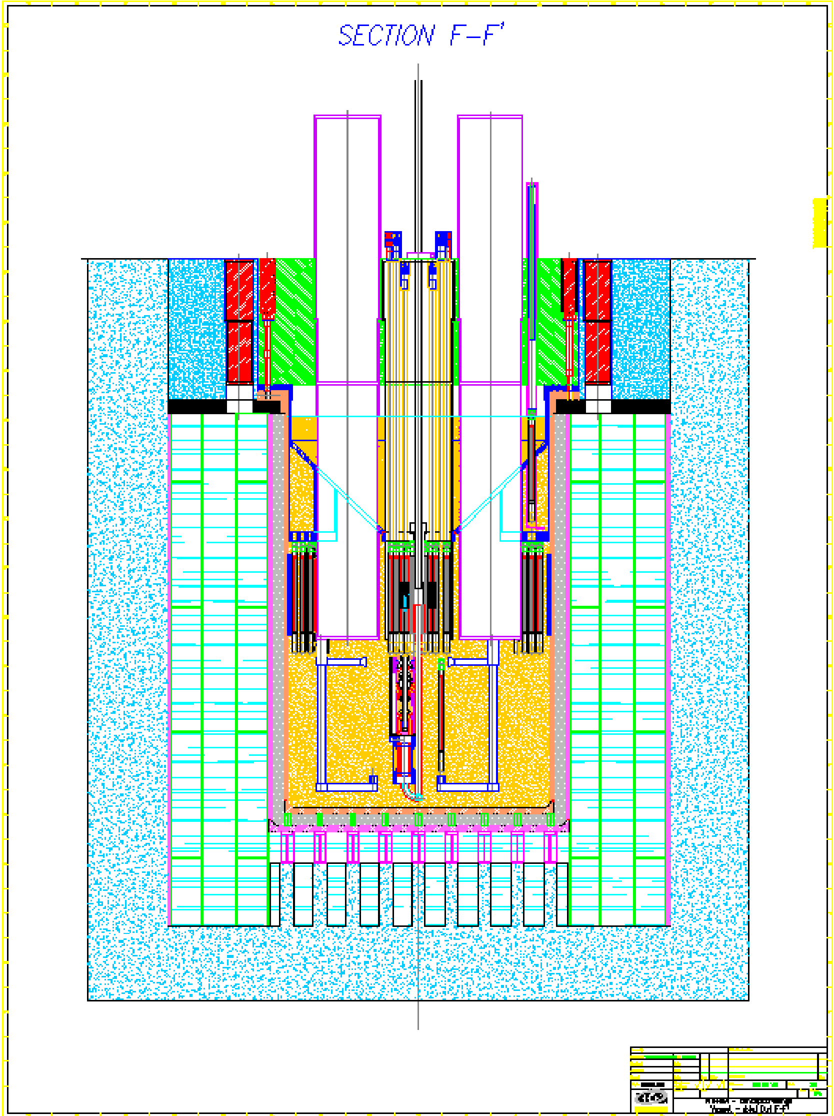
Sub-critical reactor engineering

- Pool type vessel of 4m ∅ X 7m-height
- standing vessel (presently favored but not yet frozen) to alleviate the highest T° in case of LOHS at the most stressed line of the hanging vessel
- low high flux exposure => no risk of irrad. embrit.
- Internal interim fuel storage (2 full cores, no coupling)
- 4 HX groups (2 HXs + 1 PP) => total capacity ~40 MW
- T_{in} = 200°C, T_{out} = 400°C, Secondary fluid = water
- Spallation loop inter-linking with the core, cooled via LM/LM HX with the cold Pb-Bi of the core as secondary fluid
- Fuel handling from beneath via rotating plug

MYRRHA Vertical layout (1)



MYRRHA Vertical layout (2)



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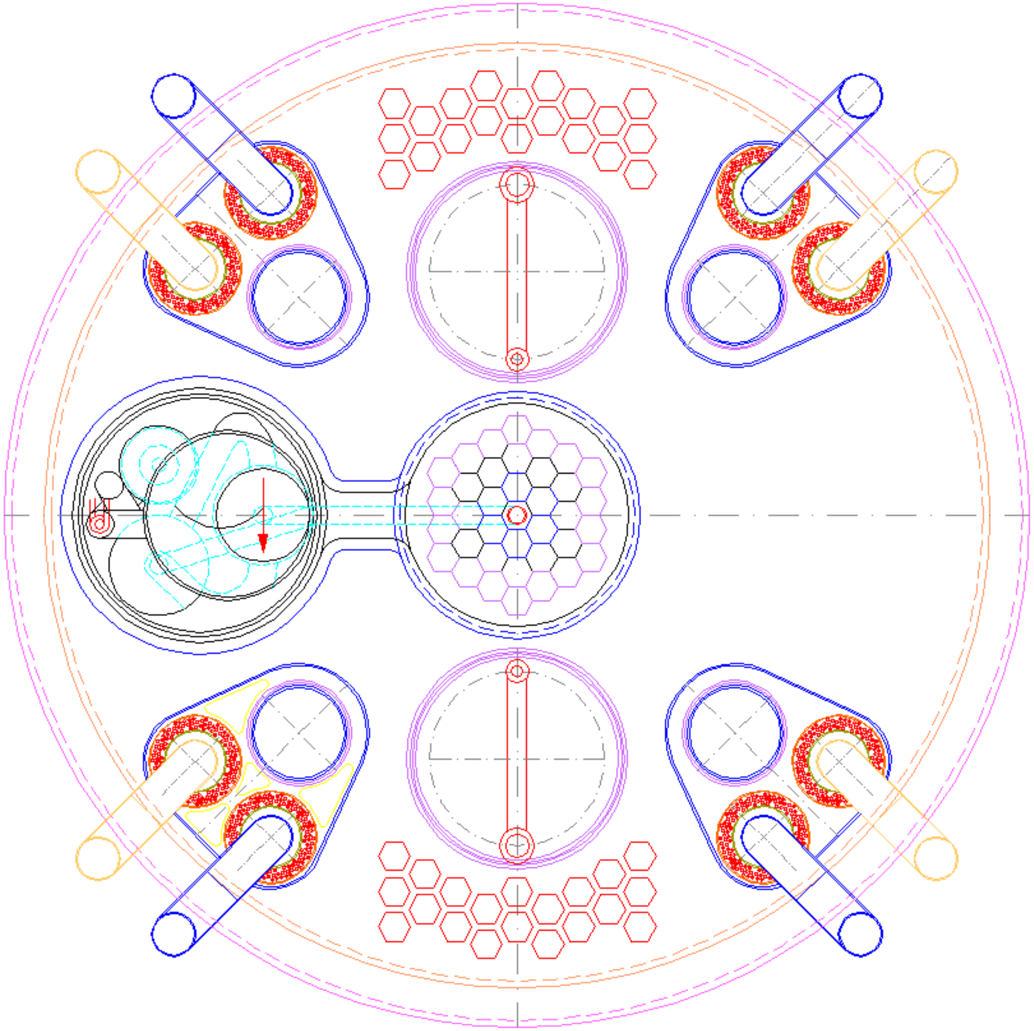
MYRRHA Radial layout (3)



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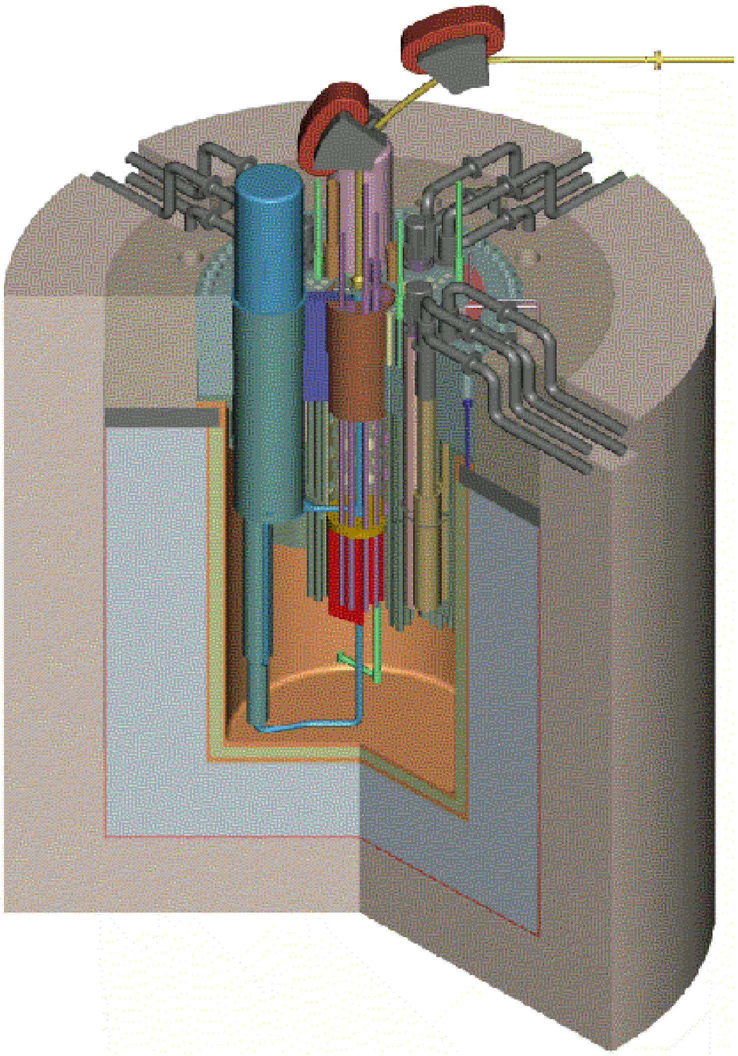
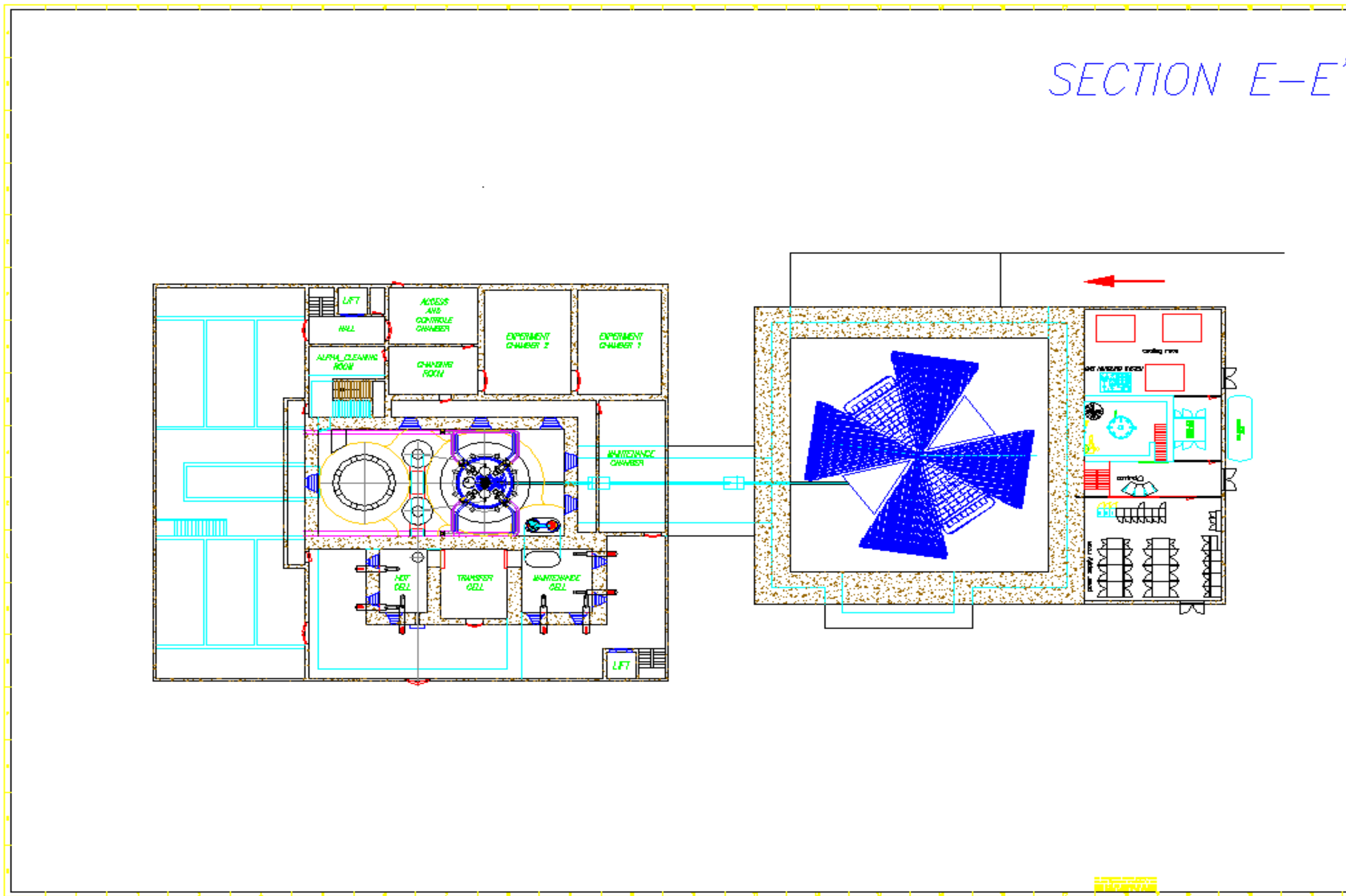
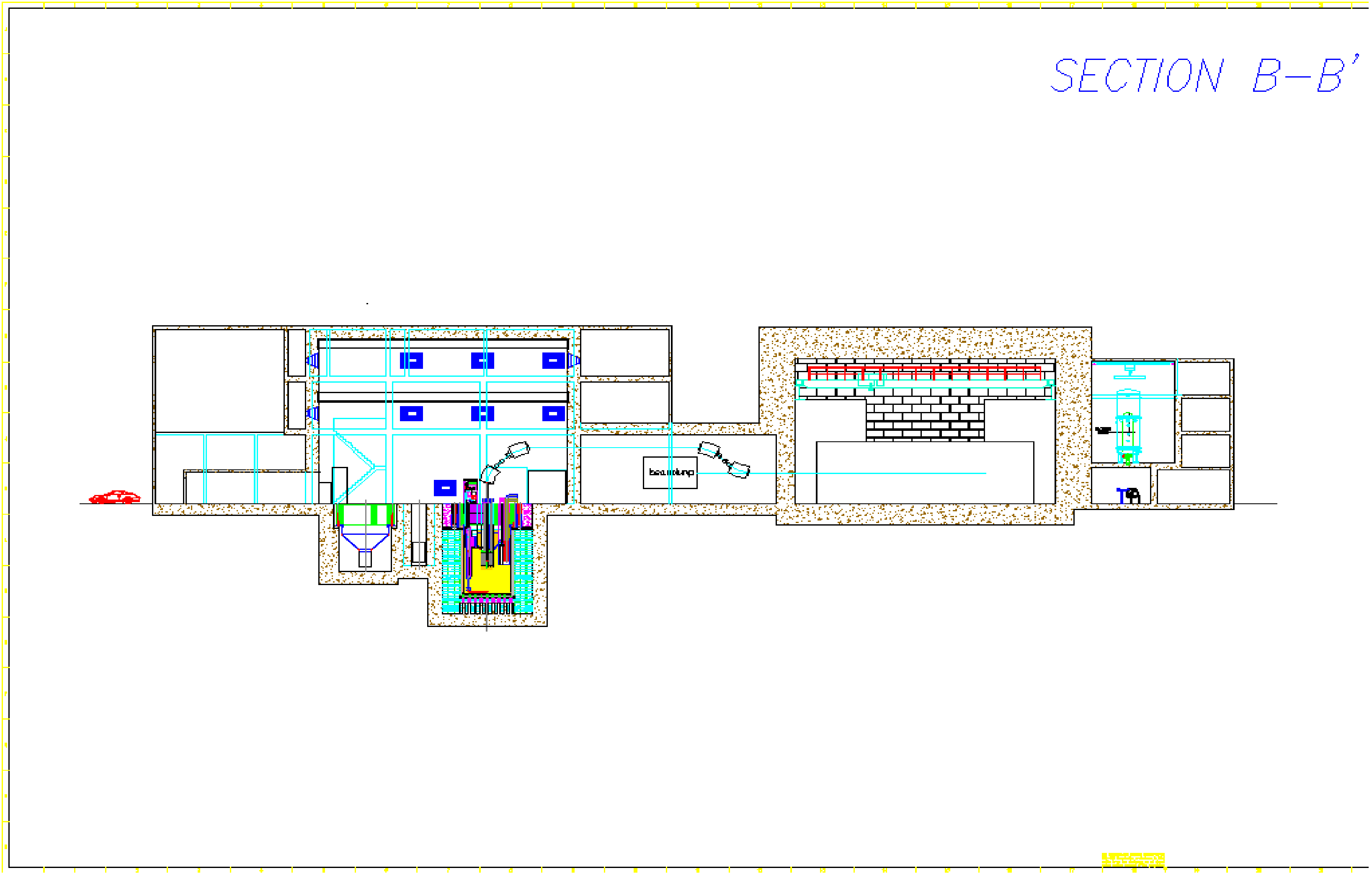
MYRRHA 3-D layout (4)



MYRRHA Complex plan view



MYRRHA Complex Vertical view



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Accelerator reliability considerations

- Achievable reliability of today's proton accelerators (few 1000's trips/year) are far away from the request of the reactors community involved in ADS dev. (few trips/year even 1 to 2 for an industrial machine). Nevertheless, clear requests are needed from the reactors community to allow the accelerators community to achieve them. Even if this is still an open debate, one can say today:
  - Integrity of the large structures of the ADS (Vessel, core support plate, diaphragm) would support up to ~5000 long beam trips for the whole life of the system (30 ~ 40 years). => **~100 long trips/year**

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Accelerator reliability considerations

- 100 long trips/year, asking for a heavy procedure of restart of the facility will not allow an economical viable operation scheme, therefore this number should be reduced by a factor 10 => **10 long trips/year**
- Short trips (<100 ms), can be accommodated thanks to the fuel inertia (T° drop after few seconds), and due to the regular replacement of the fuel (residence time ~3 years) => **few 1000's trips/year could be allowed ? (need for low cycle fatigue studies for a clear cut-off). But these short trips remain a concern for the spallation target window.**
- short trips can be a concern for the spallation target window, no clear cut can be given today, therefore a windowless design deserves a development effort

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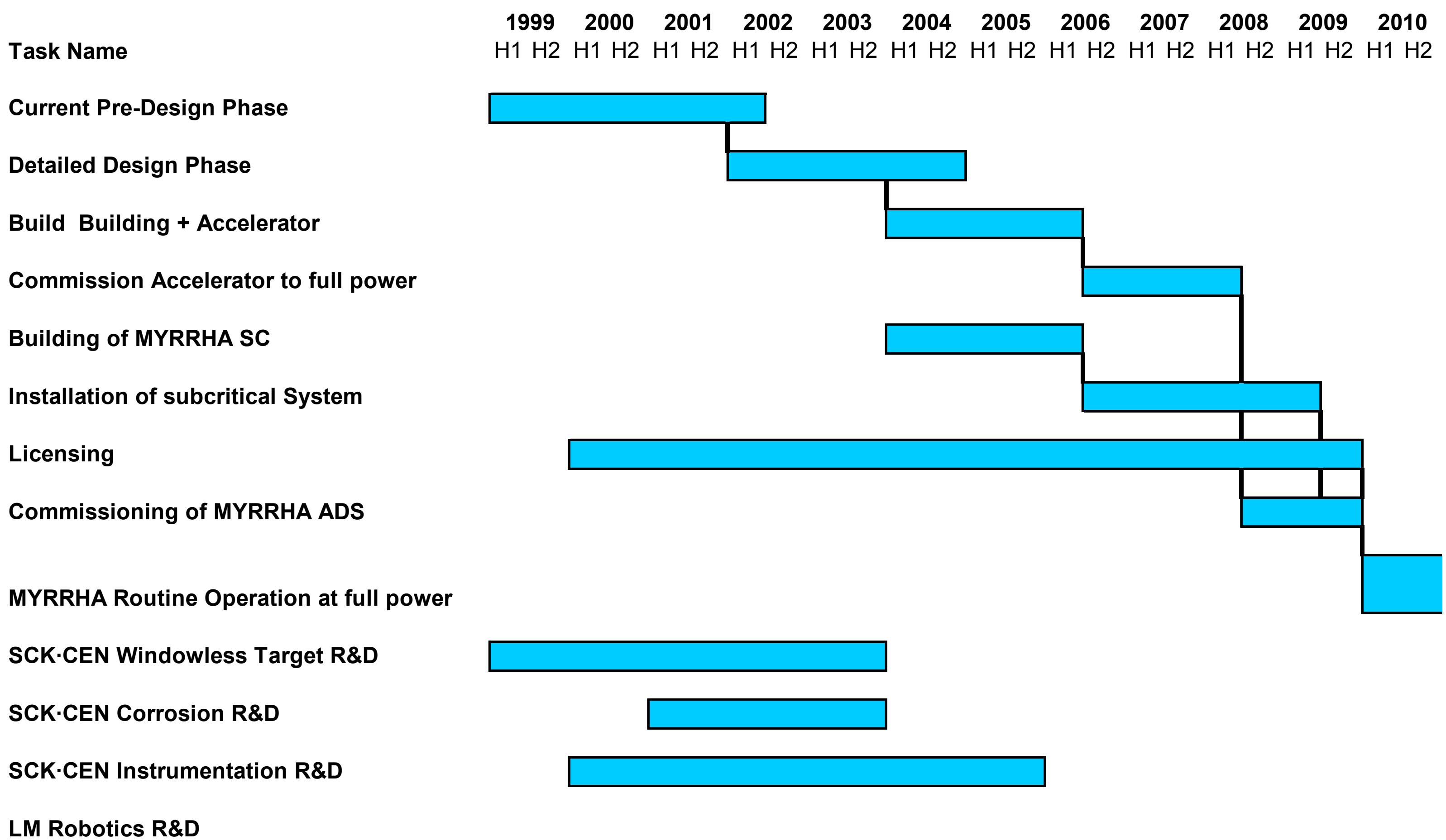
MYRRHA Time schedule



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Conclusions

- Is it worth working on a cyclotron based ADS when large ADS would be build solely with LINAC's ?
- **YES**
  - ADS development is a long run development and feedback operational experience need to be accumulated very soon,
  - Experimental ADS can be realized faster via the cyclotron route for that purpose in economical way
  - reliability improvements achieved for cyclotrons can be transferred to LINAC's
- multi-accelerator ADS can be a route for improving beam reliability => then multi-cyclotron vs. a large LINAC deserve a serious analysis