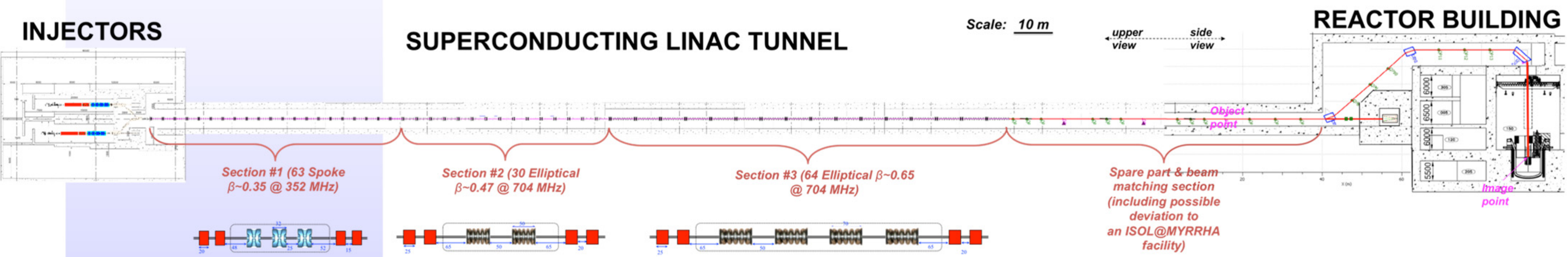
Accelerator Driven Systems



Dirk Vandeplassche, Luis Medeiros Romão

IPAC'12, New Orleans (Louisiana)

May 21, 2012

Overview

1. Introduction
2. The accelerator for ADS
3. Projects
4. Concluding remarks

Introduction

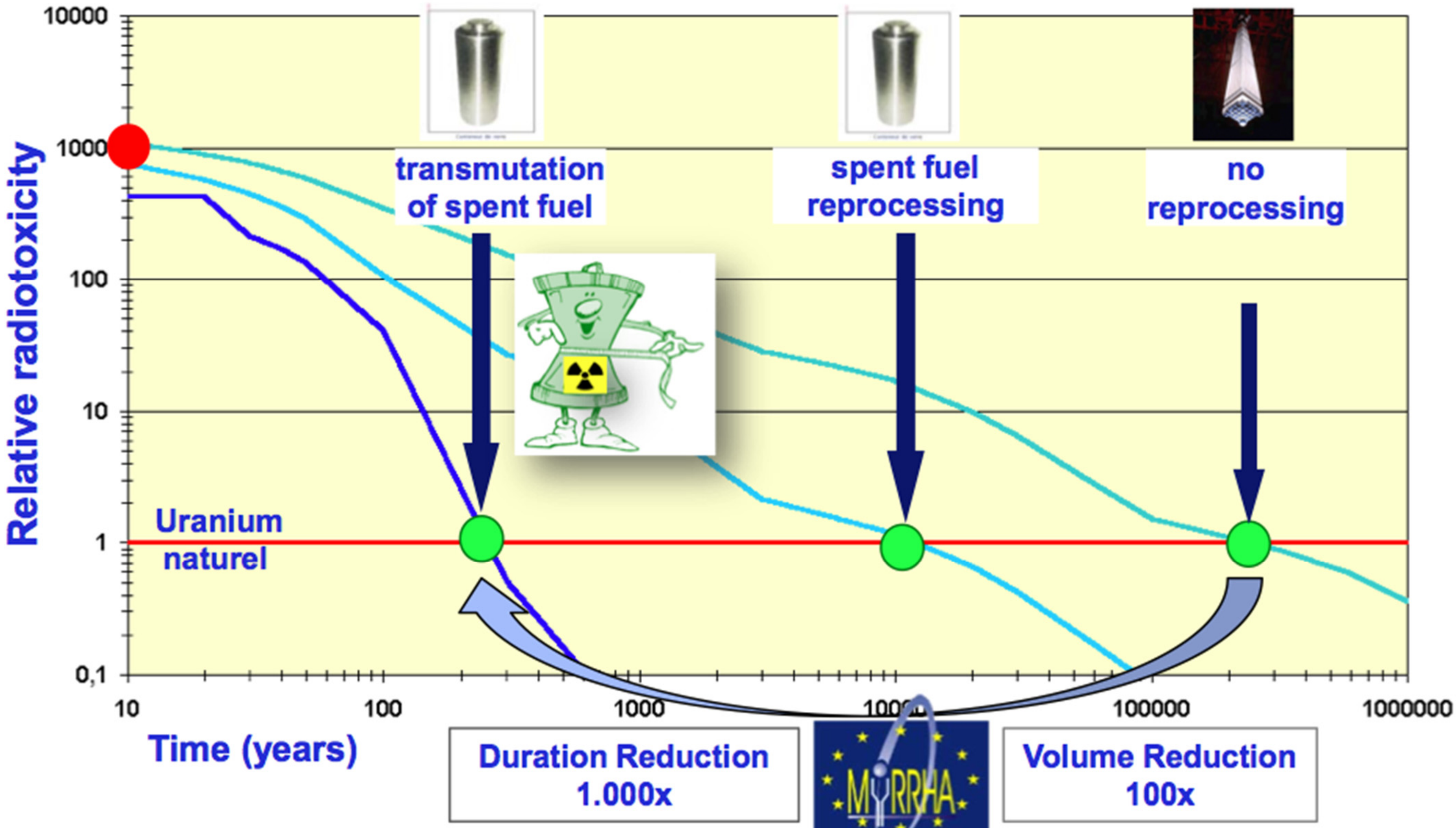
- critical fission assembly:
  - neutrons created, neutrons lost
  - steady state, equilibrium: $\frac{dN}{dt} = 0 = P - L$
- subcritical assembly: $P - L < 0, \frac{dN}{dt} = P - L + S = 0 \text{ with } N \neq 0$
- near criticality: $S << P, L$

Introduction

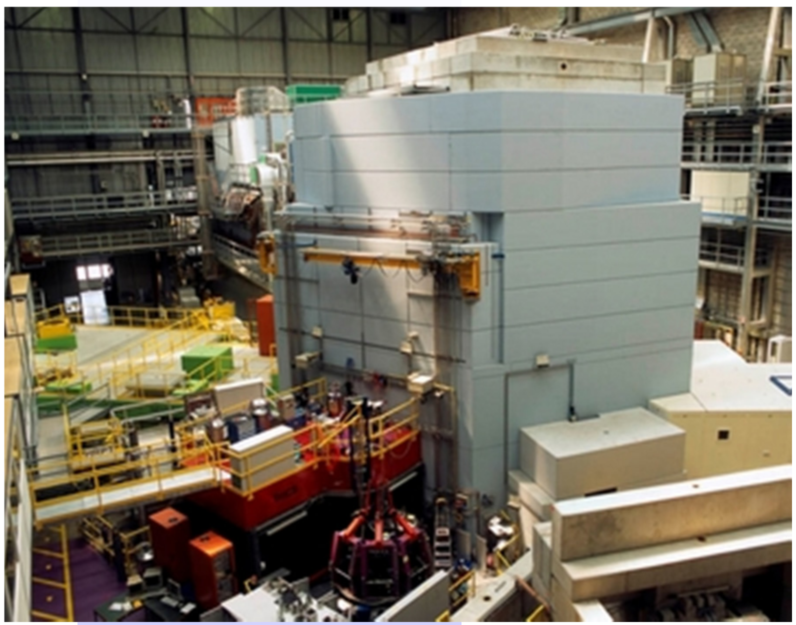
Why ADS ?

- subcritical = safety
- source driven = flexible, stable
- freedom of configuration
- domains:
    - transmutation of waste (small delayed neutron fraction)
    - Th cycle (optimized breeding)

Introduction



Accelerator for ADS



- external source *S*: spallation neutrons ?
- some numbers: 100 MW_{th}, $k_{eff} = 0.95$ → need

$$S = 5 \cdot 10^{17} \, \mathrm{n/s}$$

- 1 GeV proton beam on spallation target: ~20 n/p
- proton beam current ~4 mA

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Accelerator for ADS

- spallation → heavy metal target, liquid
  - Pb or Pb-Bi
  - reactor coolant itself (matches 1 of GENIV lines)
  - spallation loop
- CW (or rapid cycling) → cyclotron / linac

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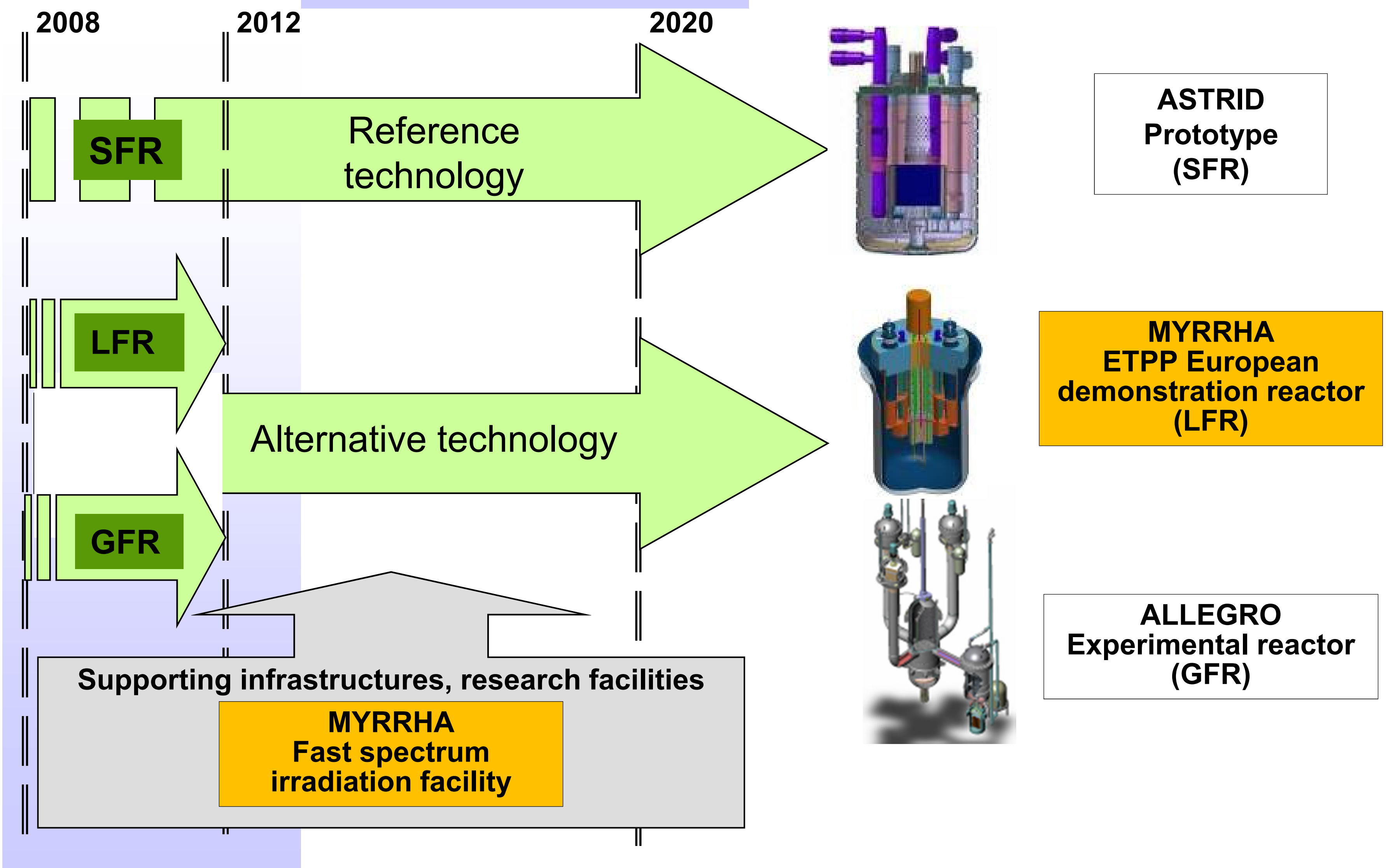
SNETP Gen. IV Systems

European Sustainable Nuclear Industrial Initiative



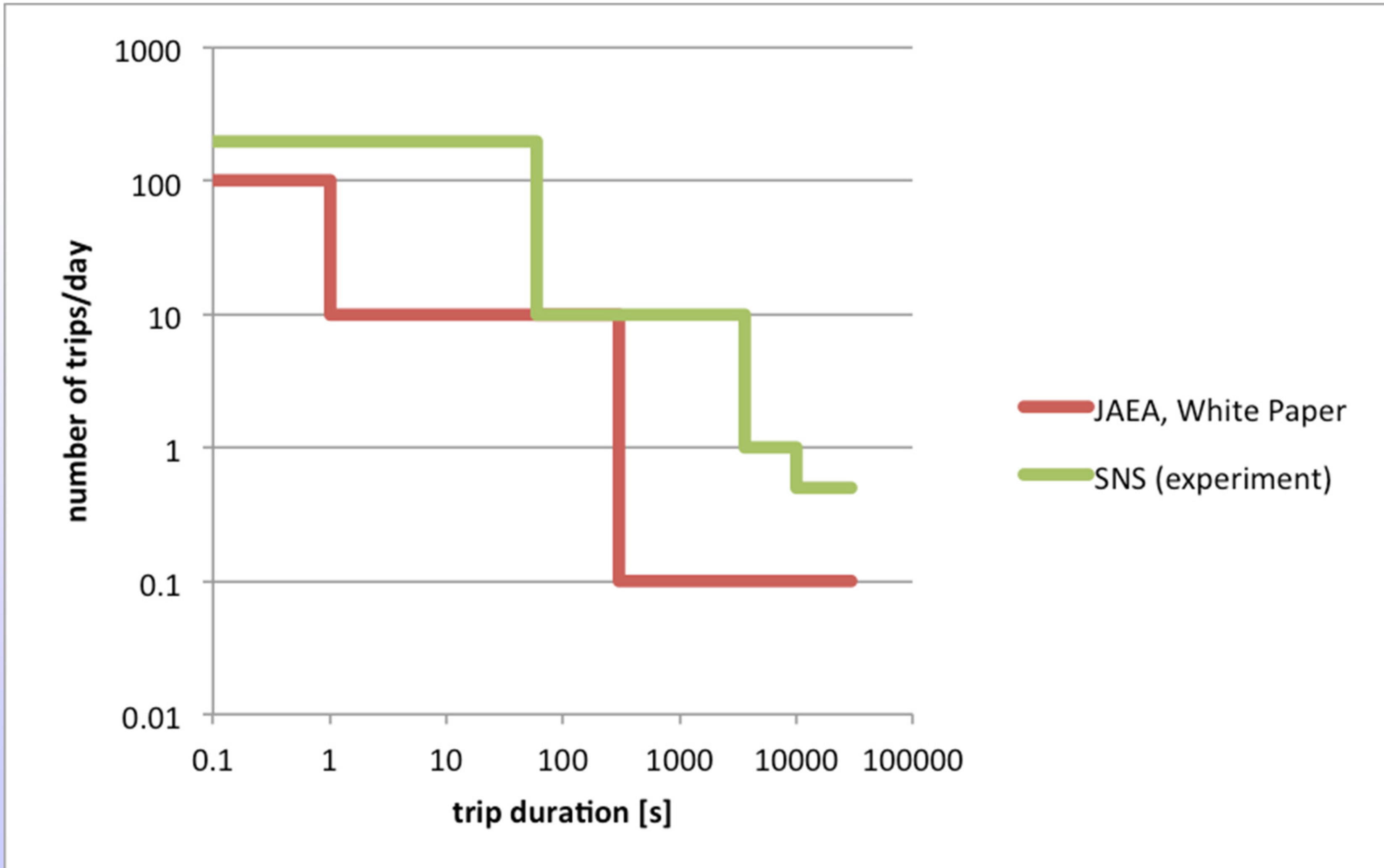
Accelerator for ADS

- reliability / availability / beam trips
  - requirements from reactor design
  - structural tolerance:

Table 1: Range of Parameters for Accelerator Driven Systems for four missions described in this whitepaper

	Transmutation Demonstration	Industrial Scale Transmutation	Industrial Scale Power Generation with Energy Storage	Industrial Scale Power Generation without Energy Storage
Beam Power	1-2 MW	10-75 MW	10-75 MW	10-75 MW
Beam Energy	0.5-3 GeV	1-2 GeV	1-2 GeV	1-2 GeV
Beam Time Structure	CW/pulsed (?)	CW	CW	CW
Beam trips (t < 1 sec)	N/A	< 25000/year	<25000/year	<25000/year
Beam trips (1 < t < 10 sec)	< 2500/year	< 2500/year	<2500/year	<2500/year
Beam trips (10 s < t < 5 min)	< 2500/year	< 2500/year	< 2500/year	< 250/year
Beam trips (t > 5 min)	< 50/year	< 50/year	< 50/year	< 3/year
Availability	> 50%	> 70%	> 80%	> 85%

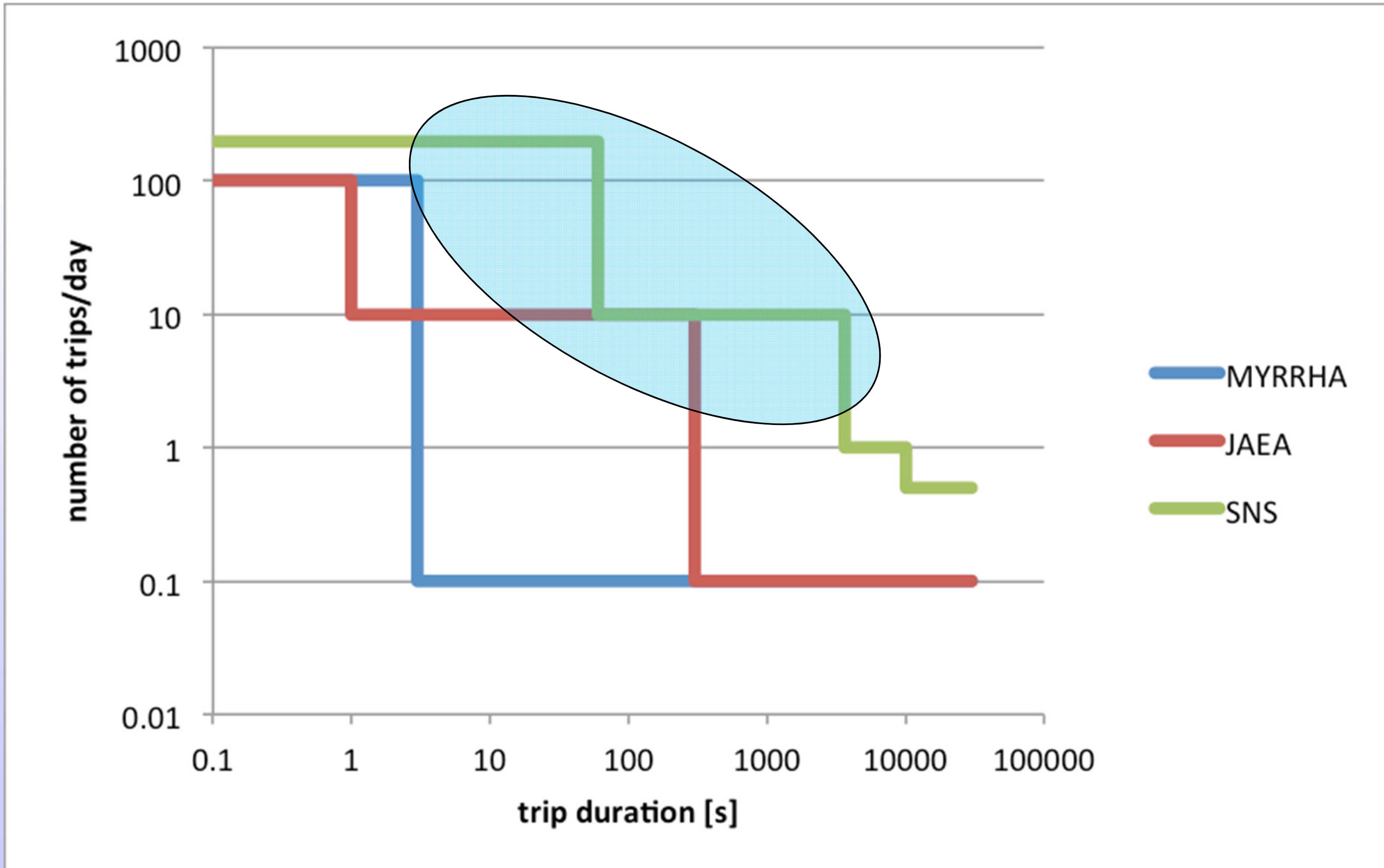
Accelerator for ADS



Accelerator for ADS

- other issues: cladding, PHENIX, licensing (CEA, KIT) →
  - present knowledge and experience leads to the following limits *for an experimental ADS*:
    - less than 10 "long" trips per operational period of 3 months
    - 3 s is the allowed delay to beam restart
  - w.r.t. behaviour under Pb-Bi (esp. cladding) more experimental evidence is needed
  - minimizing the number of beam trips is essential for the availability of the plant

Accelerator for ADS



Accelerator for ADS

simulations, analyses → MTBF > 250h *can be done*

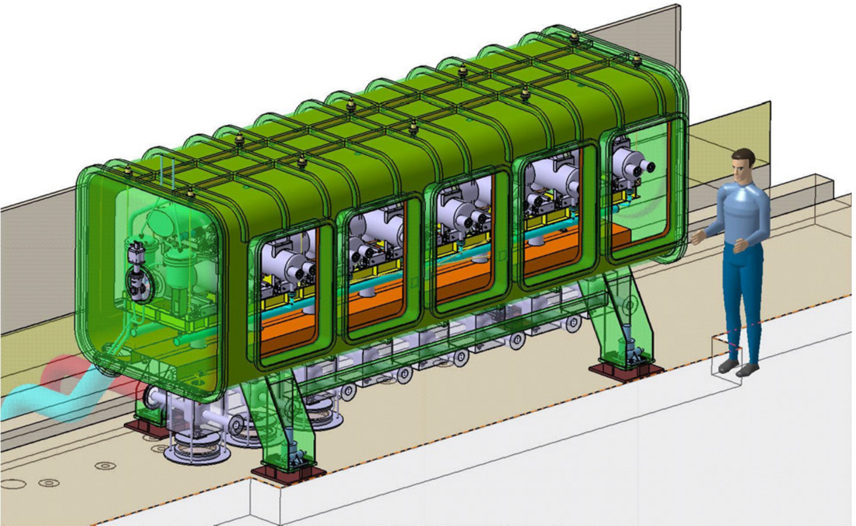
- fundamental conditions (design, layout)
  - fault tolerance
    - → redundancy
    - → tolerant beam dynamics
    - → dual injector
  - fast automated retuning

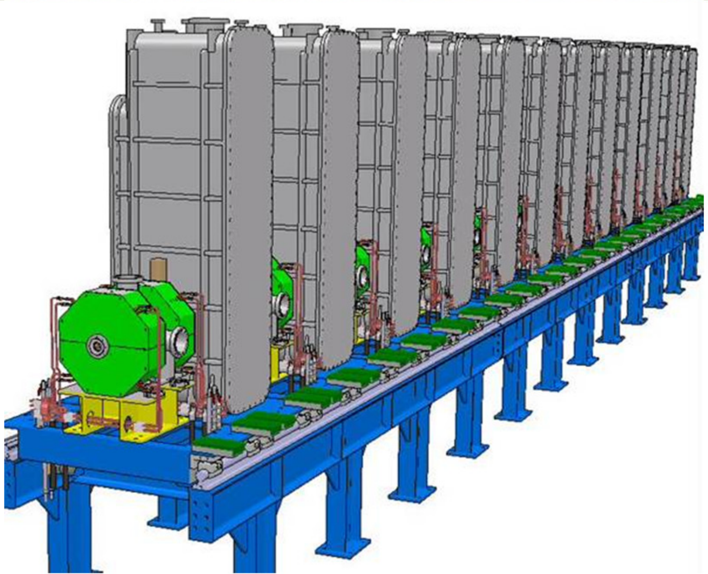
  } SC linac is the choice

- ancillary conditions: match
  1. controlled high MTBF for all components
  2. matching the availability of auxiliary systems
  3. design such that MTTR << MTBF
  4. fault tolerant control system, predictive diagnostics
  5. performant MPS: absolute protection but no false interlocks

Accelerator for ADS

We are in good company ...





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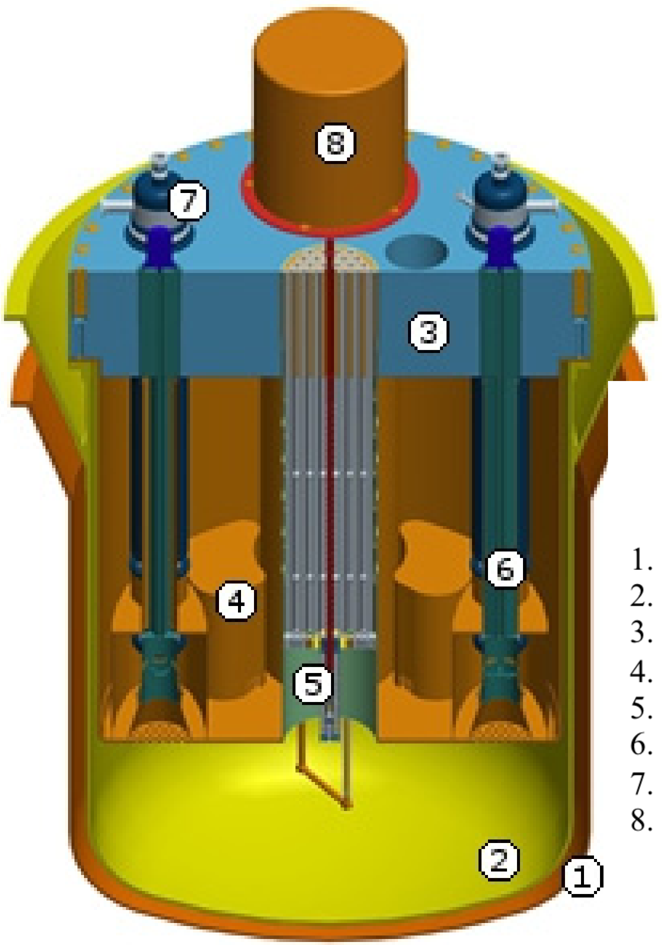
Projects

1. EUROPE
   - ADS activities supported by successive EURATOM Framework Programmes → collaborative effort

     FP5 (PDS-XADS), FP6 (EUROTRANS), FP7 (CDT, MAX, FREYA)
   - Myrrha, SCK•CEN effort on subcritical reactor since 1995
   - merge in FP6
   - MYRRHA today:
     - FASTEF reactor detailed design
     - global accelerator design
     - detailed design of accelerator components ongoing
     - conceptual design of HEBT and beam delivery
     - preliminary building definition
   - R&D phase → 2014/2015 funded
   - Belgian Federal Government commitment 40%

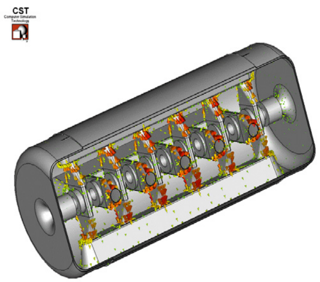
Projects

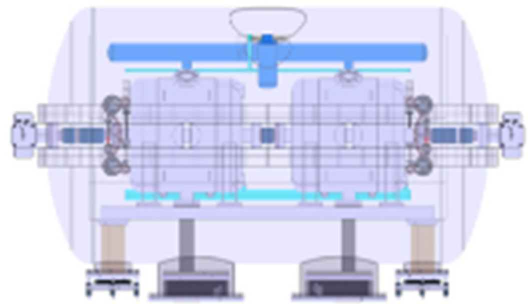


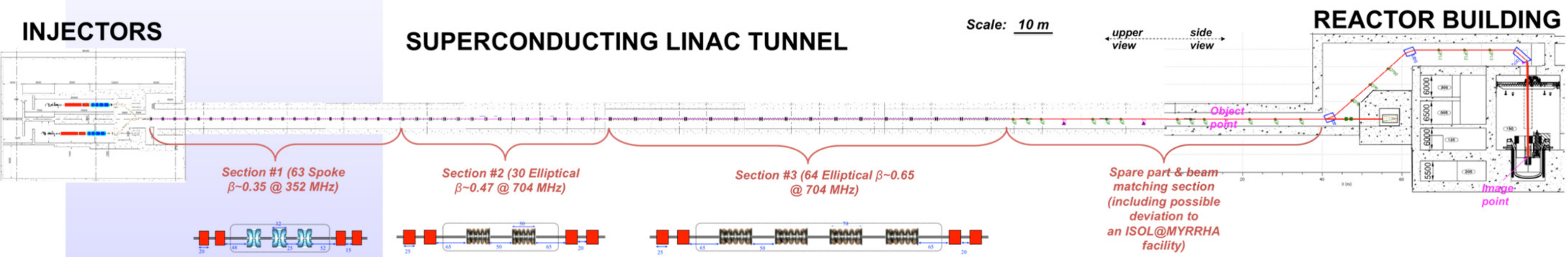
1. Outer vessel
2. Inner vessel
3. Cover
4. Diaphragm
5. Core
6. Primary Pump
7. Primary Heat Exchanger
8. In-vessel fuel handling machine

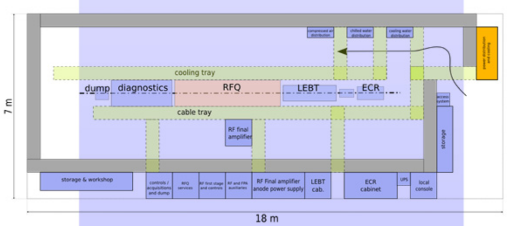
FA Length	2000 mm
Nominal Power	100 MW
Core inlet temperature	270 °C
Core outlet temperature	410 °C
Coolant velocity in core	2 m/s
Coolant pressure drop	2.5 bar
Secondary coolant	Saturated water/steam
Tertiary coolant	Air

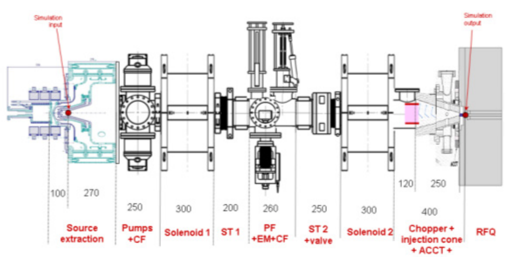
Projects

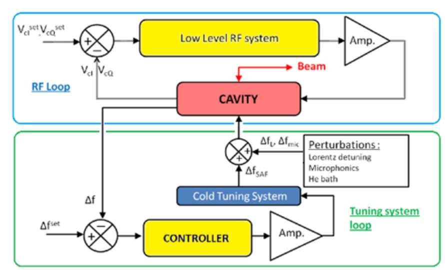

CST

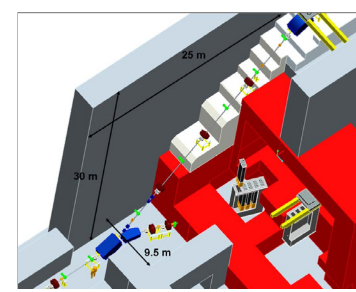



INJECTORS
SUPERCONDUCTING LINAC TUNNEL
Scale: 10 m
upper view
side view
REACTOR BUILDING
Object point
Image point
Section #1 (63 Spoke β~0.35 @ 352 MHz)
Section #2 (30 Elliptical β~0.47 @ 704 MHz)
Section #3 (64 Elliptical β~0.65 @ 704 MHz)
Spare part & beam matching section (including possible deviation to an ISOL@MYRRHA facility)

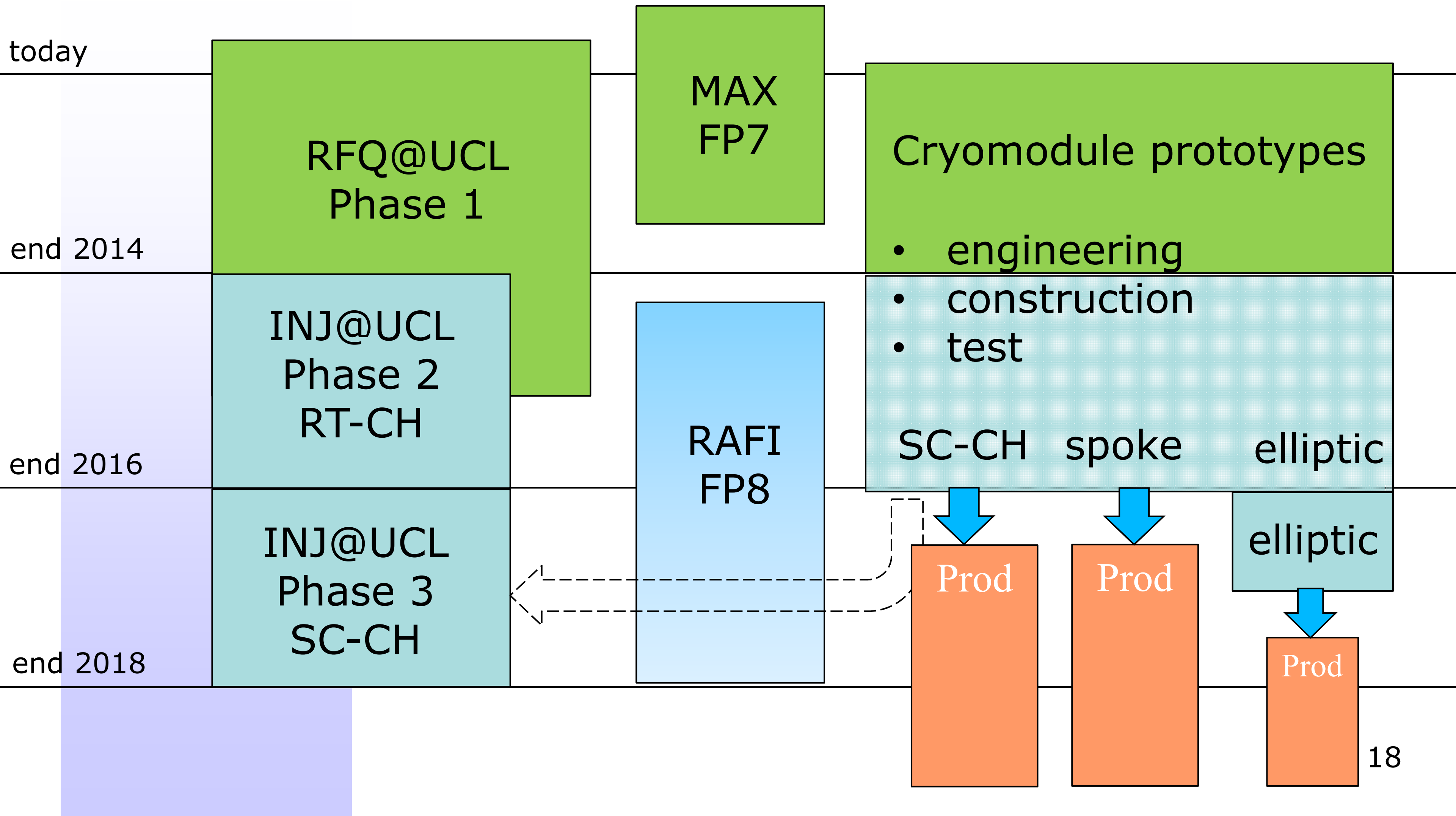

cooling tray
dump
diagnostics
RFQ
LEBT
ECR
cable tray
RF final amplifier
storage
storage & workshop
ECR cabinet
local console
7 m
18 m


100
270
250
300
200
260
250
300
120
250
400
Source extraction
Pumps +CF
Solenoid 1
ST 1
PF +EM+CF
ST 2 +valve
Solenoid 2
Chopper + injection cone + ACCT + pumps
RFQ

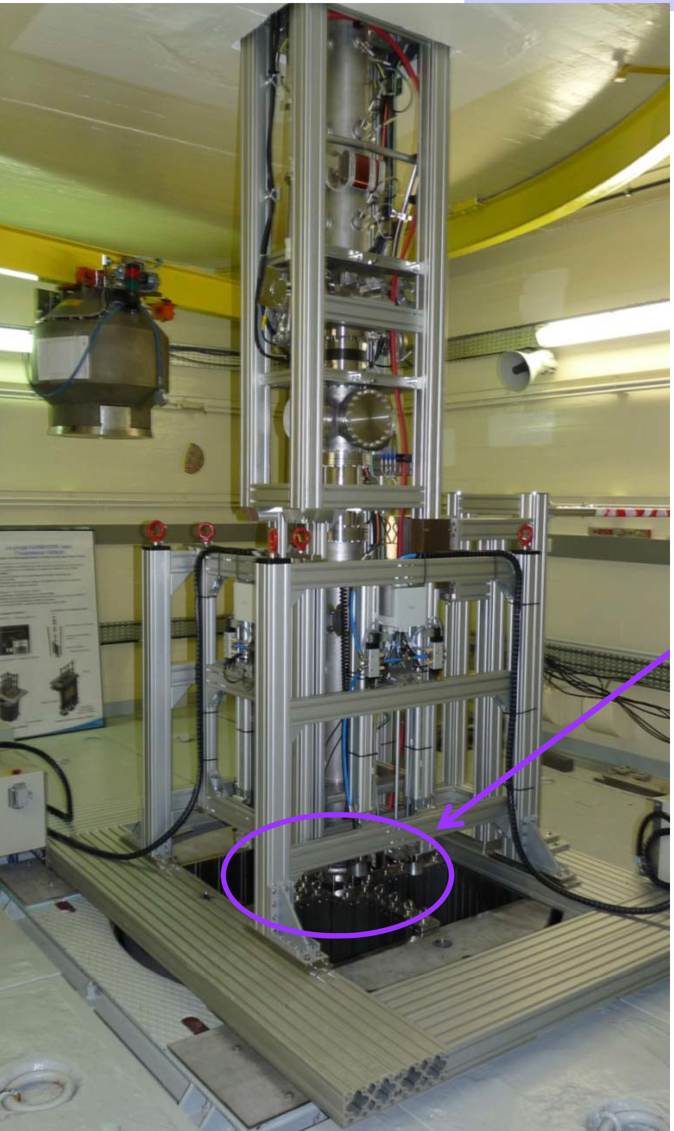

Low Level RF system
Amp.
Beam
RF Loop
CAVITY
Perturbations :
Lorentz detuning
Microphonics
He bath
Cold Tuning System
Tuning system loop
CONTROLLER
Amp.


25 m
30 m
9.5 m

MLA R&D diagram



Projects



- reactor – accelerator integration: GUINEVERE experiment
  - goal: subcriticality monitoring techniques
  - zero power VENUS-F at SCK-CEN
  - GENEPI-3C fast neutron generator
  - tight collaboration SCK – CEA – CNRS
  - starting phase of data taking

Projects

2. US
   - ADS concept designs, e.g. Argonne LDRD project "Near-Term Spent Nuclear Fuel Disposal Using Accelerator Driven System"
   - important: White Paper

Finding #14: Technology is sufficiently well developed to meet the requirements of an ADS demonstration facility; some development is required for demonstrating and increasing overall system reliability.

Finding #15: For *Industrial-Scale Transmutation* requiring tens of MW of beam power many of the key technologies have been demonstrated, including front-end systems and accelerating systems, but demonstration of other components, improved beam quality and halo control, and demonstration of highly-reliable sub-systems is required.

Projects

Accelerator and Target Technology for Accelerator Driven Transmutation and Energy Production

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[*]*Co-chairs*

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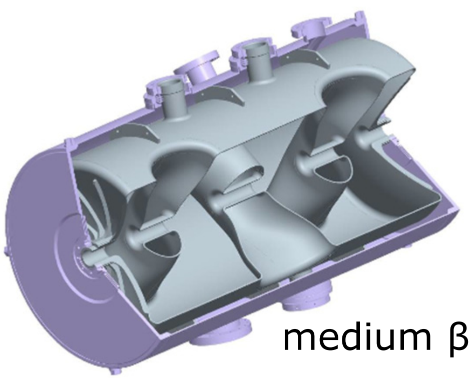
1. Accelerator Driven Systems and Their Applications

1.1 History of Accelerator Driven System Activities

Since the early 1990's, accelerator driven systems (ADS) – subcritical assemblies driven by high power proton accelerators through a spallation target which is neutronically coupled to the core – have been proposed for addressing certain missions in advanced nuclear fuel cycles. Institutes throughout the world have conducted numerous programs evaluating the role of ADS in nuclear waste transmutation and energy production. In 1995, the National Research Council (NRC) issued a report on transmutation technologies [1], which included an evaluation of one ADS concept that was under study at that time: a large-scale system that proposed using a ~100-MW accelerator to drive a thermal, molten salt subcritical core. The NRC recognized the numerous complexities associated with the system, including

Projects

- accelerator technology (SC cavities) is available, and pioneering R&D is going on
  - Argonne
  - Fermilab
  - Jlab
  - CEBAF
  - SNS
- nevertheless:

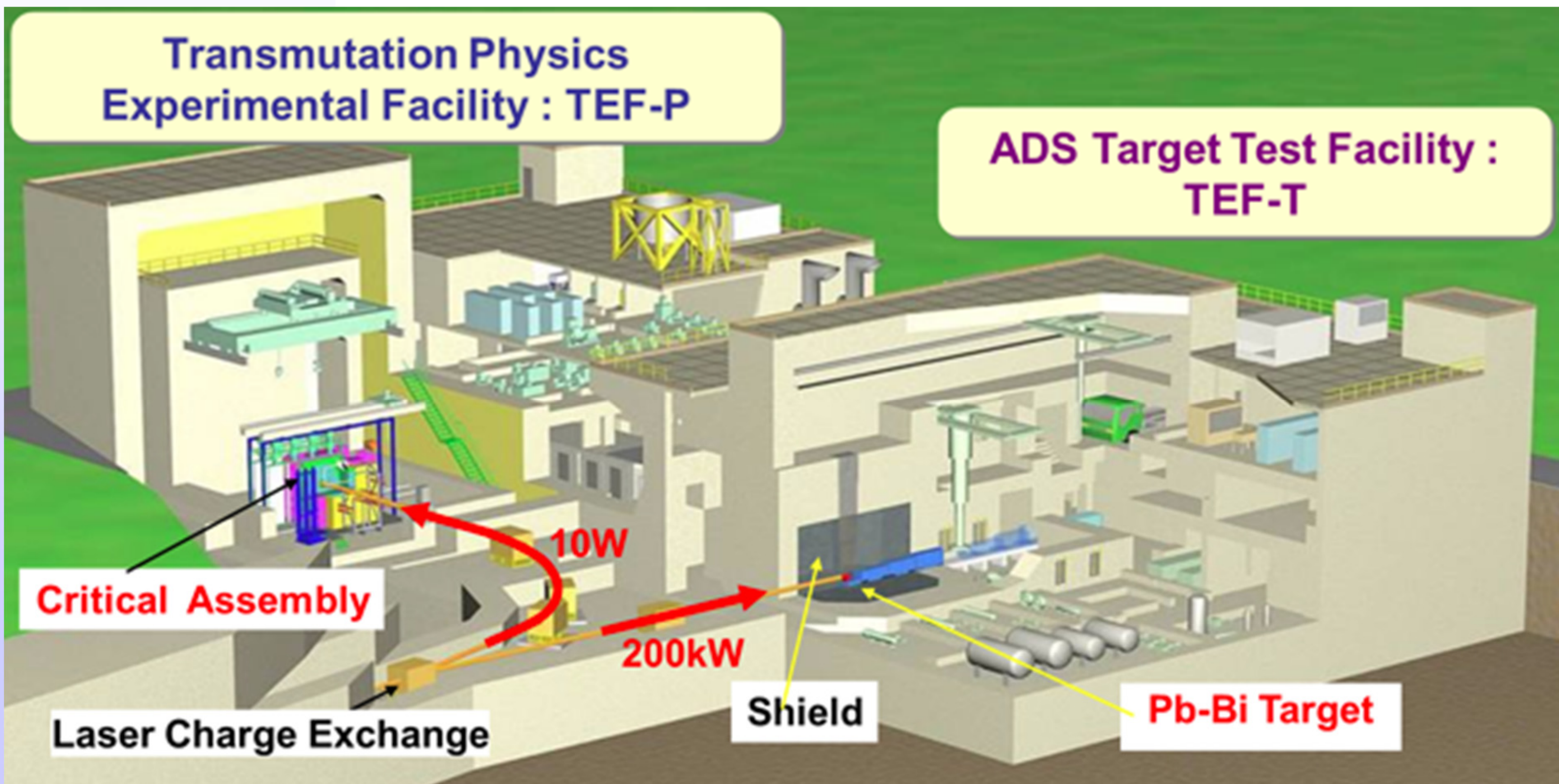


medium β triple spoke

there is no funded integrated ADS project in the US

Projects

3. Japan
   - J-PARC: concept design (800 MW), TEF
   - Superconducting RF Test Facility at KEK



Projects

4. India
   - interest in ADS through interest in Th cycle for energy production
   - main effort: Advanced Heavy Water Reactor
   - ADS also considered for transmutation
   - accelerator effort:
     - RRCAT: elliptical SC cavities (coll. FNAL), full size infrastructure for production
     - BARC: 20 MeV 30 mA injector is being developed

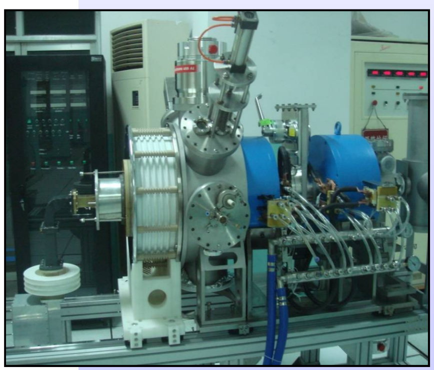
Projects

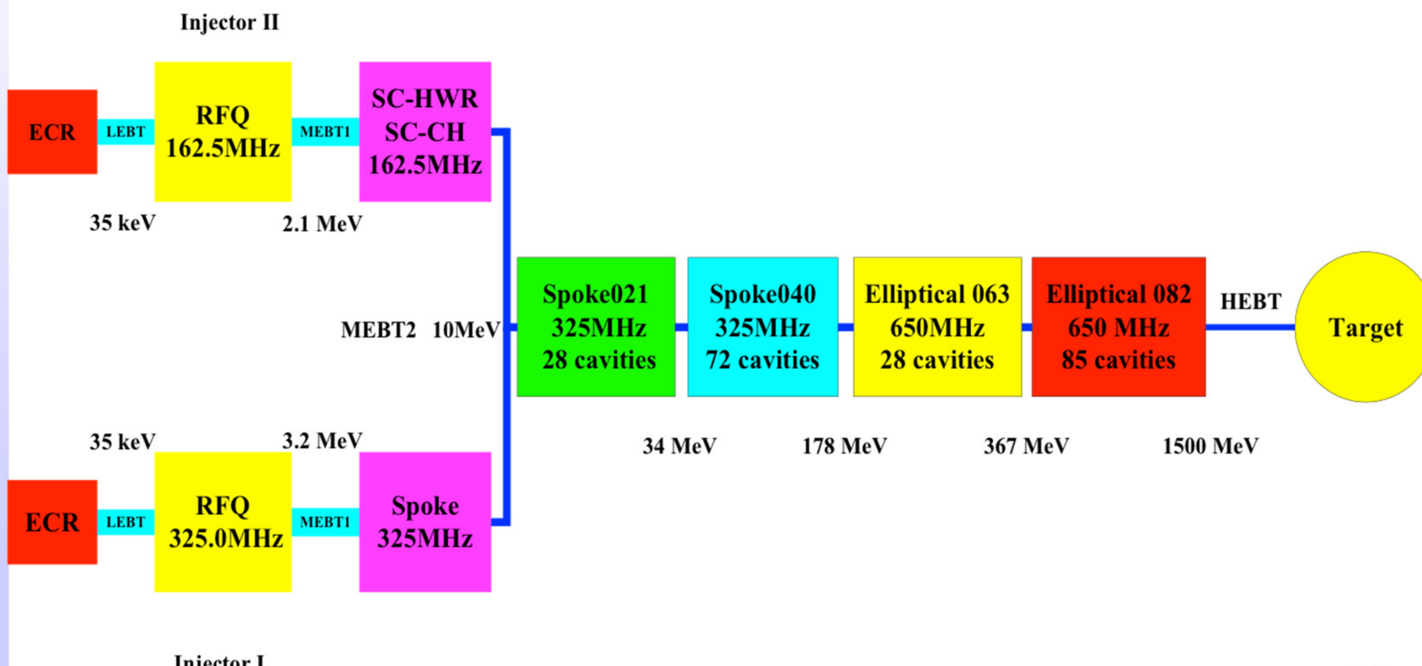
5. China

- very ambitious nuclear power program: 400 GW_e i. 2050
- waste problem considered as a bottleneck → transmutation
- long term views and R&D supported by Chinese Academy of Science
  - Th-based Molten Salt Reactor
  - C-ADS
- For phase 1/3 of both TMSR and C-ADS: budget allocated by Central Government
- C-ADS: integrated ADS project, 3 phases, site identified
  - phase 1: R&D facility
  - phase 2: experimental facility (2022)
  - phase 3: DEMO of industrial facility (2032)
  - technology: Pb-Bi cooled reactor, SC linac

Projects

- accelerator matches phased approach
  - fault tolerant design
  - fully SC after RFQ
  - 2 injectors are evaluated (IMP / IHEP)
  - beam trip tolerance = "White Paper"





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Concluding remarks

- ADS widely acknowledged, esp. for transmutation
- sense of urgency seems to be lacking
- for the accelerator, conditions are favourable:
  - wide effort on SC RF, synergies between all HPPA applications
  - more reliable and fault tolerant auxiliaries (e.g. SS RF amplifiers, modular power converters) contribute to the reliability goal of the accelerator being more realistic than ever.