EuCARD²

Status of Accelerator-Driven Systems Research and Technology Development

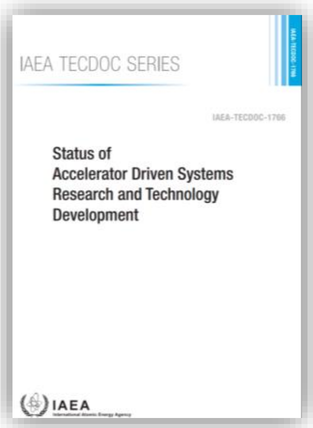
Summary of session 2: national ADS programs

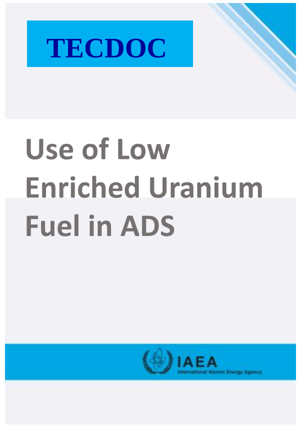
Jean-Pierre Revol

Thursday February 9, 2017

IAEA and ADS	*Stefano Monti*	
6-2-024 - BE Auditorium Meyrin, CERN	14:00 - 14:25	
Europe ADS project MYRRHA	*Peter Baeten*	
6-2-024 - BE Auditorium Meyrin, CERN	14:25 - 14:50	
China ADS project	*Wenlong Zhan*	
6-2-024 - BE Auditorium Meyrin, CERN	14:50 - 15:15	
coffee break		
6-2-024 - BE Auditorium Meyrin, CERN	15:15 - 15:45	
India ADS programme	*Pitamber Singh*	
6-2-024 - BE Auditorium Meyrin, CERN	15:45 - 16:10	
Japan ADS project	*Takanori Sugawara*	
6-2-024 - BE Auditorium Meyrin, CERN	16:10 - 16:35	
Ukraine NSC KIPT ADS project	*Yousry Gohar*	
6-2-024 - BE Auditorium Meyrin, CERN	16:35 - 17:00	
USA Progress on SRF Linacs Driving Subcritical GEM*STAR Reactors	*Rolland Johnson*	
6-2-024 - BE Auditorium Meyrin, CERN	17:00 - 17:25	

IAEA – Stefano Monti





- **Technical Working Groups** related to ADS
  - **TWG-NFCO:** nuclear fuel cycle options: innovative fuel cycles and nuclear materials management
  - **TWG-FR:** fast spectrum systems, both critical and subcritical, for energy production and transmutation of long-lived radionuclides
- **Coordinated Research Project** (CRP) on “Accelerator Driven Sub-critical Systems (ADS) and Use of Low Enriched Uranium (LEU) in ADS”
  … Continue Development of Analytical Techniques?

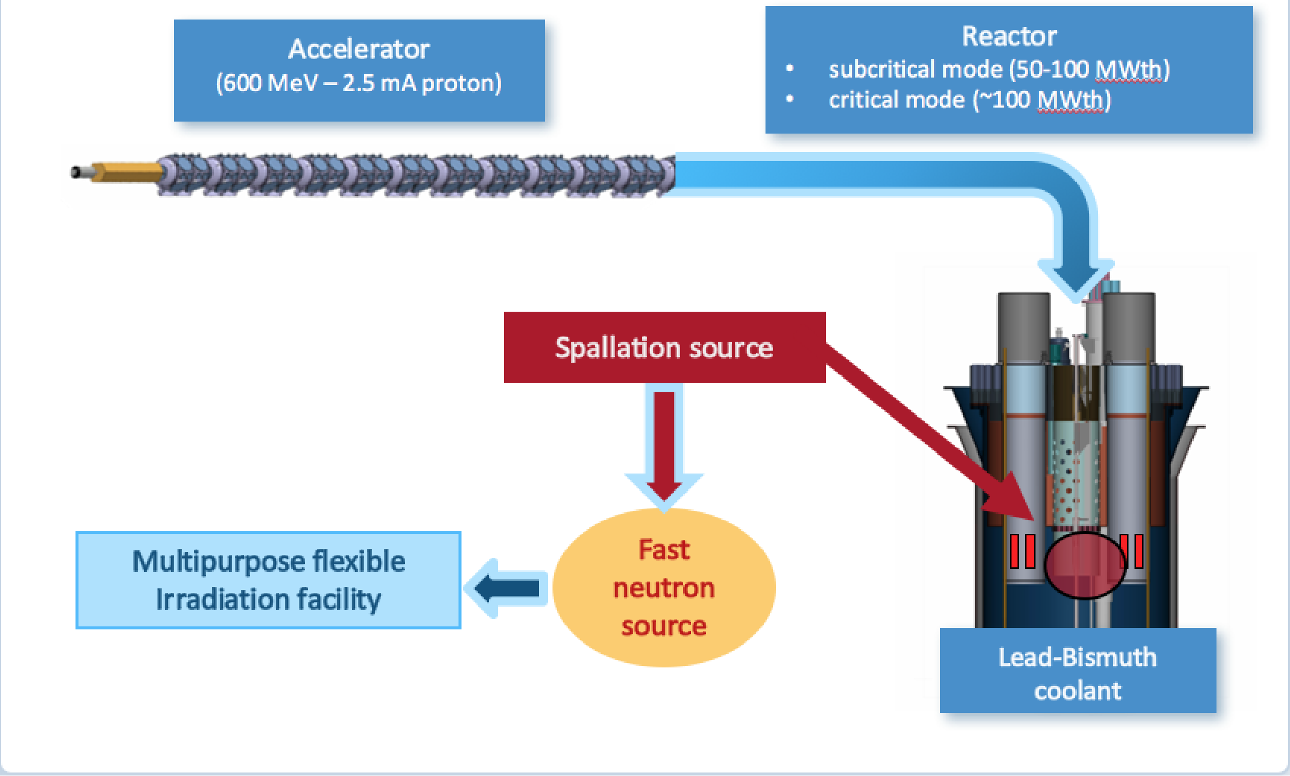
ADS Nuclear Data Library v2.0

ACE formatted Library for Accelerator Driven Systems

- IAEA Emerging Technologies Workshops: Trends and Implications for Safeguards, Vienna, 13-16 February 2017
- 3rd International Conference on Fast Reactors and Related Fuel Cycles (FR17) Yekaterinburg, RF, 26-29 June 2017
- **Explained how to make use of IAEA through IAEA member States**

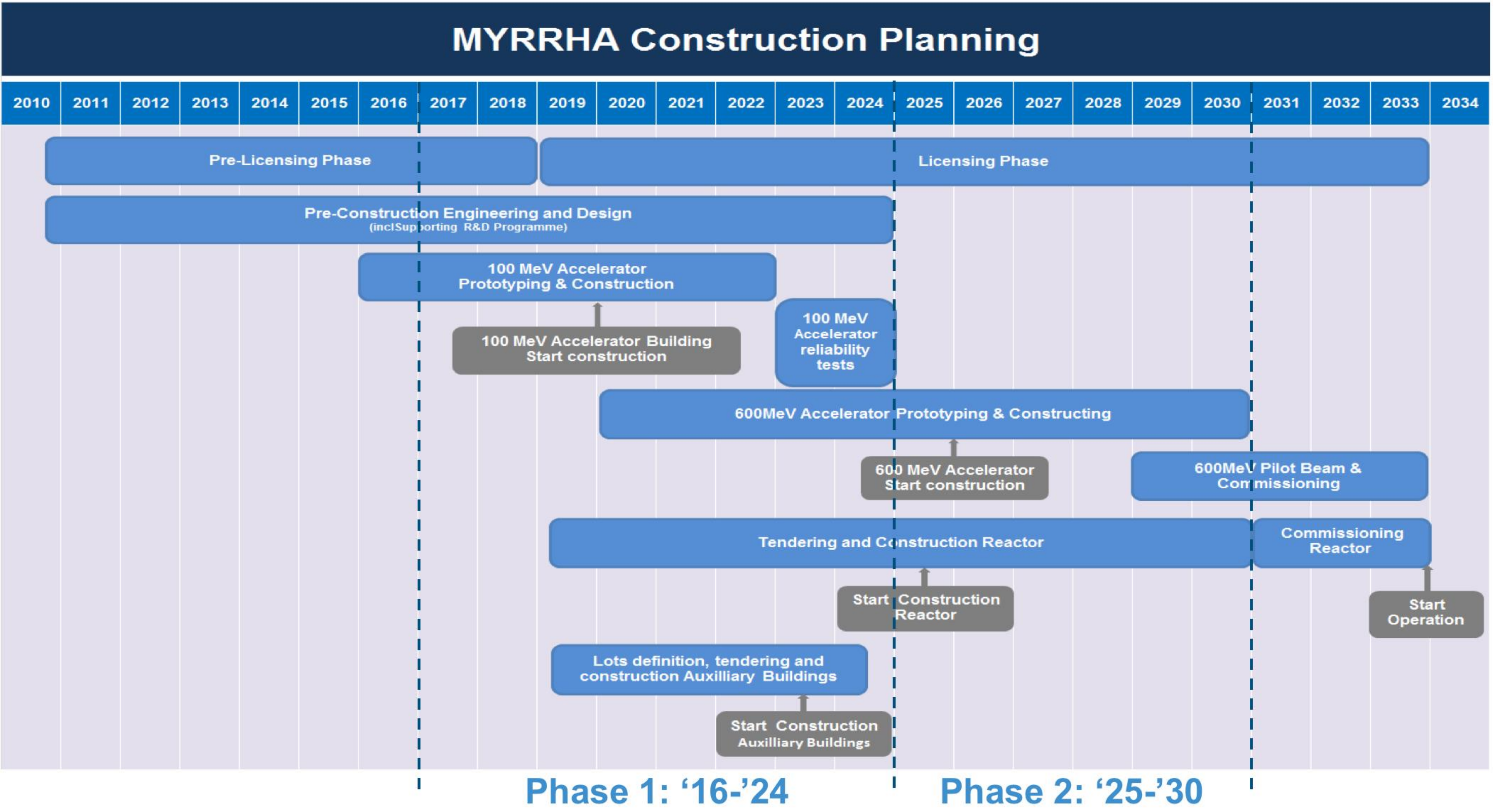
MYRRHA – Peter Baeten

- Most advanced ADS project. – Should be the flagship of ADS projects
- Strong support from the Belgium Goverment, where are the others?



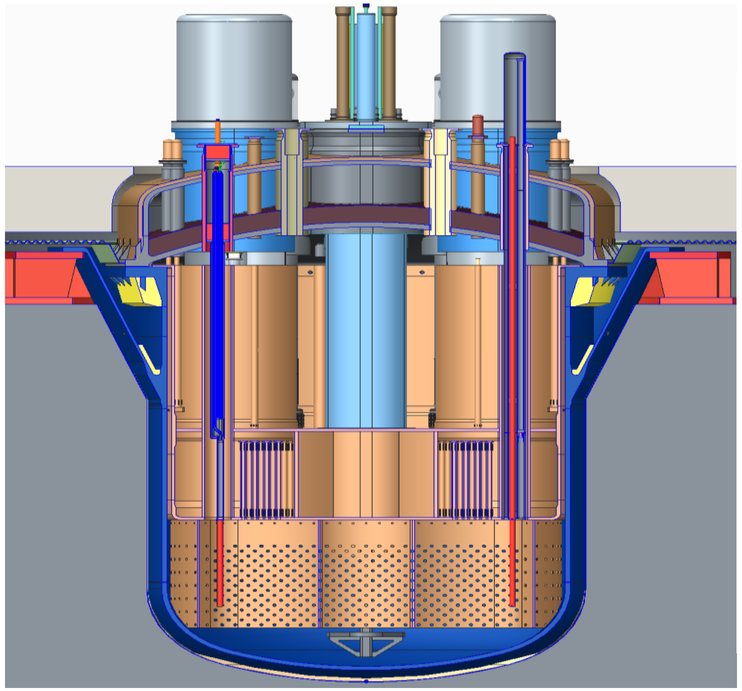
Multipurpose Facility

15 years to wait for the start of operation!



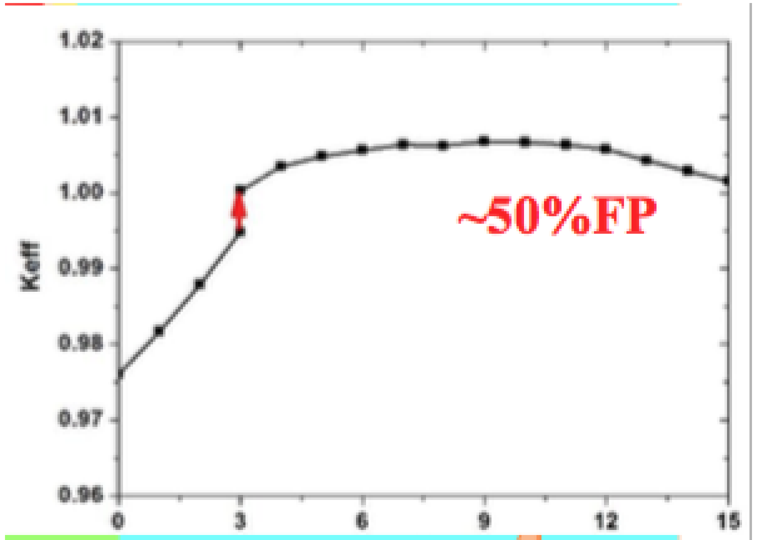
Proton target facility on the way by 2024

- Impressive amount of technical design work, with many innovative ideas in the design of components, a very broad R&D program, and also breaking new ground in the field of licencing!

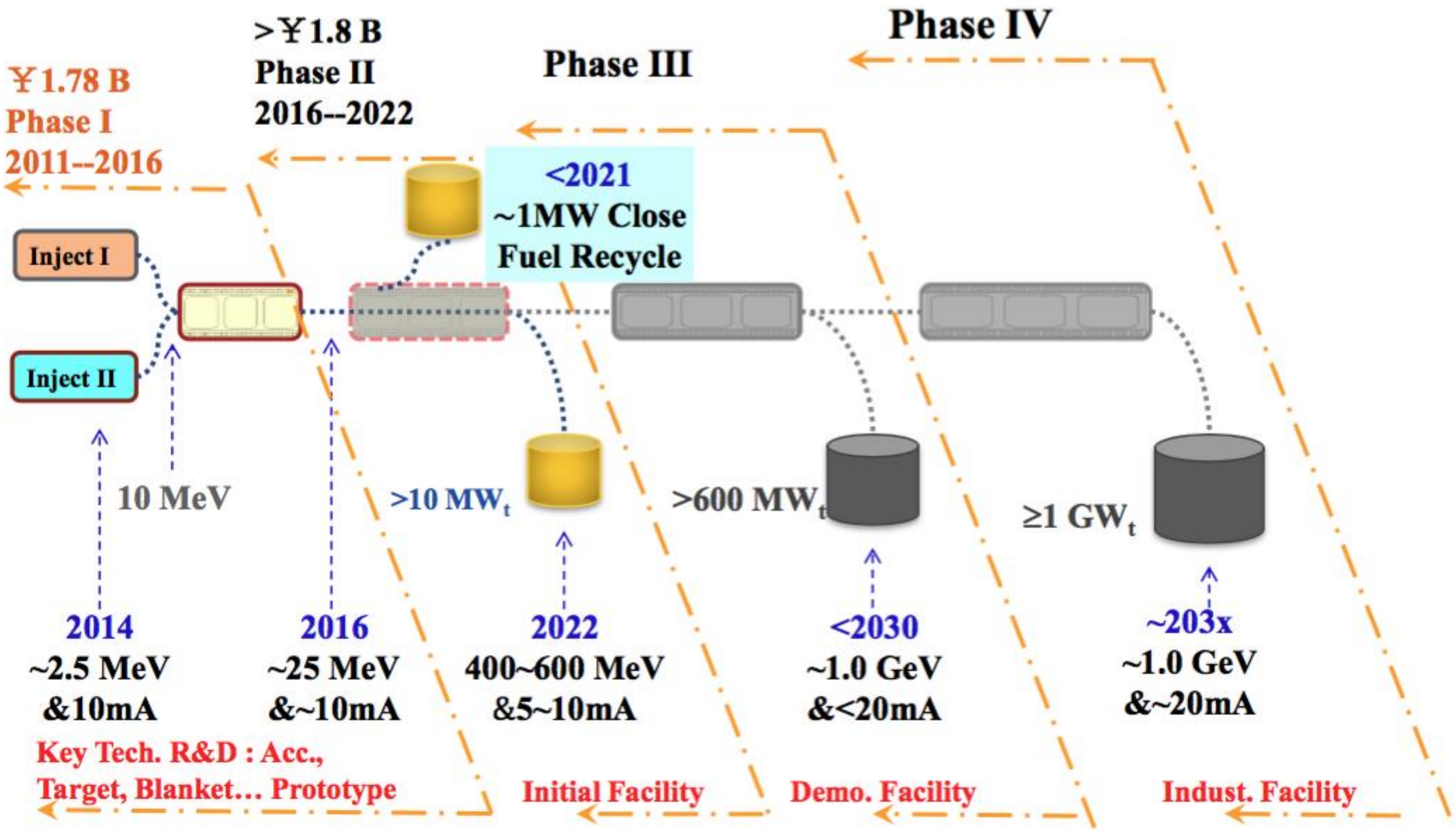


ADANES – Wenlong Zhan

- ADANES (Accelerator Driven Advanced Nuclear Energy System) after intensive R&D last 5 years in the Chinese Academy of Science.
- They changed their strategy: Optimizing resources & radiotoxicity
  - Simplify Fuel Recycling: Remove part of FPs (~50%) from spent fuel, Convert Residuals as recycle fuel
  - Power Burner: Transmuting, Breeding & Energy production by fast neutron



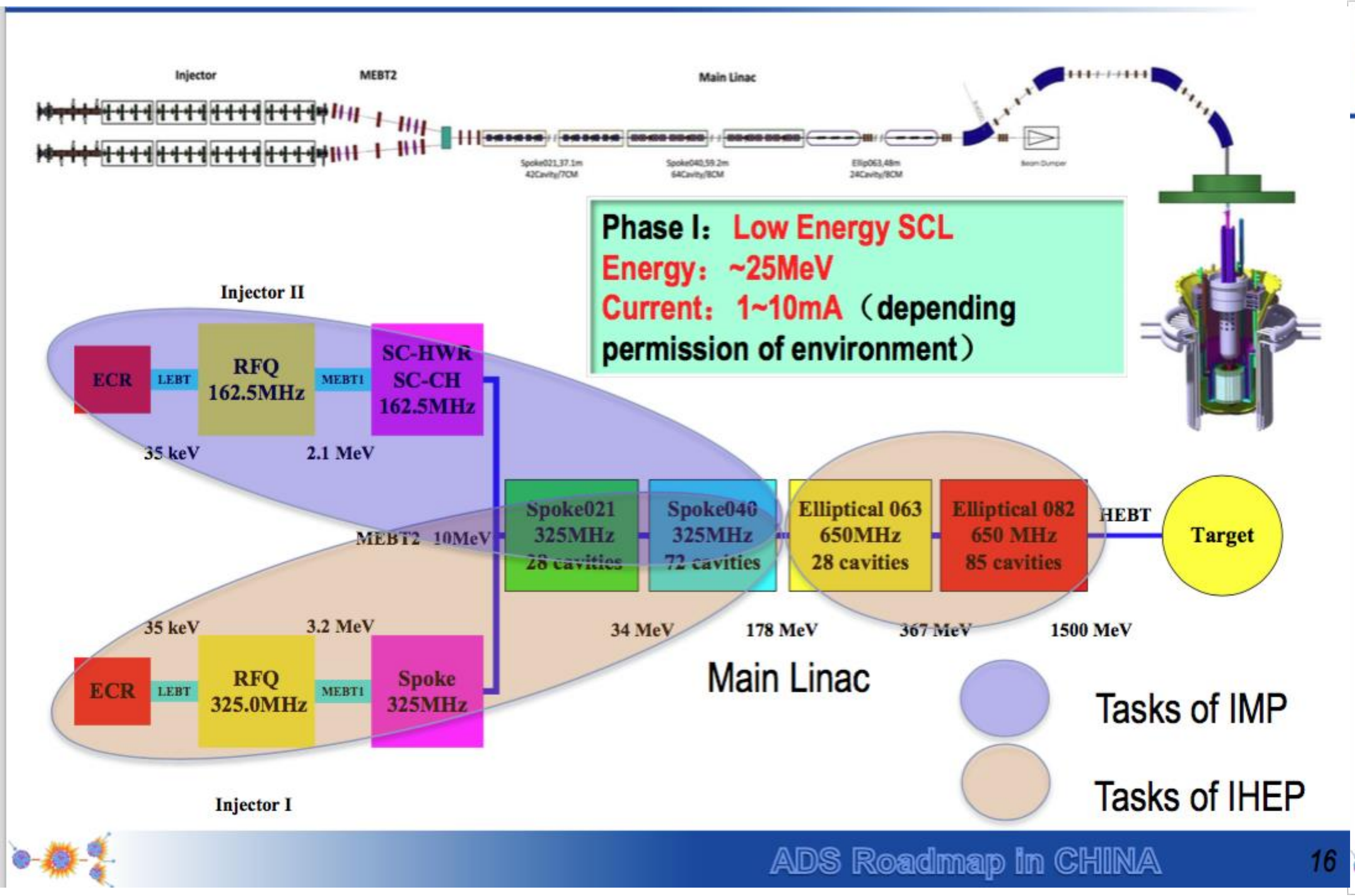
ADS/ADANES Roadmap in China



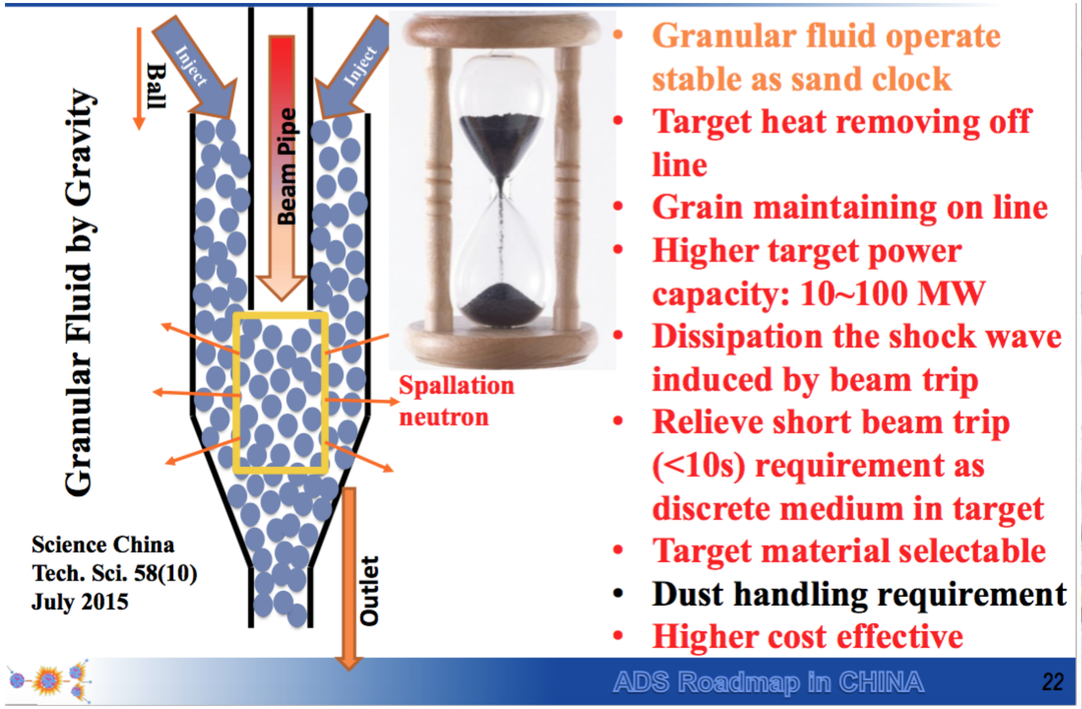
Ambitious project, to reach 1 GWe
A lot of resources
2000 people involved!

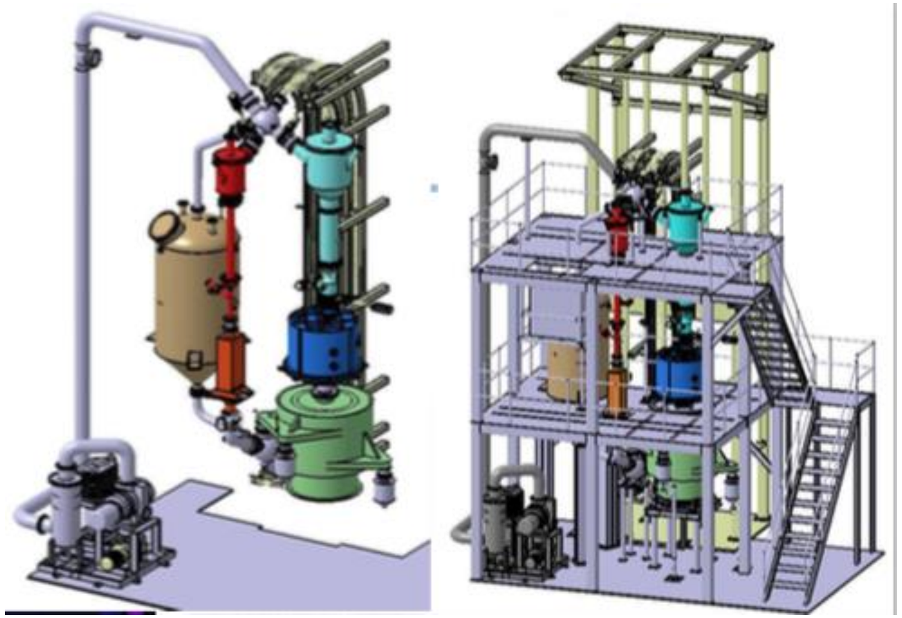
– Phase II approved by the Central Government
– Get to 10 MWt by 2022?
– 600 MWt by 2030
– Full system, on similar time scale as MYRRHA

Two injectors developed in competition between Lanzhou and Beijing
Components to be combined to reach 25 MeV, 10 mA in new site at HuiZhou in South China



Innovative approaches to the
target design





Innovative approach to the **subcritical core**:

Subcritical Fast Core (Gas+Grain→new, simplify)

LBE, Steam, Gas + Grain coolant cores R&D, Gas+Grain is more optimizing

Systematic innovative approach for the Chinese ADS programme

India ADS – Pitamber Singh

- The clear goal in India is the exploitation of their very large thorium resources
- R&D concentrates at this time on the accelerator, with an ambitious program to reach 1 GeV, 30 mA linac, in collaboration with the USA
- First stage: Low Energy High Intensity Proton Accelerator (LEHIPA) 20 MeV, 30 mA linac

Accelerator Development for ADS

LEHIPA

High current injector 20 MeV, 30 mA

Proton IS 50 keV → RFQ 3 MeV → DTL 20 MeV

Phase I

Phase II

SC Linac HWR/SSR

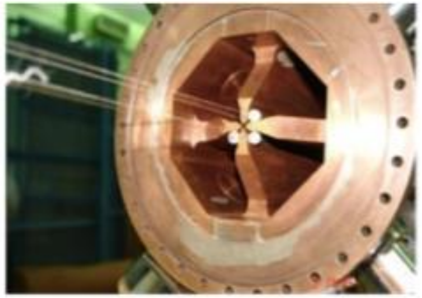
200 MeV

Phase III

SC Linac 1 GeV

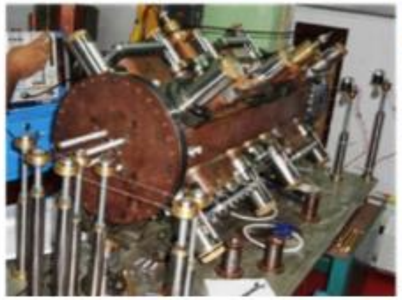
ECR Ion Source

RFQ



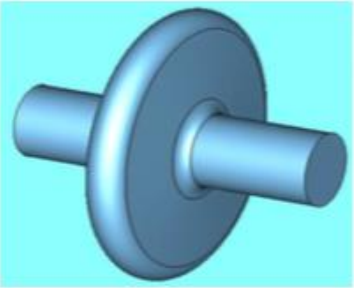
DTL

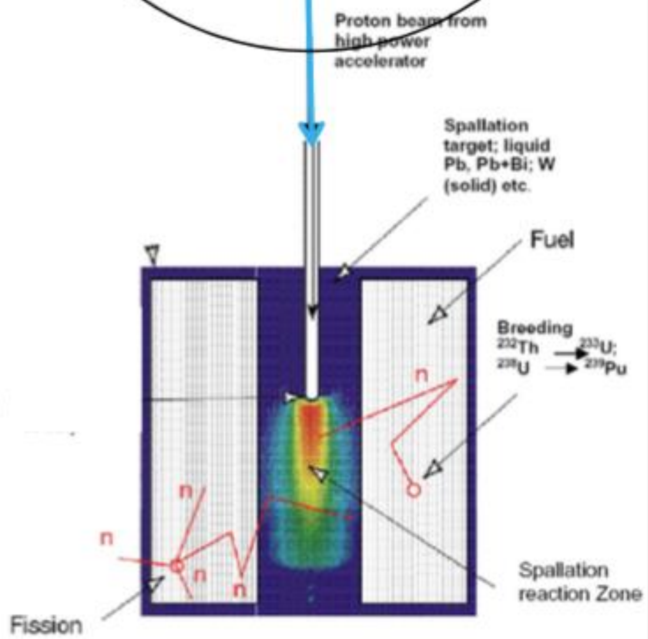
400 keV RFQ



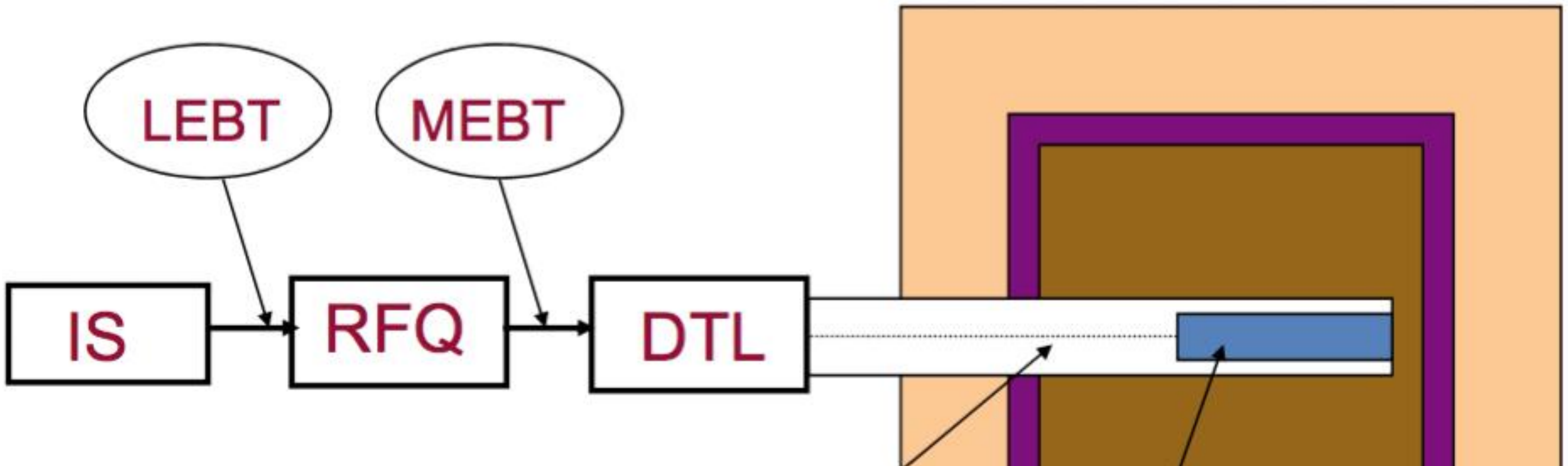
LEBT

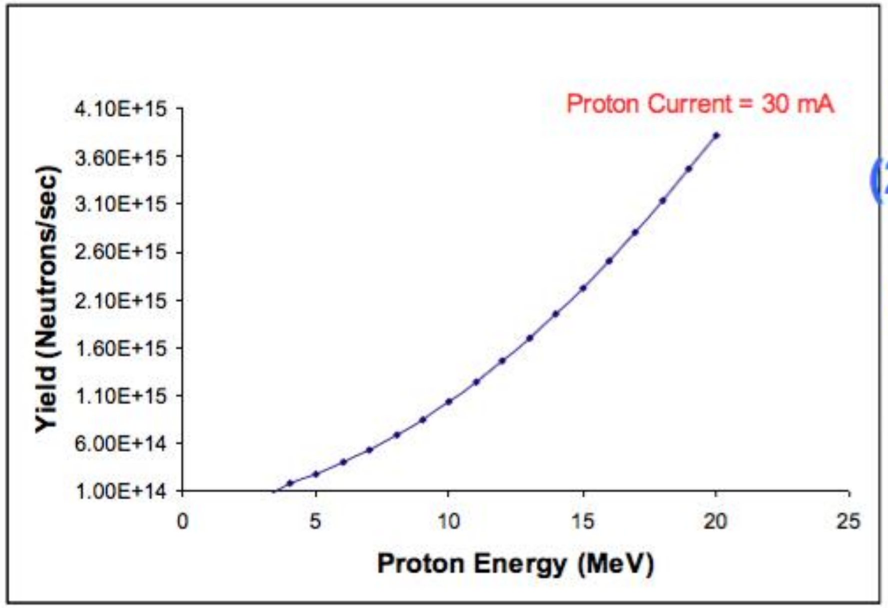
Elliptical SC Cavity





High Yield Neutron Facility





Neutron Yield for Beryllium target

$$S_0(E_P) = 4.476 \times 10^{11} \times E_P^{1.886} \times I \ \text{n/sec}$$

ADS programme in INDIA - Current Scenario

➢ **BRAHMMA – Thermal ADS**
Nat. U fuel
Deep subcritical (Keff = 0.890)

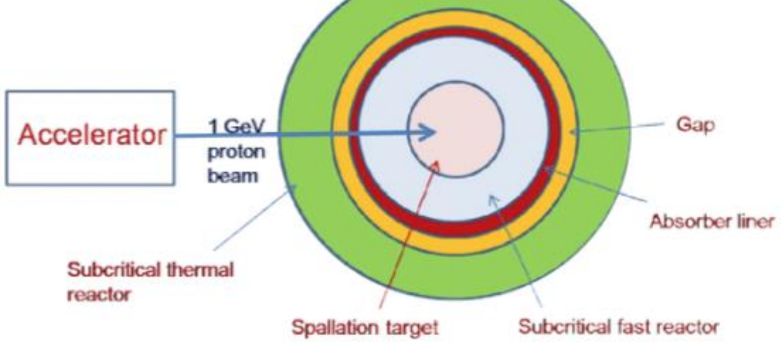
Next stages proposed

➢ Thermal ADS with higher Keff _Proposed
Similar configuration as BRAHMMA with SEU/LEU fuel
Keff ~ 0.95

➢ Fast ADS -PROPOSED
Th-Pu fuel
Keff ~ 0.97-0.98

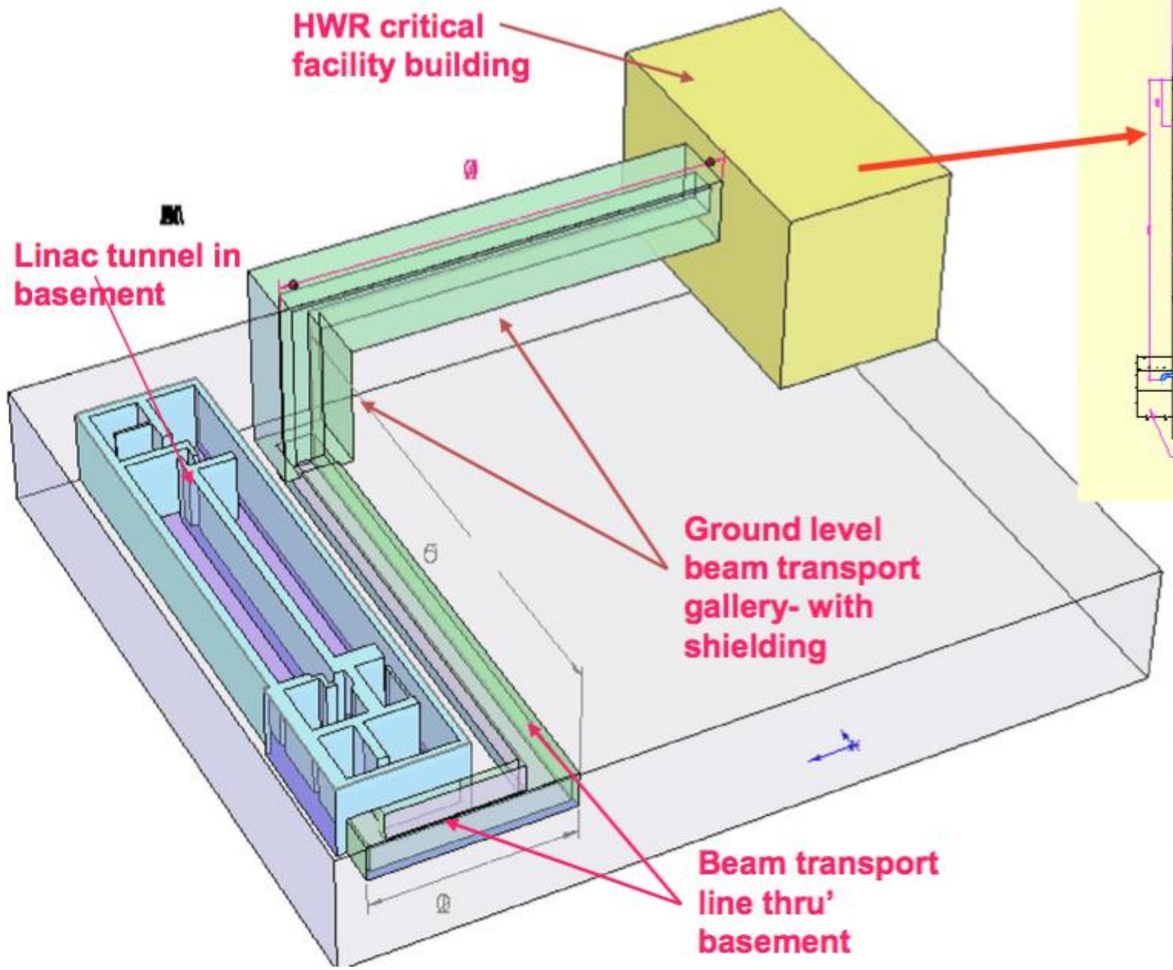
Spallation target R&D at BARC

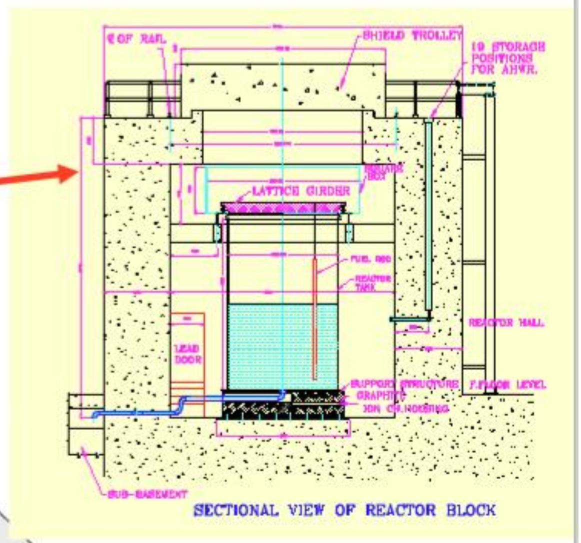
One way Coupled System for ADS



S.B. Degweker et al. ; Ann. Nucl. Energy 26, 123 (1999)

20 MeV Proton beam for ADS experiments in HWR critical facility

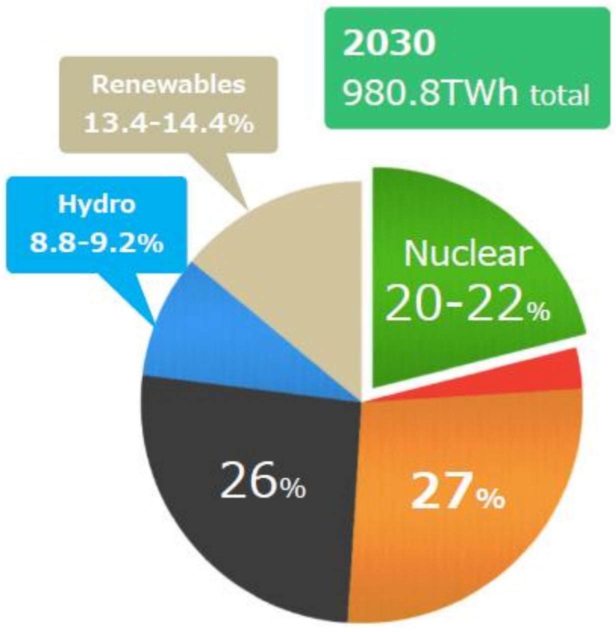




Studies have confirmed feasibility of extending 20 MeV proton beam to a target in the core of nearby HWR critical facility (commissioned)

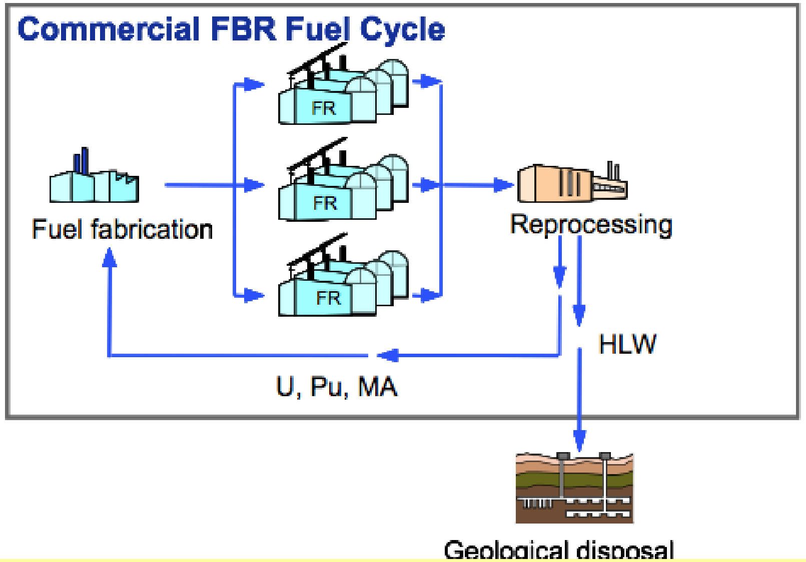
Japan ADS – Takanori Sugawara

- National Policy for Nuclear Energy
  - "Nuclear power is an important base-load power source"
  - Dependency on nuclear energy will be decreased, but Japan will continue to rely on nuclear energy in the future
  - "GOJ will promote development of technologies for **reducing the volume and harmfulness of radioactive waste**"
  - The basic policy of Japan is to promote a nuclear **fuel cycle based on reprocessing**, Pu used as fuel, MA to be transmuted



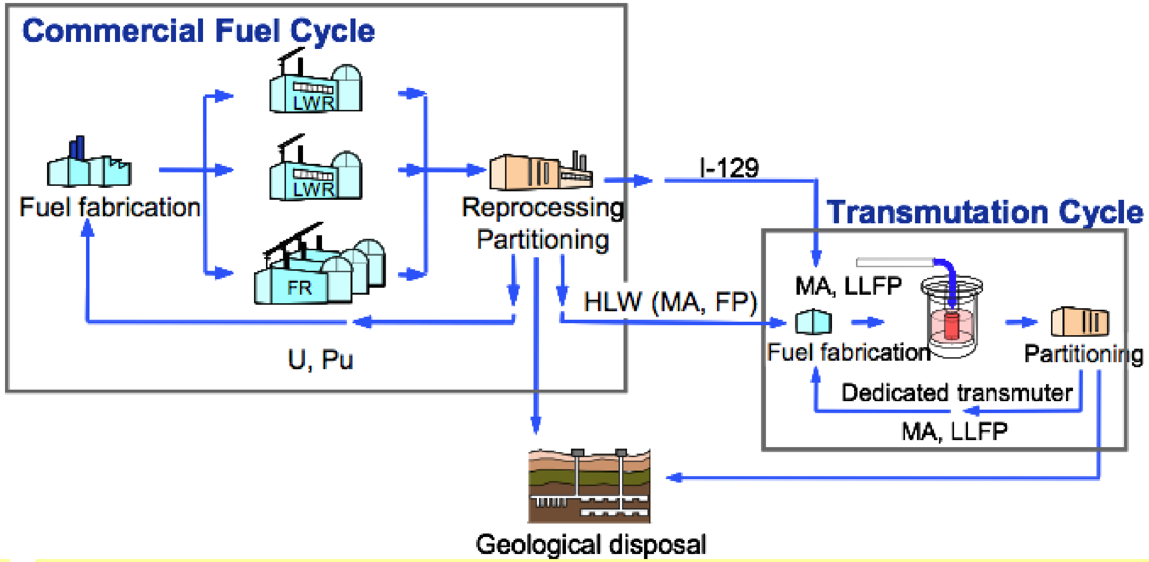
ADS is part of the plan to eliminate Minor Actinides

Homogeneous cycle



- MA is homogeneously mixed to FBR fuel with small amount up to 5 wt.%.
- **MA transmutation is performed in all electricity generating FBR plant.**

Double-Strata (ADS)



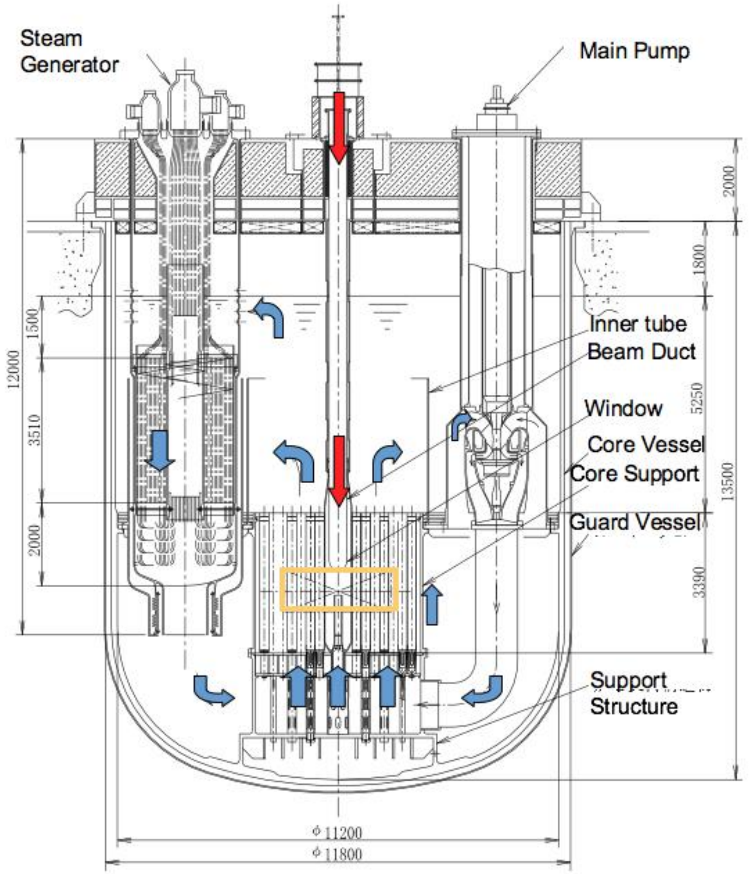
- **Dedicated (second) transmutation fuel cycle with Accelerator-Driven System (ADS) is added to commercial fuel cycle.**
- MA recovered from commercial fuel cycle is confined in the compact transmutation cycle.

ADS R&D in JAEA and J-PARC

Conceptual Design of ADS in JAEA

Purpose : MA transmutation

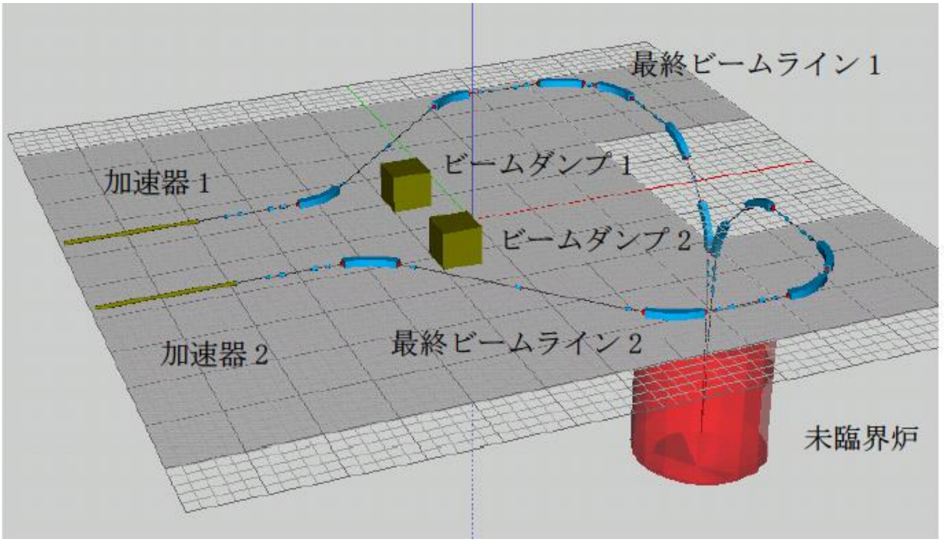
- Proton beam : 1.5GeV ~30MW
- Spallation target : LBE
- Coolant : LBE
- Subcriticality : $k_{eff} = 0.97$
- Thermal output : 800MWt
- Core height : 1000mm
- Core diameter : 2440 mm
- Fuel inventory : 4.2t (MA:2.5t)
- Fuel composition :
  (MA + Pu)N+ZrN (Mono-nitride)
  Inner : 70%MA+30%Pu
  Outer : 54%MA+42%Pu
- Transmutation rate :
  250kg(MA) / 300EFPD

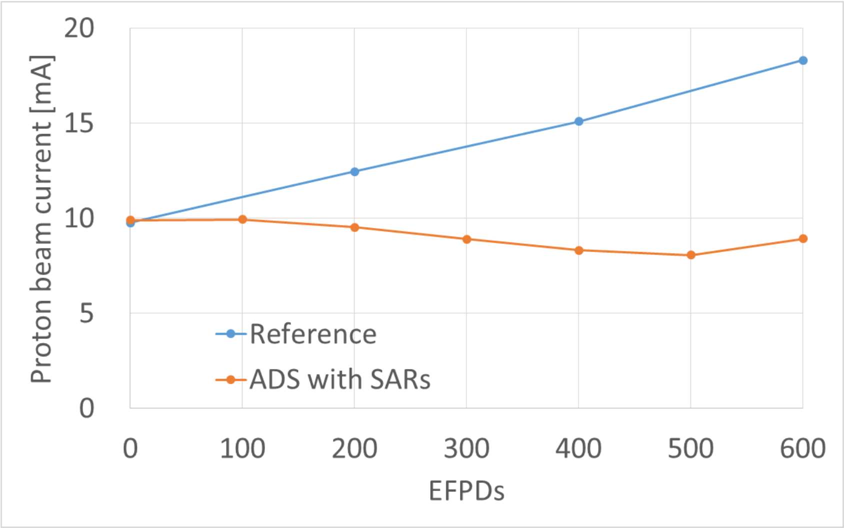


K. Tsujimoto, H.Oigawa, K.Kikuchi, et. al, "Feasibility of Lead-Bismuth-Cooled accelerator-Driven System for Minor-Actinide Transmutation", *Nucl. Tech.* 161, 315-328 (2008).

ADS R&D in Japan

- Work on **beam trips**, k_{eff} adjustment by B_4C **Subcriticality Adjustment Rod**, Reflecting the Fukushima Accident, conceptual design of DRACS (**Direct Reactor Auxiliary Cooling System**) is investigated, and on Subcritical core layout





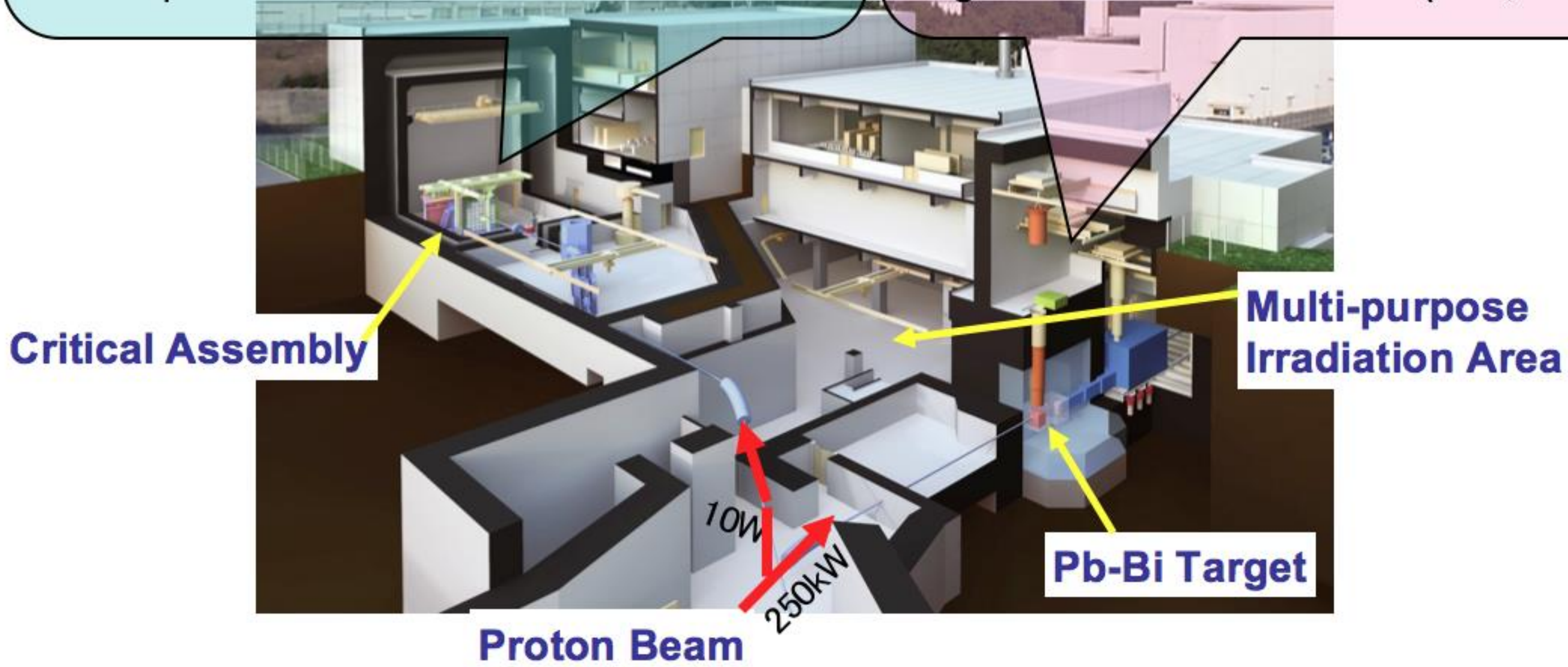
Research Plan at J-PARC

Transmutation Physics Experimental Facility: TEF-P

Purpose: To investigate physics properties of subcritical reactor with low power, and to accumulate operation experiences of ADS.
Licensing: Nuclear reactor: (Critical assembly)
Proton beam: 400MeV-10W
Thermal power: <500W

ADS Target Test Facility：TEF-T

Purpose: To research and develop a spallation target and related materials with high-power proton beam.
Licensing: Particle accelerator
Proton beam: 400MeV-250kW
Target: Lead-Bismuth Eutectic (LBE, Pb-Bi)



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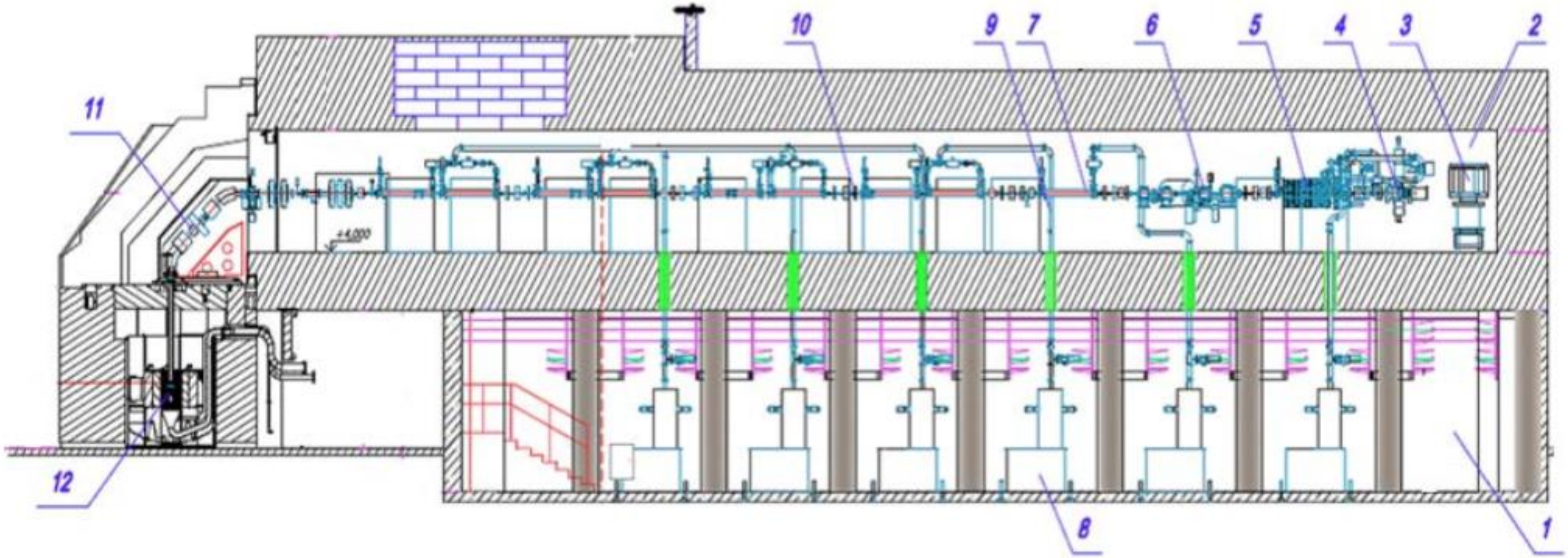
UKRAINE KIPT ADS Facility – Yousri Gohar

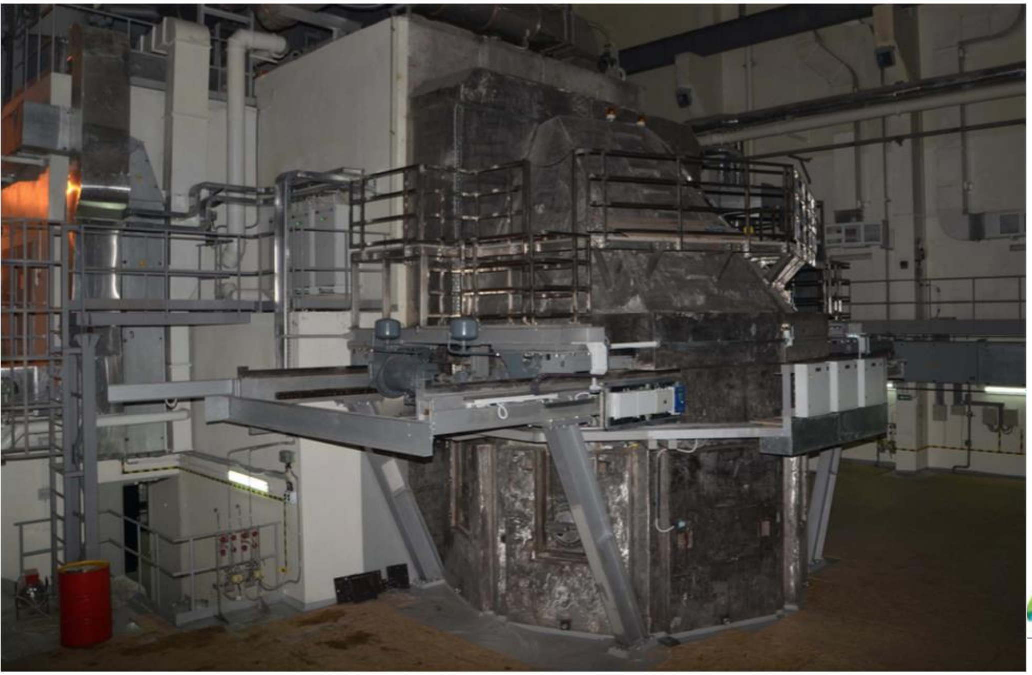
- **Real ADS, being commissioned!!**
- 100kW, 100 MeV electron beam with a thermal neutron subcritical core – Uranium fuel – energy amplification factor 2 to 3 depending on target
- Objectives:
  - Demonstrate ADS
  - Provide neutron facility for research
  - Physics and material experiment inside the subcritical core
  - Production of medical radio-isotopes and neutron therapy
  - Training young specialist for nuclear industry
- **The KIPT ADS Facility (KIPT Neutron Source Facility) is open for international cooperation as soon as it is in operation. The current schedule calls for startup in 2017.**

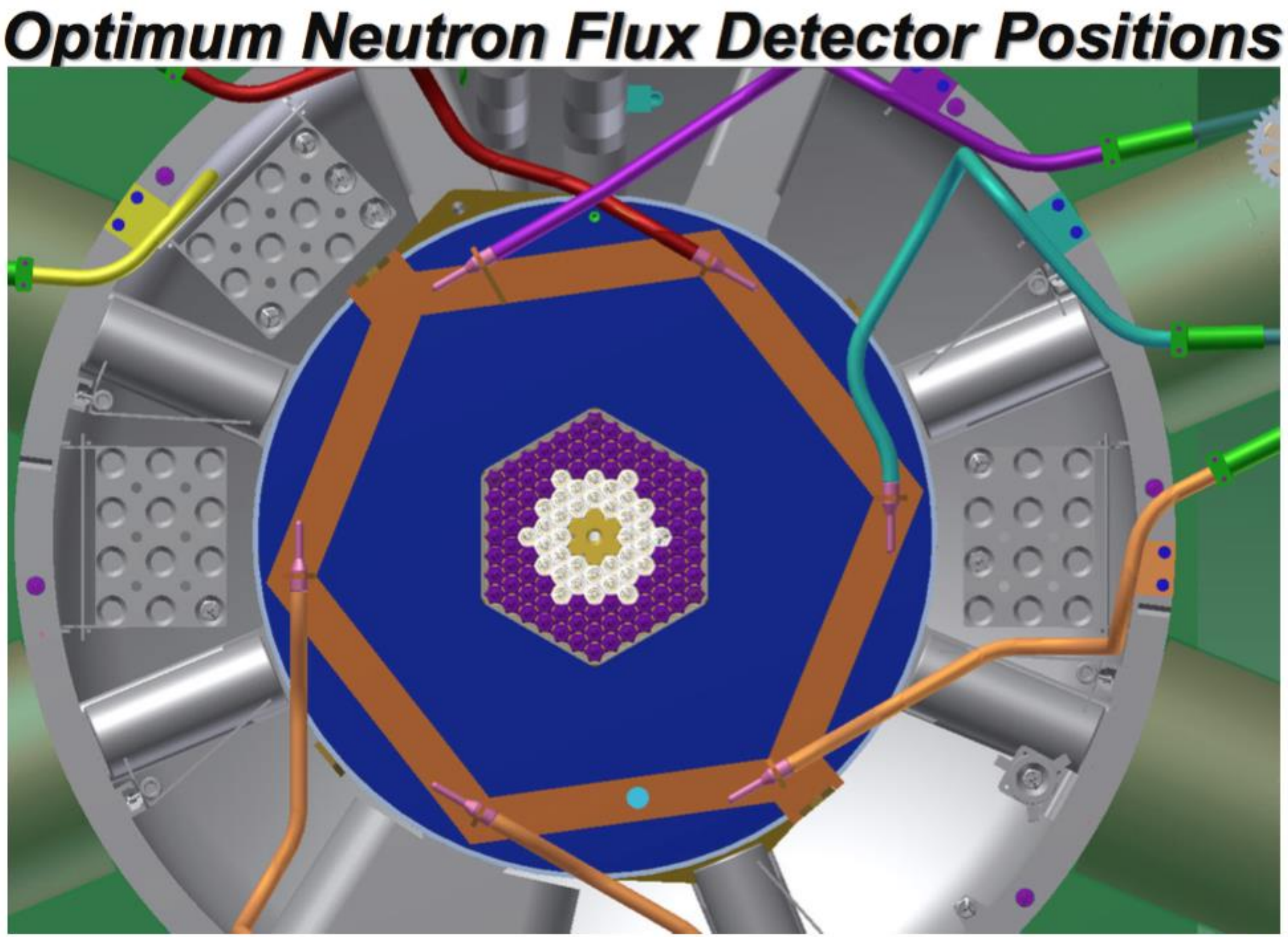
KIPT Electron Accelerator Configuration



1 - klystron gallery, 2 – Accelerator tunnel, 3 – Power supply, 4 - Electron gun, 5 - First accelerating section, 6 - Energy filter, 7 - Accelerating section, 8 - Klystron amplifier, 9 – Waveguide, 10 - Quadruple triplet magnet, 11 – Electron Transportation channel, 12 – Subcritical Assembly tank

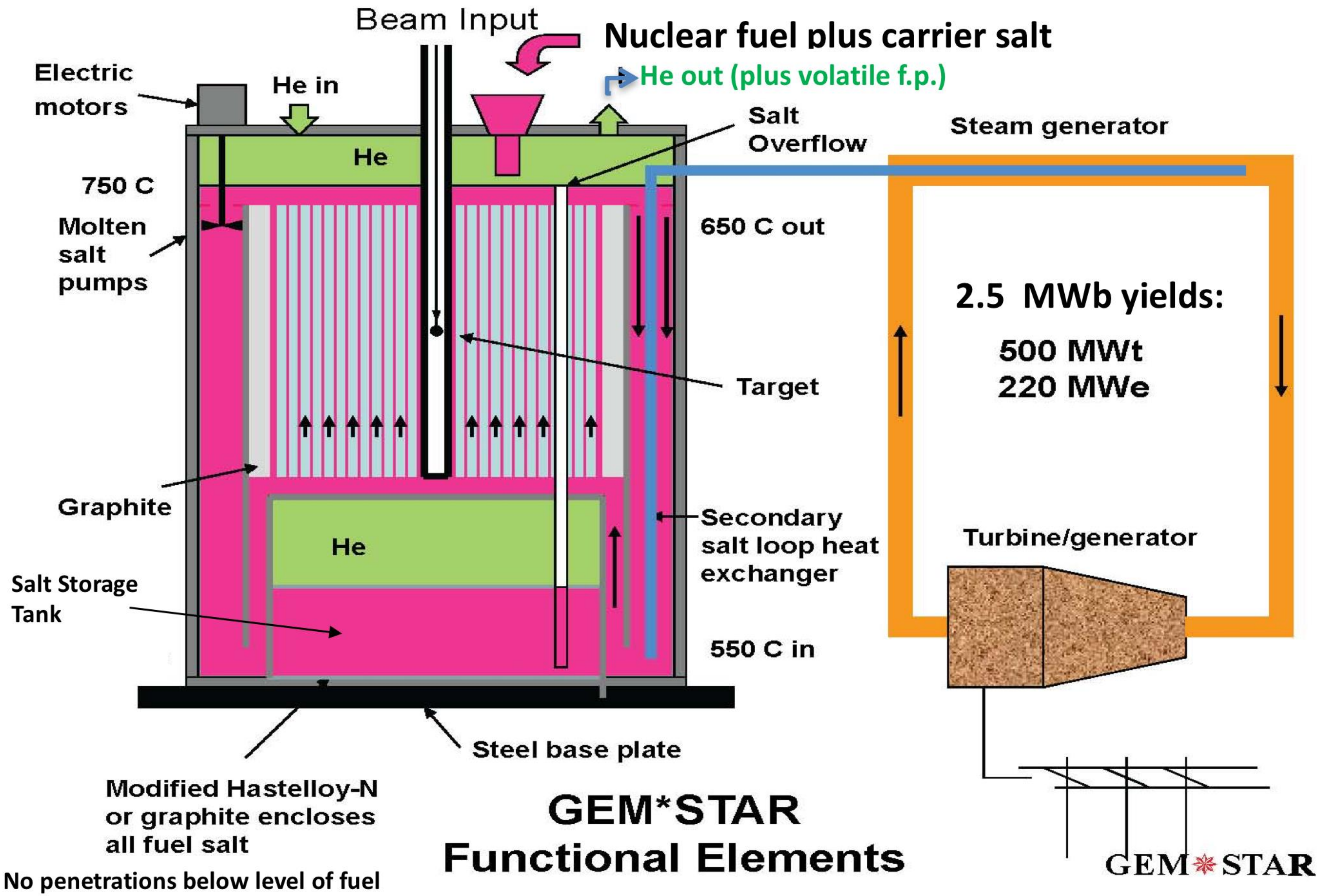
Tackling real practical problems





USA ADS: GEM*STAR – Rolland Johnson

- **Molten-salt fuel ADS**, to reduce sensitivity to beam trips (fuel pin fatigue no longer an issue)
- **Multipurpose reactor design**
  - internal spallation neutron target
  - high temperature molten-salt fuel
  - feed-bleed innovation
  - continuous purging of volatile radioactive fission products
  - burns SNF, natural uranium, thorium, or surplus weapons material
  - burns its own spent fuel
- Subcriticality, versatility, and intrinsic safety features imply
  - **less expensive to build, license, and operate than conventional reactors.**
  - especially effective to dispose of nuclear weapons materials & SNF
- SRF Linacs - powerful, reliable, affordable, and efficient
  - steep learning curve with new developments
  - e.g. magnetron power sources and cavity construction techniques
- **Goal - pilot plant demo of a GEM*STAR subcritical molten-salt fueled nuclear reactor** driven by a superconducting RF proton linac
  - Burn SNF and W-Pu



Beam Input
Nuclear fuel plus carrier salt
He out (plus volatile f.p.)
Electric motors
He in
He
Salt Overflow
Steam generator
750 C
Molten salt pumps
650 C out
2.5 MWb yields:
500 MWt
220 MWe
Target
Graphite
He
Secondary salt loop heat exchanger
Turbine/generator
Salt Storage Tank
550 C in
Steel base plate
Modified Hastelloy-N or graphite encloses all fuel salt
No penetrations below level of fuel
GEM*STAR
Functional Elements
GEM*STAR

Some GEM*STAR Advantages

Muons, Inc

- Tested technology put together in a new way.
- The reactor operates at atmospheric pressure.
  - No pressure vessel.
  - Major design simplification, and eliminates many accident scenarios.
- Volatile fission products are continuously removed.
  - Reactor contains almost a million times less than in a LWR.
- No fuel rods.
  - No Zircaloy that can instigate a hydrogen explosion (Fukishima).
  - No mechanical fatigue of UO_2 fuel rods from accelerator trips
- No critical mass is ever present, and cannot form.
- No reprocessing or isotopic enrichment is needed.
  - More proliferation resistant than other technologies.
- Burns SNF, W-Pu, U233, natural uranium, thorium, without redesign
- Passive response to most accident scenarios: turn off the accelerator – passive air cooling is then sufficient.

CONCLUSION

- **Numerous important ADS contributions** possible thanks to the development of accelerator technology
  - Nuclear waste and nuclear weapon material elimination
  - Energy production, including the use of thorium fuel – **make nuclear energy sustainable!**
  - Neutron spallation sources
  - Production of radioisotopes, as an alternative to nuclear critical reactor production
  - High intensity beams for fundamental research
    (not mentioning low energy low intensity accelerator applications)
- **Impressive effort worldwide on ADS**: Europe, China, India, Japan, USA, Ukraine, [Russia/Troitsk], (South Korea?, Africa?, Australia?, South America?)
- However, the time scales are depressing: > 2030s
- **ADS needs global cooperation** – if Fusion could do it why not ADS? One problem is that goals are quite different. For instance between China (energy) and the USA (waste elimination)
- **The issue of nuclear waste management is not yet resolved** – The reasons why the Yucca mountain project was cancelled will apply elsewhere. Why should it be different in Europe? The requirement of retrievability is orthogonal to the idea of geological storage, and makes it problematic
- The ADS community must pursue their efforts, so that the technology is ready when the time comes