IPAC'16

Busan

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Accelerator Driven Sustainable Fission Energy

Wenlong Zhan CAS

OUTLINE

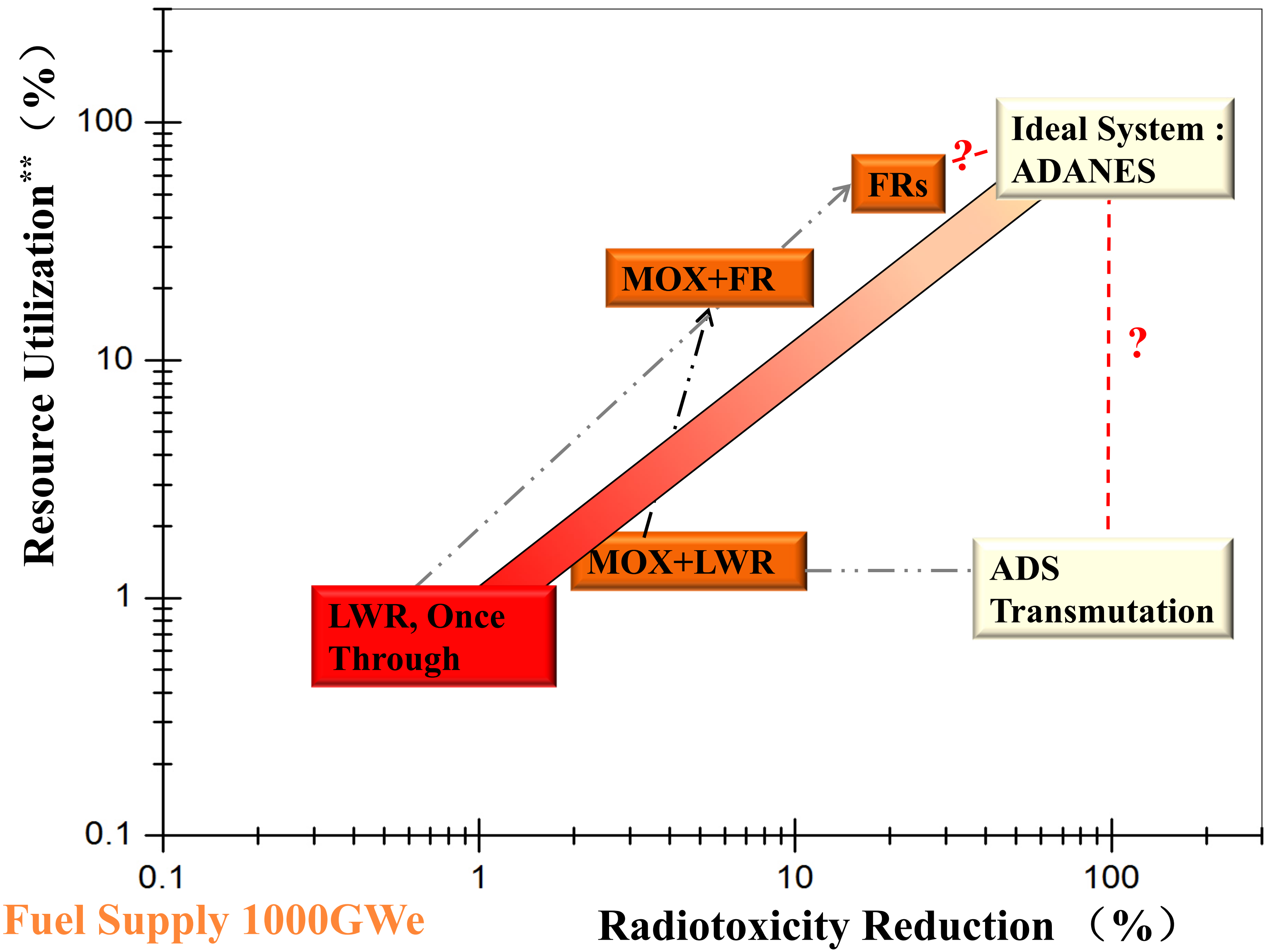
I. Introduction

- Evolution of ADS to ADANES
- Roadmap of ADS/ADANES
- New Site, New Research Center

II. Progress of ADS/ADANES

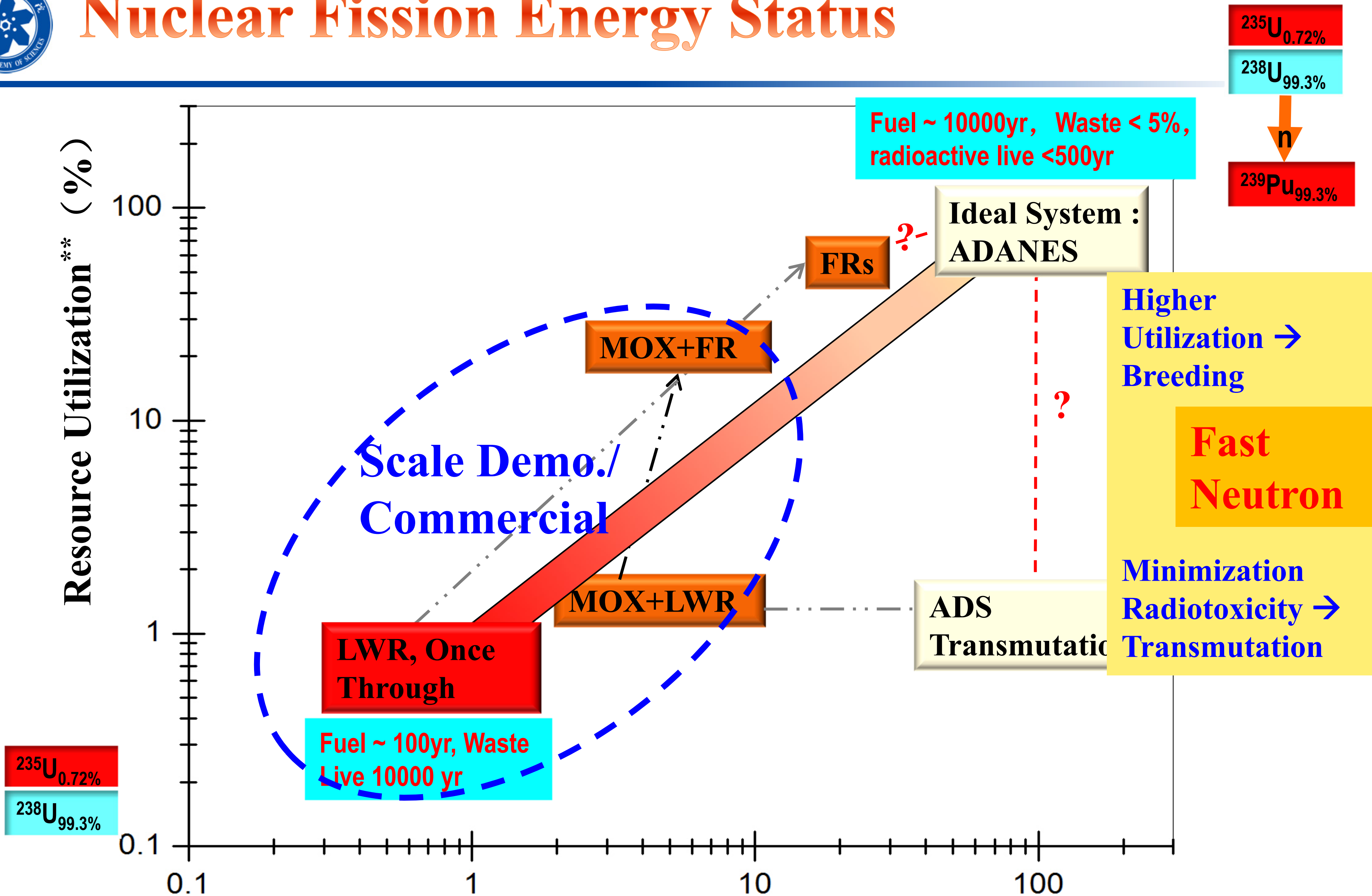
- Configuration of C-ADS
- Accelerator System
- Spallation Target
- Key Issue of AD in ADANES Burner
- …

Nuclear Fission Energy Status



**Fuel Supply 1000GWe

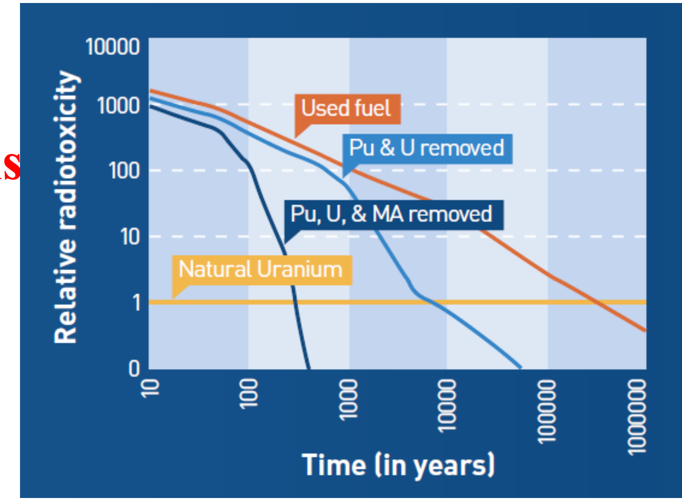
Nuclear Fission Energy Status



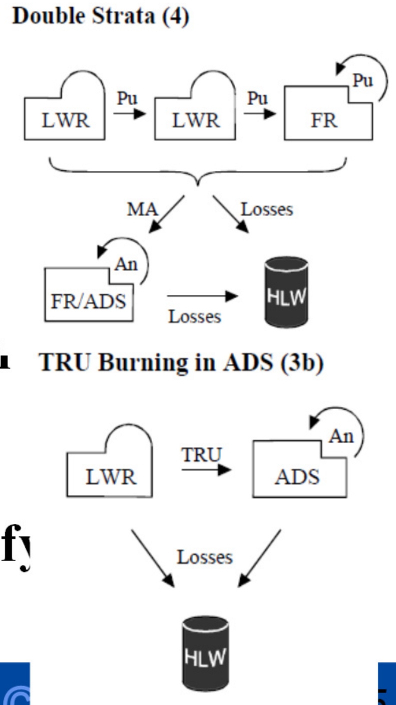
**Fuel Supply 1000GWe

Status of Close Fuel Cycle

- **Main difficulties of P&T:**
  - Extract high purity U，Pu & MA ≠ **Residuals remain MA<1% (long lifetime in waste)**
  - more Toxicity @ Complexes after few cycles
  - High purity Pu, MA fuels is：**Burning Unstable & High risk of proliferation !!**
  - **Low feasibility(final solution?), low cost effective**



- **New Approach:** (optimizing SNF resources & radiotoxicity)
  - **Simplify Fuel Recycle:** Remove part of FPs (~50%) from SNF, Convert Residuals as recycle fuel
  - **Power Burner:** Transmuting, Breeding & Energy Amplify by fast neutron for burning recycle fuel (~50% FP)



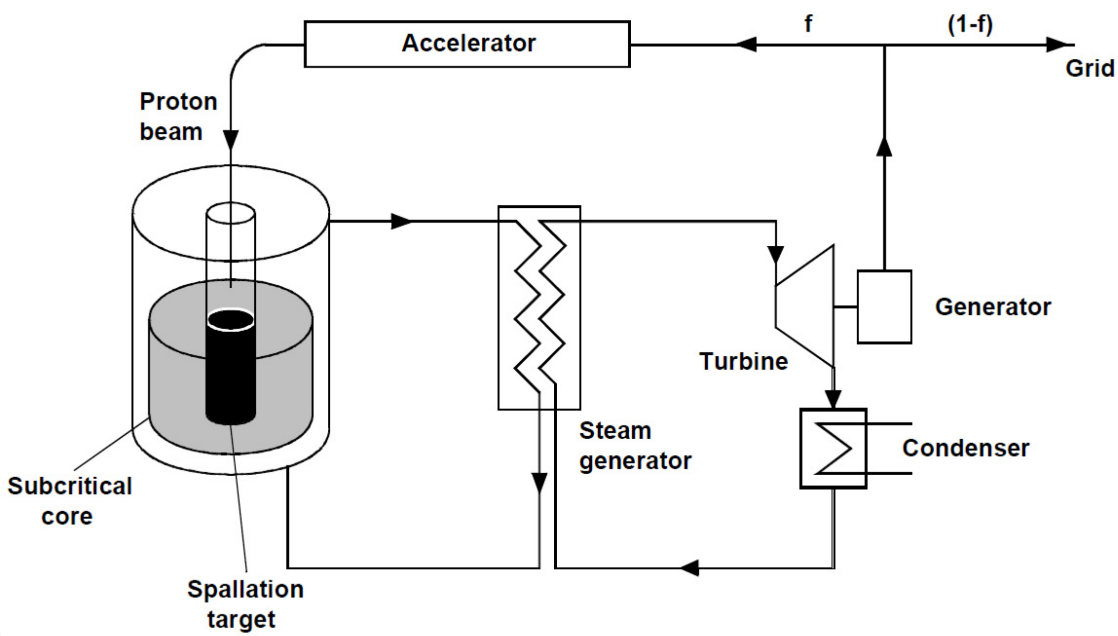
Evolution of ADS to ADANES Burner

(Accelerator Driven Advanced Nuclear System)

- **Accelerator Driven System was proposed for:**
  - Nuclear waste **transmutation** (ADS)
  - Isotopes production (ex. **Breed**, ISOL, APT)
  - **Energy Amplifier** (ADTR)…

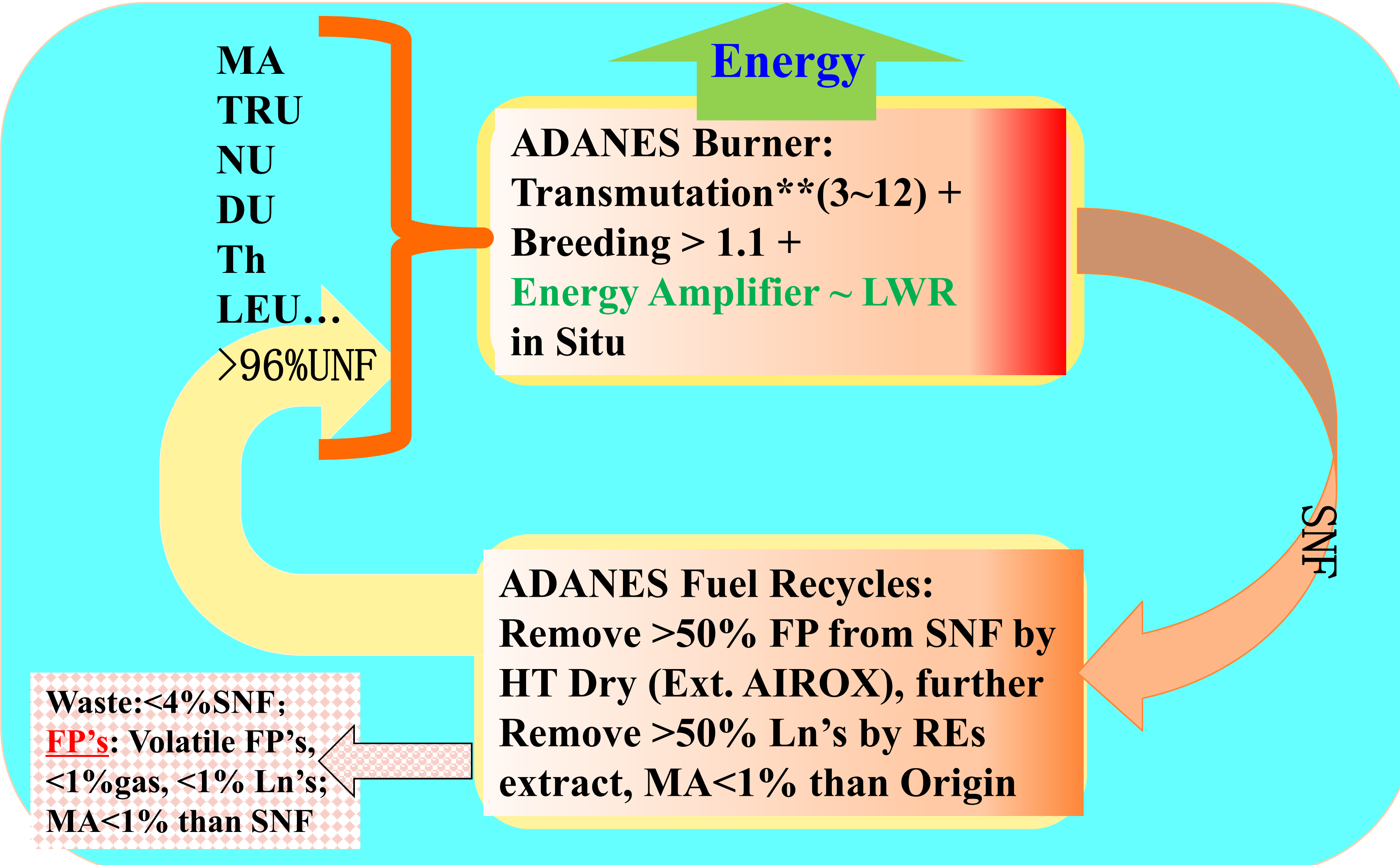
  } **ADANES Burner**

- **ADS consists of high power proton accelerator, spallation target & subcritical core mainly**



ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study, NEA/OECD, 2002

ADANES (LWR SNF: 33GWd/Ton)



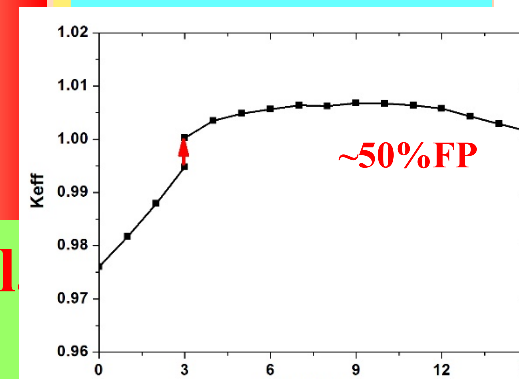
ADANES (LWR SNF: 33GWd/Ton)

MA
TRU
NU
DU
Th
LEU…
>96%UNF

Energy

ADANES Burner:
Transmutation**(3~12) +
Breeding > 1.1 +
Energy Amplifier ~ LWR
in Situ

**Burning:
SNF > 3
MA → 12



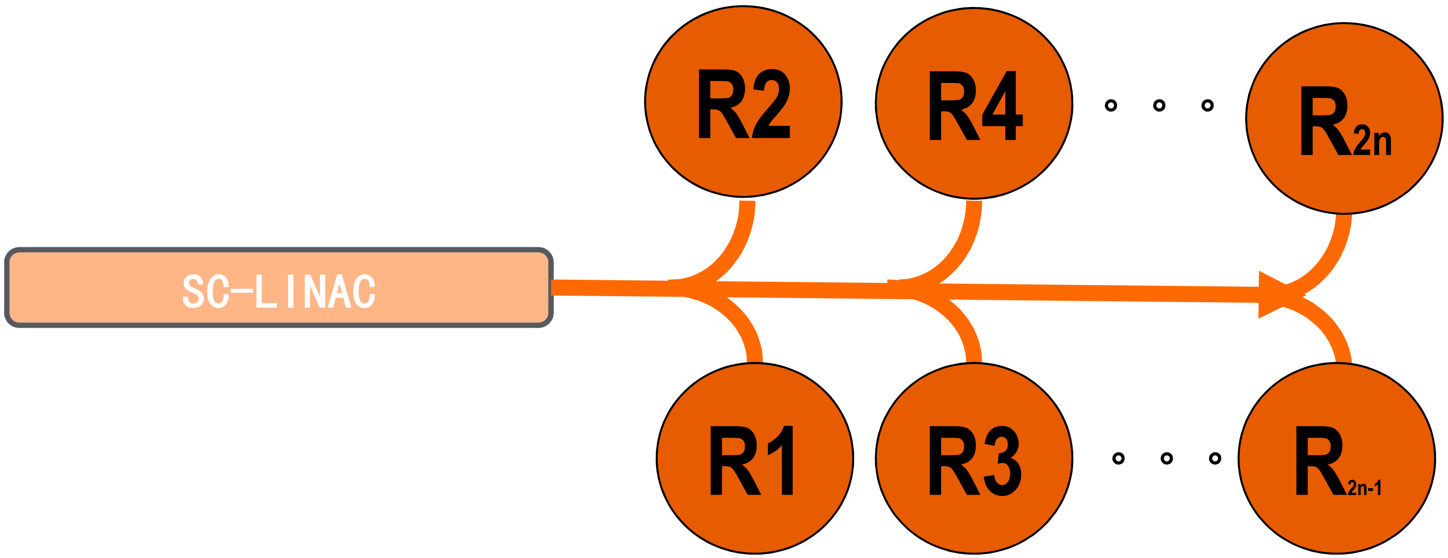
Convert SNF into Recycle Fuel,
Waste <4% SNF @ MA<1%,
τ<500Y, Sustain NE > 10000yr

SNF

ADANES Fuel Recycles:
Remove >50% FP from SNF by HT Dry (Ext. AIROX), further Remove >50% Ln's by REs extract, MA<1% than Origin

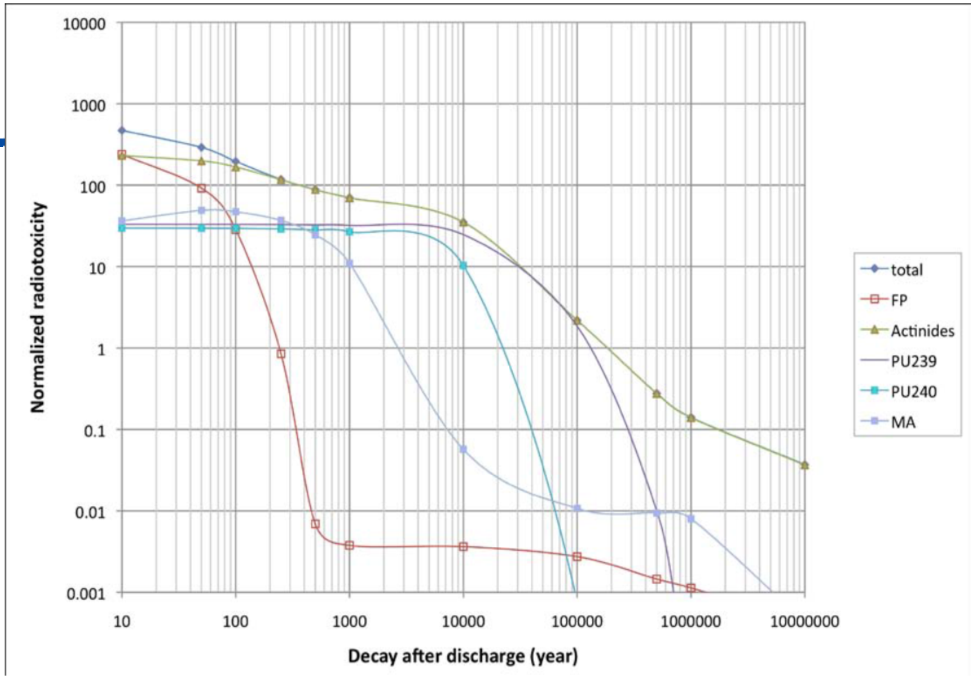
Waste:<4%SNF;
FP's: Volatile FP's, <1%gas, <1% Ln's;
MA<1% than SNF

ADANES —— Operation Mode



- **Safety, Flexibility→ Close fuel Cycle, "Raw Fuel", Higher cost effective**
- **Higher Resource Utilization, Minimization Radiotoxicity:**
  >90% resources utilization, <4% waste & 500 yr. live time
- **Duration of Accelerator Driven Subcritical Core:**
  10% ~ < 15% (depend power density, temperature, and…)
- **Efficiency of Nuclear Electricity Generator:**
  ADANES: >31%~~36% with AD
  >35~~40% without AD

Key issues for Safety



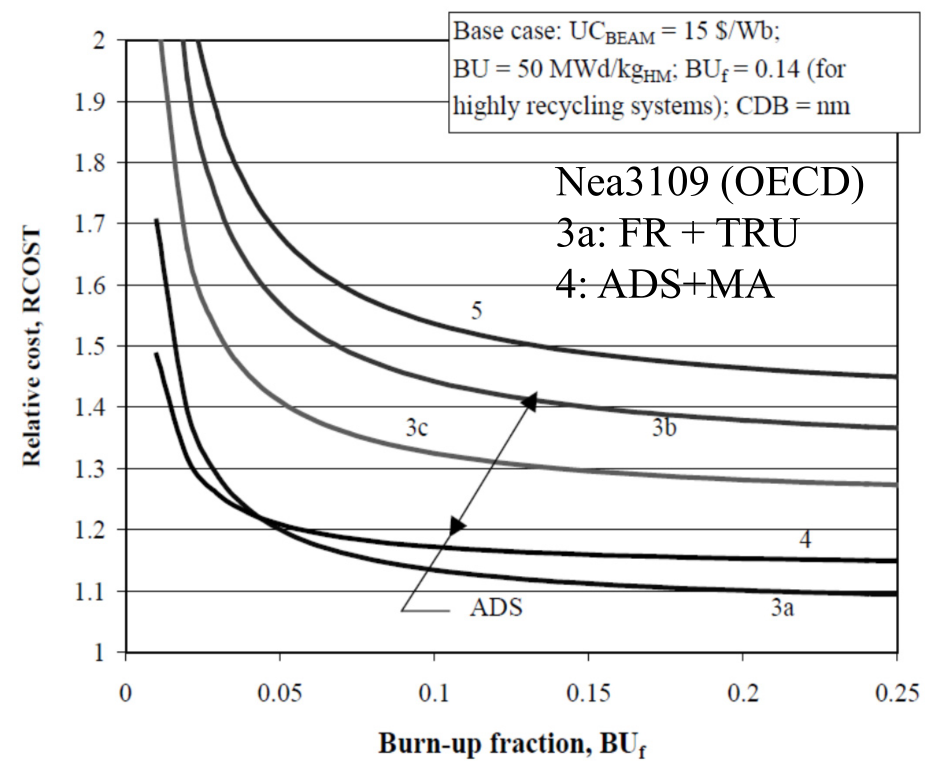
- **Reactivity Control**
  - **Subcritical core with AD**
  - **Good design reactor controller (Δk--5%) without AD**
- **Decay Heat Removing**
  - **Smaller decay heat (<10% LWR at discharge, <1/3 ~ 10yr UNF)**
  - **Neutrons, photons < 1/3 of LWR at discharge**
  - **Fuel cladding material (>1500℃) for air removing heat in accident**
- **Radioactive material confinement**
  - **Two shell of cladding to shield against radioactive releases**
  - **Cladding material (> 1500℃ & > 50MPa) to limitation of radioactive release during accident**

Cost Effective

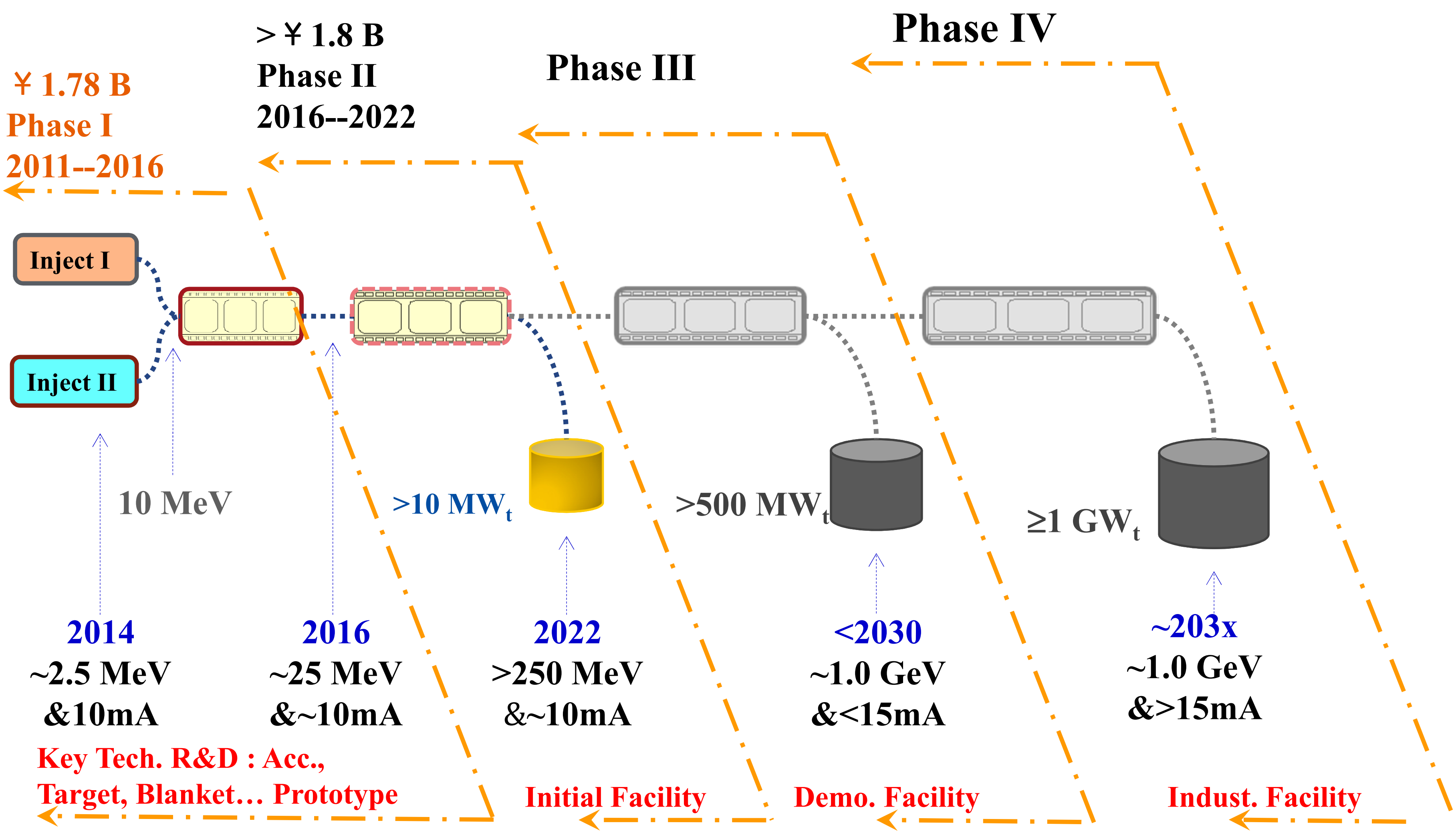
- **Close Fuel Cycle →Waste <4% volume & <500yr lifetime**
- **Resources Recycle → >90% utilization， no need to add LEU in ≥ 2nd recycle fuel**
- **UNF treatment simplified ---<1/3 of P/T Schema**
- **Deep (~30yr) burnup core**
- **Modular Reactor (Blanket)**
- **Higher T_{op} → higher η_e**
- **Part time (10%~15%) AD**
- **Optimize the AD power**

< 15MW/1GW sub-core

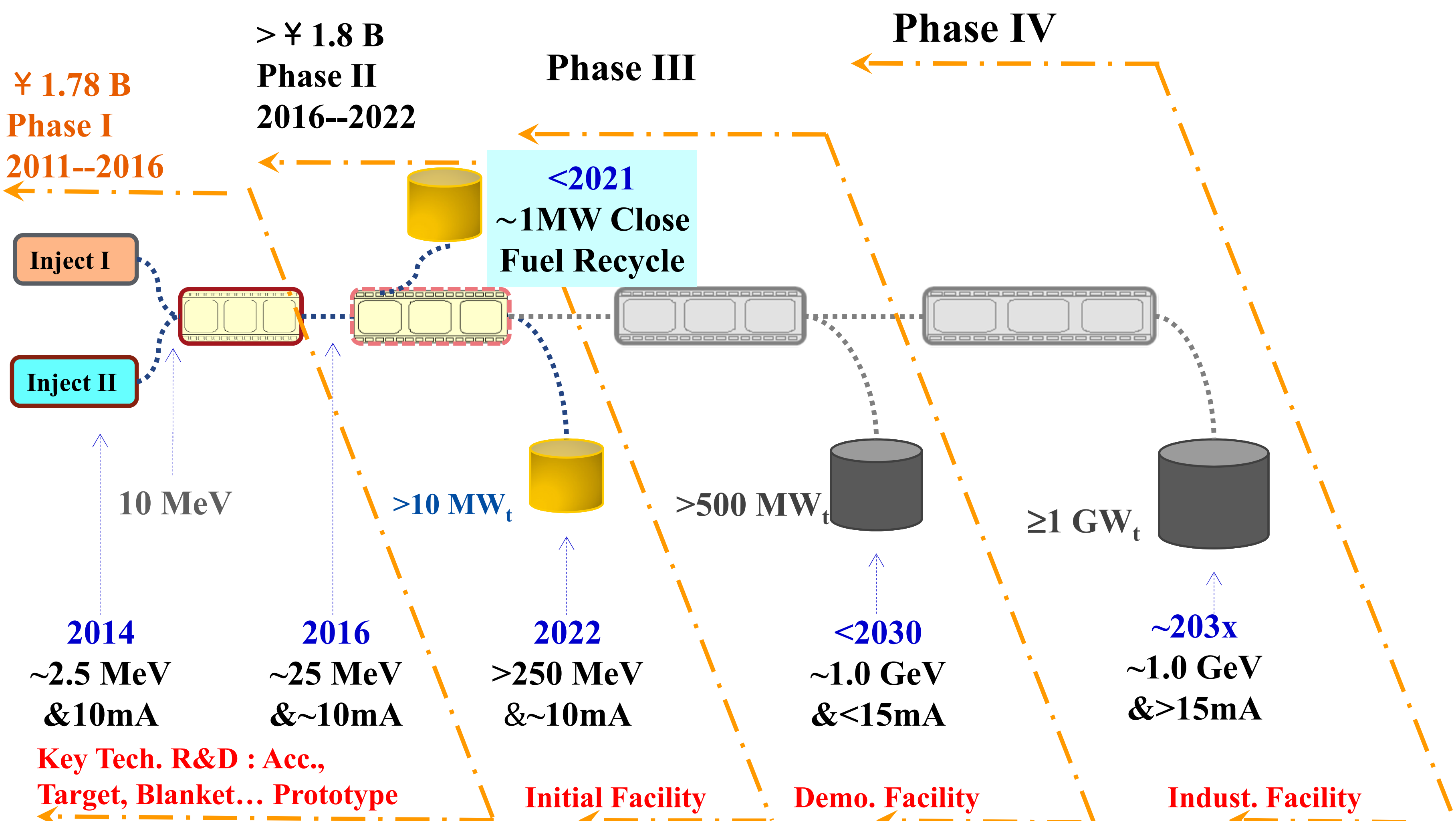
- **RCOST: ADANES< FR+TRU…**



ADS/ADANES Roadmap in China

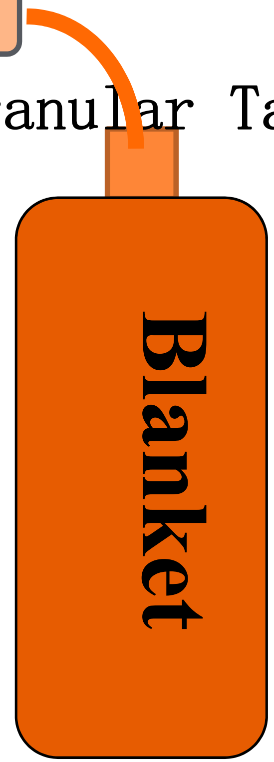


ADS/ADANES Roadmap in China



Accelerator Driven Recycling Used Fuel

SC_LINAC (~5mA@~200MeV d+Be)



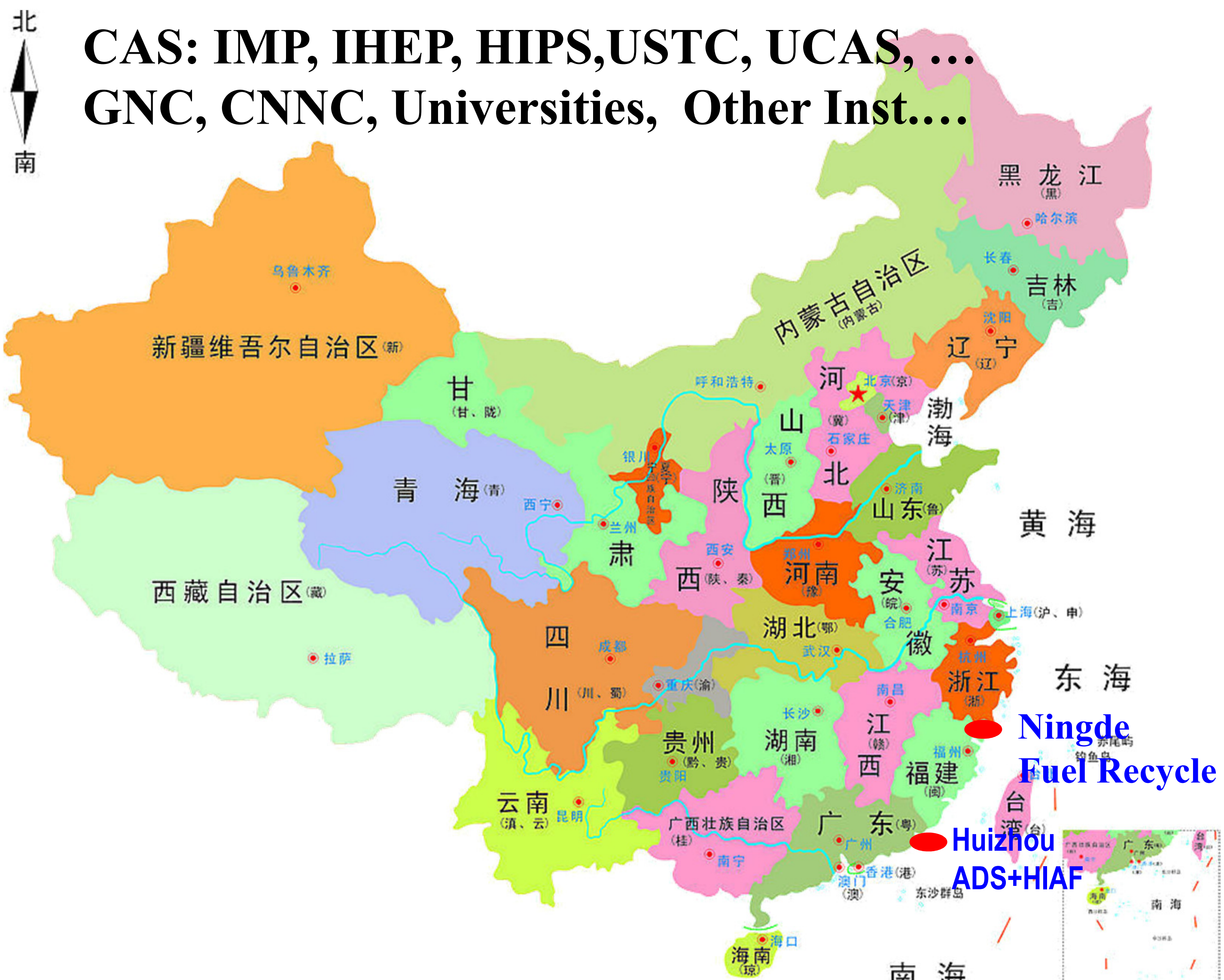
- **Fuel Recycle**
- **Compact Neutron Source:**

  1, Verify Recycle Fuel
  - **UC Fuel Properties**
  - **$^{238}U \rightarrow ^{239}Pu$ Breeding rate**
  - **Optimization of Fuel Assembling**

  2, Irradiation of Materials
  - **Cladding（SIMP、SiC_f/SiC、SiC/Ti_3SiC_2…）**
  - **Core Structure (...same as above...)**
  - **Window between Accelerator and Target**
  - **…**

New site, New open research center

CAS: IMP, IHEP, HIPS,USTC, UCAS, …
GNC, CNNC, Universities, Other Inst.…



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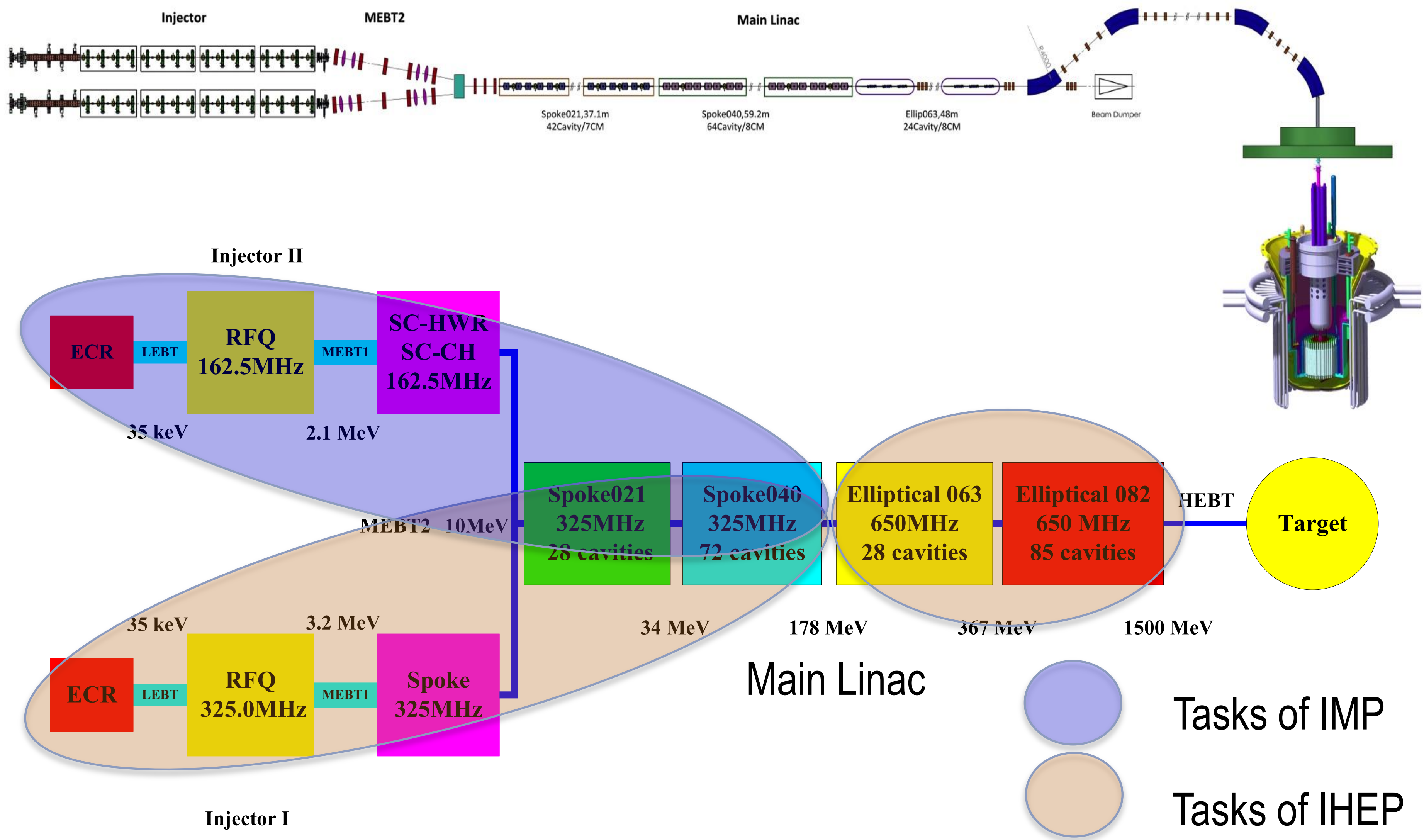
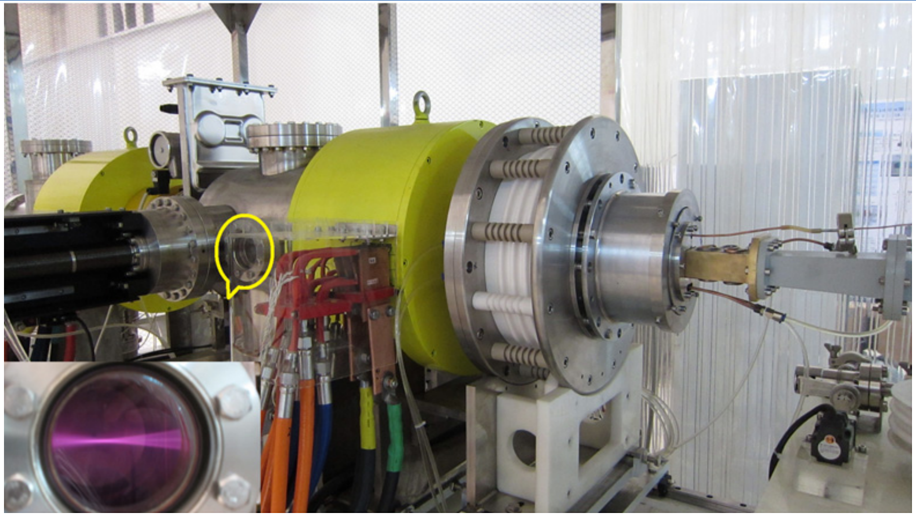
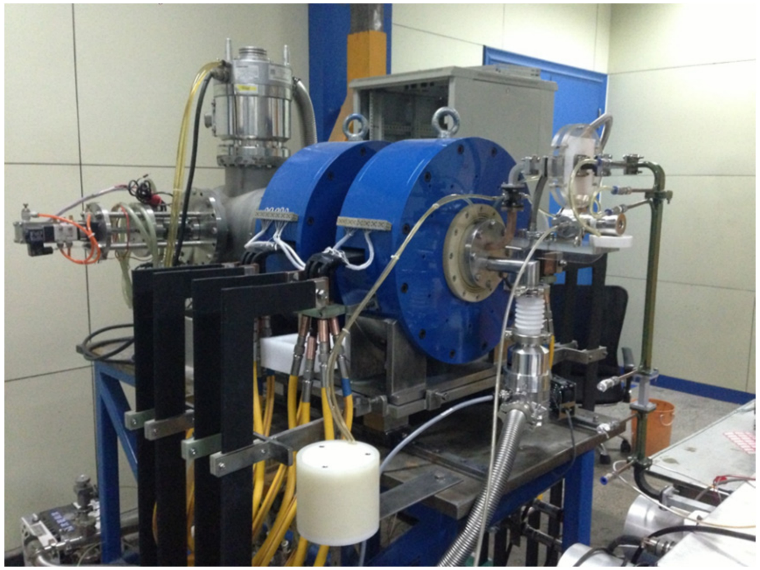
Configuration of C-ADS



ECRIS+LEBT

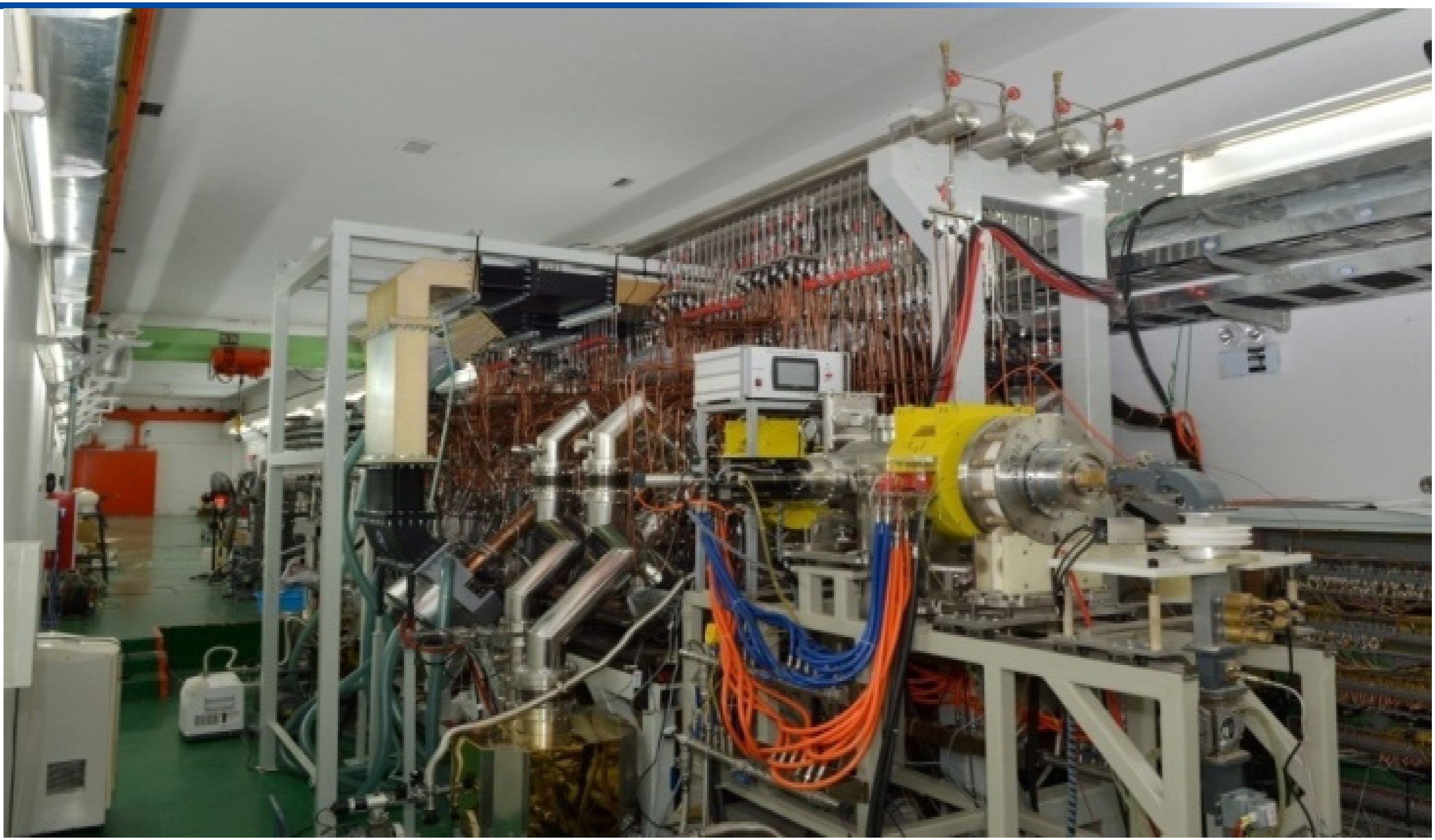


- **2.45GHz ECR Commission：>25 mA & 35 keV**
- **Improve on Reliability, Stability, maintaining in >2500hr**
- **~8 short (<1sec.) beam trip in CW operation in >100hr**



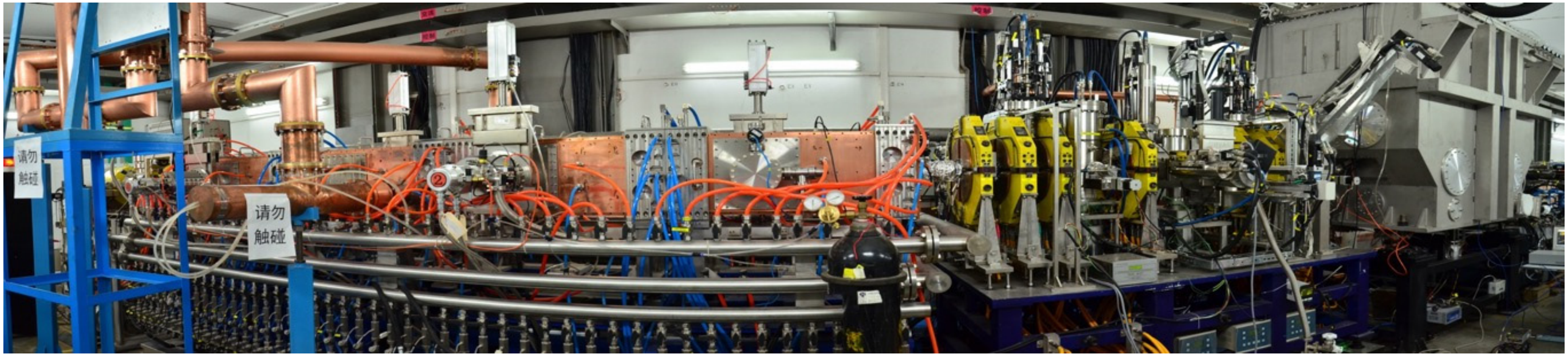
- **14~18 GHz ECR R&D pre-result：~10 mA & 35 keV**
- **Feed in RF power ~ 30W, ~300W for 14~18GHz, 2.45GHz ECRIS resp.**
- **Feed in / pumping out H_2 ~ 1/3 of 2.45GHz ECRIS (favor for D_2)**
- **Less beam trip → more stable**

Injector I：325 MHz RFQ+TCM2



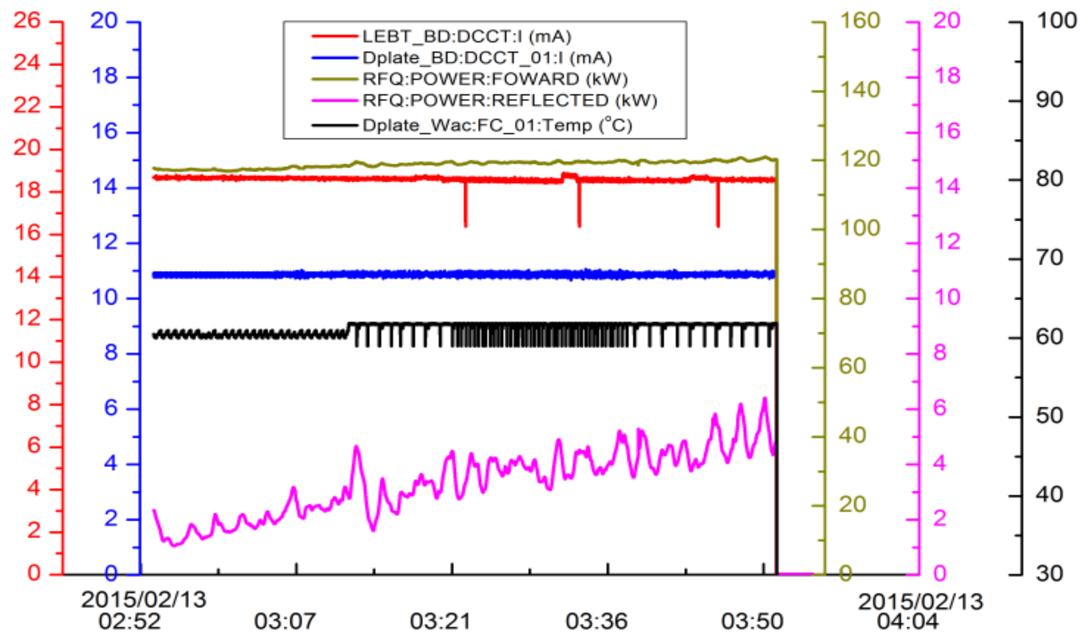
Commission: Pulse Beam, eff. >95% low duty factor~3.6MeV& 10mA

Injector II (162.5MHz): 2.5 MeV&10mA

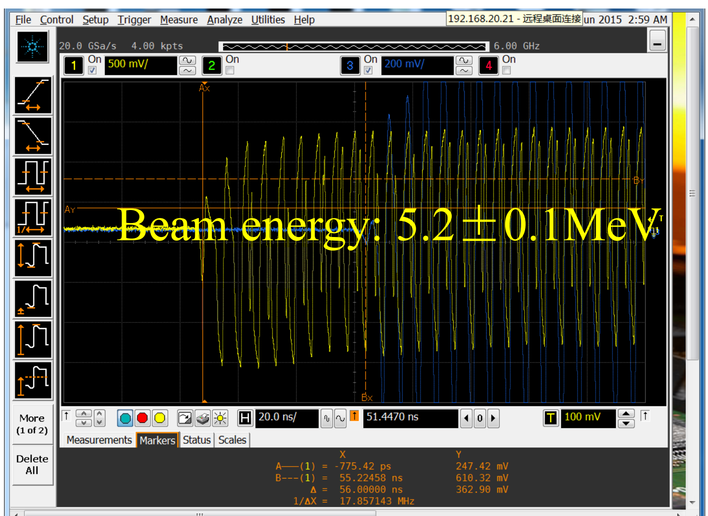


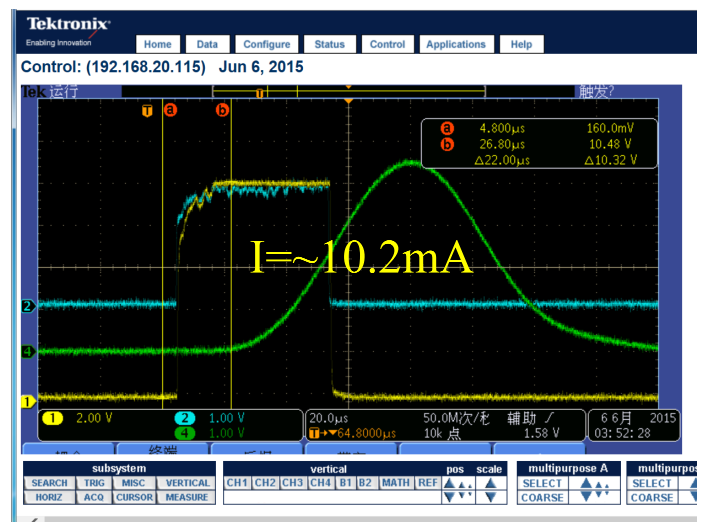
ECRIS+RFQ (>2000 hrs): >10mA@2.15MeV, CW, Eff.= 95~97%, δE/E ~1.9% (FWHM) June 30, 2014

ECR+RFQ+TCM1 >11mA@2.55MeV, CW → Eff.=95~97%, δE/E ~1.5% >Feb. 13, 2015



CM6（5 MeV&10mA）Commissioning

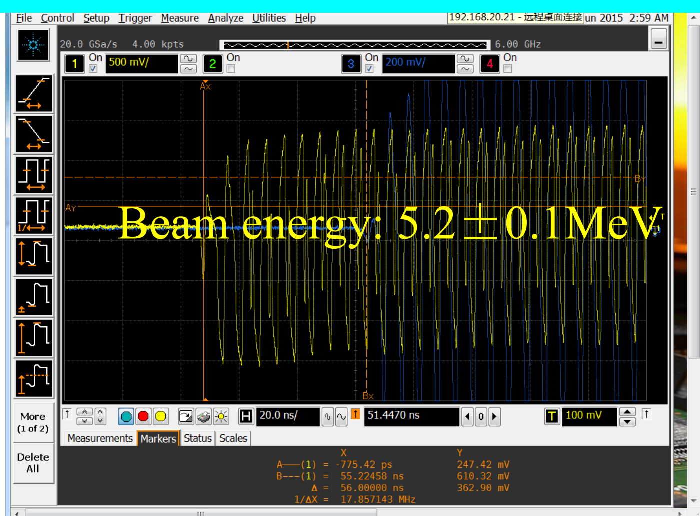


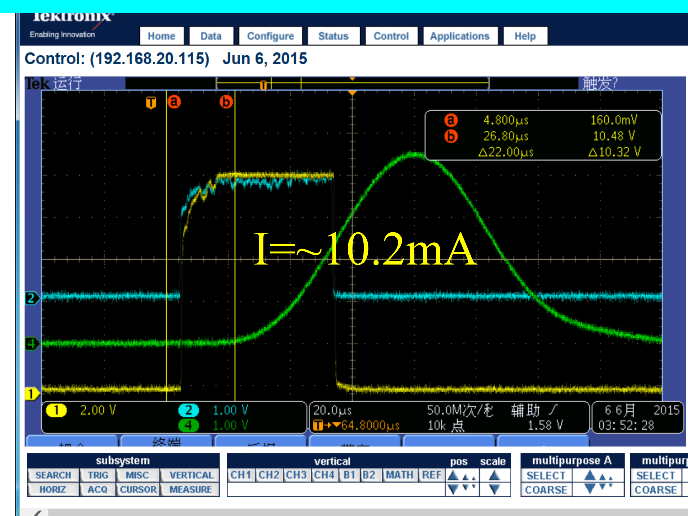


CM6（5 MeV&10mA）Commissioning

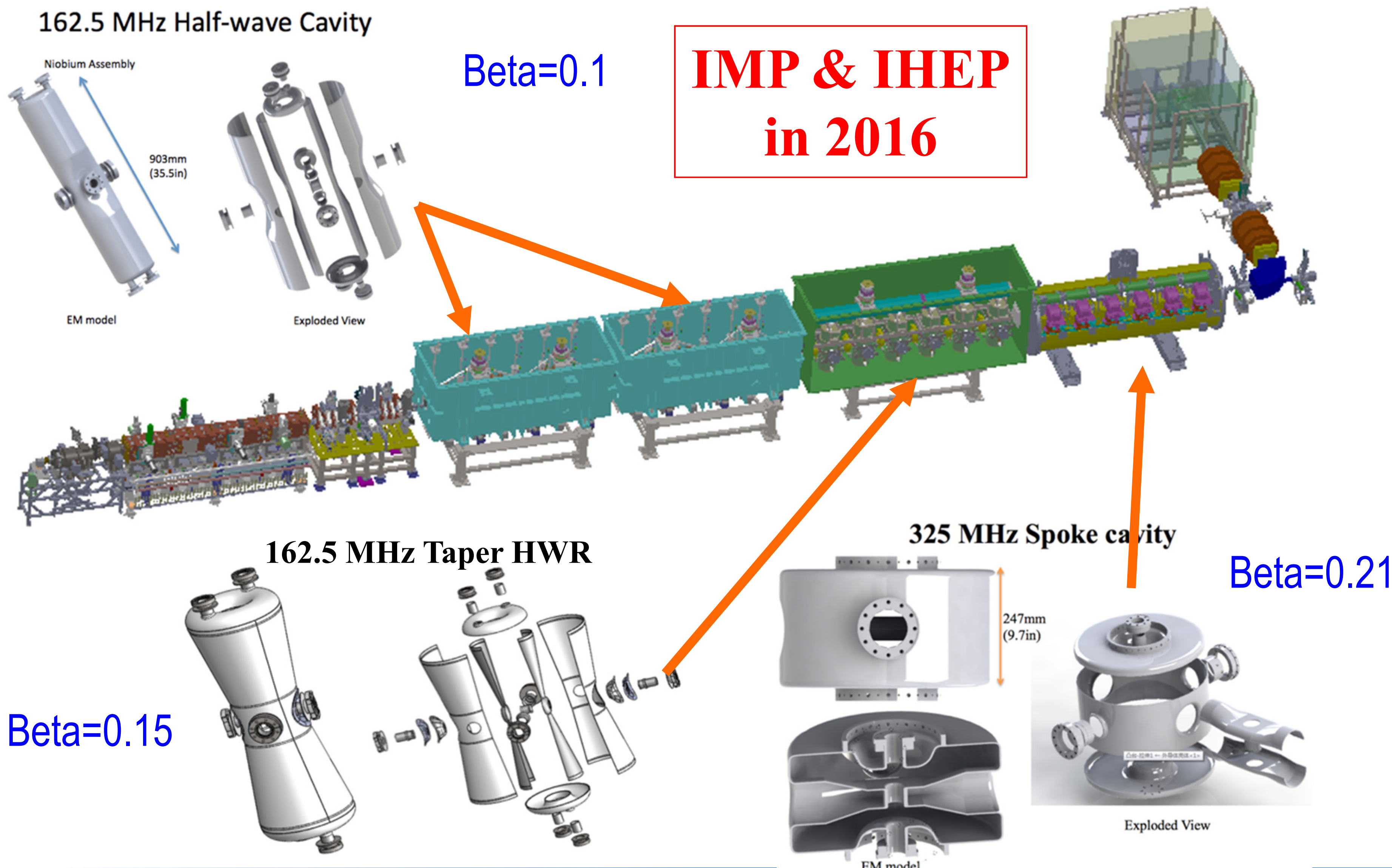
5.2 MeV&10.2 mA, 10% duty factor beam in June 8th,

5.3MeV&2.7mA CW beam in June 23 2015

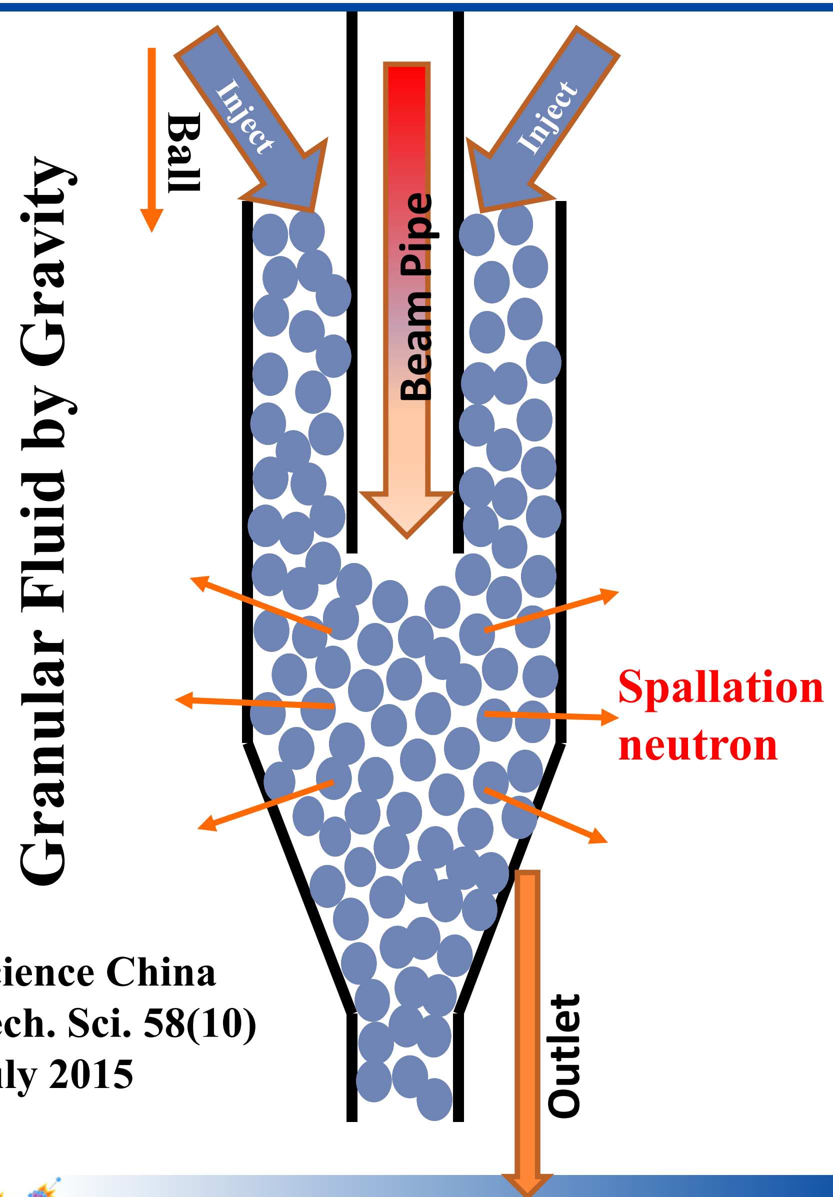




25 MeV LINAC Commissioning in 2016

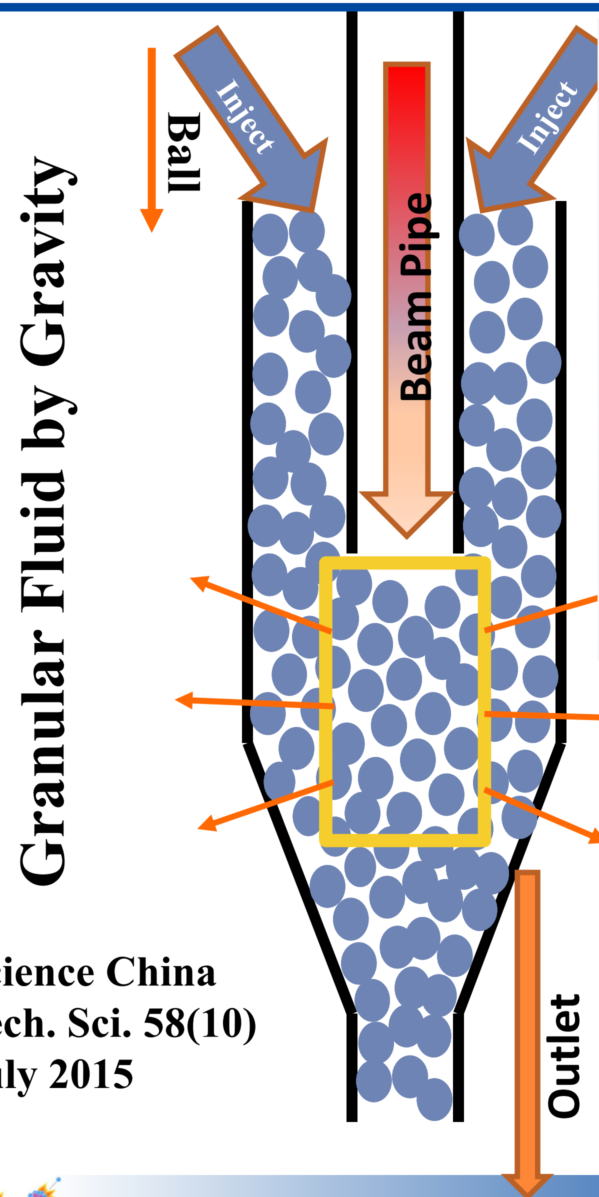


Principle of Granular Fluid Spallation Target



Science China
Tech. Sci. 58(10)
July 2015

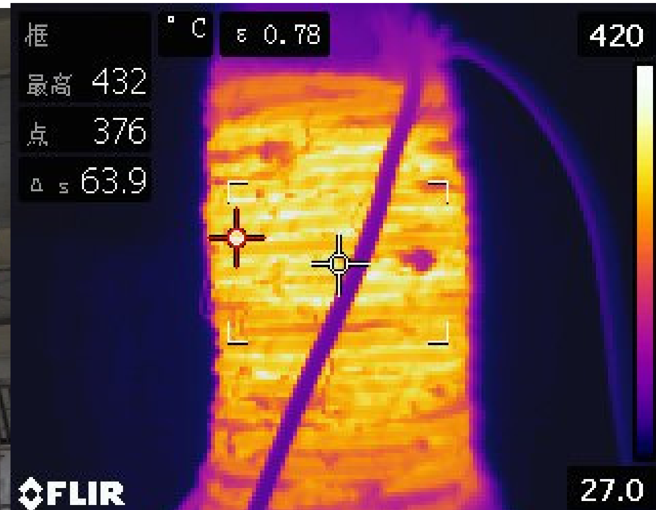
Principle of Granular Fluid Spallation Target

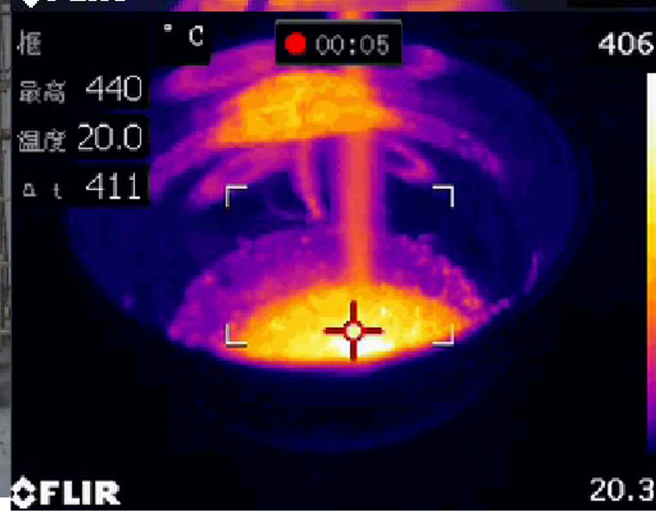


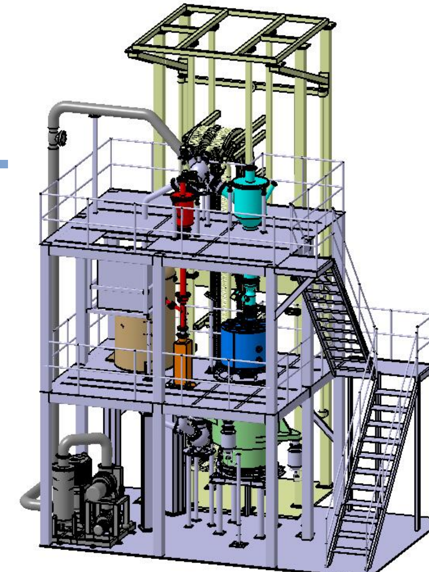
Science China Tech. Sci. 58(10) July 2015

- Granular fluid operate stable as sand clock
- Target heat removing off line and grain update on line simply
- Higher target power capacity: 10~100 MW
- Dissipation the shock wave induced by beam trip
- Relieve short beam trip (<10s) requirement as discrete medium in target
- Dust handling require
- High cost effective

Granular Loop Test





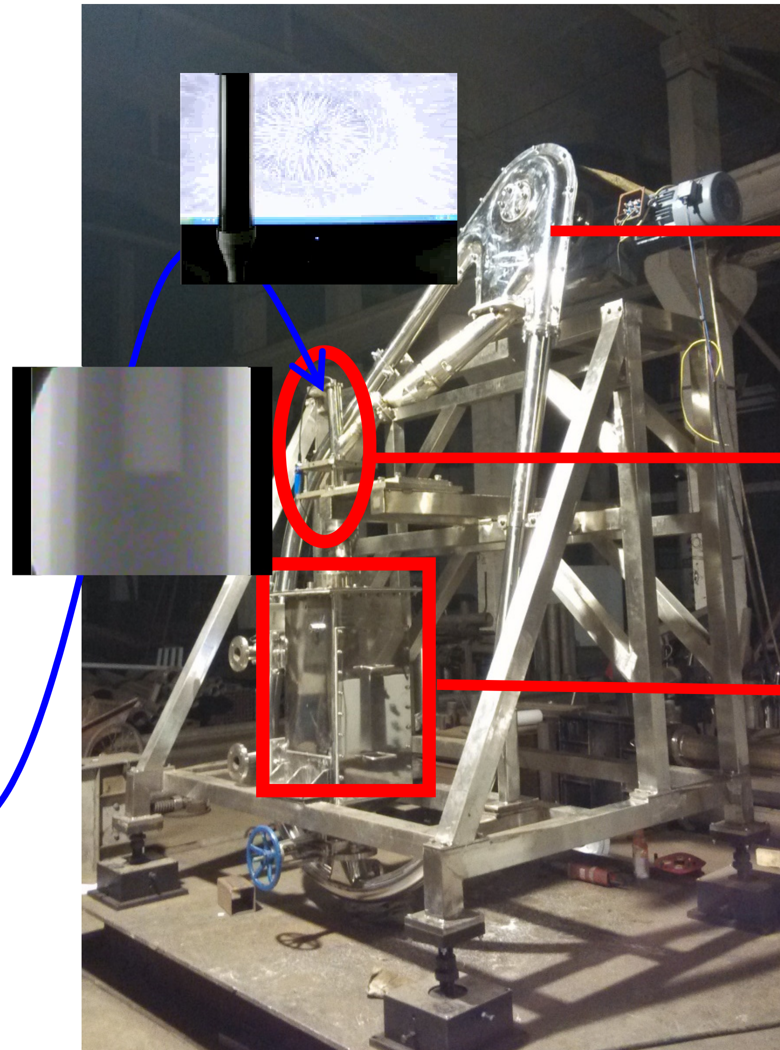


Large scale loop & HT test

Granular target test bench

Exp. of E-Beam on W Granular Target

<20mA@2.5MeV e



Identify Target Power Density of proton beam <u>1.0GeV@10~20mA</u> on W

Key Issue of AD for ADANES Burner

- Accelerator Driven (new approches, operation mode)
  - Starter of Burner → reduction requirement for power generation
  - 10~15% of Duration Burner Operation → cost effective
- Beam Power (system optimizing)
  - ~10MW_b/GW_{th}→ reduction scale of LINAC, cost effective
- Stability (key tech., system optimizing)
  - ECRIS: 14~18GHz → Low RF Power, Flow H_2 (favor for D_2), more stable
  - RFQ: 162.5MHz→ Lower power density
  - SC-Cavity → Nb (or Nb_3Sn) coating on cupper cavity → SC-cavity !?
  - Beam trip → Optimizing System: ECRIS, Target (<10Sec.), Burner operation mode…
- Reliability (key tech., new design)
  - RF PS : plug in / out
  - Beam lose : beam dynamics, collimator to mitigate halo beam ?
  - SCL : rapid fault recovery, He, plasma cleaning…
  - Target : Granular fluid, heat remove off line, grain replace on line
- …

Summary of ADS/ADANES in CAS

- ADANES Conception Proposed, AD is key issue in ADANES !
- Accelerator System (prototype in world)
  - 162.5MHz Injector >2.55MeV&11mA → 5.3MeV&2.7mA CW proton beam
- Spallation Target (new, simplify)
  - Granular fluid target is designed and prototype testing with e-beam
- Subcritical Fast Core (new, simplify)
  - (Gas + Grain) / (Water + Steam) two phase coolant core R&D to optimizing one
- Fuel Recycle (partial new, simplify)
  - HT-Dry + REs Extracting Processes R&D intensively
- ADANES Material R&D (W, Be/Alloy, SIMP, MAX, SiC_f/SiC…):
  - SIMP Steel (similar HT9) produced and Improving in 5 Tone Scale
  - SiC_f/SiC, SiC_f/Ti_3SiC_2 & other HT used in core and cladding，R&D intensively
- GPU based S-Computing used for optimization of System Design

THANKS FOR ATTENTION

Welcome to Collaboration !