SFR2017

Lanzhou

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SCL-Key Issue of ADANES in China

(Accelerator Driven Advanced Nuclear Energy System)

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OUTLINE

I. ADANES

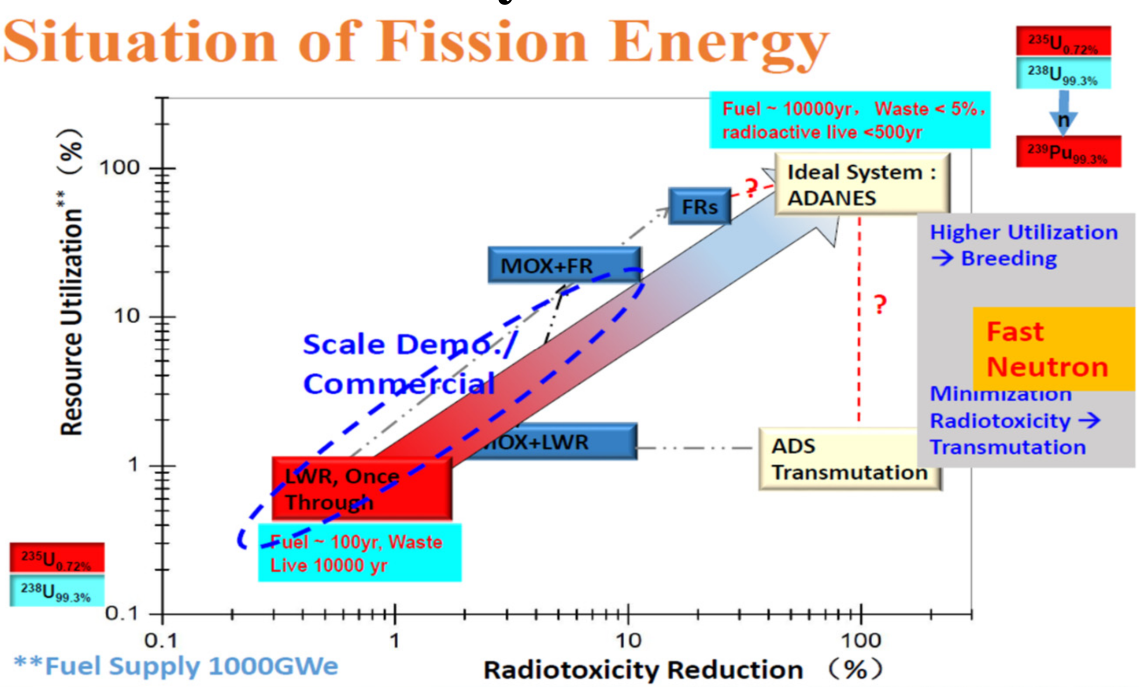
- Introduction
- ADANES Burner ← Evolution from ADS
- Roadmap of ADANES in China
- New Site, New Research Center

II. Progress of ADS/ADANES

- Configuration of C-ADS
- Accelerator System
- Spallation Target
- Other Key Issues
- …

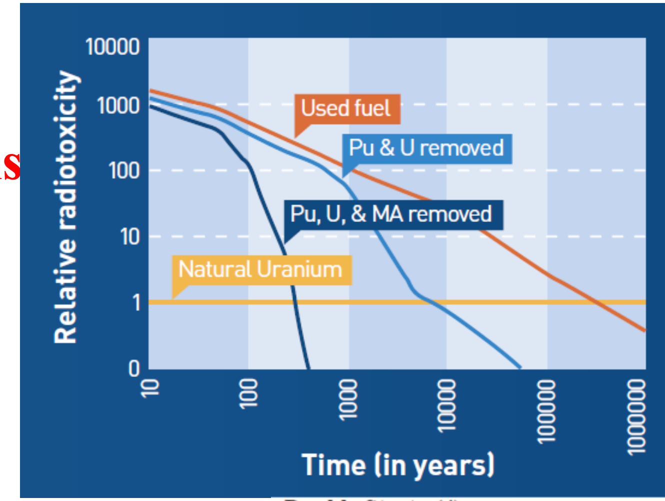
Status of Fission Energy

- **Goals of Fission Energy (from GIF2014)**
  - **Sustainability → Max. Resources & Min. Radiotoxicity**
  - **Safety and Reliability**
  - **Economic Competitiveness**
  - **Proliferation Resistance and Physical Protection**
- **Situation of Sustainability**

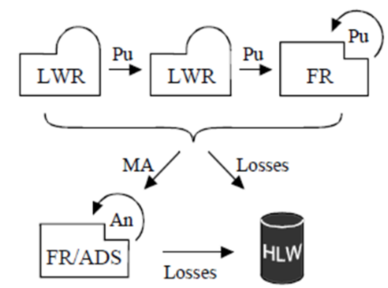


Status of Close Fuel Cycle

- Main difficulties of P&T:
  - Extract high purity U，Pu & MA ≠ Residuals remain MA<1% , Serious 2nd Contamination
  - 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

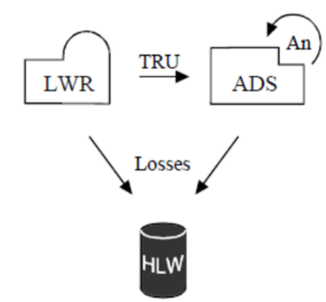


Double Strata (4)



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

TRU Burning in ADS (3b)

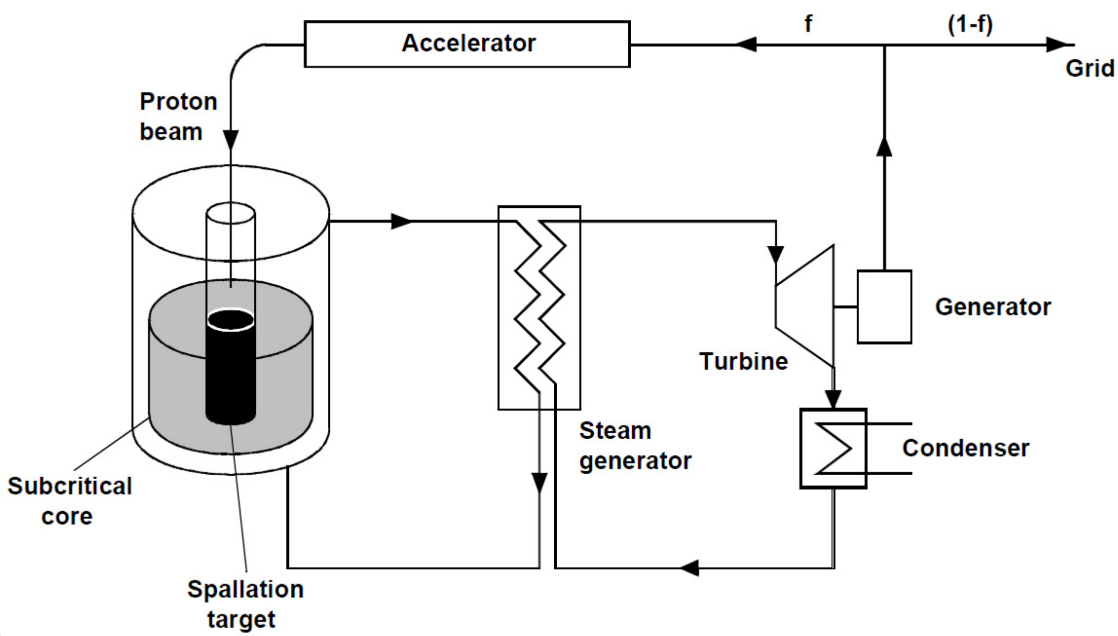


ADANES Burner Evolution from ADS

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

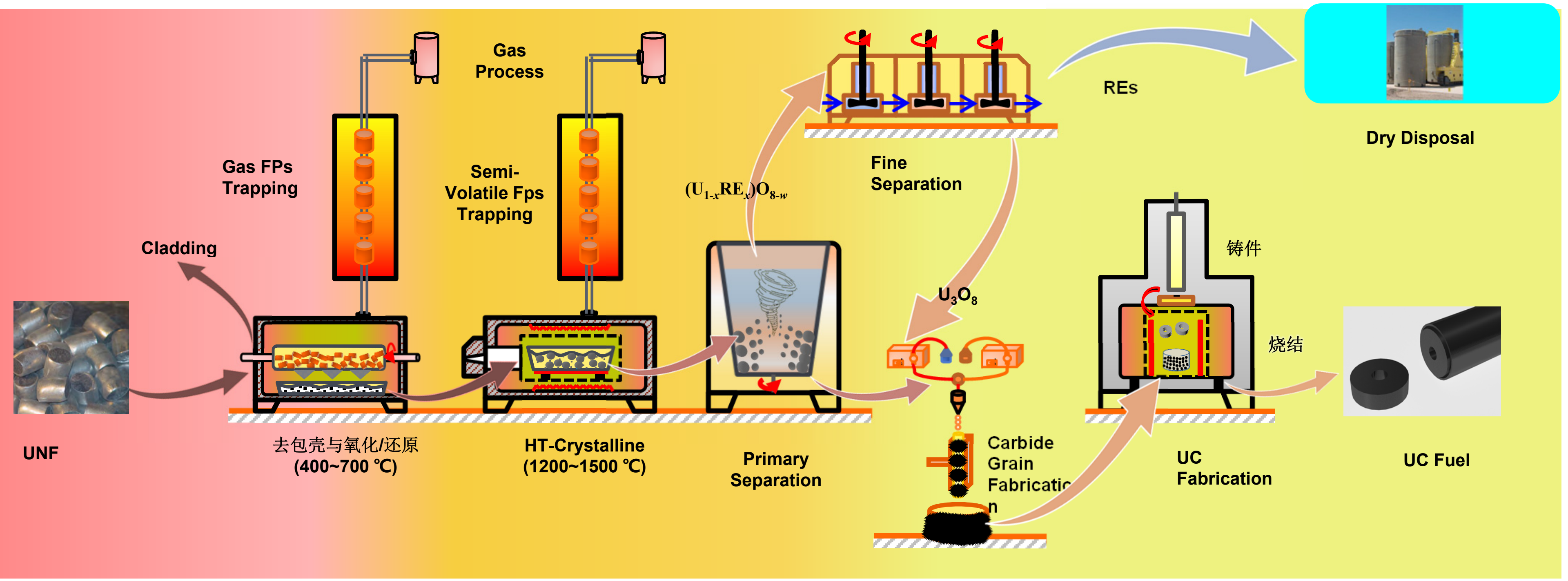
  } **ADANES Burner**

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

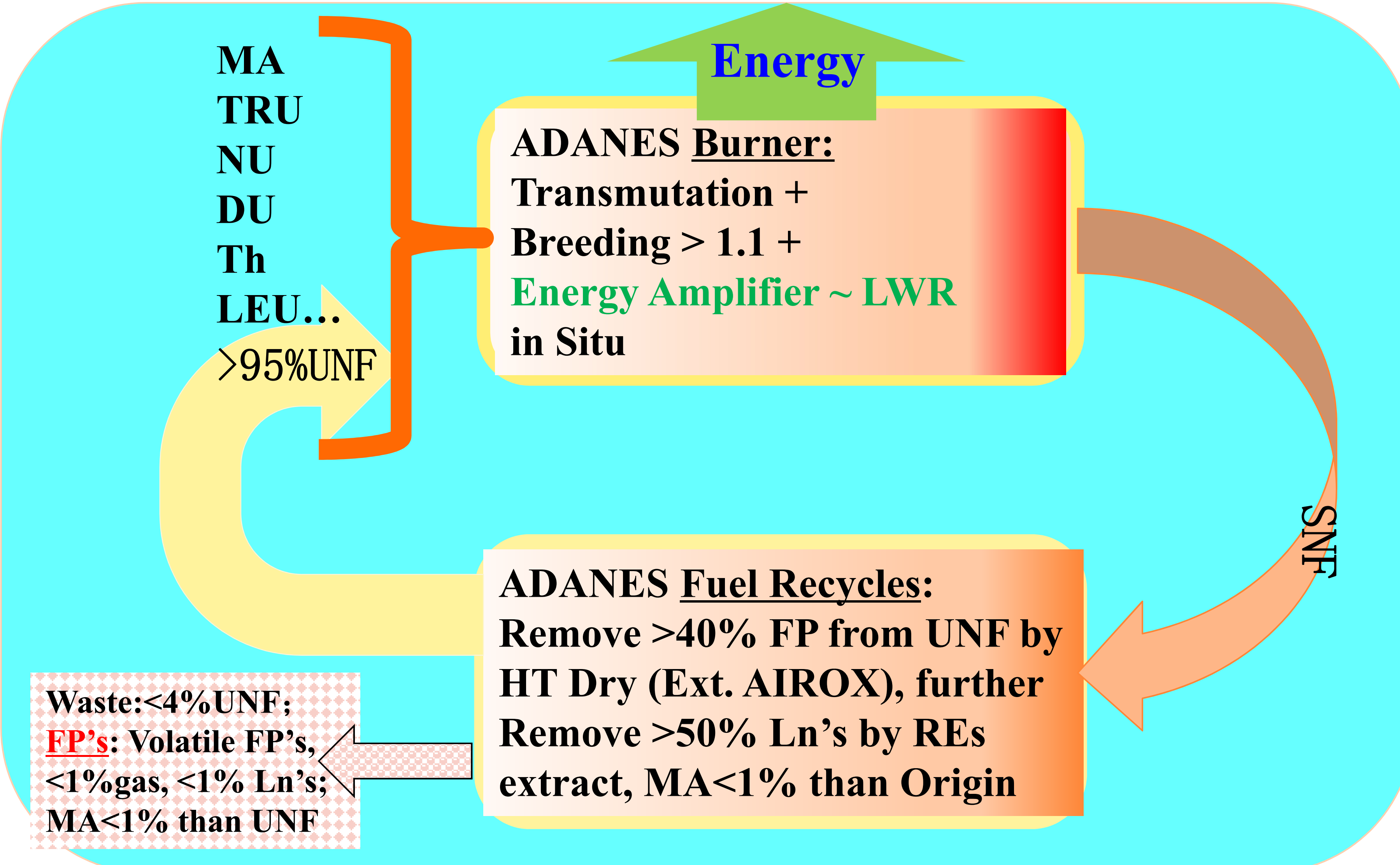


ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study, NEA/OECD, 2002

HT-Remove ~50% FP from UNF (Ext. AIROX)



ADANES Configuration (LWR UNF: 33GWd/Ton)

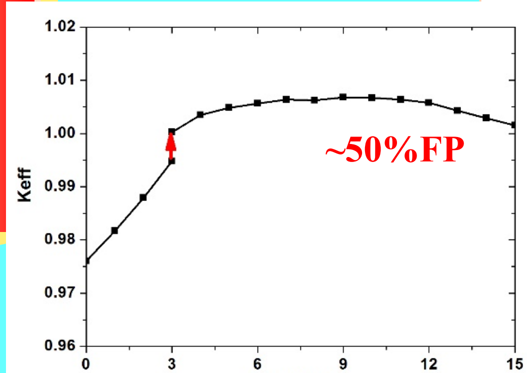


ADANES Configuration (LWR UNF: 33GWd/Ton)

MA
TRU
NU
DU
Th
LEU…
>95%UNF

Energy

ADANES **Burner:**
Transmutation +
Breeding > 1.1 +
Energy Amplifier ~ LWR
in Situ



SNF

ADANES **Fuel Recycles:**
Remove >40% FP from UNF by HT Dry (Ext. AIROX), further Remove >50% Ln's by REs extract, MA<1% than Origin

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

ADANES Configuration (LWR UNF: 33GWd/Ton)

MA
TRU
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LEU…
>95%UNF

Energy

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Transmutation +
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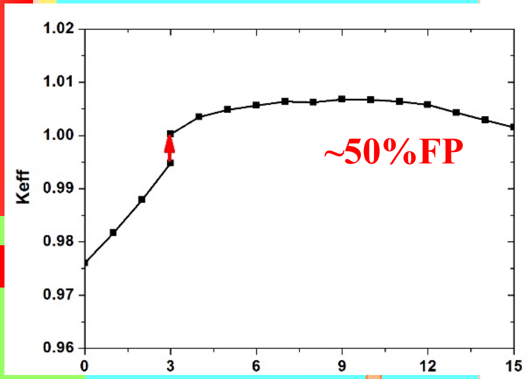

Convert UNF into Recycle Fuel
Waste <4% SNF @ MA<1%,
τ<500Y, Sustain NE > 10000yr

SNF

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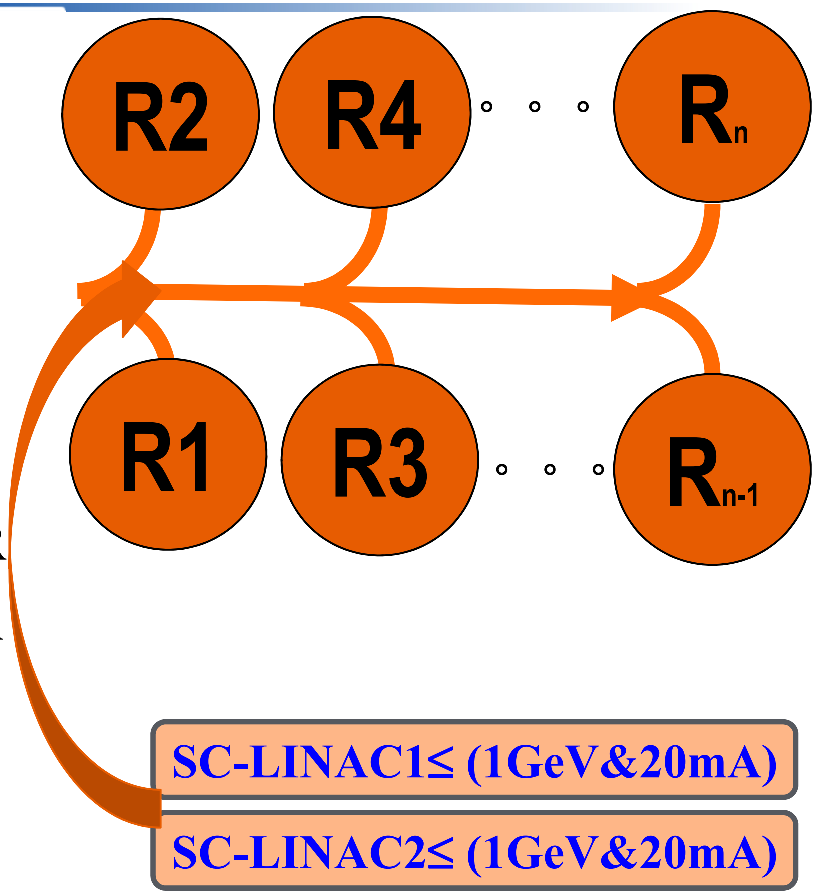
MA<1% than UNF

ADANES — Operation Mode

- ADS + Long Refueling Cycle FR → Accelerator as Starter
- AD Duration:
  10% ~ < 15% (depend on fuel, material…)
- Safety, Flexibility, Close Fuel Cycle, "Raw Fuel" → Simplify UNF Recycle
- Transmutation MA capabilities : 3~6 LWR ($3GW_{th}$) /$10MW_b$ depend on Scale & Fuel
- Max. Resources Utilize ~95%, Min. Radiotoxicity <4%, Decay Life<500yr;
- Generation E-Efficiency: PWR~33%
  ADANES (Higher Temperature):
  >31%→>36%(SH_2O)→>40%(SCO_2) (AD)
  >35%→>40%(SH_2O)→>44%(SCO_2)



**Double AD:
- ✓ Enhance Reliability;
- ✓ Increase Cost about 25% as same power SCL

Safety & Proliferation

- **Reactivity Control**
  - Subcritical → AD
  - Critical → FR

    $\Delta k>5\%$ （B_4C）

Table 4.4. Comparison of UNF Decay Heat at Discharge

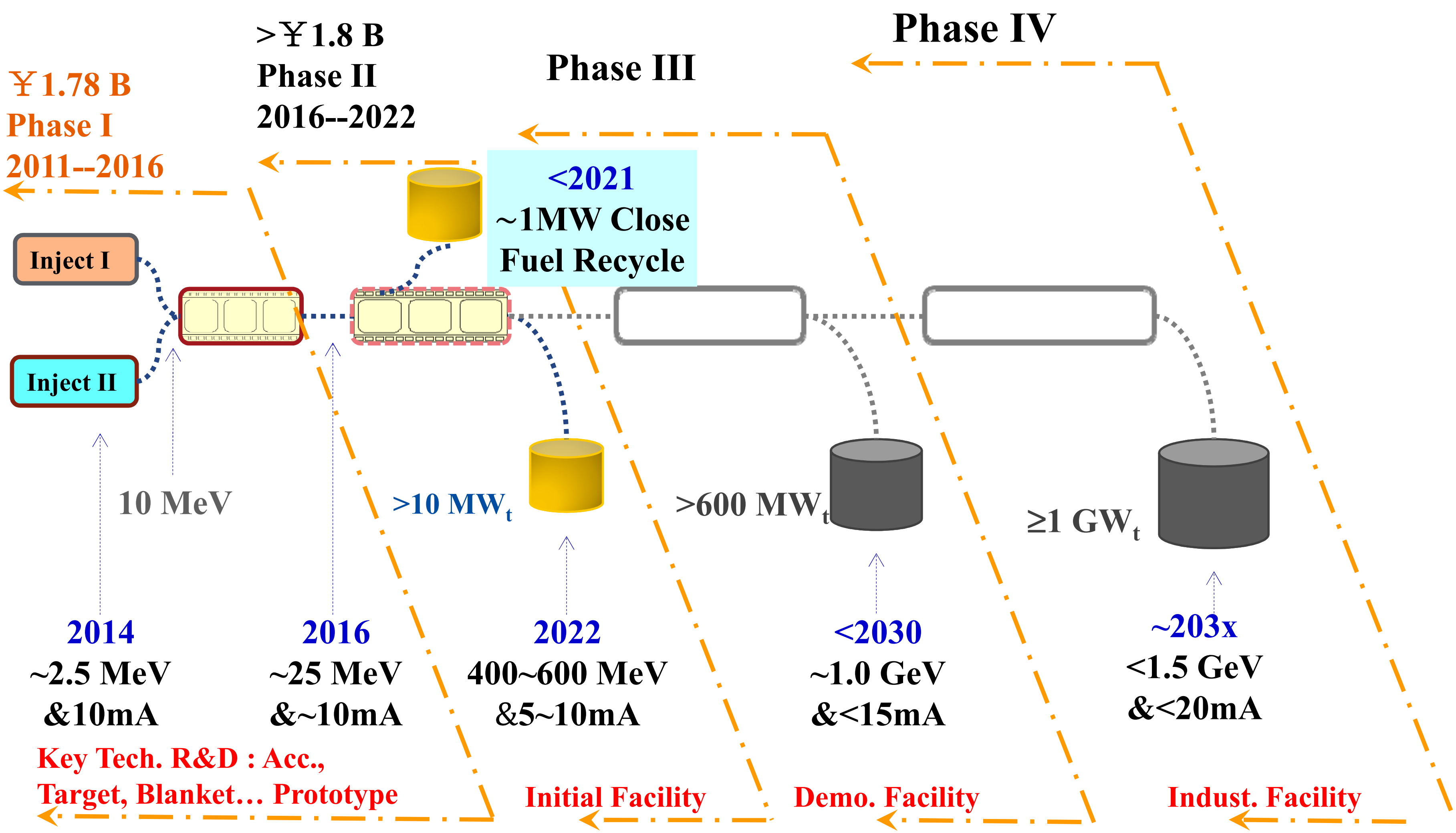
Parameter	PWR-50	PWR-100	CANDLE	SSFR	FMSR	ULFR	EM^2	TWR
Specific power density, MW/t	33.70	33.70	3.66	16.89	15.67	9.39	11.76	7.51
UNF production rate, t/GWe-yr	19.71	9.86	3.42	2.90	3.13	4.93	4.87	9.26
Decay heat per unit UNF mass, MW/t	1.99	2.00	0.24	0.76	0.74	0.63	0.68	0.43
Normalized decay heat per unit electricity generation, MW/GWe-yr	39.14	19.74	0.83	2.20	2.30	3.11	3.32	4.02

- **Decay Heat Remove** (Ref. Fuel Recycle Analysis of Once Through… ANL-FCRD-308, 2010)
  - **Smaller decay heat source** (<10% PWR at discharge, <1/3 ~ 10yr UNF)
  - **Weaker neutron, gamma source** < 1/3 of PWR at discharge
  - **Fuel Cladding material** (>1500℃) for removing heat by air in accident

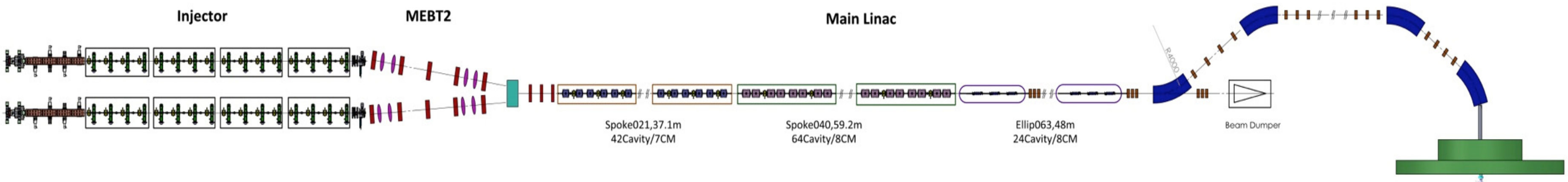
- **Confinement of radioactive material**
  - Multilayer confine fuel against radioactive material release during accident
  - ATF fuel cladding to limit radioactive containment **within control region**

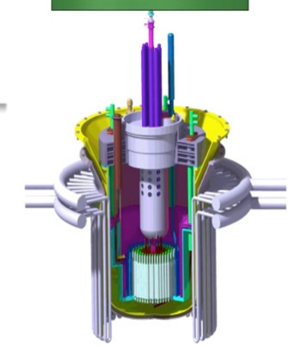
- **Proliferation resistance and physical protection**
  - No enrichment， no attractive for weapon and against the acts of terrorism

Roadmap of ADANES in China



CIADS Project (Phase 2)





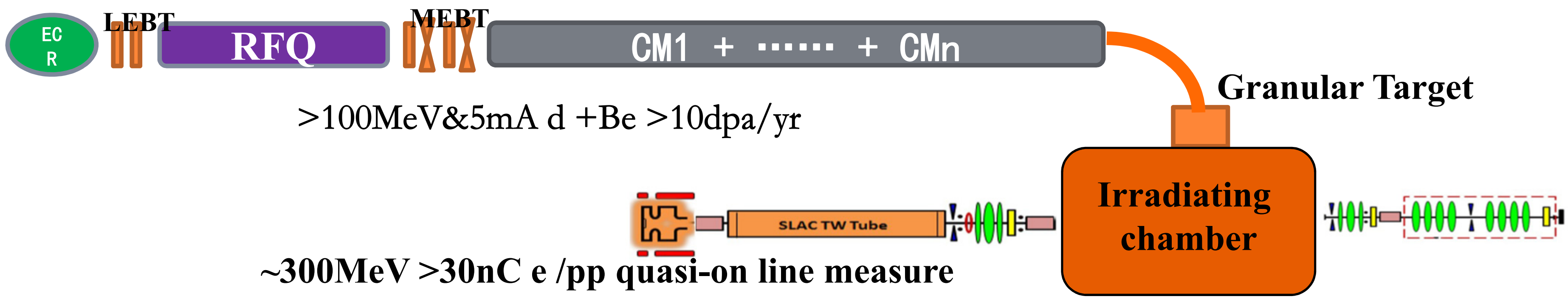
☐ CIADS Main Parameters:

- ➢ **High CW Power (>2.5MW, >500MeV) SC-LINAC**
- ➢ **High Power (>2.5MW) Spallation Target**
- ➢ **Sub-Core (<10MWth)**
- ➢ **Coupling all Components → Full System (~10MW)**

☐ CIADS Time Schedule :

- ➢ **2018—2023**

Accelerator Driven Recycling Used Fuel



- **Fuel Recycle**
- **Compact Neutron Source (10~50dpa)**

1, Verify Recycle Fuel

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

2， Irradiation of Materials

- **Cladding（SiC_f/SiC…）**
- **Core Structure (Oxide + Carbide Ceramics…)**
- **Window between Accelerator and Target**

Researches on Intense Beam at CIADS+HIAF

I. Nuclear Physics
- Nuclear Structure & Nuclear Astrophysics
- Nuclear Matter & Hadron Nuclear Physics

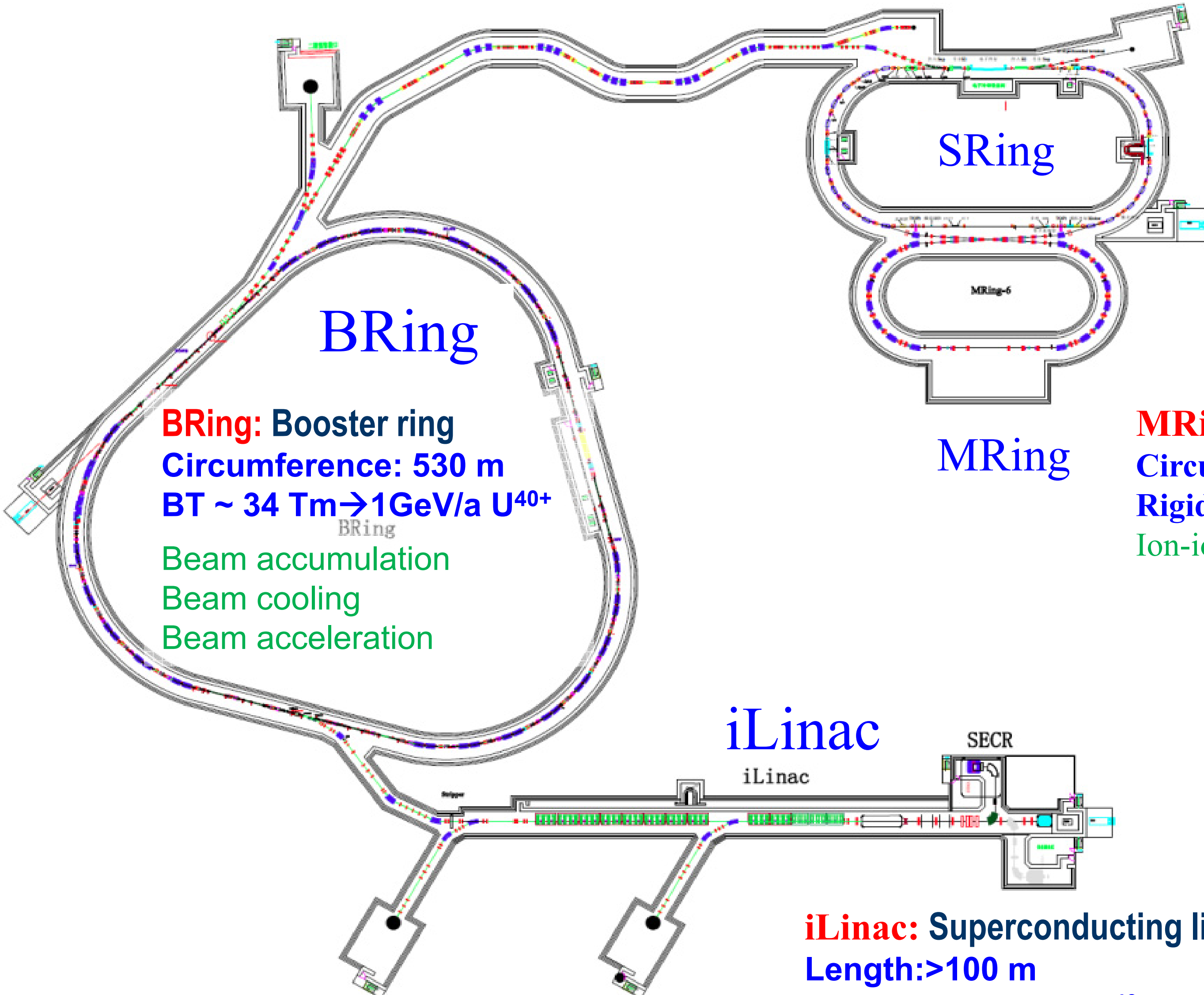
II. Foundation Physics
- Ultra-high E_Field QED
- Researches by Polarized nucleon, DAR neutrino, μ, π...

III. Nuclear Energy
- ADS → ADANES Burner

IV. Irradiative Material，Biology
- Compact, High Flux Neutron Source (10~50dpa)
- Ion Therapy

V. Convert UNF → Recycle Fuel

Configuration of HIAF



SRing: Spectrometer ring
Circumference: 265m
BT ~15 Tm→1GeV/a U^{92+}
Electron/Stochastic cooling
Two TOF detectors
Four operation modes

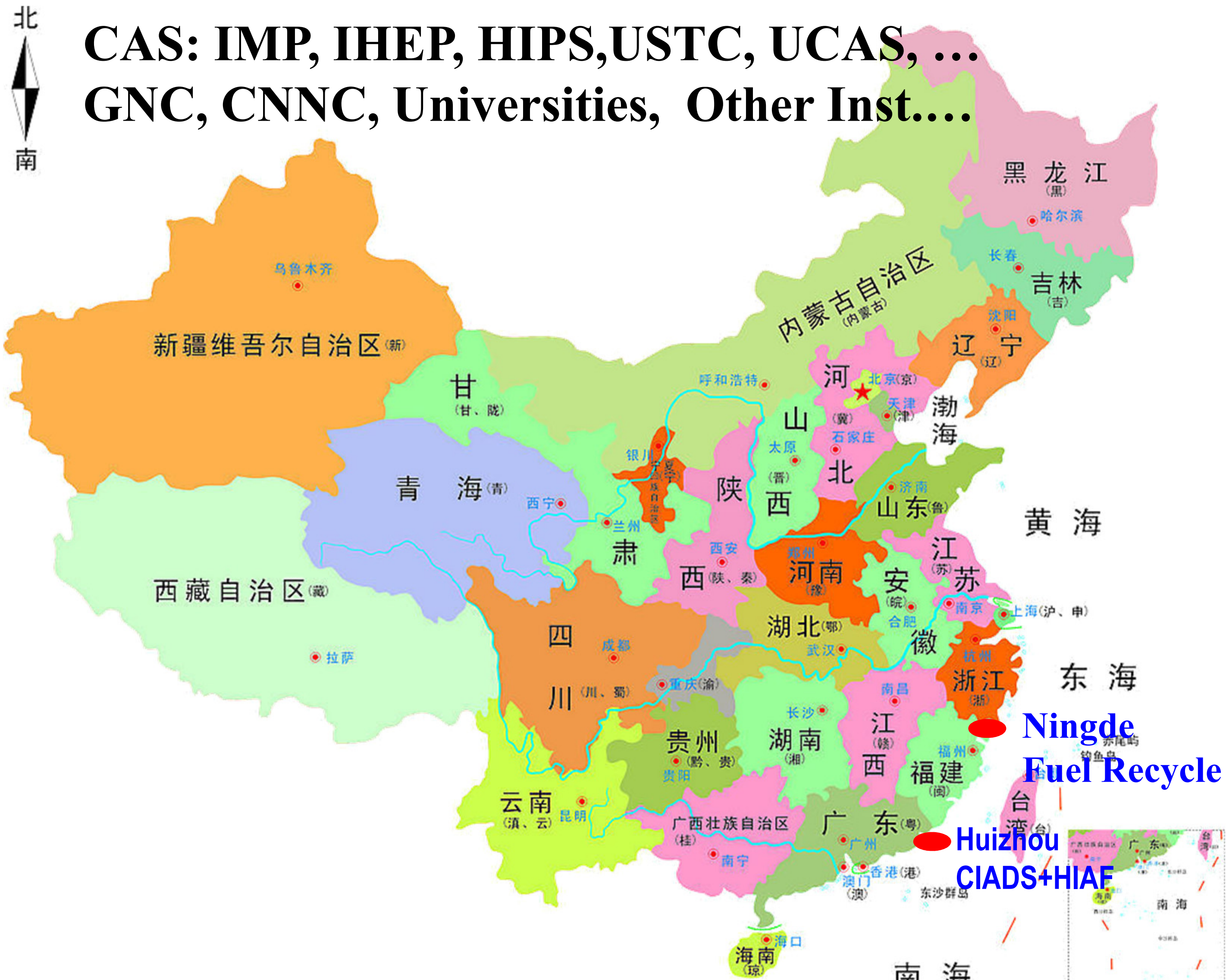
BRing: Booster ring
Circumference: 530 m
BT ~ 34 Tm→1GeV/a U^{40+}
Beam accumulation
Beam cooling
Beam acceleration

MRing: Figure "8" ring
Circumference: 268 m
Rigidity: 15 Tm
Ion-ion merging

iLinac: Superconducting linac
Length:>100 m
Energy: 20 MeV/u(U^{40+})

New site, New open research center

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



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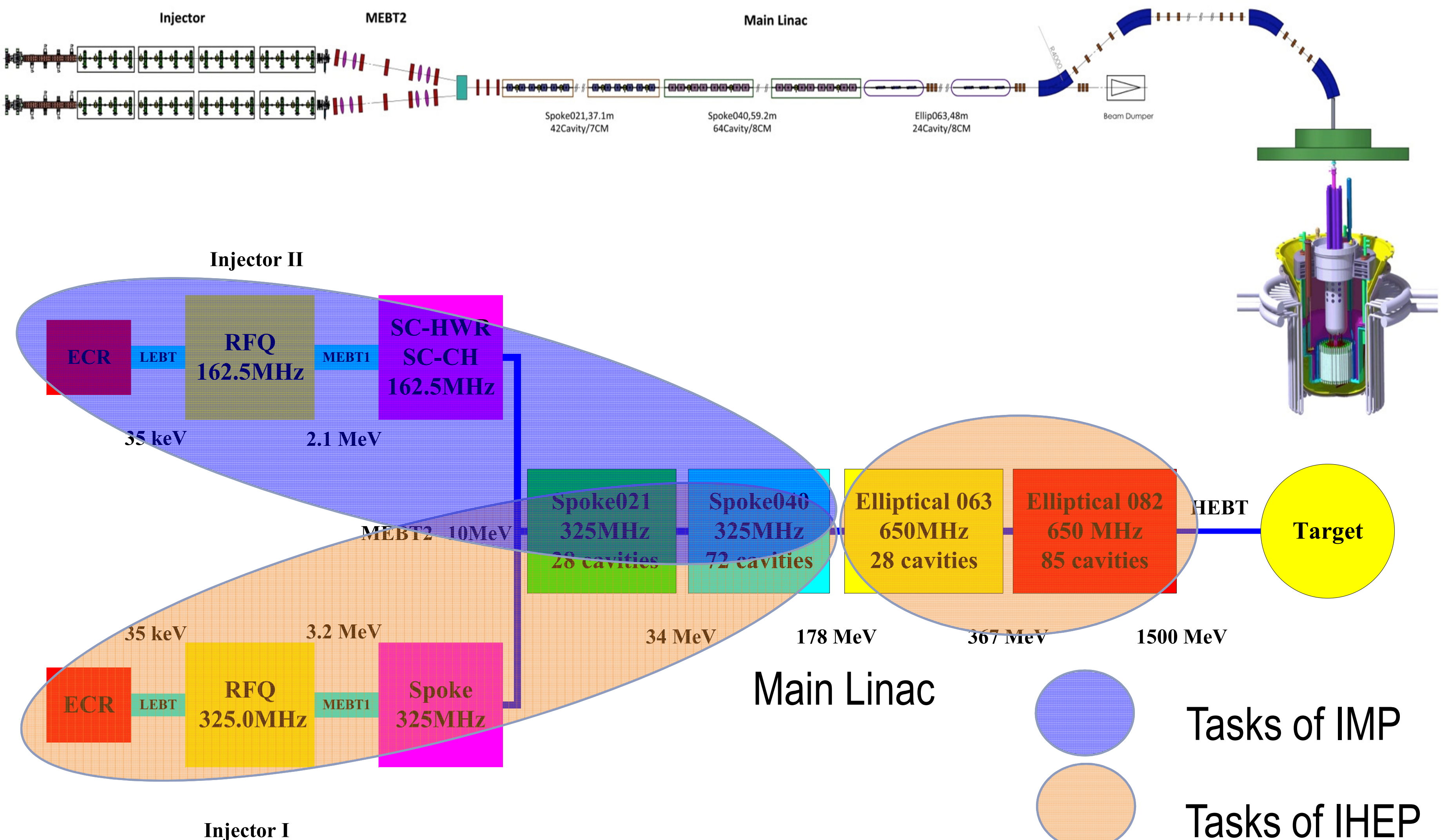
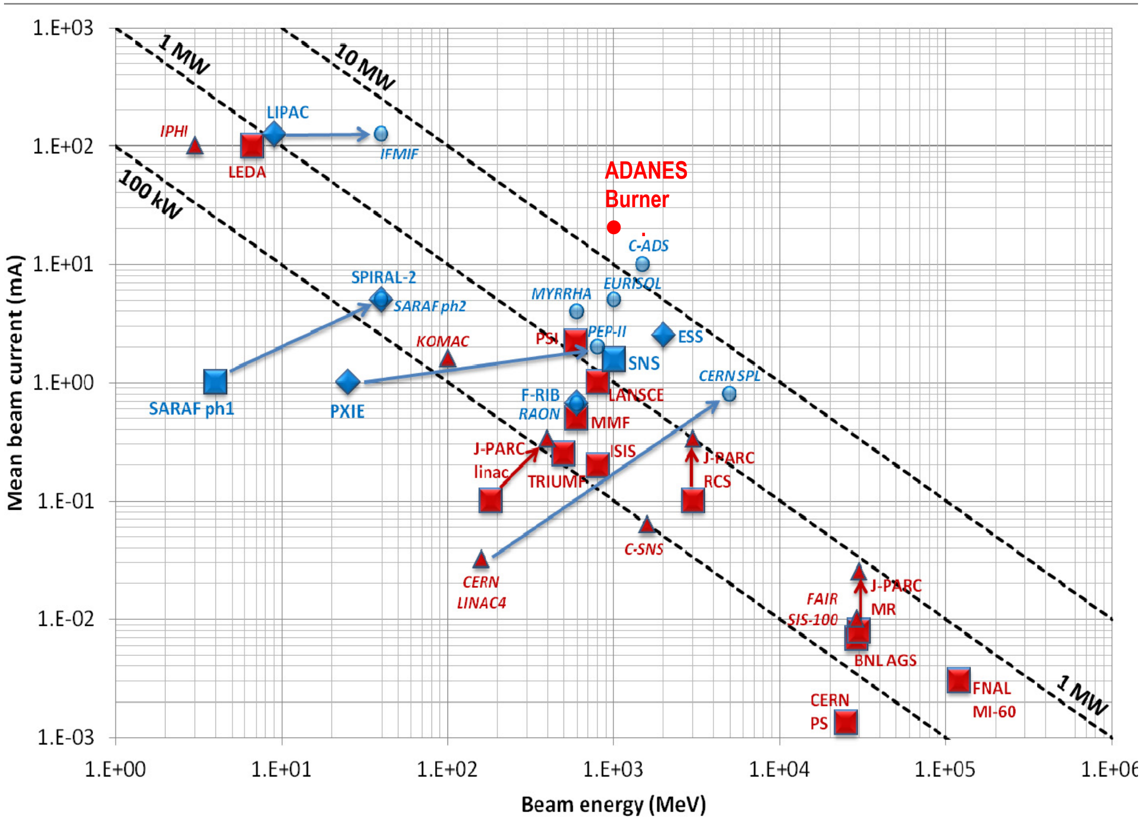
Configuration of C-ADS



Challenge of SCL for ADS/ADANES

- **Scale**
  - **Transmutation Demo**
  - **Industrial transmutation**
  - **Industrial Power Generation (IPG)**

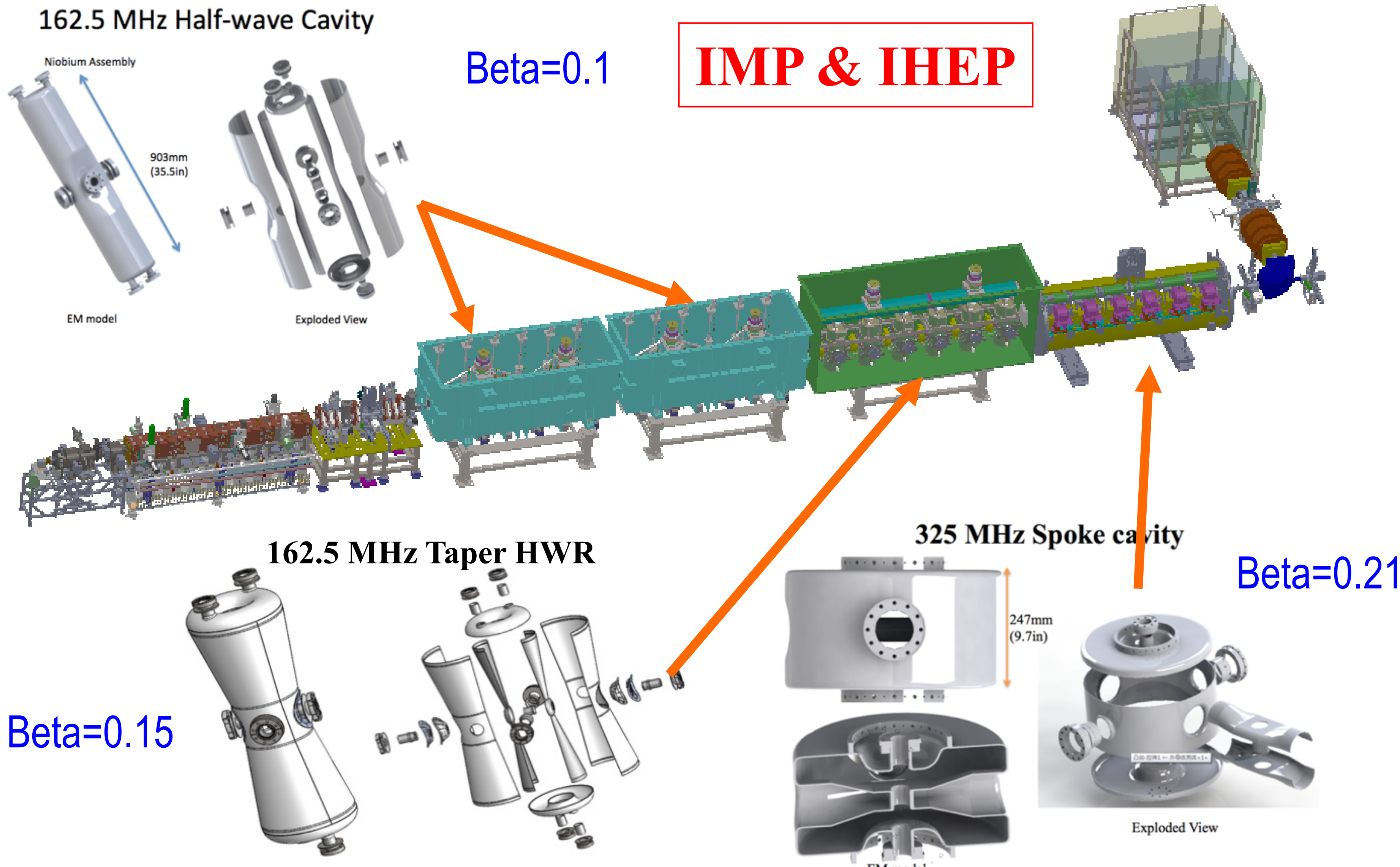


- **Mean Beam Power (IPG) : 10~20MW**
  - **Energy : ~1GeV**
  - **Mean current : 10~20mA**

- **Beam Strips & Availability（IPG）**

t < 1 sec.	1 < t < 10 sec.	10s < t <5 min.	t > 5min.	Availability
< 25000/yr.	< 2500 / yr.	< 250 / yr.	< 3 / yr.	> 85%

25 MeV LINAC Commissioning



25 MeV SCL (CW)

25MeV SCL :

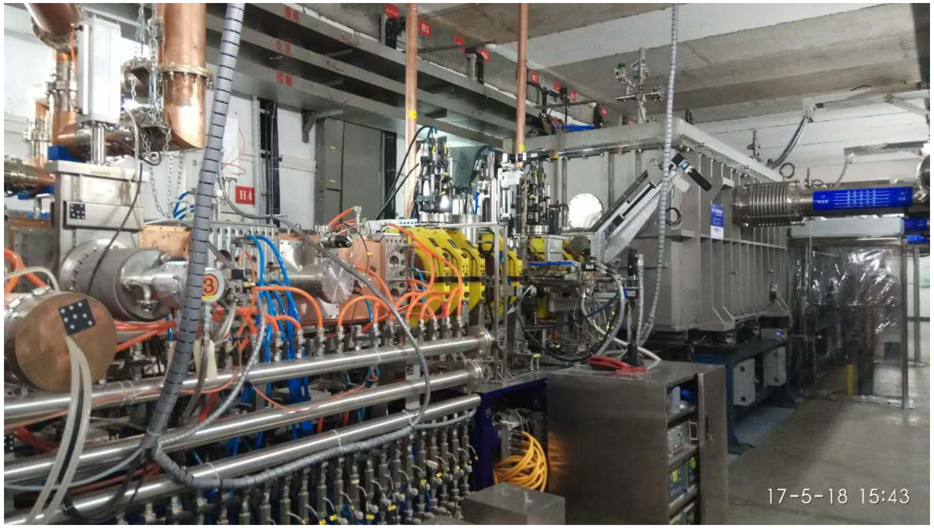
- **Ion Source : ECR**
- **RFQ, 162.5 MHz**
- **1st CM, 2nd CM :**

  6*HWR, 162.5 MHz
- **3rd CM :**

  5*THWR, 162.5MHz
- **4th CM :**

  7*Spoke， 325MHz

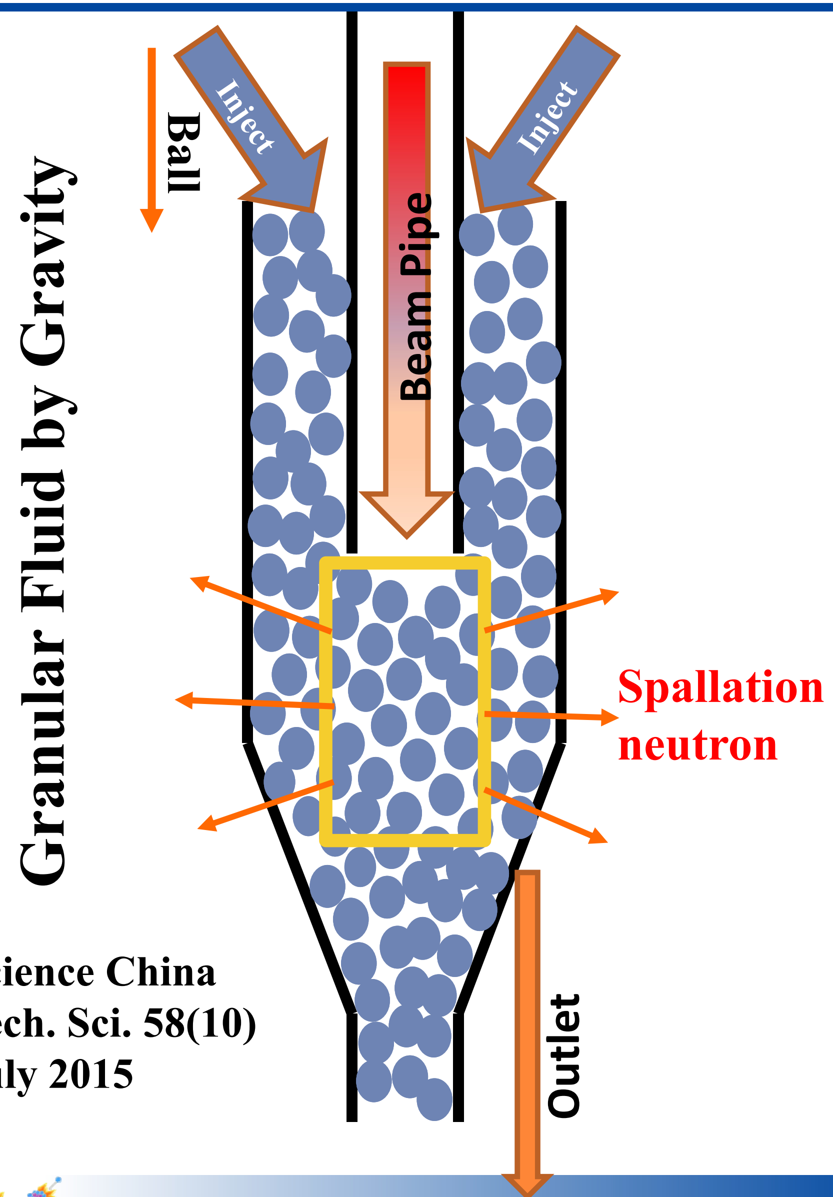
12mA/pulse, 0.2mA/CW



25MeV Front view

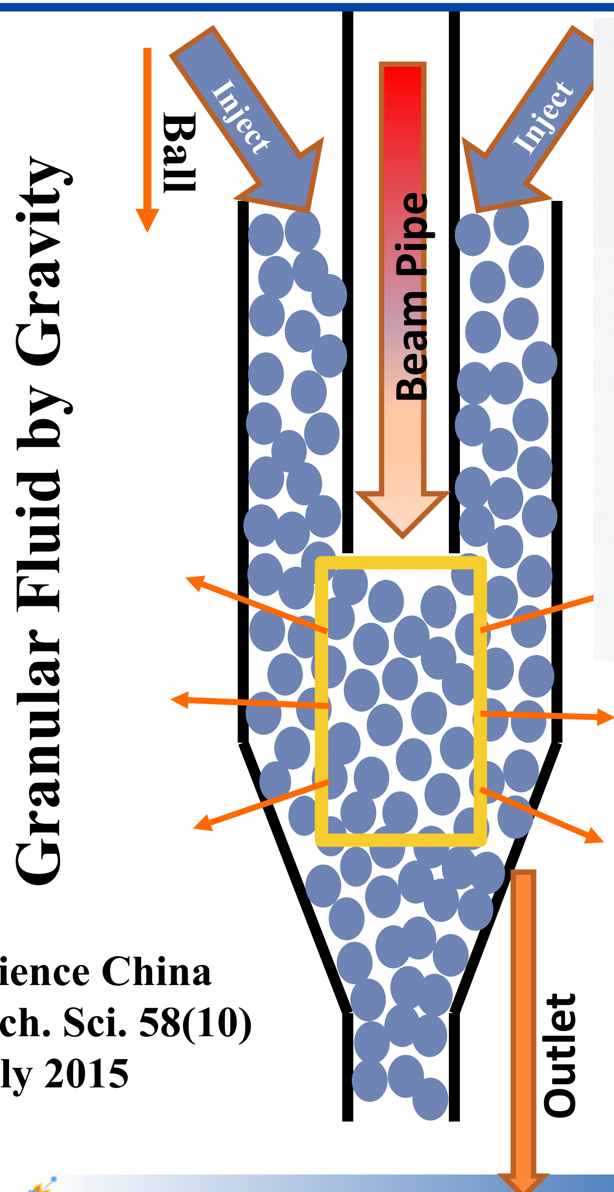
25MeV Back View

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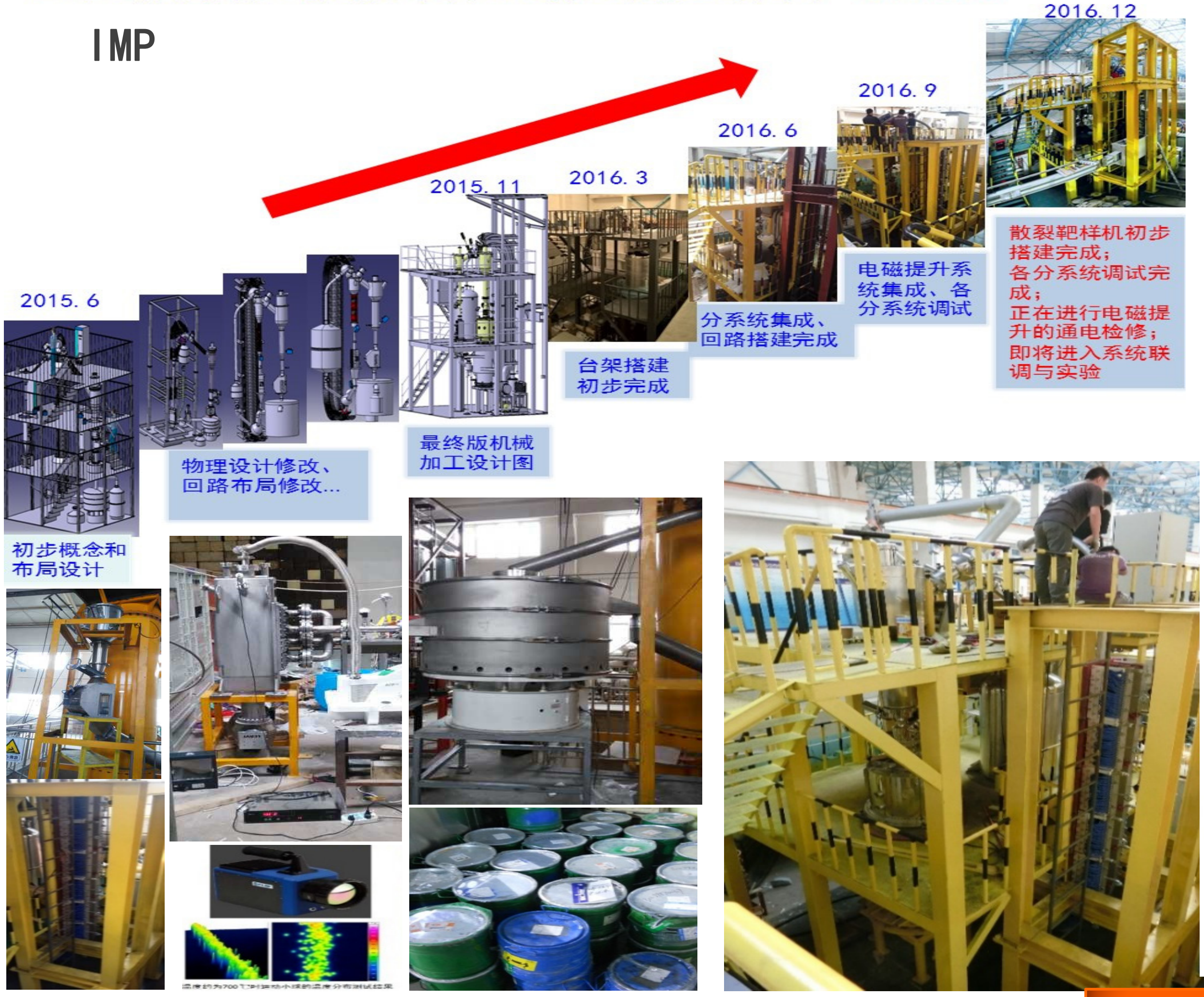
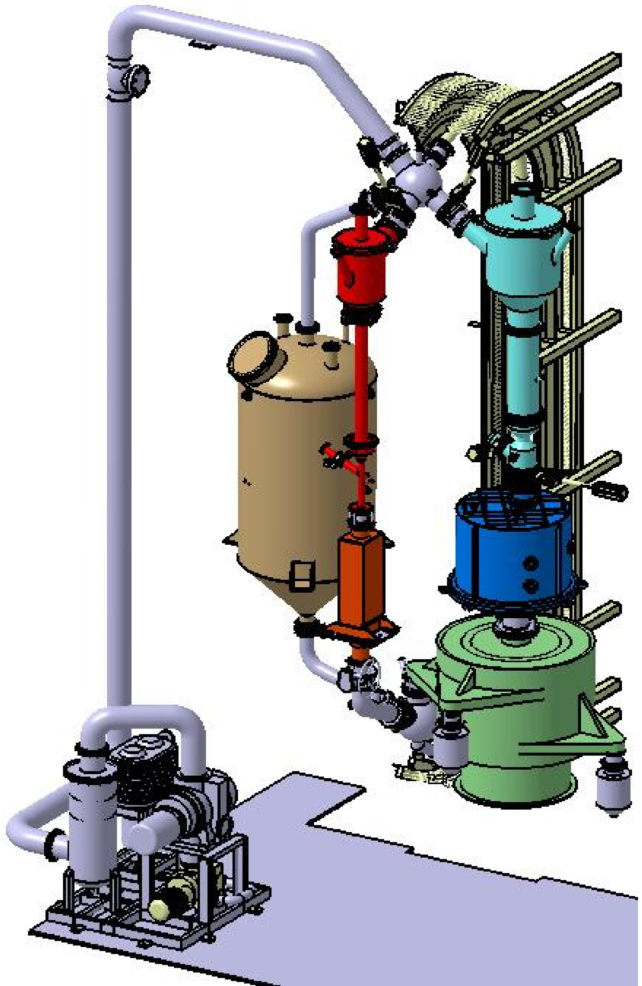
- Granular fluid operate stable as sand clock
- Target heat removing off line
- Grain update on line
- Higher target power capacity: 10~100 MW
- Dissipation the shock wave induced by beam trip
- Relieve short beam trip (<10s) requirement as discrete medium in target
- Target material selectable
- Dust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

Dense Granular Target Test Bench

重金属颗粒流散裂靶试验装置研制—进展&进程

IMP

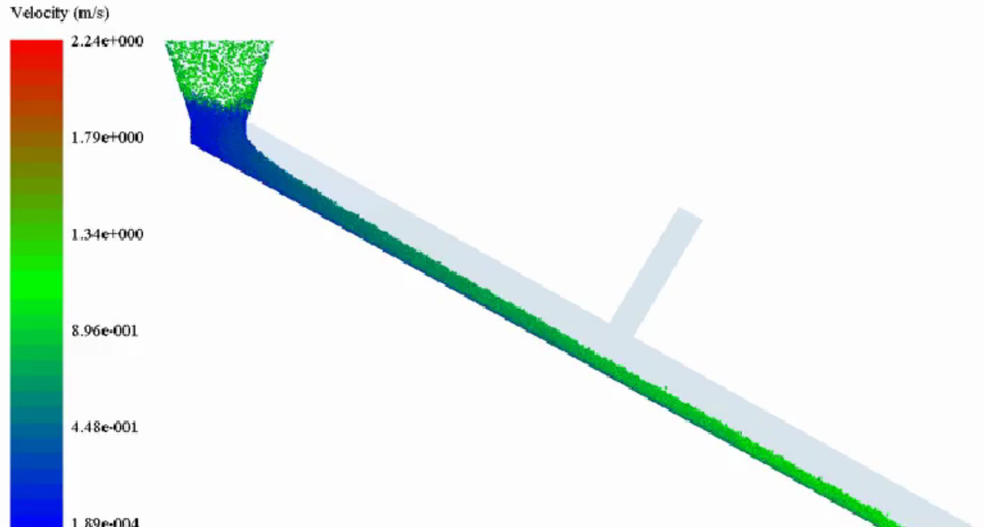


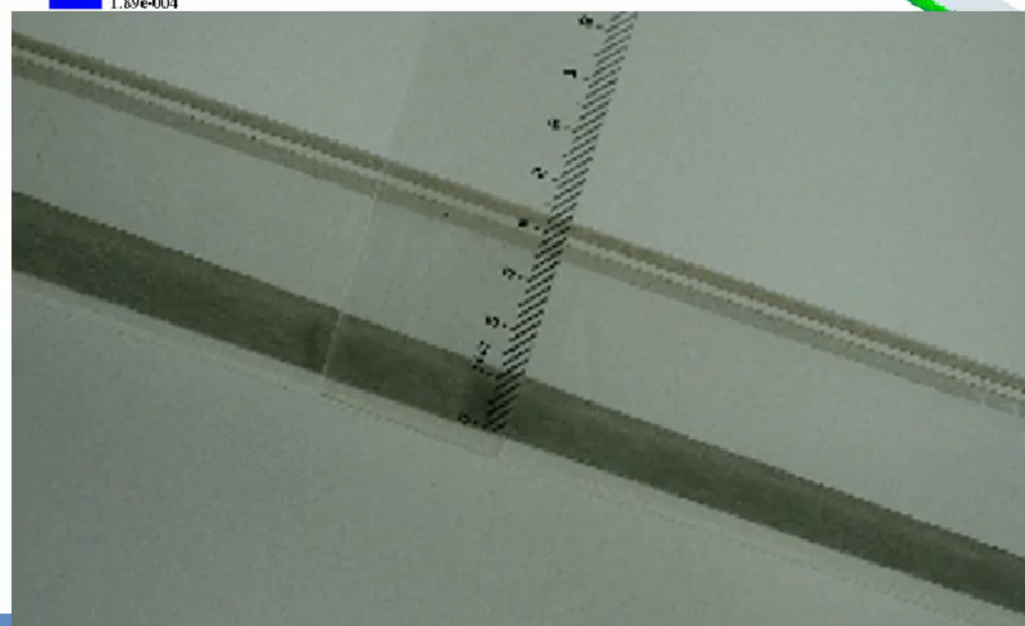


Test-Bench Checked 2017.6

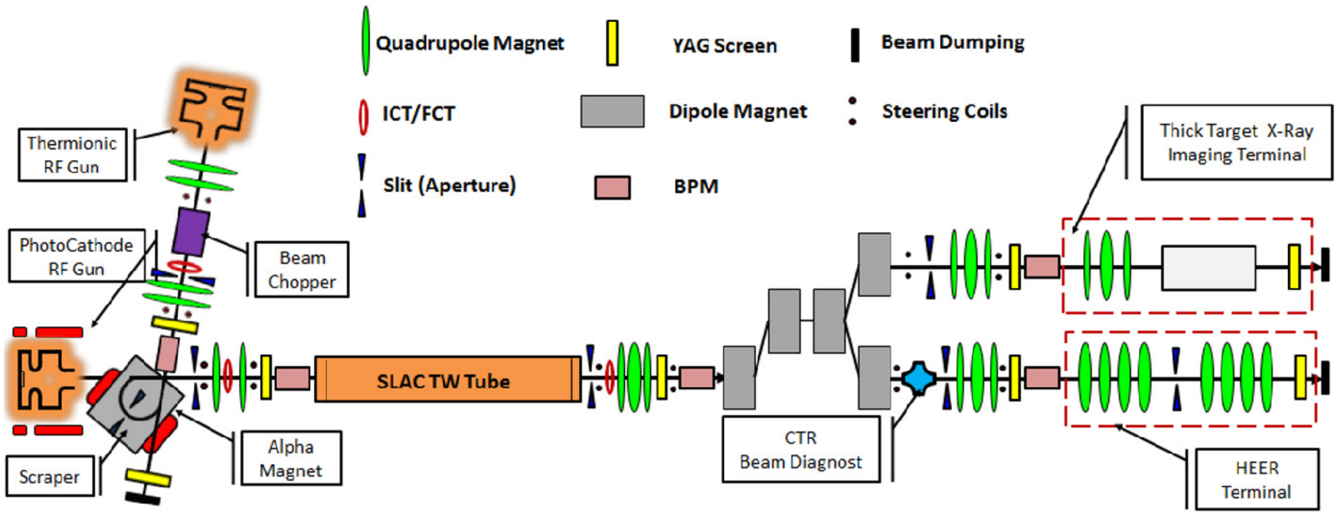
Granular Target for Compact Neutron Source

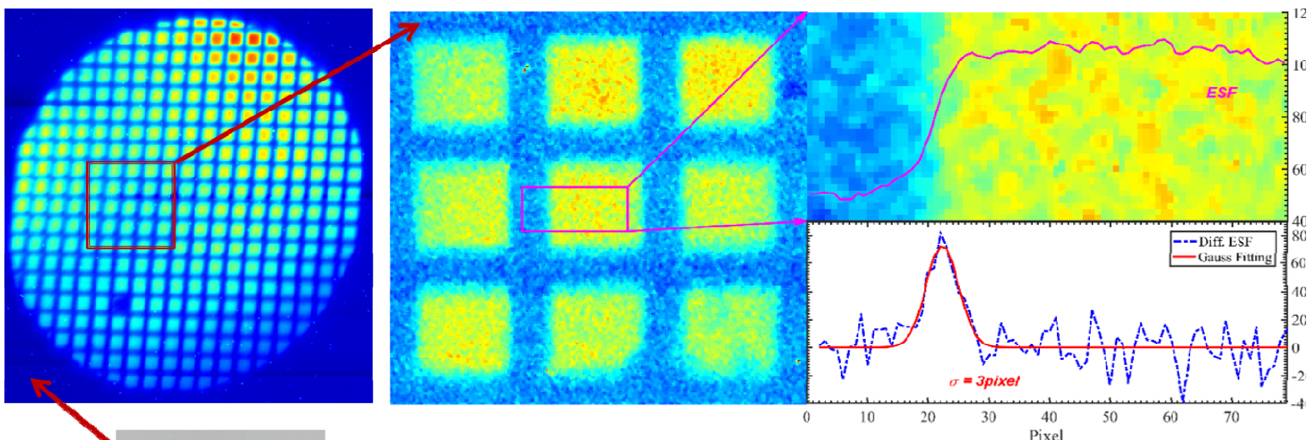
- Granular of Be Alloy/Be_2C driven by gravity;
- The high power dense of deposited energy by D beam
- Offline heat exchanger;
- Low Evaporation pressure
- Small size of the irradiative target keep high neutron flux

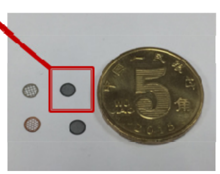




45MeV E-Beam measurement quasi- on line







$$\sigma(\mu m) \cong 3\ pixel * \frac{90\mu m}{(1185 - 1115)pixel} = 3.9\mu m$$

Summary of CIADS/ADANES

- ADANES Conception Proposed, Approaches under optimizing
- Accelerator System (prototype in world)
  - Injector >2.55MeV&11mA → 5.2MeV&4.7mA CW, → >10MeV&1~2mA/CW, →25MeV&12mA/pulse 0.2mA/CW
- 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 (SIMP Steel, SiC_f/SiC, Ceramic, …)
  - SIMP Steel, SiC_f/SiC, & Oxide, Carbide Ceramic for cladding & core, R&D
- GPU based S-Computing used for optimization of System Design

THANKS FOR ATTENTION

Welcome to Collaboration !