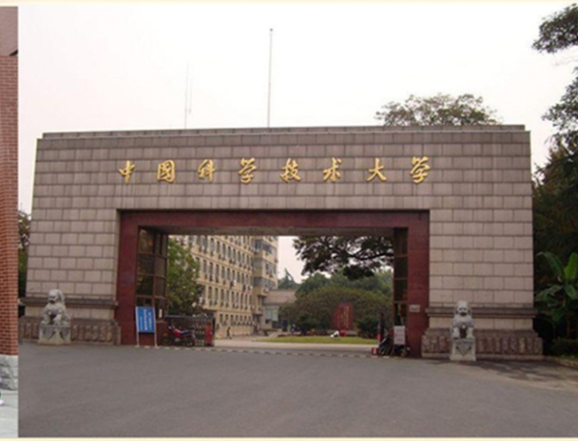
Institute of Nuclear Energy Safety Technology, CAS · FDS Team



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Latest Fusion R&D Activities at INEST

Presented by Yican Wu

(Zhibin Chen on behalf)

Contributed by FDS Team

Institute of Nuclear Energy Safety Technology (INEST)

Chinese Academy of Sciences

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Outline

I. Highlights of Fusion R&D Activities

- Fusion Neutron Sources
- Neutronics Methodology and Simulation
- Materials and TBM Technologies
- Fusion Safety

II. International Communication and Collaboration

1. Fusion Neutron Sources

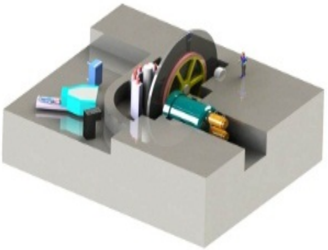
Development of the HINEG Fusion Neutron Sources

(High Intensity D-T Fusion Neutron Generator)

10^{12}-10^{13} n/s

HINEG-I
D-T Fusion Neutron Generator
(Under Operation)

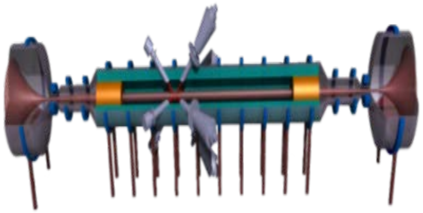
- Verification of neutron cross section data, induced radioactivity…
- Test of tritium production ratio of TBM mock-up
- Test of neutron detectors, electronics, new shielding materials…
- Study of biological effects under neutron radiation
- Nuclear technology applications…



10^{15}-10^{16} n/s

HINEG-II
D-T Multi-beam Fusion Neutron Source
(solid/gas target)

- Test of Materials irradiation damage (2 dpa/FPY)
- Validation and calibration of materials irradiation experimental data
- Study of coolant/materials interaction under neutron irradiation



10^{17} -10^{18} n/ s

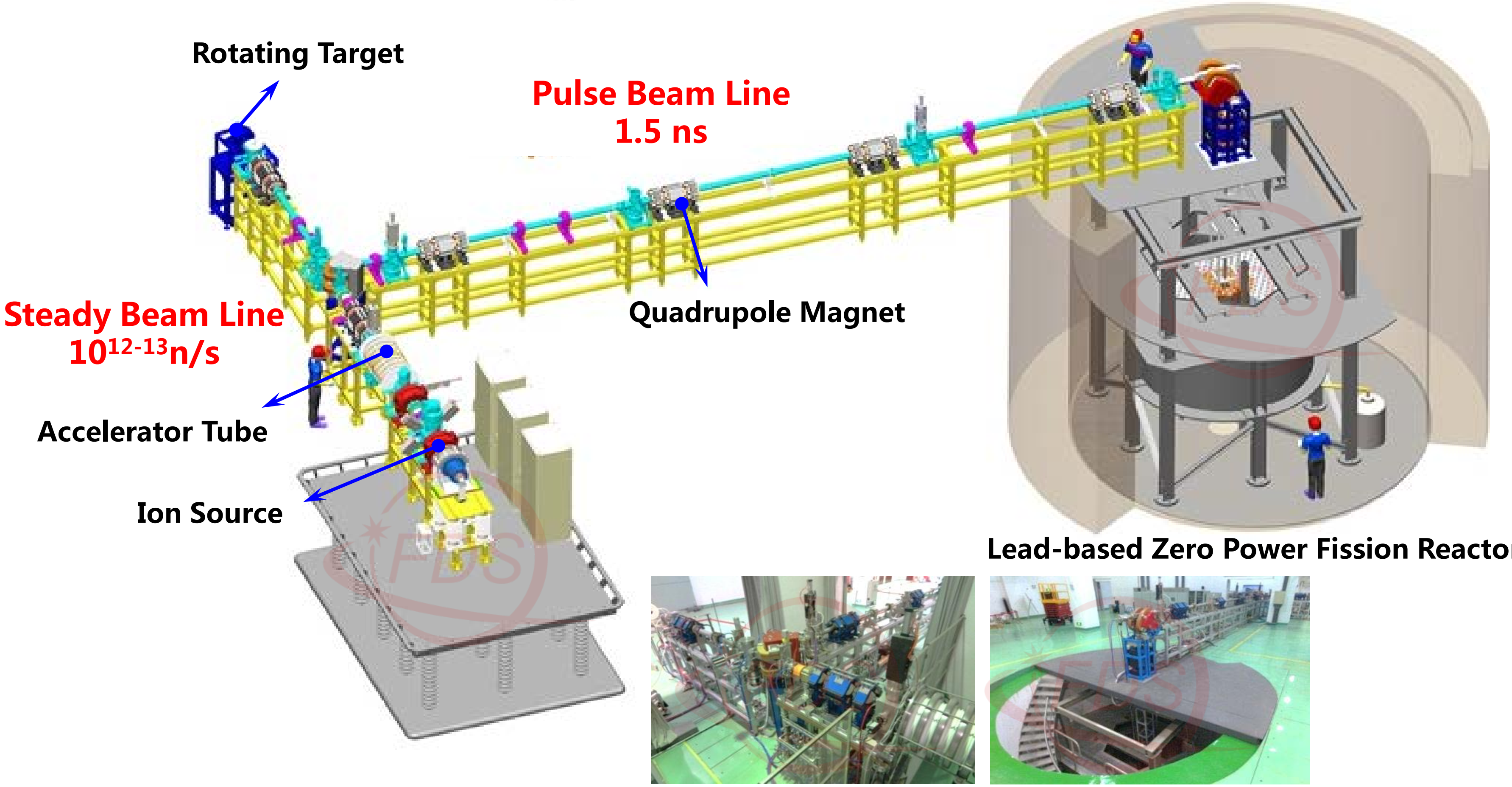
HINEG-III
GDT-based Fusion Neutron Source

- Full lifetime test of fusion materials (≥20 dpa/FPY)
- Component test of blanket and divertor
- Reliability data of nuclear components
- Transmutation of radioactive waste

Neutronics Design Validation → Material Irradiation Test → Component Performance Test

HINEG-I: D-T Fusion Neutron Generator

Coupling with Lead-based Zero Power Fission Reactor



Fusion neutrons with yield of 6.4×10^{12}n/s

HINEG-II: D-T Multi-beam Fusion Neutron Source

(solid target option)

Goals

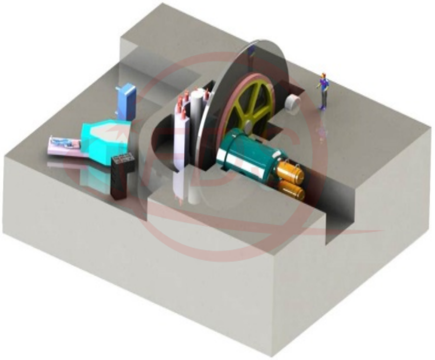
- Materials irradiation damage (2 dpa/FPY)
- Validation and calibration of materials irradiation experimental data in other ion/neutron source (e.g. reactor, spallation)
- Study of coolant/materials interaction under neutron irradiation (e.g. corrosion, sputtering etc.)

Challenges

- 20A steady-state ion source
- High thermal loading large-size rotating target (40 kW/cm^2)

Main Parameters

- Neutron yield: 10^{15}-10^{16} n/s
- Beam current: 20 A (D^+) +20 A (T^+)
- Beam energy: 200 keV



Conceptual design of HINEG-II (refer to "Sorgentina" of ENEA)

The evaluation and preliminary analysis of other options for HINEG-II are under way.

Design optimization and R&D for key technologies of HINEG-II are on going in collaboration/discussion with ENEA…

Based on HINEG-III (GDT based fusion neutron source), INEST and BINP jointly initiated an international mega-science project proposal

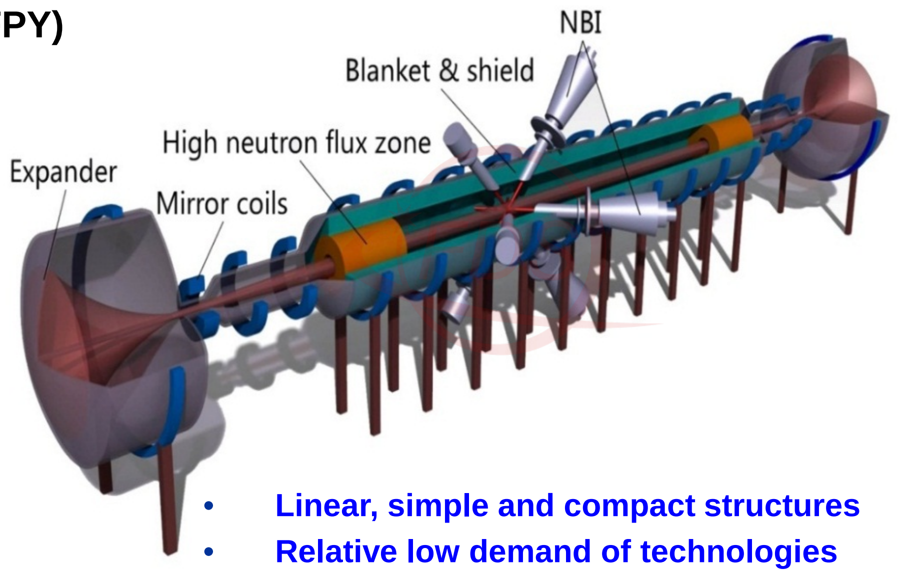
Axisymmetric LInear Advanced Neutron sourCE (ALIANCE)

Goals

- Full lifetime test of fusion materials (≥20 dpa/FPY)
- Component test of blanket and divertor
- Reliability data of nuclear components
- Validation of radioactive waste transmutation

Design target

- Availability: > 70%
- Operation mode: steady-state
- Tritium consumption rate: <200 g/FPY
- Neutron flux and test volume:
  ≥ 2 MW/m^2 (> 10 L)
  1~2 MW/m^2 (~100 L)



- Linear, simple and compact structures
- Relative low demand of technologies

An international preparatory committee for the mega-science project was established in 2018, with more invitations on-going.

Development Strategy of ALIANCE project

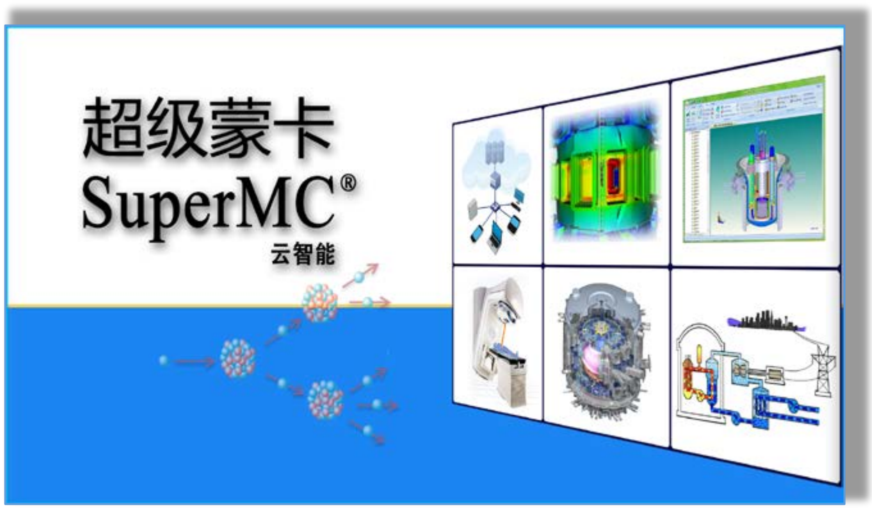
- **ALIANCE-I: Steady State GDT machine**
  - Development of continuously operating low power NBI
- **ALIANCE-II: D-D GDT neutron source (>10^{13} n/s)**
  - Demonstrate the GDT machine as a steady state neutron source with high availability
  - Schemes to flatten the gradient of neutron flux
- **ALIANCE-III: D-T GDT neutron source (> 10^{18} n/s)**
  - Development of tritium cycling technologies
  - Development of multifunctional experimental platforms (materials, components, nuclear technology applications, etc.)

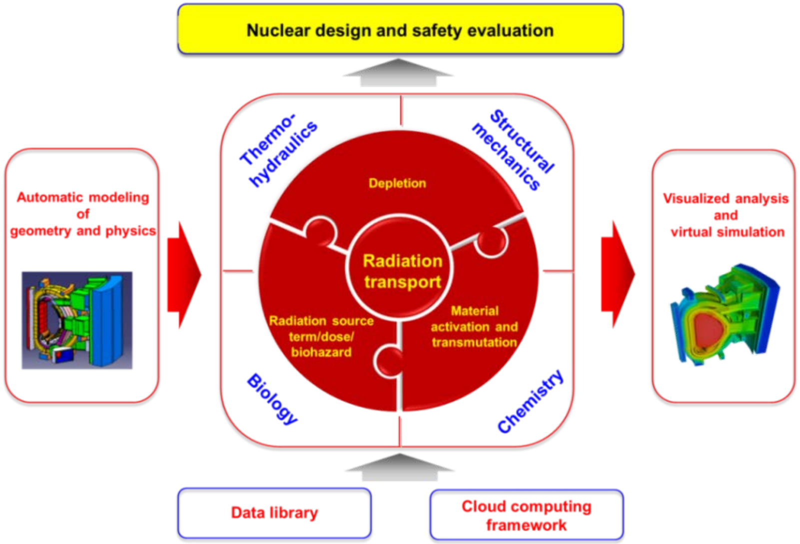
2. Neutronics Methodology and Simulation

SuperMC: Super Multi-functional Calculation Program for Nuclear Design & Safety Evaluation

20+ years continuous development
400+ person years investment

- **Whole neutronics process simulation:** neutron transport, depletion, activation and dose calculation
- **Multiple physics simulation:** neutronics, thermo-hydraulics, structural mechanics, etc.





SuperMC 3.4 is released in ISFNT-14 (2019)

SueprMC: New Capabilities of SuperMC V3.4

Enhancements in neutronics calculation

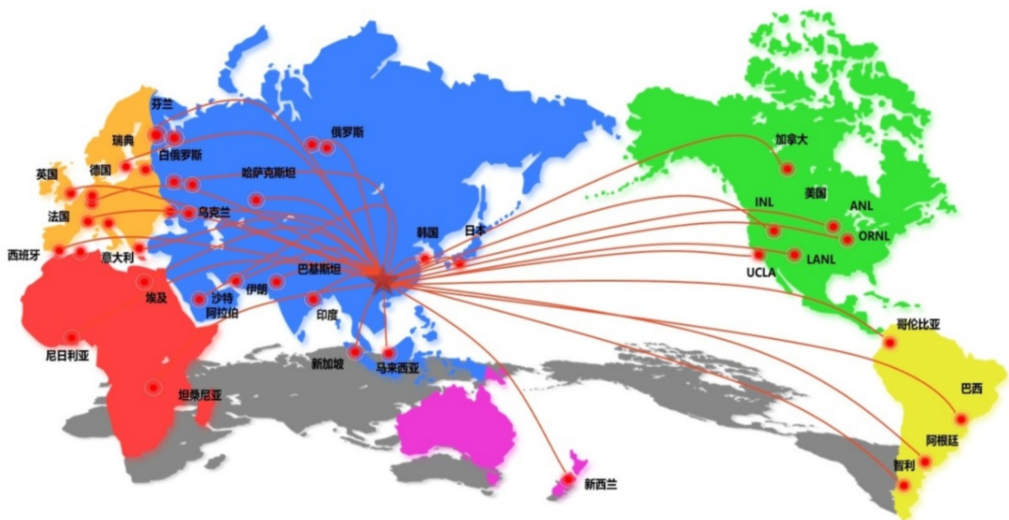
- **Shutdown dose rate calculation based on inner-coupling accurate generation of collision response**
- **Critical search of boron concentration and control rod position based on adjoint flux**
- **Transport-burnup coupling calculation based on improved semi-predictor-corrector (ISPC), etc.**

Advances in user-friendliness

- **Cloud computing based on mobile phone APP & website**
- **Physical parameter settings using interactive interface (source, tally, etc.)**
- **3D visualization for cell tally results and source distribution, etc.**

SuperMC: Widely Applied in the World

- Widely used in the field of nuclear energy (fission/fusion/hybrid system), as well as extended nuclear technology application fields (well logging, nondestructive testing, radiotherapy, etc.)
- Applied in many projects: International Thermonuclear Experimental Reactor (ITER), Joint European Torus (JET), Facility for Rare Isotope Beams, CLEAR, TMSR, etc.



Available from OECD/NEA and RIST/NCC

http://www.oecd-nea.org/tools/abstract/detail/iaea1437

http://www.tokai.rist.or.jp/nucis/codetable.html

Contact information: SuperMC@fds.org.cn

3. Materials and Blanket

China Low Activation Martensitic steel

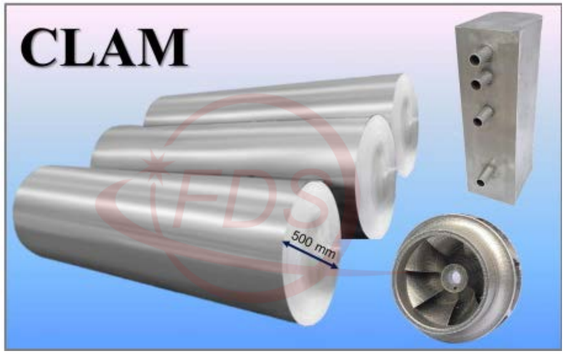
CLAM: 0.1C-9Cr-1.5W-0.2V-0.15Ta-0.45Mn

❖ Heat & Irradiation Resistant Design

- **W content design:**
  - ✓ High strength with the reduction of brittle Fe2W formation
- **Ta content and precipitation design:**
  - ✓ Relatively high Ta for dispersed nano scale TaC phase
  - ✓ Accurate TMT processing for high density of TaC

❖ Component fabrication technologies

- ✓ Fabrication of 1/3 scaled DFLL-TBM by welding technologies
- ✓ Breakthrough in 3D printing of blanket first wall



3×6-ton Ingots & Components

	C	Cr	W	V	Ta	Mn
CLAM	0.10	9.0	1.5	0.20	0.15	0.45
CLF-1	0.11	8.5	1.5	0.30	0.10	0.5
Eurofer97	0.10	9.0	1.1	0.20	0.12	0.4
F82H	0.10	8.0	2.0	0.20	0.03	0.12

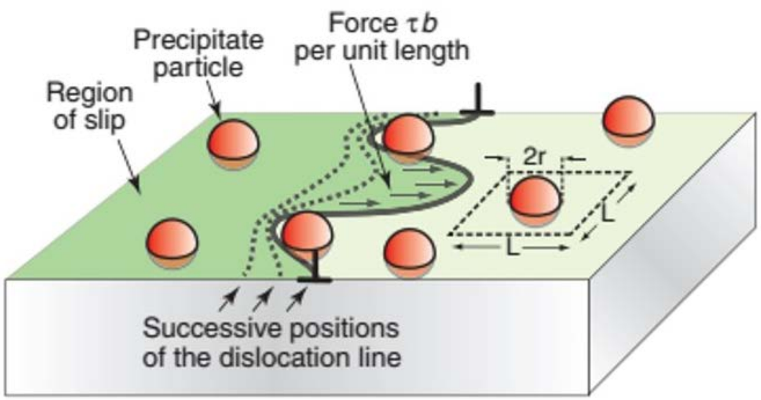
Chemical compositions of different RAFM steels

Industry RAFM steel standard based on CLAM has been implemented in 2018（ HJB1016-2018 ）

Next Generation Structural Material: ODS-CLAM

Supported by National Key Program of China (MCF), 2018-2023

- **High performance of ODS-CLAM:**
  - **Irradiation resistance:**
    - ✓ Swelling after 200 dpa ion irradiation: <0.1%
  - **High temperature strength:**
    - ✓ Yield strength at 700 ºC: >500 MPa
    - ✓ Creep life at 120 MPa/650ºC: >10,000 hr

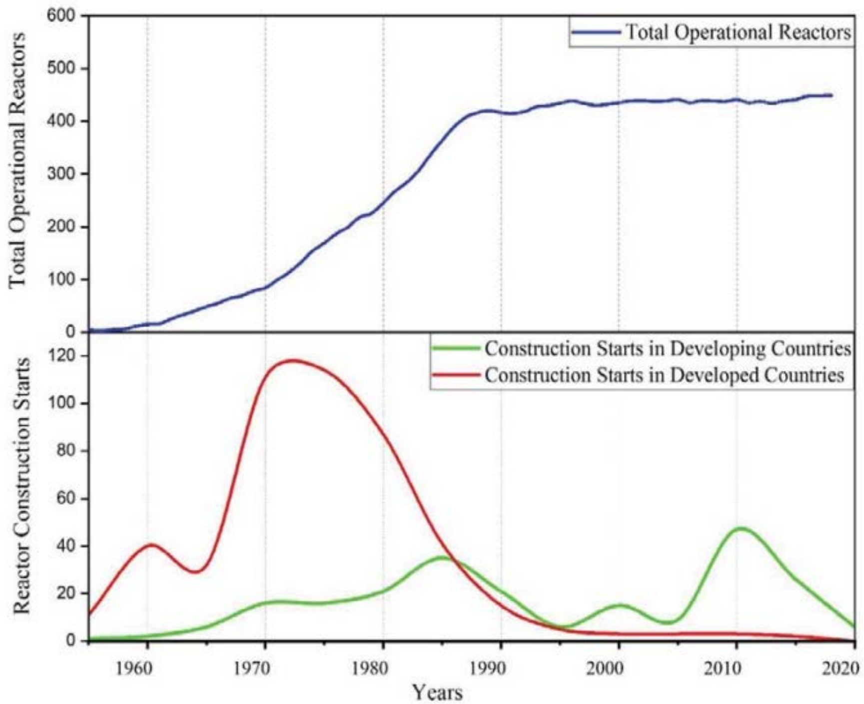


- **Smelting mass production technologies**
  - ✓ Nanoparticles: <10 nm, >10^{24} m^{-3}
  - ✓ Complex component fabrication by additive manufacturing

4. Fusion Safety

Nuclear Safety in the Unexpected Second Nuclear Era

Not adequate understanding of nuclear safety even for the fission reactor



Nuclear reactor construction starts & total operational reactors

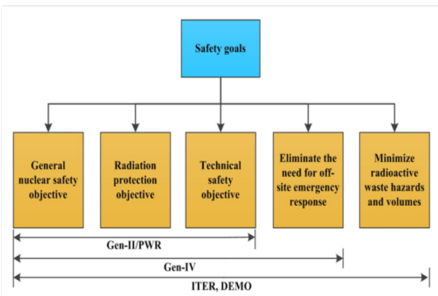
Close coupling of technical and social factors for transforming the concept of nuclear safety

Wu Y. *et al.* Nuclear Safety in the Unexpected Second Nuclear Era, *PNAS,* 2019, 116(36): 17673-17682

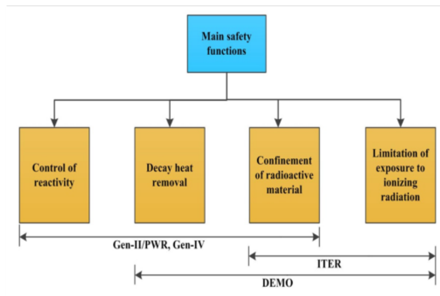
Identification of Safety Gaps for Fusion DEMO Reactors

❖ **DEMO safety issues and safety approach, and the international DEMO safety R&D activities are reviewed and safety R&D gaps are presented**

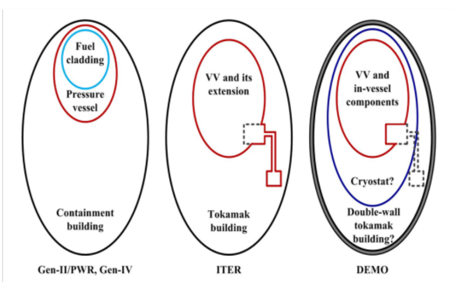
◻ Fundamental Safety Objectives



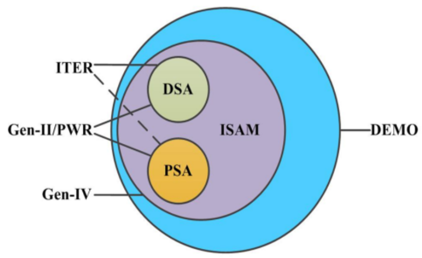
◻ Main Safety Functions



◻ Defense in Depth and Multiple Barriers



◻ Safety Assessment Methodology



Wu Y. *et al.* Identification of safety gaps for fusion demonstration reactors.

***nature energy* 1, 16154, doi:10.138/nenergy.2016.154 (2016).**

Quantitative Safety Goals for Fusion Reactors (accidents an example)

Facility	Safety requirement	Emergency evacuation guidelines
AP1000	EPRI URD[1]	10 mSv (24 hours, site boundary), frequency<10^{-6}
ITER	France ASN[2]	sheltering: 10 mSv (48 hours); evacuation: 50 mSv
Fusion facility	U.S. DOE[3]	sheltering/evacuation: 10 mSv (7 days)

[1]URD,1999; [2]ASN report,2015; [3]DOE-STD-6002,1996

* Calculated according to DOE-STD-6002 (1996) and INEEL/EXT-03-00405 (2003).

Public Evacuation Dose limit:

Early dose (7 days) for most exposed individual at site boundary, 10 mSv

Implication on DEMO and FPP:

- ✓ **Hugely reduce inventories of radioactive materials in VV (e.g. 33 g tritium for 100% release)**
- ✓ **Decrease release fraction as large as possible (e.g. 330g tritium for 10% release)**

Outline

I. Highlights of Fusion R&D Activities

II. International Communication and Collaboration

International Cooperation on Fusion Nuclear Technology and Safety

- ☐ **IEA-ESEFP ExCo Chair (2013.9-2018.1)**
- ☐ **IEA-NTFR ExCo Chair (2019.09-)**

2019 IEA ESEFP ExCo Meeting

ExCo Members from：

1. **MOST, China（INEST being the representative ）**
2. **EC, Europe**
3. **IPR, India**
4. **QST, Japan**
5. **NFRI, Korea**
6. **ROSATOM, Russia**
7. **DOE, USA**

……

2019 IEA NTFR ExCo Meeting

World Summit on Nuclear Energy Safety Technology (10-16 May 2020)

Satellite Meetings

- SNINS: Symposium on Neutronics and Innovative Nuclear Systems
- CASLER: International Co-operative Alliance for Small LEad-based Fast Reactors
- CAS-RAS Bilateral Meeting on ALIANCE
- INEST International Advisory Board

Fliers on the registration desk

Institute of Nuclear Energy Safety Technology, CAS · FDS Team

Pre-announcement of the 4th World Summit on Nuclear Energy Safety Technology

In order to advance the sustainable development of nuclear energy and promote wider application of nuclear technology, the World Summit on Nuclear Energy Safety Technology (SNEST) is initiated by the Institute of Nuclear Energy Safety Technology (INEST), Chinese Academy of Sciences, and organized by INEST and other international organizations of the field. Nowadays SNEST has been recognized as one of the premier international gatherings for nuclear energy safety technology, promoting the exchange of information on all scientific, engineering and other technical aspects of the fields.

The 4th SNEST will be held in Hefei, China from May 10 to 16, 2020. Many Nobel Laureates, leaders of international organizations and top 500 enterprises of the world, would be on hand for the prestigious event that will bring collaborations among international scientists and engineers. The topics of 4th SNEST provide the excellent opportunity for discussing and exchanging the nuclear energy safety issues, and identifying means to resolve these issues. In addition, a number of satellite meetings, workshops and related academic activities will also be held linking to the 4th SNEST.

Thanks to the support of International Atomic Energy Agency (IAEA), International Energy Agency (IEA), Nuclear Energy Agency in Organization for Economic Cooperation and Development (OECD/NEA), International Thermonuclear Experimental Reactor organization (ITER), Ministry of Science and Technology of China (MOST), Chinese Academy of Sciences (CAS), Chinese Academy of Engineering (CAE) etc., the SNEST has been successfully held three times, and attracted extensive attention of scientists and celebrities in the world.

Contact Information

If you need any Visa information or other help, please do not hesitate to contact:
E-mail: snest@fds.org.cn
Tel. : +86 551 65593681

15th International Symposium on Fusion Nuclear Technology

13-17 September 2021, Hefei, China

Hosted by the Institute of Nuclear Energy Safety Technology, CAS (INEST)

Summary

1. In the field of fusion research, INEST concentrates on the Nuclear Technology and Safety.

2. In 2019, INEST has made good progress on neutron source, neutronics software, fusion safety, material development, etc.

3. INEST is always open to domestic & international cooperation.

Thanks for Your Attention!

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