Institute of Nuclear Energy Safety Technology, CAS
Key Laboratory of Neutronics and Radiation Safety, CAS

Better Nuclear Energy Technology, Better Life!

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Latest Fusion R&D Activities at INEST

Presented by Prof. Yican Wu
(Director-General of INEST)

Contributed by FDS Team
Institute of Nuclear Energy Safety Technology (INEST)
Chinese Academy of Sciences (CAS)

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Outline

I. Brief Introduction to INEST

II. Highlights of Fusion R&D Activities

III. Summary
History of INEST • FDS Team

INEST • FDS Team

*Frontier Development of Science*

ASIPP: Institute of Plasma Physics, CAS
## Personnel

<table>
<thead>
<tr>
<th>Employees</th>
<th>Students</th>
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<tbody>
<tr>
<td>• Staff: ~400</td>
<td>• Postgraduates: ~100</td>
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<tr>
<td>• Guest scientists: ~50</td>
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Current members: >500
Orientation of INEST

• The professional institute focuses on design and R&D of advanced nuclear energy systems and safety technologies, and aims to be
  1. The International center for nuclear safety research
  2. The national education center for nuclear safety
  3. The professional supporting center of nuclear safety technology for power plants and facilities

• The independent nuclear safety evaluation center.
Scientific Programs at INEST

Under Three National Mega-Programs:
• Strategic Priority Research Program of CAS
• ITER Related International & Domestic Program
• Nuclear Energy & Safety Technology Innovation Program

Carrying Out Four Types of Research Projects:
• Physics & Safety of Nuclear Energy
• Lead-based reactors (GEN-V, ADS, SMR, etc.)
• Fusion nuclear technology & materials
• Nuclear technology applications
Outline

I. Brief Introduction to INEST

II. Highlights of Fusion R&D Activities
   • Fusion Neutron Sources
   • Neutronics Methodology and Simulation
   • Fusion Safety
   • TBM and Related Technologies

III. Summary
1. Fusion Neutron Sources
HINEG-I: Fusion-Fission Hybrid Neutron Source

Applications:
Steady Beam: V&V of neutronic method and software, etc.
Pulse Beam: Nuclear data measurement, etc.

Fusion neutrons with yield up to $6.4 \times 10^{12} \text{n/s}$ have been generated
HINEG-I Main Sub-systems

- Ion Source and Low Energy Beam Transportation
- Steady Beam Line
- Rotating Target
- Control Room
Fusion Neutron Driven
Hybrid Nuclear Energy System Testing Facility: CLEAR-A0

The construction of CLEAR-A0 was finished in the early of 2017
HINEG-II: High Intensity Steady Neutron Source  
(Preliminary Scheme)

- **Neutron yield:** $10^{15}$-$10^{16}$ n/s

**Objectives**
- Materials Irradiation
- Neutronics Performance Test

R&D for key components of HINEG-II is on-going
HINEG-III
Conceptual Design Based on Gas Dynamic Trap

Two Options:

- **GDT-VFNS**: Fusion Materials and Component Testing facility
- **GDT-Hybrid**: Fusion-Fission Hybrid System

IAEA Coordinated Research Project F1.30.15
2. Neutronics Methodology and Simulation
Super Multi-functional Calculation Program for Nuclear and Radiation Simulation: **SuperMC**

- **Full functional neutronics calculation** for transport, depletion, activation, dose etc
- **CAD/Image-based accurate automatic modeling** for complex irregular geometry
- **Intelligent data analysis** based on multi-D/multi-style visualization
- **Network-based access** on cloud computing platform
Widely Used Worldwide

- Application in 30+ Major Nuclear Projects
  - **Europe:** International Thermonuclear Experimental Reactor (ITER), Joint European Torus (JET), Wendelstein 7-X stellarator
  - **USA:** Facility for Rare Isotope Beams
  - **CHINA:** HPR1000, Experimental Advanced Superconducting Tokamak (EAST)

- **60+ Countries**

Objective: Predict the activation of materials for accelerating the procedure of ITER neutronics studies without running codes

The activation data handbook using SuperMC

- Activation data: 90 natural elements (H-U), 17 widely used materials, neutron spectra at 6 typical locations (upper cryostat, rear of equatorial port, beneath lower port extension, cryostat basement, port cell, neutral beam cell)
- Activation properties: activity, dose, decay heat, ingestion dose, transmutation graph, main contribution to activity, photon spectrum
- Interface program for easy activation assessment

Activation results of 316L

Activity of typical materials in upper cryostat

Transition graph of Fe due to activation at the rear of equatorial port
3. Fusion Safety

(Magnetic D-T Tokamak)
Combination of International Efforts

- **IEA Framework**
  - Technology Collaboration Program (TCP) on a Co-operative Program on Environmental, Safety and Economic Aspects of Fusion Power (ESEFP)

- **ExCo Members**
  - China: Y. Wu, INEST
  - Europe: D. Maisonnier, EC
  - Japan: Y. Sakamoto, QST
  - Korea: K. Kim, NFRI
  - Russia: A. Kalashnikov, ROSATOM
  - USA: D. Clark, DOE

- **Subtasks**
  - Task 1 In-vessel Tritium Source Terms
  - Task 2 Transient Thermo-fluid Modeling and Validation Tests
  - Task 3 Activation Production Source Terms
  - Task 4 Safety System Study Methodology
  - Task 5 Failure Rate Database
  - Task 6 Radioactive Waste Study
  - Task 7 Socio-Economic Aspects of Fusion Power
  - Task 8 Magnet Safety
  - Task 9 Fusion Power Plant Studies
Exchange of latest progress in fusion safety

Discussion:
- Quantitative Safety Assessment of Fusion Power Plants
- Fusion Safety Issues and Impact on Design and R&D Needs (ISFNT-13 Plenary)

Agree to further enhance the international collaboration

May organize the 3rd workshop in 2019
Fusion Energy to be the Ideal Nuclear Energy Source (From Safety Perspective)

- **ORE:** as lower as possible
  - lower than that of current PWR;

- **Accident:** no damage to public
  - Elimination of off-site evacuation;

- **Radioactive waste:** no burden to future generations of people
  - Can be recycled after limited period;

- **Nuclear proliferation:** no potential to produce weapon material
  - Higher technical barrier for malicious utilization

It is necessary to review the safety of the D-T tokamak FPP based on current state of knowledge, and provide in-depth suggestions for fusion safety towards ideal nuclear energy source.

- Combination of International Energy Agency (IEA) Technology Collaboration Program (TCP) on Environmental, Safety, and Economic aspects of Fusion Power (ESEFP)

- Reviewed DEMO safety issues and safety approach, and the international DEMO safety R&D activities.

- Presented safety R&D gaps

Quantitative Safety Assessment of Fusion Power Plants

Aims to investigate:
1. what can we learn from the existing PWR safety demonstration?
2. what can we do to make fusion energy the ideal nuclear energy source?

PWR Model (AP1000)
- Core power/Unit size (GWe) 3.40 / 1.1
- Active fuel length 4.3 m
- Average linear power 5.71kW/ft
- Fuel / Clad UO₂/ZIRLO™

FPP Model (PPCS Basis)
- Fusion power/Unit size (GWe) 3.41 / 1.45
- Major / Minor radius (m) 7.5 / 2.5
- Structure / PFM Eurofer / tungsten
- Blanket Coolant PbLi/He/ Water
- Divertor Coolant He/ Water

The preliminary findings were reported in ISFNT-13 as a plenary. More detailed work is still on-going.
4. TBM and Related Technologies
The Role of INEST in CN ITER TBM Program

- Leading the R&D of CN DFLL TBM (Liquid Breeder)
- In Charge of CN HCCB TBM (Solid Breeder) on Structure Materials, Safety Technology, etc.

PD phase of CN HCCB TBM Program officially started at 2016
Development of China Low Activation Martensitic steel: CLAM candidate structural material for CN ITER TBM

- Nominal composition: 9Cr-1.5W-0.2V-0.15Ta-0.45Mn-0.1C
- 18-ton (3 ingots) smelting: good control of composition (2017)
- High-dose neutron irradiation experiments

Spallation neutron irradiation ~ 21dpa, Fission neutron irradiation ~3 dpa

2017, industry standardization in China and code qualification for RCC-MRx of CLAM steel have made steady progress, with breakthroughs such as the approval of Material Specification by ANB.
LiPb/He-Dual Coolant Fusion Blanket/Safety Test Loop: DRAGON-V

To support the design validation of DEMO blanket with the parameters covering the requirements of China ITER-TBM and CFETR.

- **Experimental functions**
  - MHD effect
  - Heat transfer
  - Material corrosion under strong magnetic field

- **Main design parameters**
  - Max. temperature: 1100°C
  - Max. flow rate of PbLi: 40kg/s
  - Helium pressure: 10.5MPa

In 2017, DRAGON-V was constructed and operated with the highest temperature of 500°C
Accident Evolution/Verification Testing Facility

- **Experimental functions**
  - Vapor explosion of lead-based alloys contacting with water
  - Steam bubble transportation monitoring
  - In-box LOCA
  - Heat-exchanger technique validation

- **Main parameters**
  - Temperature: 200~550°C
  - Max Pressure of the vessel: ~25MPa
  - Lead-based alloys inventory: ~3t
Summary

1. In the field of fusion research, INEST concentrates on the **Nuclear Technology and Safety**, as it is indeed the key to finally realize the fusion as the ultimate energy source.

2. In 2017, INEST has achieved many milestones on HINEG neutron source, **Neutronics Theory and SuperMC Software**, Fusion Safety, and TBM Program, etc.

3. INEST is always open to domestic & international Cooperation.
FUNFI-3
3rd International Conference on Fusion Neutron Sources and Subcritical Fission Systems
19-21 Nov. 2018, Hefei, China, hosted by INEST, CAS

- **FUNFI3:**
  - An outstanding exchange platform on most recent advancements in various aspects of fusion neutron sources and subcritical systems
  - FUNFI1: 2011, Varenna, Italy, ENEA
  - FUNFI2: 2016, Rome, Italy, ENEA

- **Conference Topics**
  - Development Strategies for Fusion Neutron Sources and Subcritical Systems
  - Fusion Systems
  - Subcritical Fission Systems
  - Level of Readiness of Technologies

- **Key Dates**
  - 15 Jun. 2018 Abstract Submission Deadline
  - 15 Sept. 2018 Online Registration Deadline
  - 29-31 Oct. 2018 Conference Convened

- **Chairman:** Yican Wu
- **Co-Chairman (preliminary):**
  - A. Pizzuto (IT)
  - W. Stacey (USA)
  - A. A. Ivanov (RUS)

- **International Advisory Committee**
  - A. Pizzuto, F. P. Orsitto, M. Lontano, M. Tardocchi, G. Gorini, A. Botrugno (IT)
  - A.A. Ivanov, A. Krasilnikov (RUS)
  - R. Goldston, W. Stacey (USA)
  - V. Moiseenko (UA)
  - O. Agren (SE)
  - M. Gryaznevich (UK)
  - H. Ait Abderrahim (BE)
  - Y.Wu, Z. Chen, M. Wang, J. Jiang (CN)

- **Contact Information:** Email: funfi3@fds.org.cn  Contact person: Y. Wang
SNINS

1st Symposium on Neutronics and Innovative Nuclear System (SNINS)

- An international symposium as an exchange platform on most recent advancements in the neutronics and innovative nuclear systems
- **25-27 April 2018, Hefei, Anhui, China**, hosted by INEST, CAS

**Conference Topics**
- Neutron and photon radiation protection and shielding
- Radiation source such as tritium
- Radiation experiments and measurement technology
- Radiation in environment
- Strategy and innovative concepts

**Key Dates**
- **1 March 2018** Abstract Submission Deadline
- **15 March 2018** Online Registration Deadline
- **25-27 April 2018** Conference Convened

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Thanks for Your Attention!

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