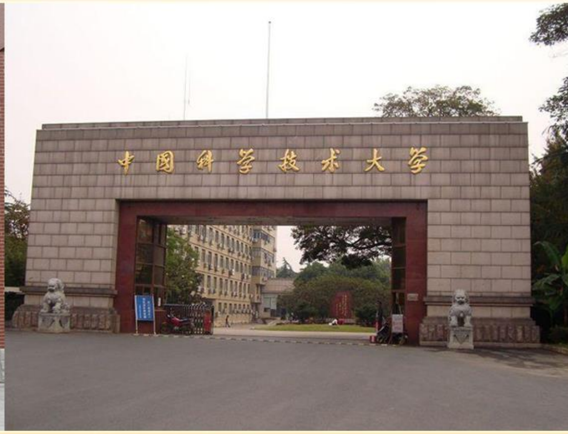
Institute of Nuclear Energy Safety Technology, CAS

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）
www.fds.org.cn

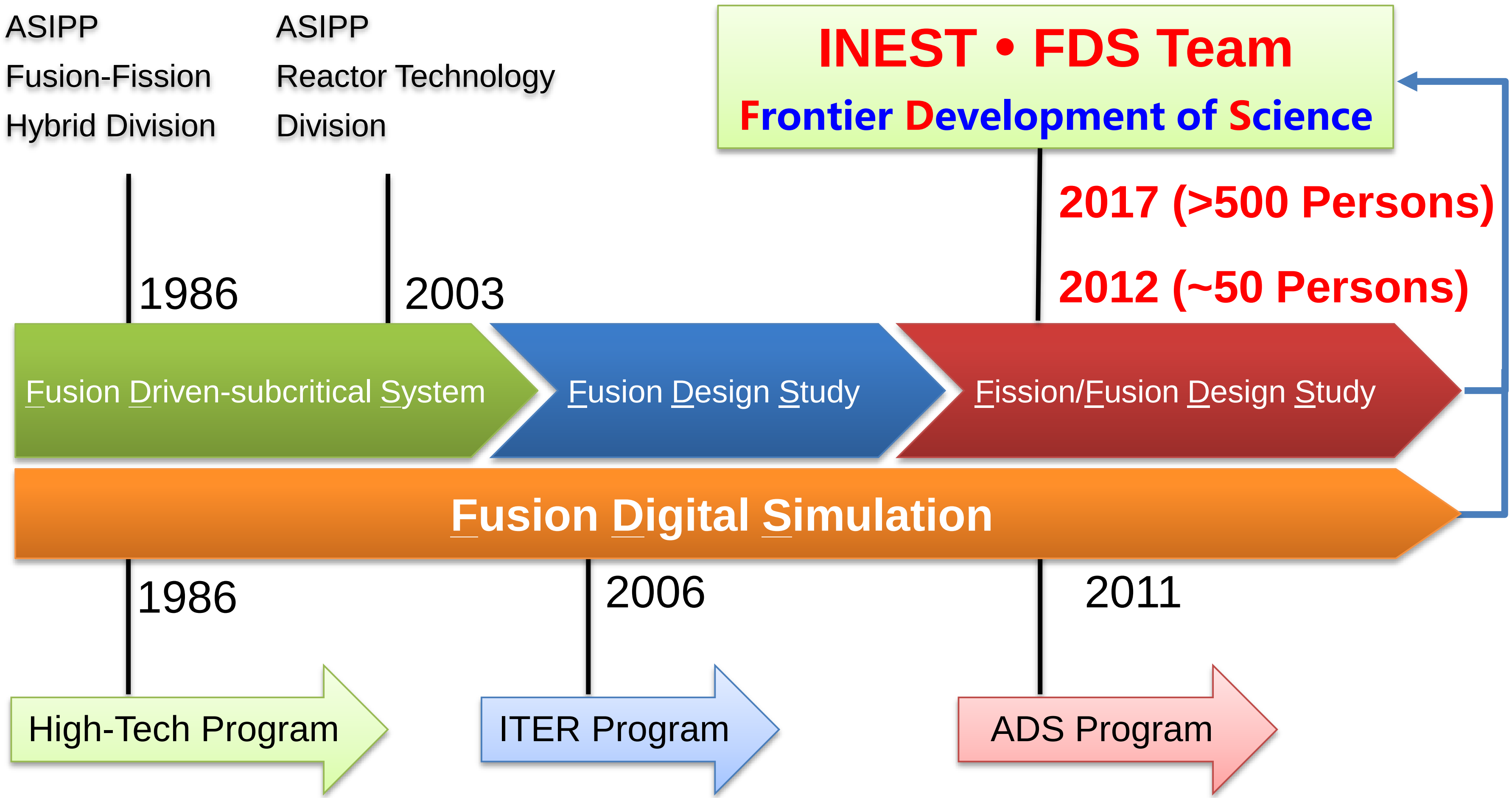
Outline

I. Brief Introduction to INEST

II. Highlights of Fusion R&D Activities

III. Summary

History of INEST • FDS Team



*ASIPP: Institute of Plasma Physics, CAS

Personnel

- **Employees：**
  - Staff： ~400
  - Guest scientists: ~50
- **Students:**
  - Postgraduates： ~100

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

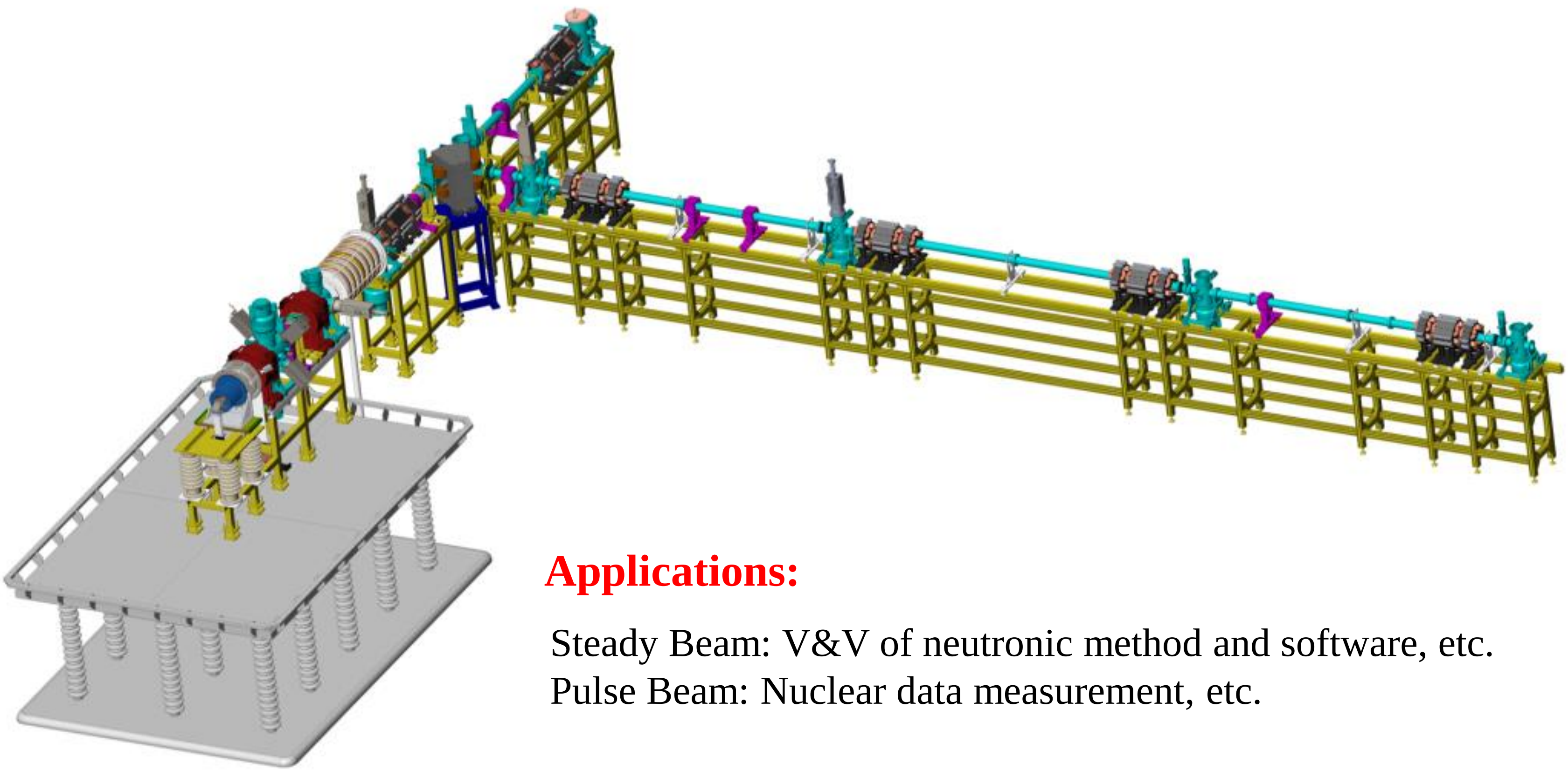
II. Highlights of Fusion R&D Activities

- 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

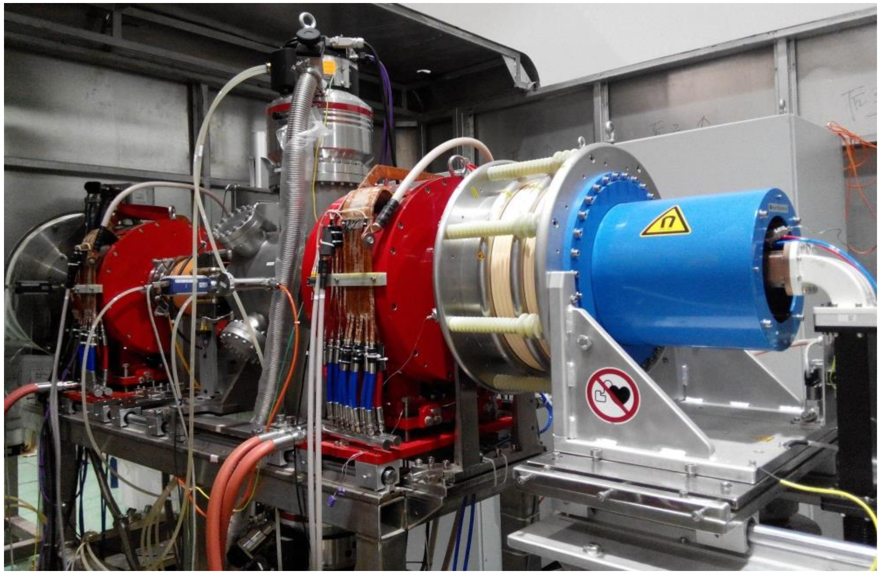


Applications:

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

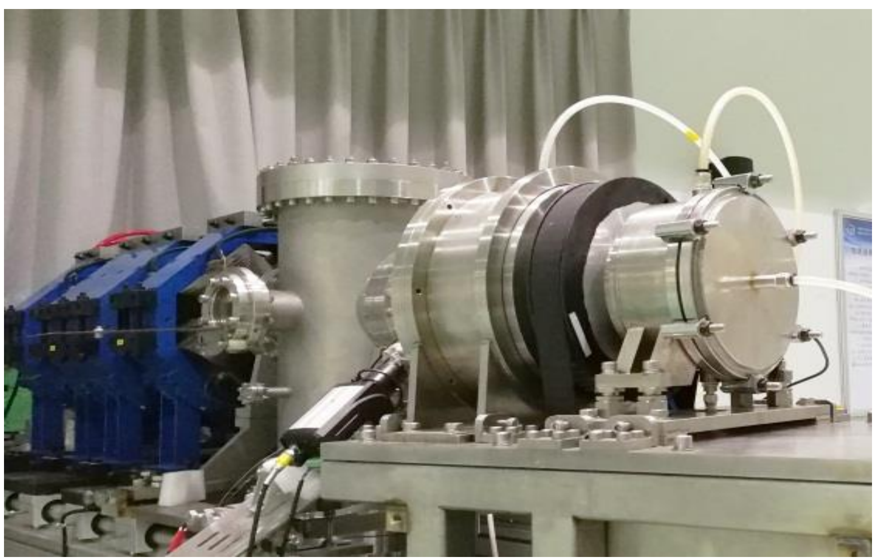
Fusion neutrons with yield up to 6.4×10^{12}n/s have been generated

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

HINEG-I

Fusion Neutron Source

CLEAR-0

Lead-based Subcritical/critical Zero Power Reactor

CLEAR-A0

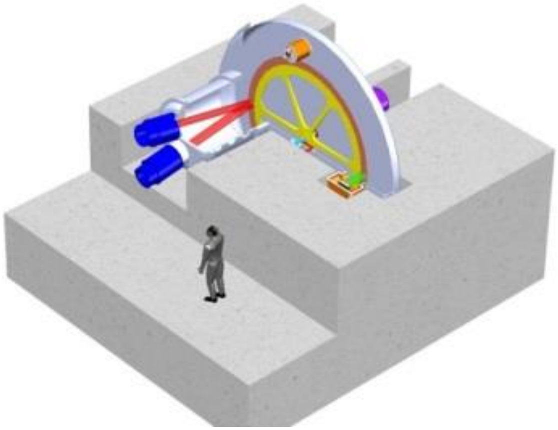
Hybrid Neutronics Testing Facility

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**



Conceptual Design Option

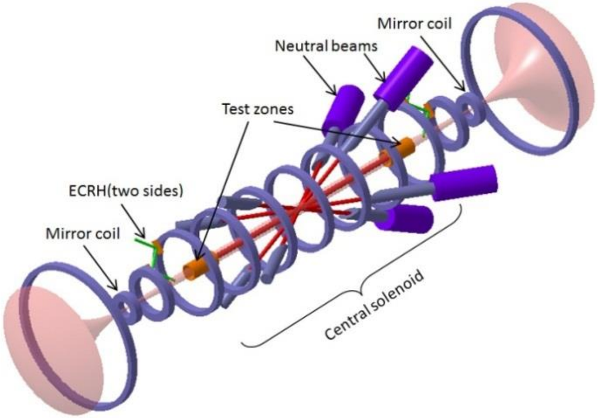
- **Objectives**
  - Materials Irradiation
  - Neutronics Performance Test

R&D for key components of HINEG-II is on-going

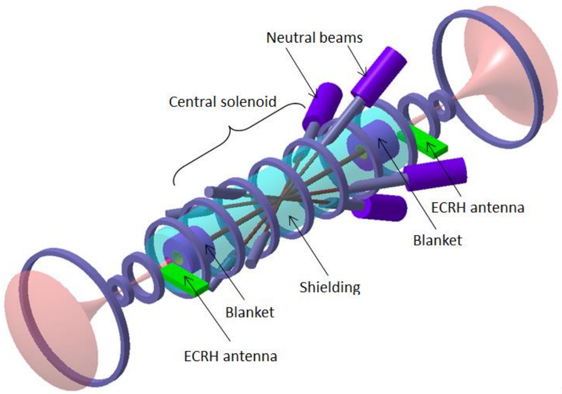
HINEG-III
Conceptual Design Based on Gas Dynamic Trap

Two Options:

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



GDT-VFNS

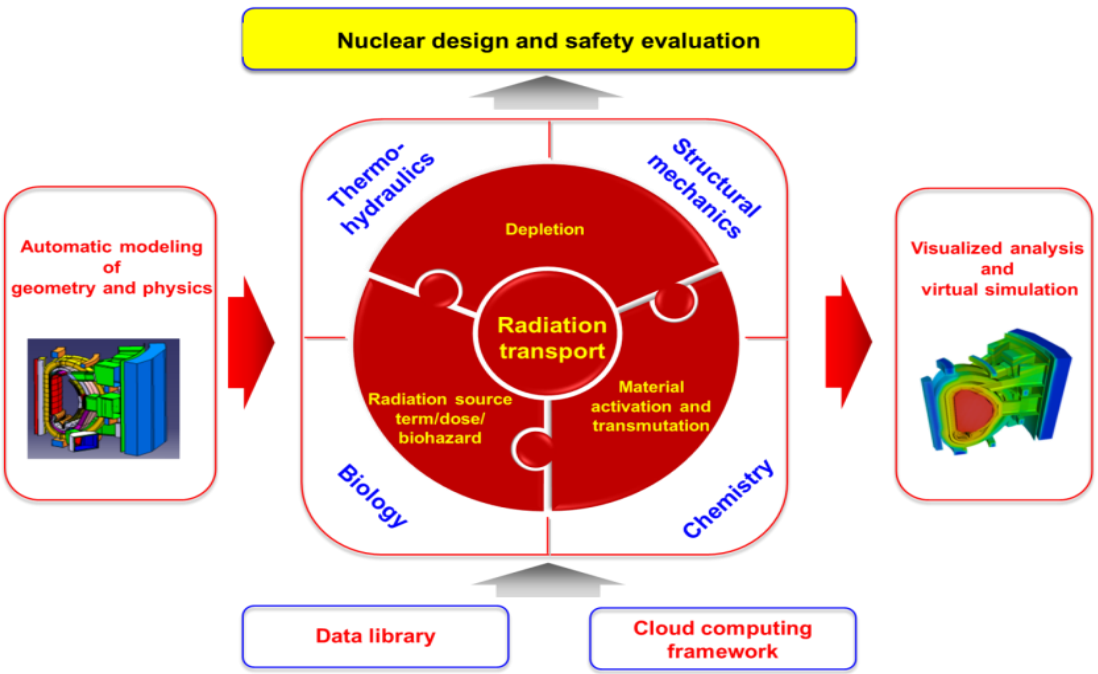


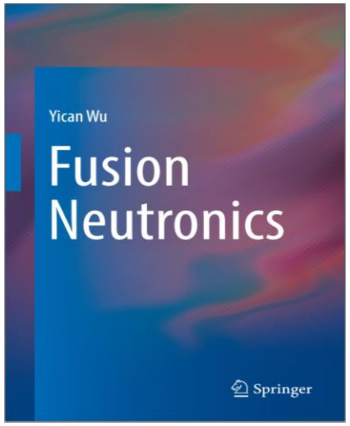
GDT-Hybrid

- **IAEA Coordinated Research Project F1.30.15**

2. Neutronics Methodology and Simulation

Super Multi-functional Calculation Program for Nuclear and Radiation Simulation: SuperMC





published by Springer 2017

- **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)

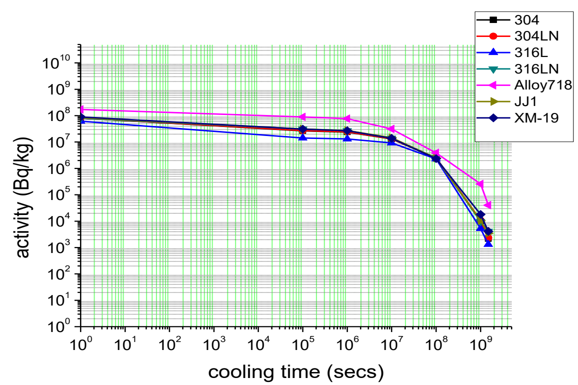
■ 60+ Countries

■ Indexed by OECD/NEA: www.oecd-nea.org/tools/abstract/detail/iaea1437

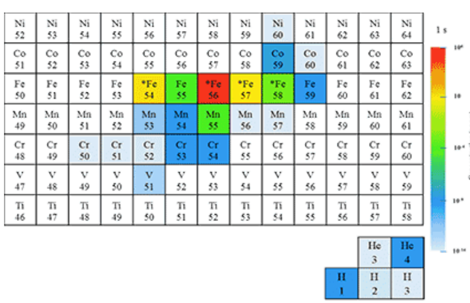
Production of Activation Data Handbook for ITER

- **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）

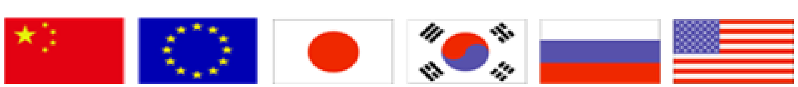
Combination of International Efforts

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

2nd International Workshop on ESEFP (23rd Sept. 2017, Kyoto, Japan)

- 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;

Operational & Maintenance

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

Accidental

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

Decommissioning

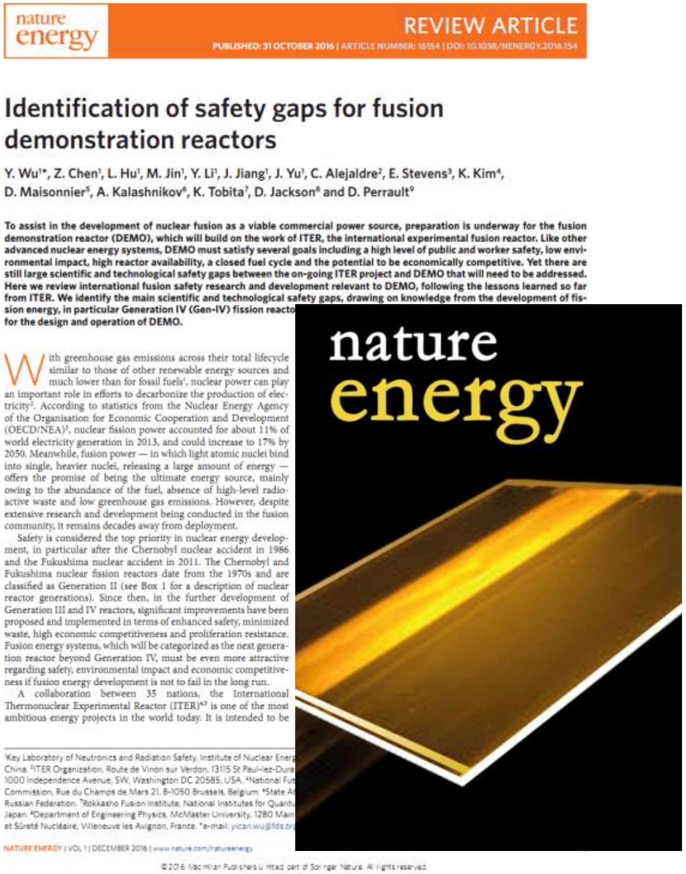
- **Nuclear proliferation: no potential to produce weapon material**
  - Higher technical barrier for malicious utilization

Non-proliferation

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

Identification of Safety Gaps for Magnetic Fusion DEMO Reactors (2015~2017)

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


nature energy | REVIEW ARTICLE

Identification of safety gaps for fusion demonstration reactors

Y. Wu[1*], Z. Chen[1], L. Hu[1], M. Jin[1], Y. Li[1], J. Jiang[1], J. Yu[1], C. Alejaldre[2], E. Stevens[3], K. Kim[4], D. Maisonnier[5], A. Kalashnikov[6], K. Tobita[7], D. Jackson[8] and D. Perrault[9]

To assist in the development of nuclear fusion as a viable commercial power source, preparation is underway for the fusion demonstration reactor (DEMO), which will build on the work of ITER, the international experimental fusion reactor. Like other advanced nuclear energy systems, DEMO must satisfy several goals including a high level of public and worker safety, low environmental impact, high reactor availability, a closed fuel cycle and the potential to be economically competitive. Yet there are still large scientific and technological safety gaps between the on-going ITER project and DEMO that will need to be addressed. Here we review international fusion safety research and development relevant to DEMO, following the lessons learned so far from ITER. We identify the main scientific and technological safety gaps, drawing on knowledge from the development of fission energy, in particular Generation IV (Gen-IV) fission reacto... for the design and operation of DEMO.

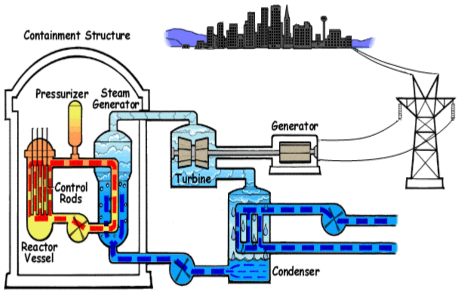
- Reviewed DEMO safety issues and safety approach, and the international DEMO safety R&D activities.
- Presented safety R&D gaps

Y. Wu, Z. Chen, L. Hu, M. Jin, Y. Li, J. Jiang, J. Yu, C. Alejaldre, E. Stevens, K. Kim, D. Maisonnier, A. Kalashnikov, K. Tobita, D. Jackson & D. Perrault. Identification of safety gaps for fusion demonstration reactors. *Nature Energy* 1, 16154, doi:10.138/nenergy.2016.154 (2016).

Quantitative Safety Assessment of Fusion Power Plants

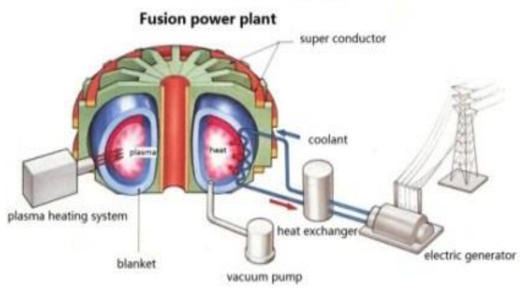
Aims to investigate:

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 UO_2/ZIRLO^{TM}



FPP Model (PPCS Basis)

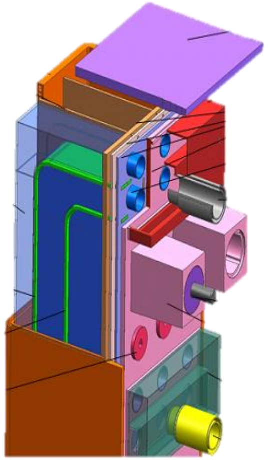
- Fusion power / Unit size (GWe) 3.41 / 1.45
- Major / Minor radius (m) 7.5 / 2.5
- Structure / PFM Eurofer / tungsten
- Blanket Coolant PbLi/ He/ Water
- Divertor Coolant He/ Water

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.



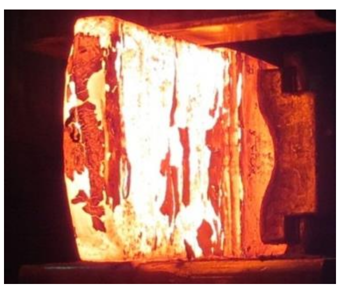
PD phase of CN HCCB TBM Program officially started at 2016

Development of China Low Activation Martensitic steel: CLAM

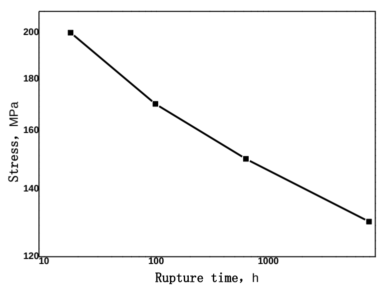
candidate structural material for CN ITER TBM

- **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**

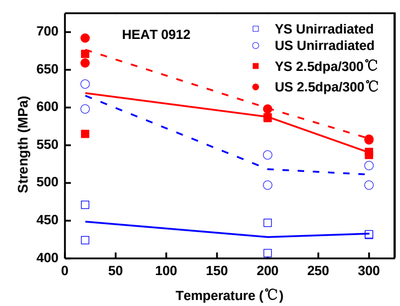
Spallation neutron irradiation~ 21dpa, Fission neutron irradiation ~3 dpa



Forging ingot



Creep test ~10,000 hrs



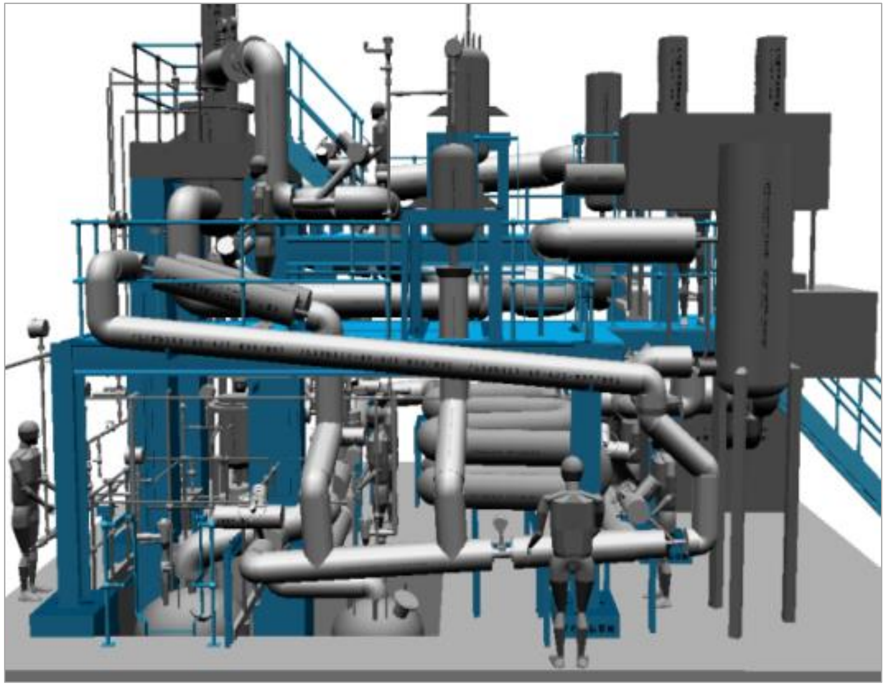
Neturon Irradiation

Nuclear Reactor Material Database (NRMD)

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℃
- 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℃

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℃
- 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

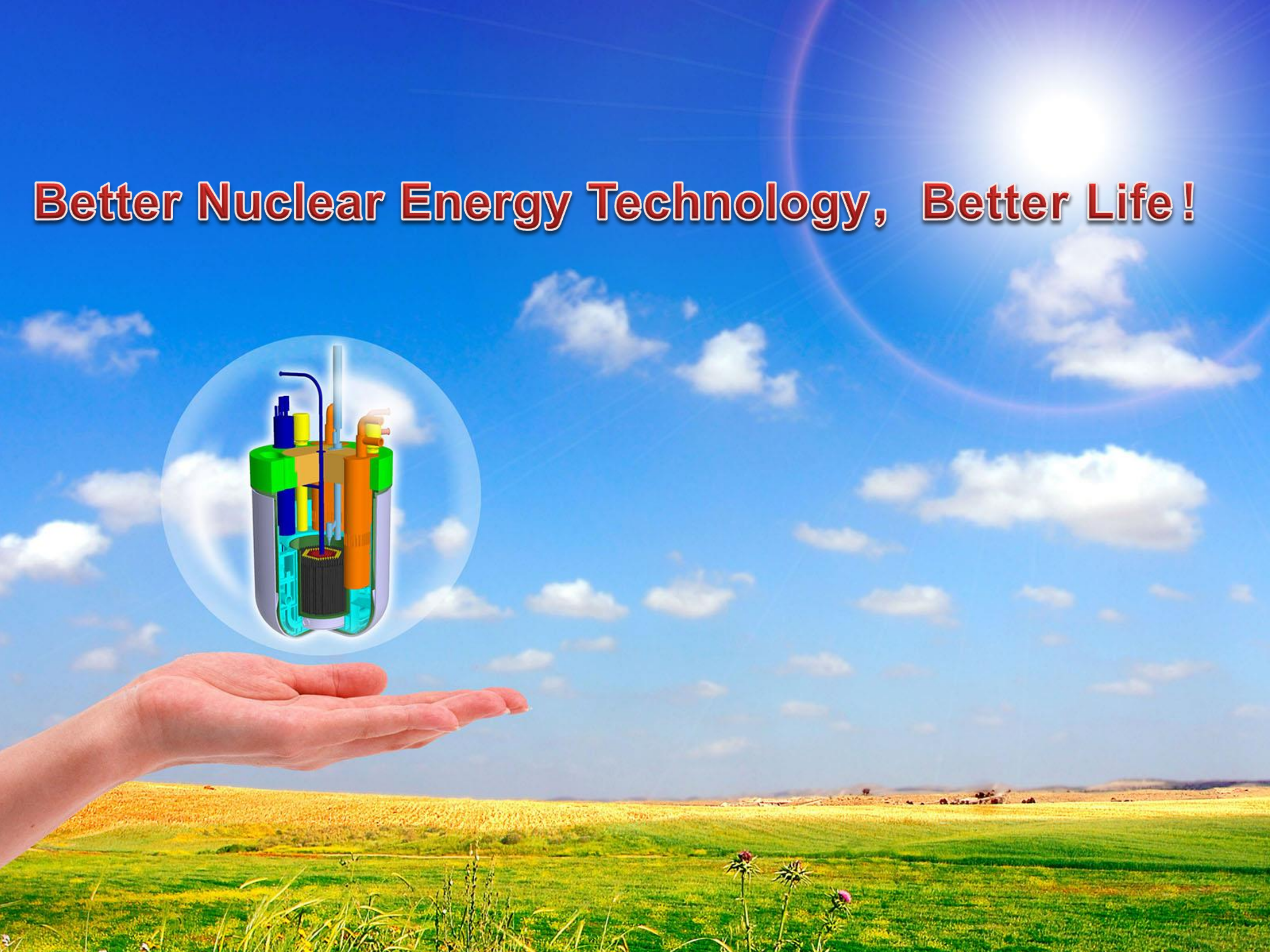
- A. Pizzuto, F. P. Orsitto, M. Lontano, M. Tardocchi, G. Gorini, A. Botrugno (IT)
- A.A. Ivanov, A. Krasilnikov (RUS)
- R. Goldston, W. Stacey （USA）
- V. Moiseenko (UA)
- O. Agren (SE)
- M. Gryaznevich (UK)
- H. Ait Abderrahim (BE)
- Y.Wu, Z. Chen, M. Wang, J. Jiang (CN)

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
- **Contact Information**
  - **Email:** fusionrp@fds.org.cn
  - **Tel:** +86-551-65593681
  - **Fax:** +86-551-65593681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Thanks for Your Attention！

Website: www.fds.org.cn

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