Collaboration in Fusion Codes & Standards: Practices from SWIP and a Call for Global Partnership

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Southwestern Institute of Physics (SWIP), China Fusion Energy Company

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Brief introduction of SWIP/CFEC

核工业西南物理研究院 Southwestern Institute of Physics 中核集团 CNNC

CFEC: Reactors engineering，system integration.

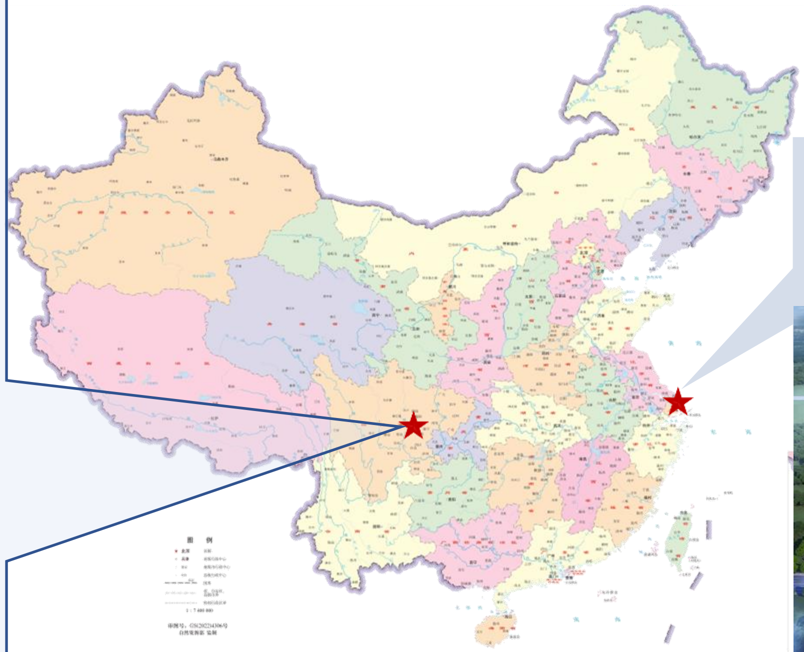
SWIP: Source of original technologies

Shanghai & Chengdu: Accelerating Development.

Shuangliu, Chengdu

(HL-3)

Tianfu, Chengdu



Minhang, Shanghai

Brief introduction of SWIP

Southwestern Institute of Physics (SWIP) —— since 1965

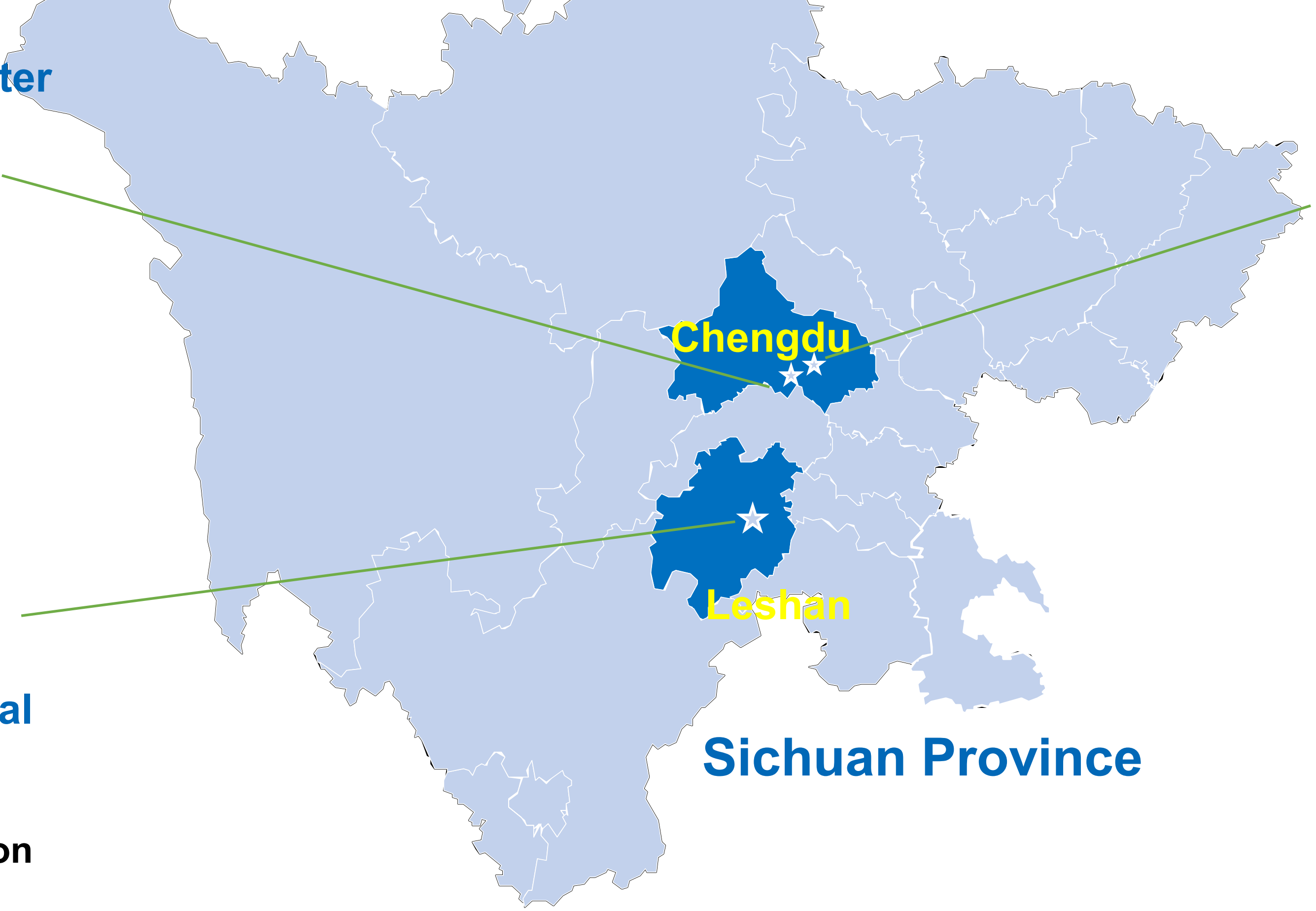
Earliest institute for fusion energy research in China

Plasma Application Center

Spin-off technologies application

Engineering & Technical College

Education and technology industrialization



Sichuan Province

Center for fusion tech.

Tianfu District

Center for Fusion Science (CFS)

Shuangliu District

Center for fusion technologies

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Fusion Technology R&D Center

~ 30 km from CFS (HL-3 tokamak)

Comprehensive nuclear fusion research base in coming years, includes **Five parts**:

- Integrated design of fusion reactor
- R&D of machine components of fusion reactor
- R&D of auxiliary systems of fusion reactor
- Fusion plasma research
- Fusion technology innovation zone

Fusion devices developed by SWIP

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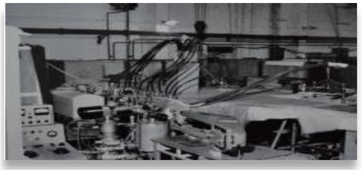
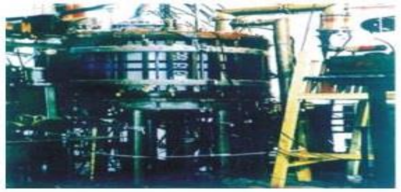
> 20 fusion devices of various magnetic configurations since 1969

θ-pinch, stellarator, magnetic mirror, tokamaks, etc.





1969

Θ pinch-3
1969

LingYun stellarator
1971

- Θ pinch-4
- MM-2

1972

MM-1 magnetic mirror
1975

PT tokamak
1977

- MM-3
- RF
- WeiHuan-1 tokamak

1978

1979

- CF-1
- MM-5
- FY-1 tokamak
- 1981

MM-4
1982

- CF-2
- HL-1 tokamak

1984

WeiHuan-2
1985

MM-4U
1987

1989

MM-2U
1989

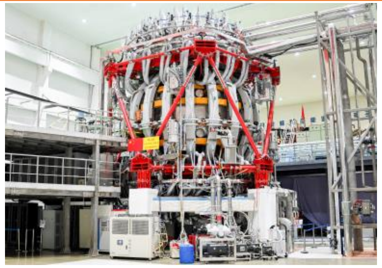
RFP
1990

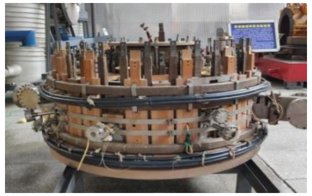
HL-1M
1994

1999

HL-2A
2002

HL-2M
2020





Tokamaks developed by SWIP

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Size

Parameters

$n\,T_i\,\tau_E$

HL-1 (1984)

Radius 1.02 / 0.20 m

First mega-science project of magnetic fusion in China

HL-1M (1994)

Radius 1.02 / 0.24 m

Plasma current >300 kA
Plasma fueling by SMBI proposed for the first time

HL-2A (2002)

Plasma current 0.45 MA
Radius 1.65 / 0.4 m

First diverted tokamak in China.
Important milestones achieved in fusion field

HL-3 (2020)

Plasma current 2.5 (3) MA
Radius 1.78 / 0.65 m

Largest tokamak in China with highest parameter and advanced divertor

Perspectives from SWIP

- **Internationally harmonized Codes and Standards are indispensable for achieving safe, reliable, and commercially viable fusion energy.**

01

Ensuring Safety & Licensing

Establish the technical basis for safety demonstration, regulatory approval, and public confidence.

02

Guaranteeing Reliability & Investment

Define requirements for component and system reliability, de-risking technology development and attracting investment.

03

Enabling a Global Supply Chain

Facilitate technical interoperability, quality assurance, and mutual acceptance of components across borders.

04

Accelerating Commercialization

Provide a predictable and consistent framework to reduce project risks and streamline the path to deployment.

- **To enable the timely and widespread commercial deployment of fusion energy.**

A Key Driver in China's Fusion Energy Program

- **SWIP is positioned at the heart of a comprehensive national network, uniquely integrating R&D, commercialization, and industrial supply chains for effective standards development.**

Governmental engagement

Backed by our state-owned parent company, China National Nuclear Corporation (CNNC), which possesses a proven track record in nuclear code development and strong governmental engagement.

Driving Commercialization

Works in synergy with CFEC, the entity dedicated to advancing fusion energy commercialization, ensuring our R&D and standards work are market-relevant.

Leading in R&D

As the core research institute, we provide the foundational science and engineering expertise, operating major facilities like HL-2/3 and design of DEMO

Leveraging a Broader Network

Collaborates with a network of subordinate industrial companies and academic partners, connecting fundamental research with manufacturing and education.

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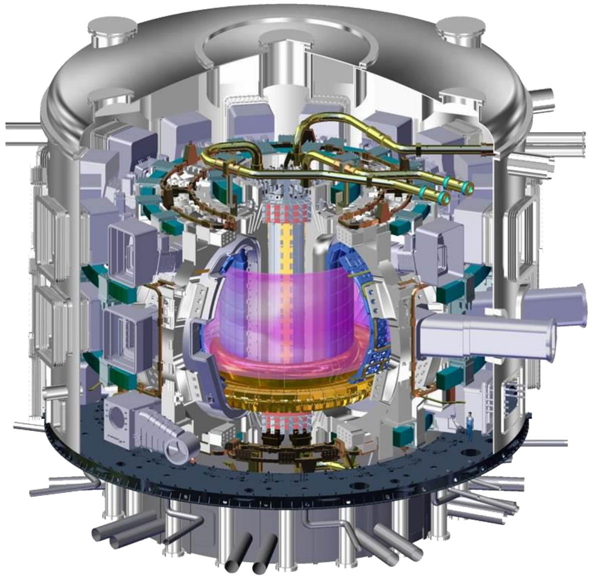
SWIP's Proactive Role in Standardization

- **SWIP is a leading contributor, actively shaping the national fusion standard system and translating cutting-edge project experience into concrete standards.**



Substantial Contribution to Standard Development

- ✓ 53 specialized fusion standards by end of 2024
- ✓ Leading author for 40 standards; co-author for 13

Standards Forged in Real Projects

- ✓ Incubated from major programs:
  - ITER Procurement Packages (Magnet Supports, First Wall, TBM)
  - HL-3 engineering R&D
- ✓ Covering key areas: engineering manufacturing, testing, diagnostics, nuclear safety

Enabling Industrial Application & Certification

- ✓ Direct application in product engineering certification (e.g., neutron multiplier beryllium pebbles)
- ✓ Supporting material procurement for ITER

Domestic Foundation: Building a Coherent Standard System

- **Building a comprehensive national framework to create foundational processes and expertise for global collaboration.**

Systematic Framework Development

Organizing standards into key technological domains
Creating a structured and coherent national system

Institutional Expertise Cultivation

Skilled team developed through high-volume standard development
Proven proficiency in the entire standards lifecycle

Practical Process Insights

Deep understanding of technical consensus-building challenges Experience in defining robust, universally applicable requirements

Breakthrough: 1st Published ISO Fusion Standard

SWIP successfully led the development and publication of the first-ever ISO standard dedicated to fusion, demonstrating the viability of international collaboration.

A Pioneering Milestone for Fusion: ISO 4233:2023: "Reactor technology — Nuclear fusion reactor — Hot helium leak testing method for high temperature pressure-bearing components in nuclear fusion reactors"

INTERNATIONAL STANDARD

ISO 4233

First edition
2023-03

Reactor technology — Nuclear fusion reactors — Hot helium leak testing method for high temperature pressure-bearing components in nuclear fusion reactors

Technologie du réacteur — Réacteurs à fusion nucléaire — Méthode de contrôle d'étanchéité par détection de fuite d'hélium à chaud pour les composants sous pression à haute température de réacteurs à fusion nucléaire

Ongoing Efforts: New Standard Drafts in the ISO Pipeline

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- **Building on the first success, we are actively promoting new international standards, navigating the complexities of the process.**

Reference	Title	Current stage	Committee	Action
ISO/PWI 19327 ed.1- id.85788	Reactor technology — Fusion reactors — design and assessment of remote maintenance system for divertor of magnetic confinement fusion reactor	**00.60** Since 2023-01-17	ISO/TC 85/SC 6/WG 2	
ISO/PWI 19326 ed.1- id.85787	Reactor technology — Fusion reactors — Design and assessment for remotely-handled components of magnetic confinement fusion reactor	**00.60** Since 2023-01-17	ISO/TC 85/SC 6/WG 2	
ISO/PWI 19243 ed.1- id.85740	Structural design criteria for in-vessel components of magnetic confinement fusion reactor via elastic analysis method	**00.60** Since 2023-01-17	ISO/TC 85/SC 6/WG 2	
ISO/AWI 23010 ed.1- id.87348	Reactor Technology — Technical specifications for Fission Research Reactor — Waste and Decommissioning	**20.00** Since 2024-07-30	ISO/TC 85/SC 6/WG 2	
ISO/AWI 22996 ed.1- id.87347	Reactor Technology — Fission Research Reactor — Design and Operation	**20.00** Since 2024-07-30	ISO/TC 85/SC 6/WG 2	
ISO/CD 19696 ed.1- id.85970	Fusion technology — Magnetic confinement fusion — Test methods for low temperature mechanical properties of electrical insulation materials of superconducting devices	**30.60** Since 2025-10-25	ISO/TC 85/SC 6/WG 2	
ISO/PWI 26208 ed.1- id.92830	Fusion technology — Magnetic confinement fusion — Requirement for performance tests of superconducting magnet	**00.00** Since 2025-09-22	ISO/TC 85/SC 6/WG 2	
ISO/DIS 19991 ed.1- id.86045	Fusion technology — Experimental magnetic confinement fusion facilities — Supersonic molecular beam injection fueling technique for fusion devices	**40.20** Since 2025-09-30	ISO/TC 85/SC 6/WG 2	
ISO 4233:2023 ed.1- id.79826	Reactor technology — Nuclear fusion reactors — Hot helium leak testing method for high temperature pressure-bearing components in nuclear fusion reactors	**60.60** Since 2023-03-06 Next SR : 2028-01-15	ISO/TC 85/SC 6/WG 2	

SC6:
Reactor Technology
(7/9 fusion)

Fueling
Magnets
Tritium breeding
Remote handling

Collaboration: Achieving Sino-French Standard Reciprocity

■ **SWIP is pioneering bilateral standard alignment**

- **Active in RCC-MRx China User Group:** Facilitated by ITER China, engaging directly with French AFCEN association for code alignment.
- Concrete Achievement: Standard Integration: 3 Chinese fusion standards incorporated into the RCC-MRx 2022 edition as referenced RPP norms.
- Driving Global Technical Dialogue: Active participation in AFCEN international congresses and user group meetings; Sharing application results and promoting technical exchange.

7th AFCEN International Conference

8th AFCEN International Conference

Key technologies area

- **Following a phased roadmap, we are advancing standards in key technologies to drive fusion innovation and accelerate the development of a comprehensive fusion standards system**

聚变/Fusion

- 聚变堆主机与运行 Fusion reactor device and operation
  - 聚变堆总体设计 Overall design of fusion reactor
  - 燃烧等离子体物理 Combustion plasma physics
  - 聚变堆运行与控制 Fusion reactor operation and control
  - 主机工程技术 Device engineering technology
- 燃料生产与循环 Fuel Production and Circulation
  - 包层技术 Blanket technology
  - 氚循环 Cycling of tritium
- 核安全体系 Nuclear safety system
  - 核安全要求与许可 Nuclear safety requirements and permits
  - 核安全评估与管理 Nuclear safety assessment and management
- 数字托卡马克 Digital tokamak
  - 大数据 Big data
  - 数字孪生 Digital twin
  - 数字堆设计专用软件 Specialized software for digital reactor design

Key Challenges in International Joint Development

- **Our collaborative projects reveal common, surmountable challenges that require structured approaches to overcome.**

01 Reconciling Diverse Technical Viewpoints

Diverging opinions rooted in national research priorities and technology pathways (e.g., blanket concepts, material choices).

02 Managing Multi-stakeholder Consensus

Balancing varying requirements from research institutions, industry vendors, and future regulators.

03 Navigating Process & Communication Efficiency

Complex ISO procedures with lengthy review cycles. Significant overhead in cross-time-zone and cross-language communication.

Lessons Learned & The Imperative for a Global Platform

Our experience confirms that a long-term, stable, and inclusive platform is the critical enabler to systematically address collaboration challenges and accelerate C&S development.

- **Validated Success Factors:**

01 **Early Engagement & Trust Building**

02 **Dedicated Project Leadership**

03 **Precise Scope Definition**

04 **Efficient Digital Collaboration**

- **The Identified Gap & Solution:**
  - ✓ Ad-hoc groups lack the stability for long-term planning.
  - ✓ A dedicated global platform is needed to institutionalize these success factors.
- **How a Platform Accelerates C&S:**
  - ✓ Provides a standing forum for continuous dialogue, pre-normative research, and early consensus.
  - ✓ Builds persistent communities of practice around key technical areas.
  - ✓ Reduces transaction costs by establishing common workflows and trusted networks.

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Global Landscape: Current Efforts & The Critical Gap

➢ **Efforts scattered across different bodies (e.g., ISO, ASME, IAEA, ITER).**

ASME: **ASME Section III Division 4** Fusion Energy Devices Code	IAEA: Tech. doc on fusion safety and regulation; safety report	ITER: ITER-fusion standards; decades of experience and expertise

➢ **Fusion standardization housed under a fission-oriented committee (ISO/TC85/SC6)**

➢ **Identified Systemic Limitations:**

✓ **Temporary & Ad-hoc Working Groups:** Lack long-term stability and a strategic roadmap.

✓ **Suboptimal Structure:** Fusion-specific needs are not prioritized within fission-dominated frameworks.

✓ **Lack of a Central Coordinating Platform:** Leads to duplication and gaps.

✓ **Limited & Inaccessible Expert Roster:** Working groups rely on ad-hoc nominations, leaving many fusion experts from national programs without a clear path to contribute.

Key Gaps & Priority Action Areas

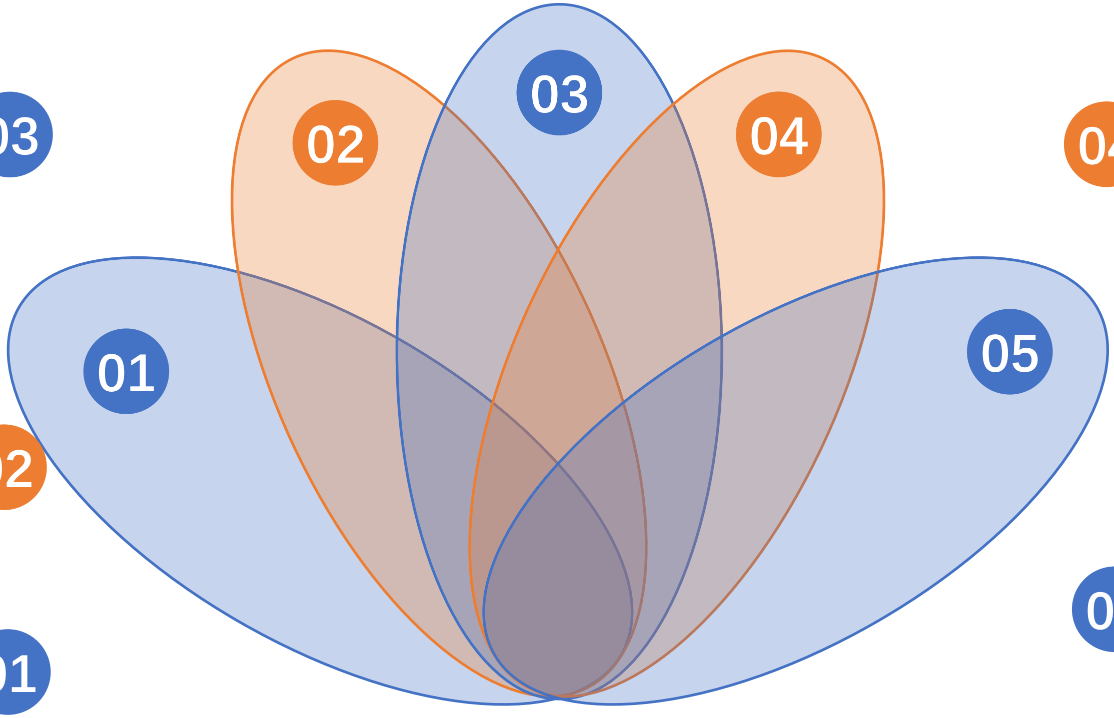
- We must collectively identify and prioritize standards in domains critical to licensing, investment, and global supply chains.

•Proposed High-Priority Domains for Collaboration:

03 Qualification of Fusion-Specific Materials

02 Safety Classification & Safety Case Framework

01 Terminology



04 Tritium fueling, breeding and recycling Systems

05 Remote Maintenance & Decommissioning

The Need for a Global Collaborative Framework

- **We propose initiating a discussion on establishing a more robust and inclusive global framework, potentially under IAEA auspices, to urgently address fusion C&S needs.**

  - **The Identified Need:** Current efforts are valuable but insufficient for the scale of the commercialization challenge.
  - **A Proposed Path Forward:** Explore the creation of a dedicated, standing global collaborative framework for fusion C&S.
  - **Core Objectives of Such a Framework**: Provide long-term stability and strategic direction.
  - Ensure **broader inclusion** of global fusion expertise.
  - **Coordinate efforts** to systematically close priority gaps.

Proposed Directions for a Collaborative Framework

- **Based on our experience, we suggest the international community consider several key features for an effective partnership.**

Suggested Guiding Principles:

✓ Strategic Oversight: A governance body with high-level representation to set priorities.

✓ Technical Execution: Thematic working groups open to global experts, focused on key domains (e.g., Safety, Materials).

✓ Knowledge Sharing: A centralized platform for sharing drafts, research, and best practices.

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Summary

- **Building a common framework for fusion energy is a shared challenge that demands a collective response.**

- **Shared Learning:** Our experience at SWIP underscores both the necessity and the complexities of international C&S development.
- **Collective Imperative:** The current fragmented landscape calls for a more structured and inclusive approach to collaboration.
- **Unified Goal:** Accelerating fusion commercialization through robust, globally accepted standards.
- **A Call for Collective Action:** Let us advance this discussion within the international community to pave the way for a coordinated global effort.