Radiation Protection and Safety Consideration for CFETR

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Contents

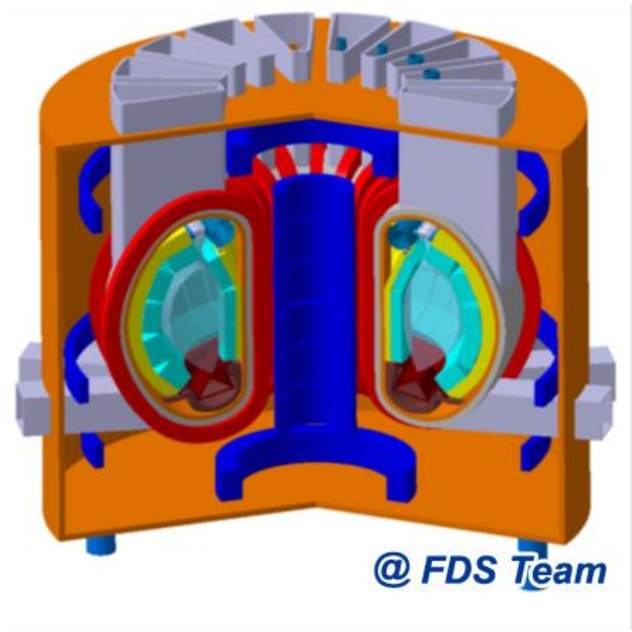
I. Safety Analysis

- **Blanket Concept**
- **Safety Analysis**

CFETR: Options for Liquid Blanket

Multi-Types-of-Blankets

Multi-Testing-Phases



- Option I : Liquid PbLi-based blanket for tritium breeding and energy production
  --- SLL/DLL/DFLL

- Option II : Uranium-loaded hybrid blanket for energy production

- Option III : Spent fuel-loaded hybrid blanket for energy production and waste transmutation

Safety Analyses

- Static analyses
- Dynamic analyses
  - Kinetics parameters
  - Accident analysis
    - Plant states and Selection of reference transients
    - Startup of Reactor
    - Unprotected Plasma OverPower (UPOP)
    - Unprotected Loss of Flow Accident (ULOFA)
    - Unprotected Loss of Coolant Accident (ULOCA)
    - Collapse Accident

Plant States and Selection of Reference Transients

- **Operational states**
  - **Normal operation**
    - **Startup/Shutdown of the Reactor**
  - **Anticipated operational occurrences (AOOs)**
    - **Protected Plasma OverPower (PPOP)**
    - **Unprotected /protected Transient OverPower (UTOP)**
- **Accident conditions**
  - **Within design basis accident (DBA)**
    - **Unprotected Plasma OverPower (UPOP)**
    - **Protected Loss of Flow Accident (LOFA)**
    - **Protected Loss of Coolant Accident (LOCA)**
    - **Protected Loss Of Heat Sink (LOHS)**
  - **Severe accidents**
    - **Unprotected Loss of Flow Accident (ULOFA)**
    - **Unprotected Loss of Coolant Accident (ULOCA)**
    - **Collapse Accident (CA)**

II. Radiation Protection

- **Object and Principle**
- **Research Contents**
- **Codes and Data Libraries**

Object and Principle

Object:

1. To ensure the device safe operation (component and personnel safety)
2. Evaluation of radioactive waste

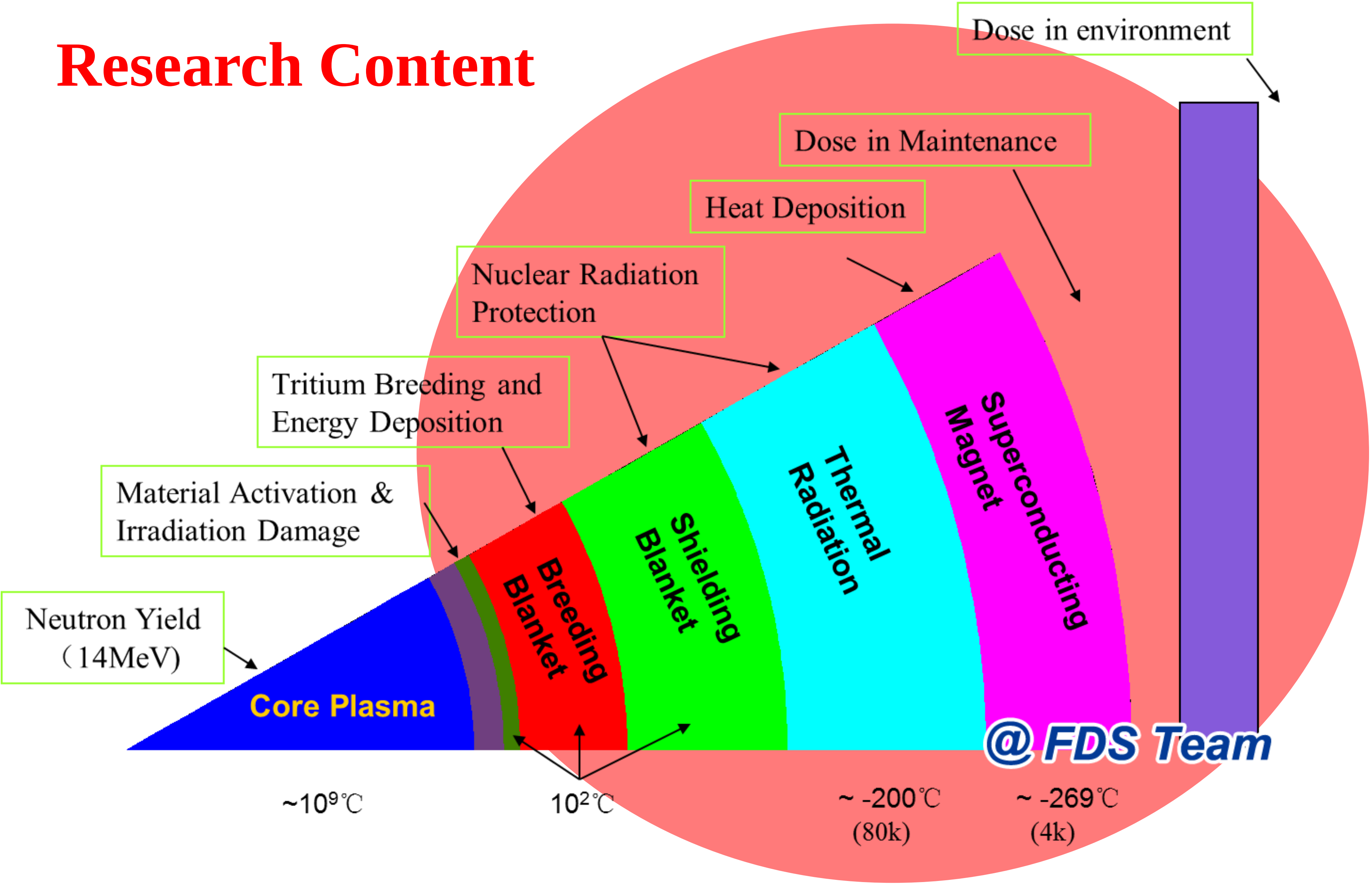
Principle: ALARA (As Low As Reasonable Achievable)

Radioactive division

Zone		Radiological Zone Identification	Total dose - external and internal exposure (1)	External exposure to hands, forearms, ankles and feet (2)
Unregulated zone		White zone	Effective dose < **80 μSv/month**	
Supervised zone		Blue zone	Effective dose per hour < **7.5 μSv**	< 0.2 mSv/h
Controlled zone	-	Green zone	Effective dose per hour < **25 μSv**	< 0.65 mSv/h
	Specially regulated	Yellow zone	Effective dose per hour < **2 mSv** and Dose equivalent rate < 2 mSv/h	< 50 mSv/h
		Orange zone	Effective dose per hour < **100 mSv** and Dose equivalent rate 100 mSv/h	< 2.5 Sv/h
	Forbidden	Red zone	Effective dose per hour **> 100 mSv** or Dose equivalent rate > 100 mSv/h	> 2.5 Sv/h

(1) Total dose rate is the sum of external dose rate and internal dose rate.
(2) In case of exposure of the eye lens (crystalline), these values should be multiplied by 0.3.

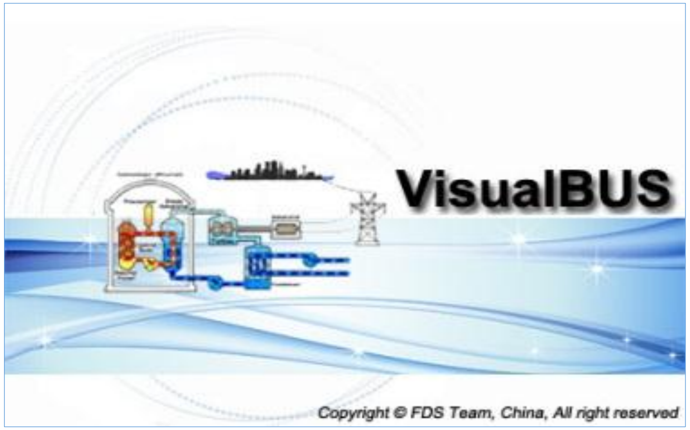
Research Content



Codes， Data Libraries and Design Validation

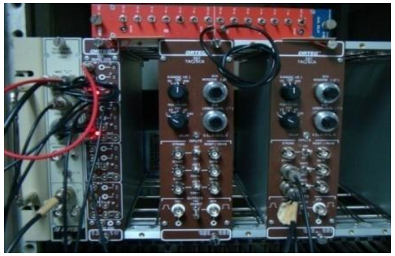
Calculation and Analysis：

- Radiation Transport
- Material Activation & Irradiation Damage
- Radiation Dose



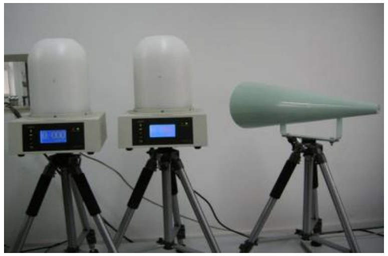
Measurement：

D-T neutron generator

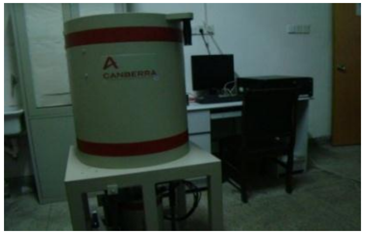


Time of flight (TOF)

Bonner sphere spectrometer



He-3 neutron intensity monitor



HpGe spectrometer

NaI photon spectrometer

Tritium monitor

Portable neutron detector

VisualBUS
CAD-based Multi-Functional 4D Neutronics Simulation System

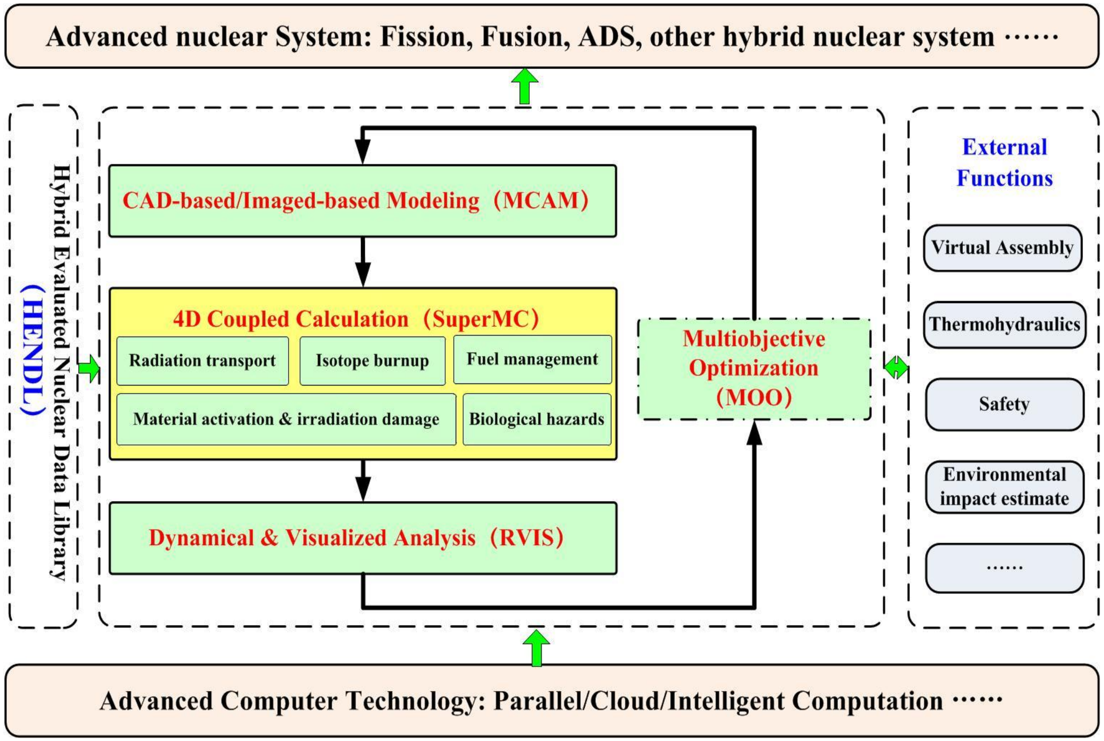
Main Functions:

CAD-based/Imaged-based Modeling
- Monte Carlo (MC) geometries
- Discrete Ordinates (SN) geometries
- MC-SN coupled geometries
- CT/MRI/Color images

4D Coupled Multi-Process Calculation
- Radiation Transport
- Isotope Burnup
- Material Activation & Irradiation Damage
- Radiation Dose
- Fuel management

Dynamical & Visualized Analysis
- Static / dynamic physical data fields
- Human virtual roaming & dosimetry assessment

Multi-objective Optimization
- Artificially intelligent algorithms
- Space optimization of irregular complex solutions

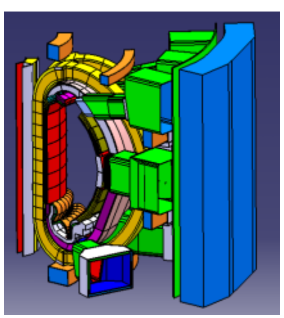


- **Hybrid Evaluated Nuclear Data Library** for fusion/fission/hybrid systems
- **External functions for other physics process simulations** such as virtual assembly, thermal-hydraulics, safety, environmental impact estimate etc.

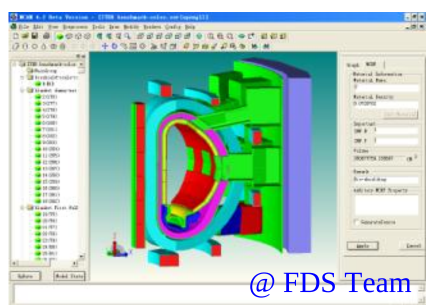
MCAM4&5: Automatic Modeling for Nuclear Systems

CAD ←→ MC (MCNP / TRIPOLI / Geant4 / FLUKA / …)

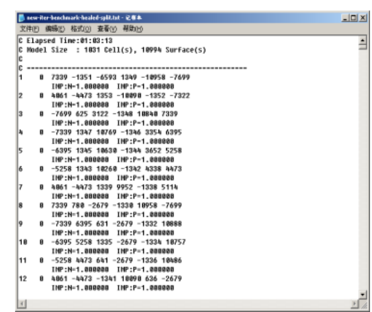
Converter	**CAD → MCNP Conversion**
Inverter	**MCNP → CAD Reverse Conversion**
Preprocessor	**Model Simplifying & Repairing**
Analyzer	**MCNP Model Analyzing & Editing**
Creator	**CAD Geometry Model Creating**



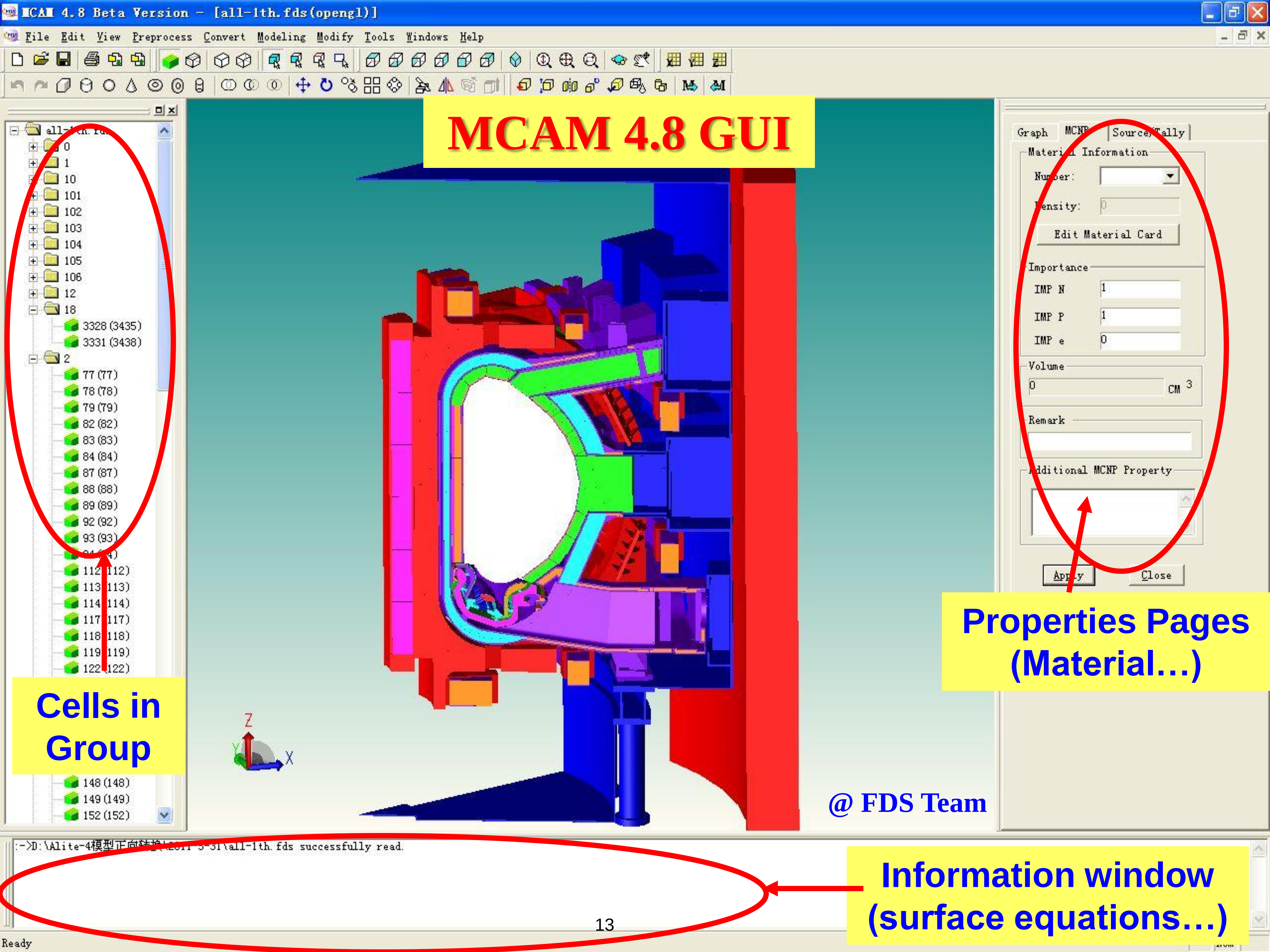
CAD model



Model in MCAM



MC model


MCAM 4.8 Beta Version - [all-1th.fds(opengl)]
File Edit View Preprocess Convert Modeling Modify Tools Windows Help
MCAM 4.8 GUI
Graph MCNP Source/Tally
Material Information
Number:
Density:
Edit Material Card
Importance
IMP N 1
IMP P 1
IMP e 0
Volume
0 CM 3
Remark
Additional MCNP Property
Apply Close
Cells in Group
Properties Pages (Material…)
@ FDS Team
Information window (surface equations…)
Ready

SuperMC：Super Monte Carlo Simulation Program

Major Features：

- Calculation of particle transport with Monte Carlo method, coupling with MOC / SN methods.
- Physical calculation functions for Radiation Transport / Isotope Burnup / Material Activation & Irradiation Damage / Radiation Dose/ Fuel Management.
- Direct integration of CAD-based/Imaged-based Modeling, Multi-Process Calculation and Dynamical & Visualized Analysis.
- Adoption of parallel, cloud and intelligent computing technologies and service architecture.
- Modular design for extension and integration easily.
- Open and easy user interfaces for various applications based on WWW.

Starting Points:

- Learning from advantages of each state-of-the-art codes MCNP / TRIPOLI / GEANT / FLUKA / EGS etc.
- Making use of already developed technologies in VisualBUS4.
- Being Driven by ADS/FDS/Medical Physics projects.

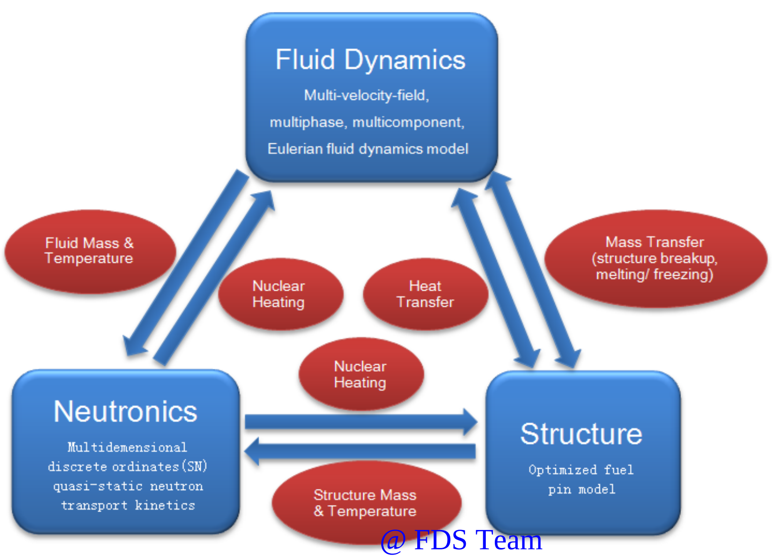
NTC: Neutronics-Thermohydraulics Coupled Simulation Program

Automatic coupling calculation

- → Multi-group SN quasi-static neutron transport equation
- → Multi-velocity-field, multiphase, Eulerian, fluid-dynamics model

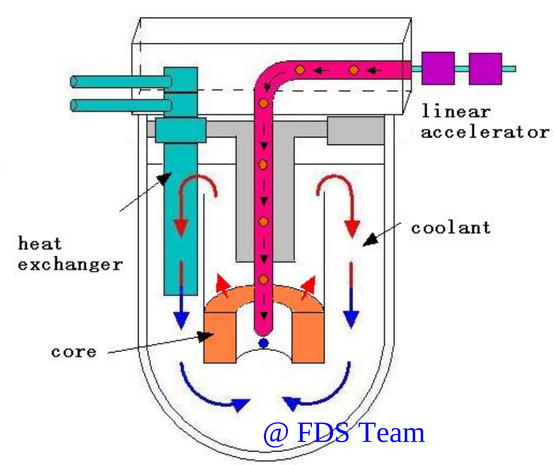
Transients safety analysis

- → DBA (design basic accident) analysis
- → Severe accident analysis
- → Thermal reactor / fast reactor / subcritical reactor transient safety analysis

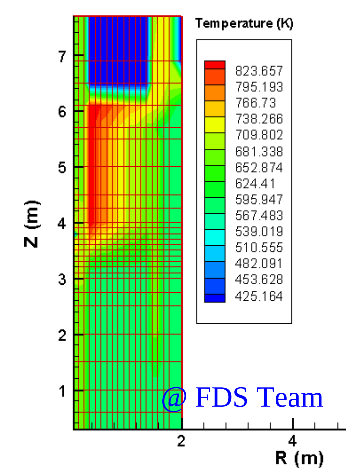


NTC Code Overall Structure

→ Application on ADS system



ADS system



Temperature distribution

RVIS: Nuclear Radiation Virtual Simulation and Assessment System

ALARA design of work scenarios in 3D virtual environment

- **Modeling stage for work scenarios modeling**

  CAD models import, models simplify, voxel models generate …

- **Design stage for scenarios definition**

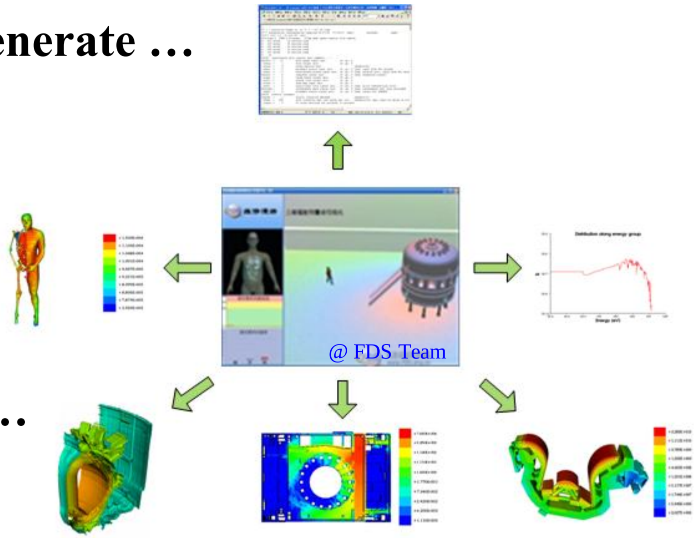
  Shield/repair/decommission scenarios definition …

- **Assessment stage for scenarios assessment**

  dose calculation, virtual simulation, dose assessment…

- **Optimization stage for scenarios optimization**

  ALARA evaluation, comparison of different work scenarios, follow-up design …



Hybrid Evaluated Nuclear Data Library - HENDL

- From **various international evaluated neutron nuclear data libraries**, such as **FENDL, ENDF/B, JENDL, JEF** and **BROND**
- Including **Multi-function Working Libraries**, **Transport.lib, Burnup.lib, Activation.lib, Iriradiation.lib, Dose-factors.lib**
- **Including High neutron energy cross section Library up to 150MeV, HENDL-ADS applied in ADS system**

Many Kinds of Group Energy Structure

— **HENDL/CG (27n/21g)**

— **HENDL/MG (175n/42g)**

— **HENDL/FG (315n/42g)**

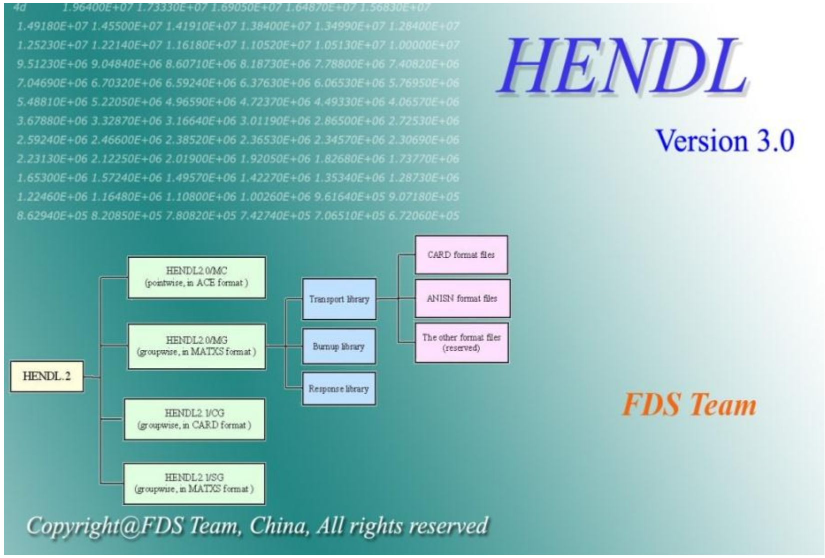
— **HENDL-ADS/MC (point-wise)**

Various Kinds of Physics Effects

— **Resonance self-shielding**

— **Temperature Doppler**

— **Thermal neutron up-scattering**

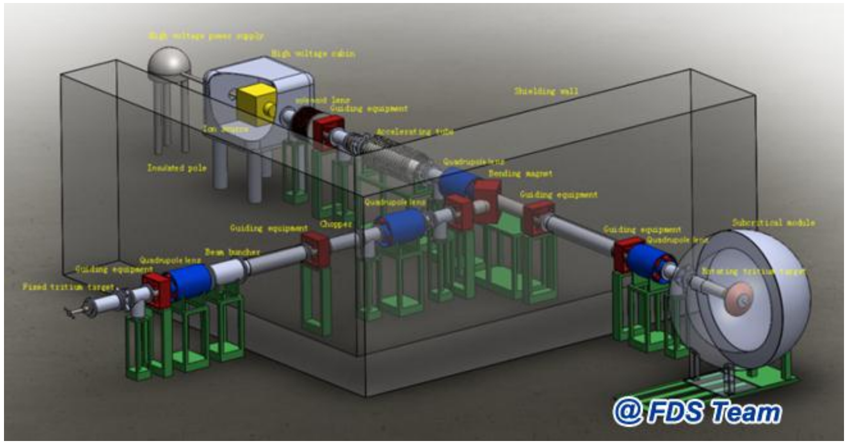


High Intensified Neutron Generator（HINEG） for Validation of Codes and Data Libraries

1. Parameters

(1) Steady intensity： 10^{13} n/s

(2) Pulse width： 1.5ns



2. Main functions:

(1) Neutronics

(2) Radiation protection

(3) Nuclear technology

Summary

- The static and dynamic parameters will be calculated for specific CFETR scenario.
- Several codes and data lib. have been home-developed and improved recently.
- High Intensified Neutron Generator is necessary for validation of fusion nuclear codes and data libraries.

The End

Thanks for your attention !

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