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# Progress on the Neutronic and Shielding Analyses of CFETR

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## Introduction

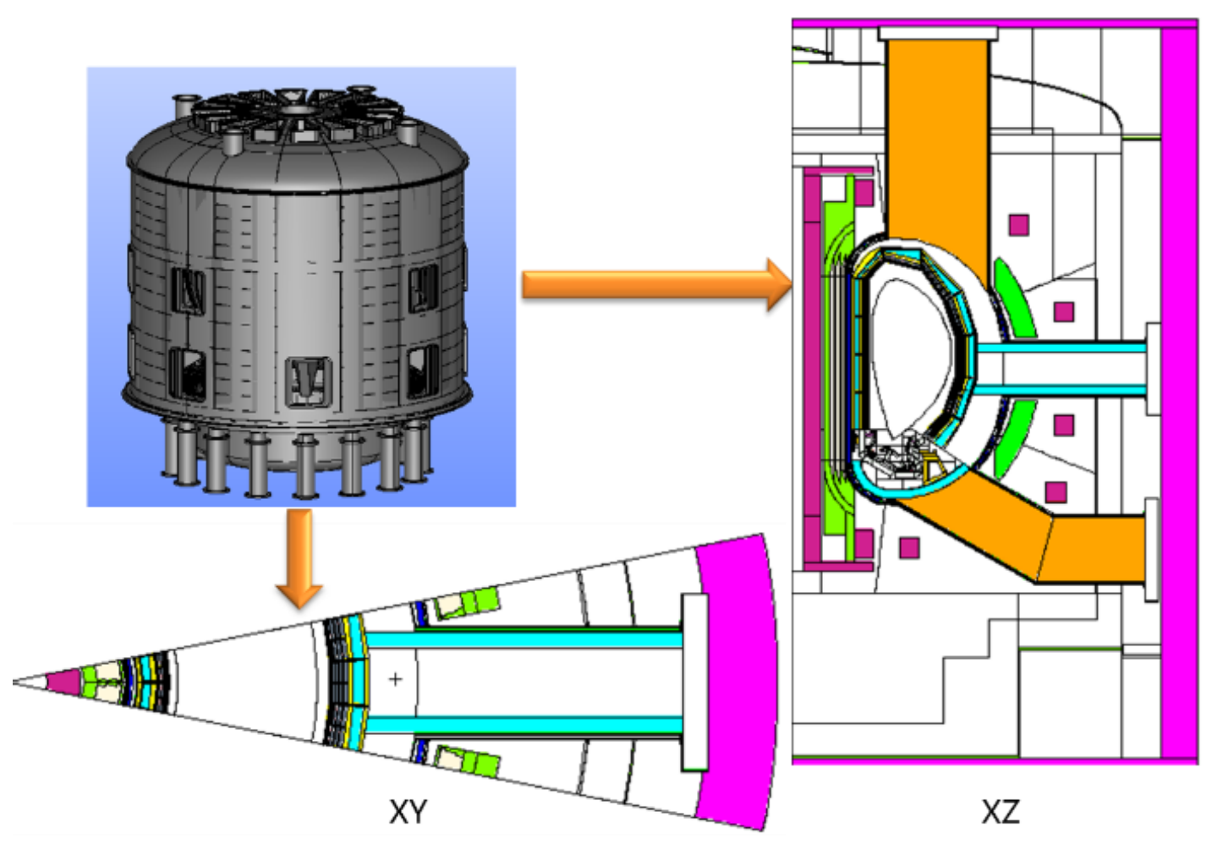
- CFETR is the next device in the roadmap for the realization of fusion energy in China.
- Tritium breeding blanket is one of the key components of CFETR with functions of tritium breeding, heat generating and nuclear shielding. Currently, HCCB TBB is the primary option for CFETR.
- For CFETR, the neutronic and shielding analyses are indispensable for the performance and safety design of the reactor, which strongly impact the key design features, such as tritium self-sufficiency, heat generation, activation of structural materials, shielding and radioactivity safety, etc.
- The major components of CFETR tokamak shall provide adequate shielding to ensure that the TF coils will not be damaged by irradiation during the whole life of CFETR.

## ANALYSIS METHOD AND MODEL

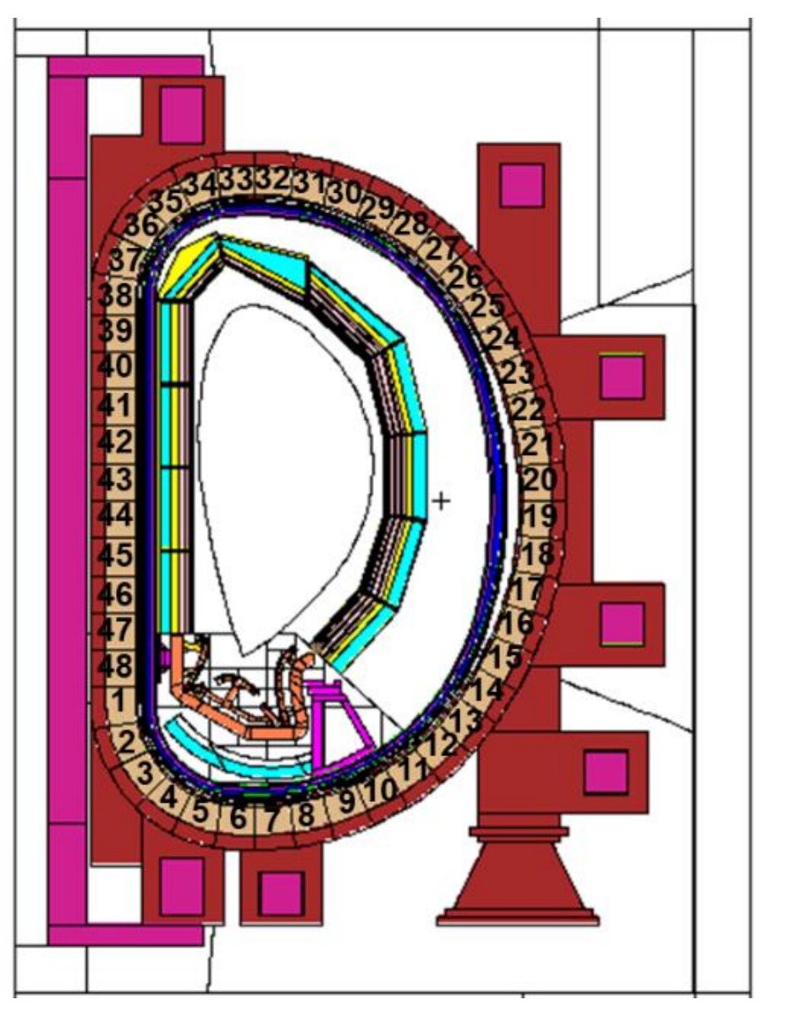
- Transport code and activation code:
  - MCNP, FISPACT-2007
- Analysis model:
  - One VV sector model (22.5° ) with reflecting boundary
  - Including plasma, blanket, divertor, VV, TS, TF coils, PF coils, CS coils, cryostat, Bio-shield and port models
  - TF coils are divided into 48 segments along the poloidal direction for shielding analysis
- Reducing the MCNP calculation errors:
  - Simulating 10 billion particles
  - Using bias reduction techniques (such as WWP, ESPLT, FCL, etc.)
- The assumed irradiation scenario is used for activation and shielding analyses of CFETR.

| Fusion power (MW) | Operating time (year) | Duty cycle |
|---|---|---|
| 1000 | 10 | 0.5 |
| 1500 | 4 | 0.5 |
| 2000 | 1 | 0.5 |

*Assumed irradiation scenario of CFETR*



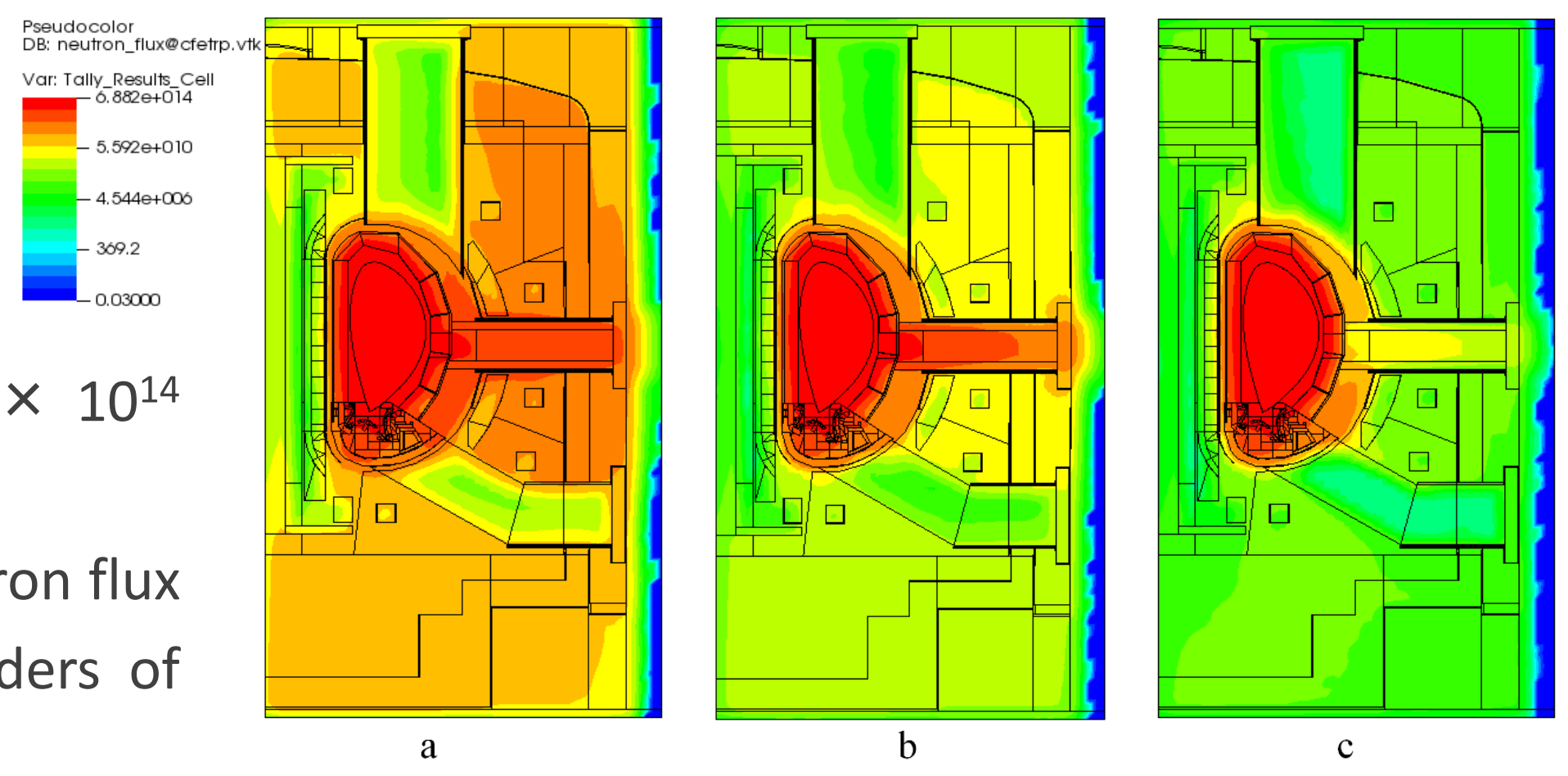
*Neutronic analysis model of CFETR*



*48 TF coils segments*

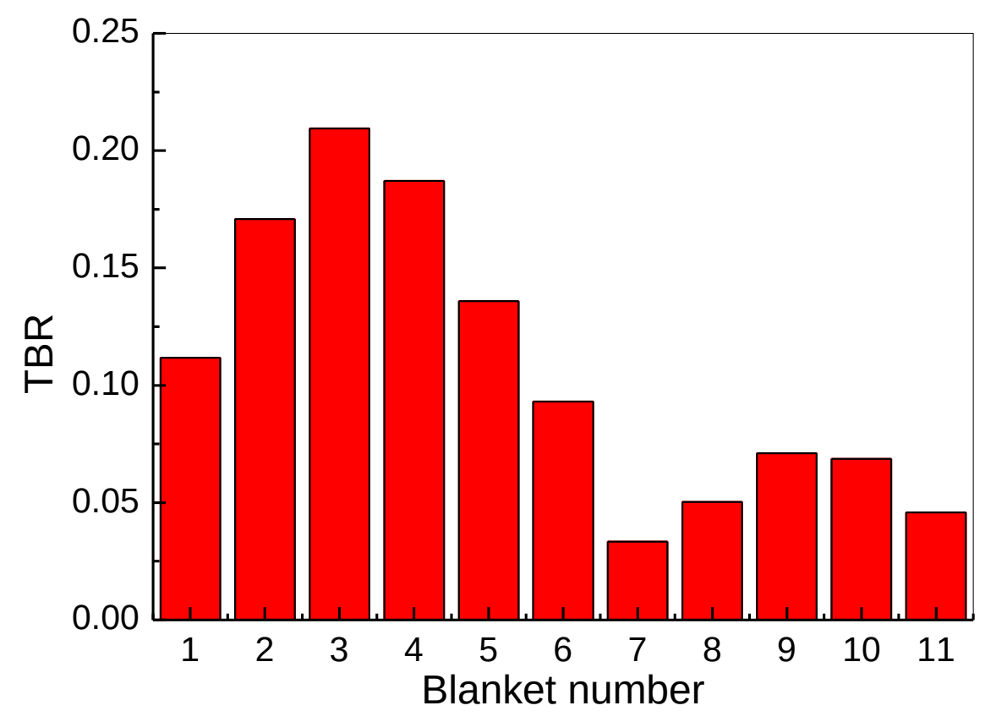
## NEUTRON TRANSPORT CALCULATION

- Neutron transport calculation has been performed with 1500 MW fusion power.
- Global neutron field:
  - Model A: include NBI port, no shielding
  - Model B: include NBI port and shielding
  - Model C: include shielding, no NBI port
  - The peak neutron flux of CFETR is about 6.9 × $10^{14}$ n/cm²/s.
  - If considering the neutron shielding, the neutron flux in most meshes decreases obviously (~2 orders of magnitudes) .
  - If considering the NBI port, the neutron flux in the NBI port increases sharply (~3 orders of magnitudes).



*Neutron flux distributions of 3 models for CFETR*

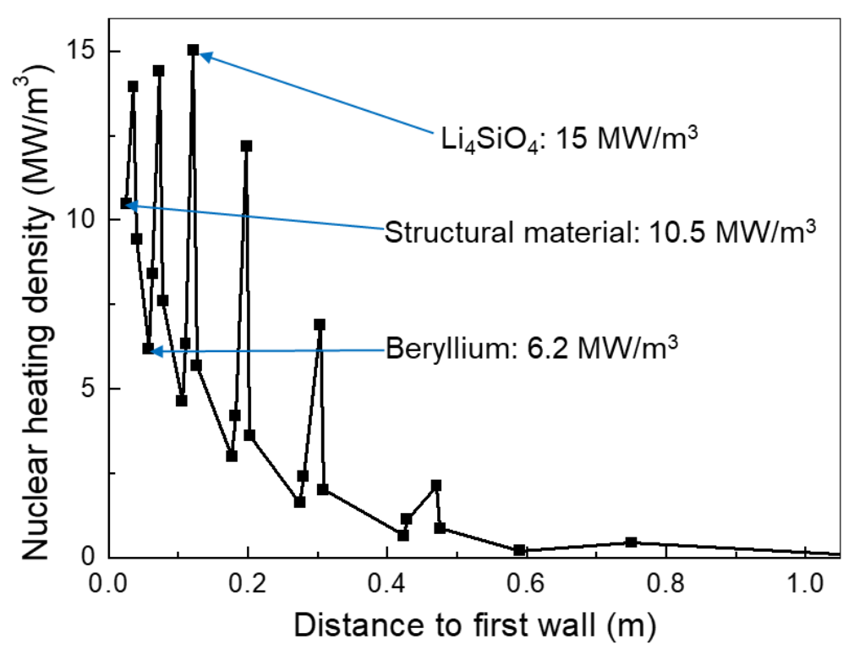
- TBR:
  - After several rounds of neutronic design and optimization, the TBR of HCCB TBB is 1.177.
  - The TBR drops to 1.101 by considering the influence of auxiliary systems, which can meet the design objectives of CFETR.



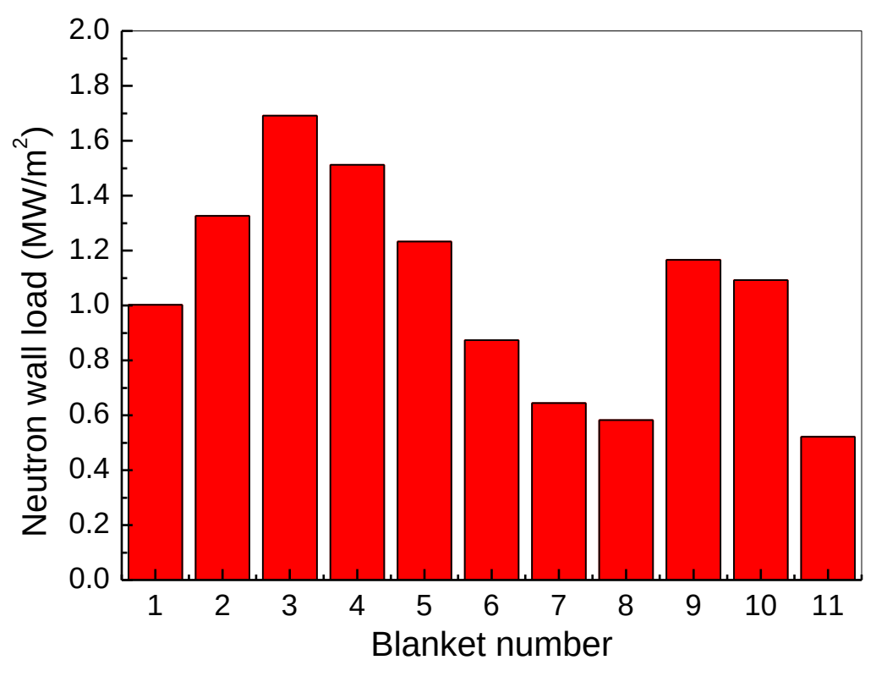
*TBR contribution of HCCB TBB*

| System | ΔTBR | TBR |
|---|---|---|
| ECRH | -0.01170 | 1.165 |
| ICRH | -0.00849 | 1.157 |
| LHW | -0.00283 | 1.154 |
| NBI | -0.01373 | 1.140 |
| Diagnostic system | -0.03949 | 1.101 |

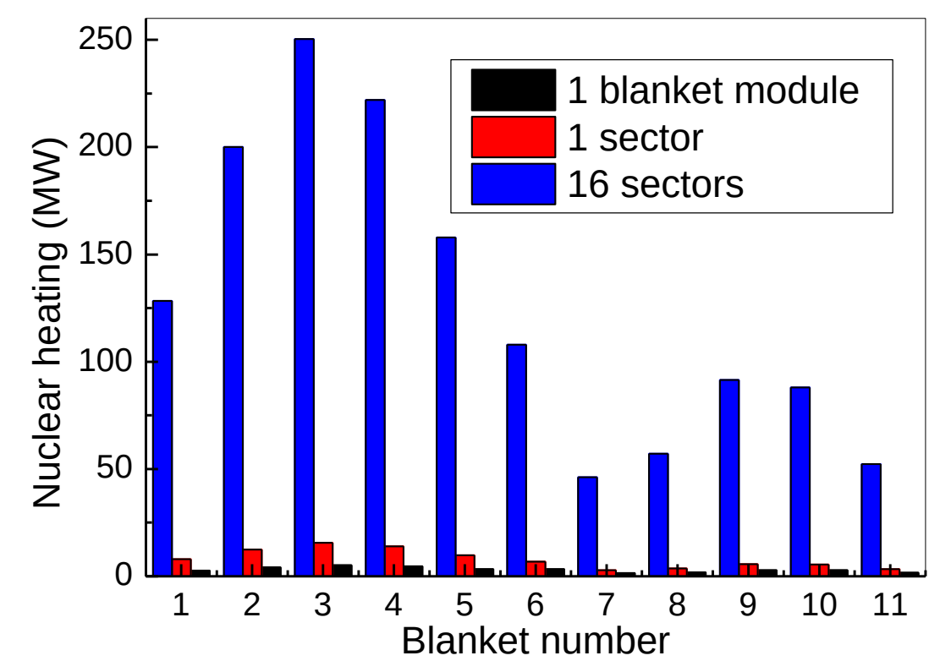
*The influence of auxiliary systems on TBR*



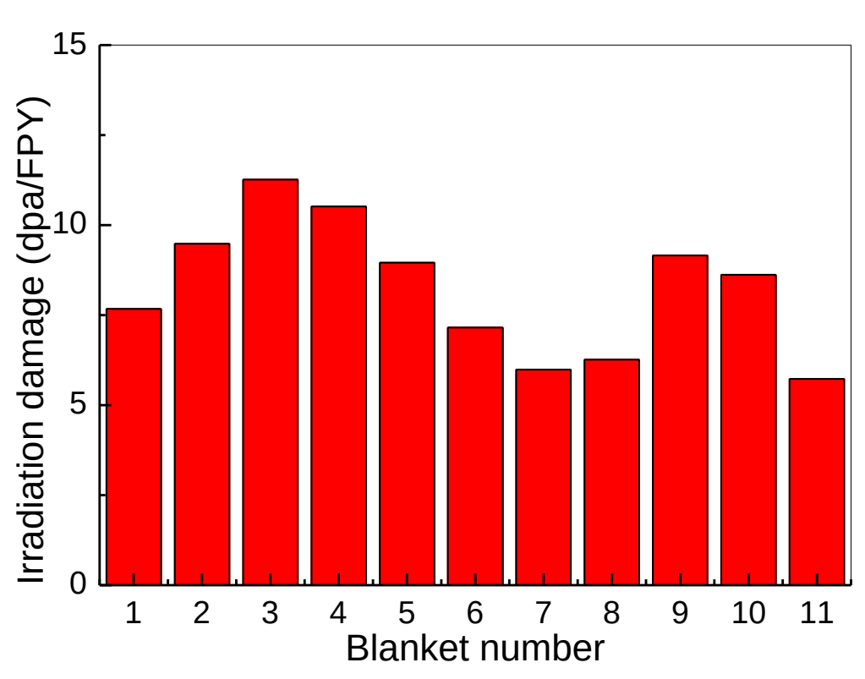
*Nuclear heating density distribution in blanket module #3*



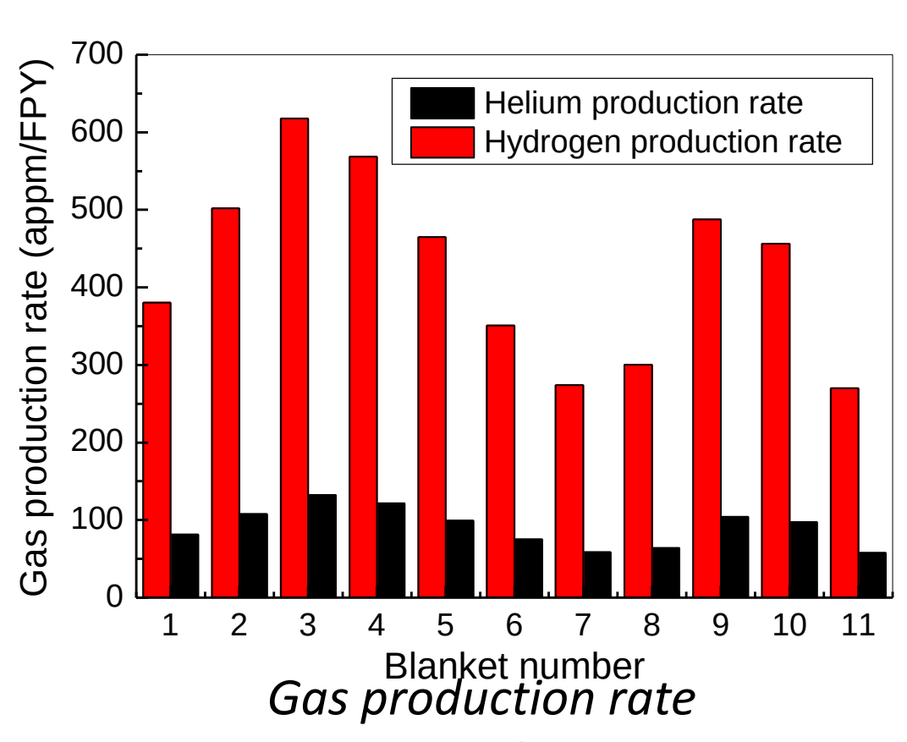
*Neutron wall load distribution of HCCB TBB*



*Nuclear heating distribution of HCCB TBB*



*DPA distribution of HCCB TBB*

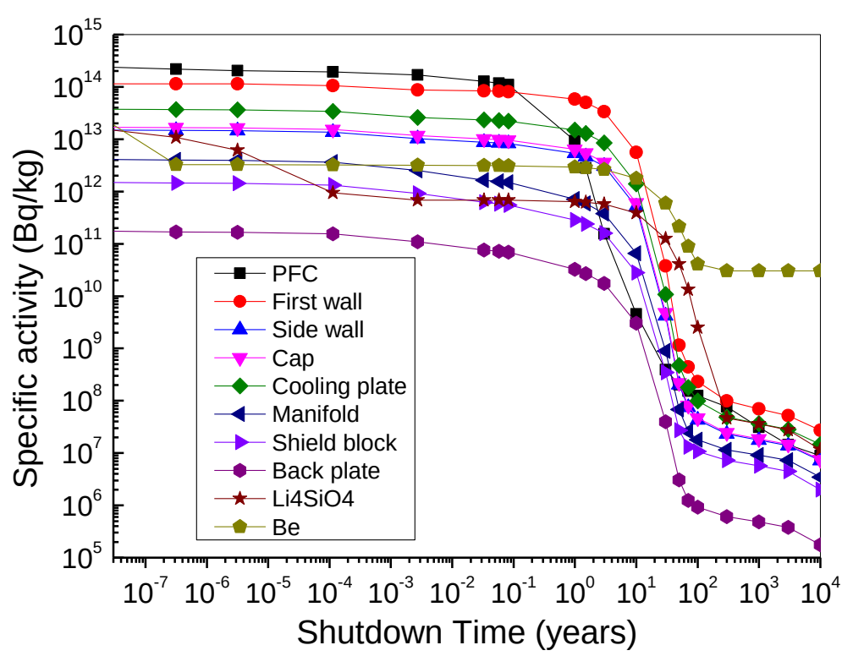


*Gas production rate distribution of HCCB TBB*

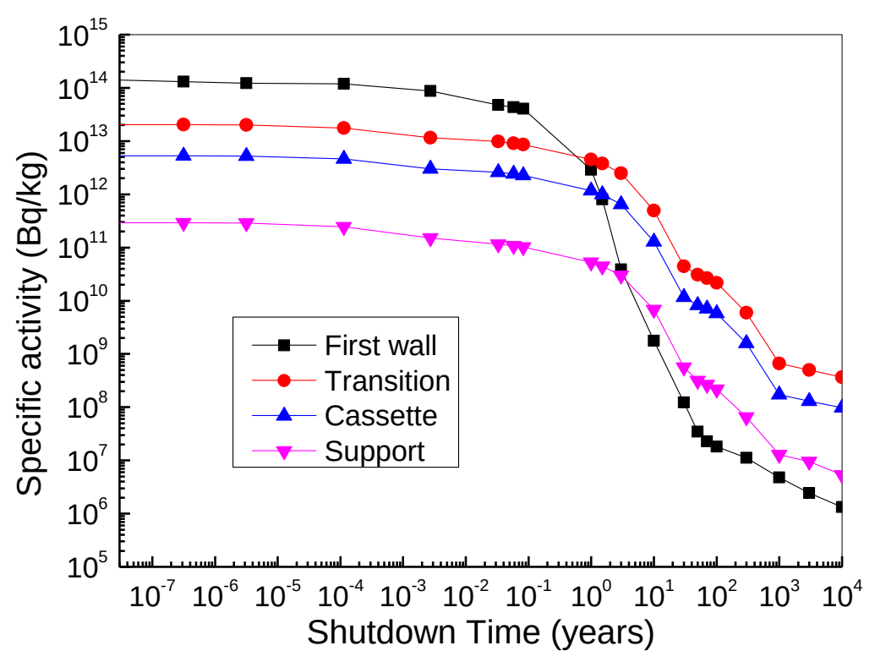
- Other nuclear parameters:
  - The total nuclear heating of HCCB TBB is 1402 MW.
  - Blanket module #3 is subjected to the strongest neutron irradiation.
  - For HCCB TBB, the maximum neutron wall load, nuclear heating density and irradiation damage are 1.69 MW/m², 15 MW/m³ and 11.3 dpa/FPY, respectively.

## ACTIVATION ANALYSIS

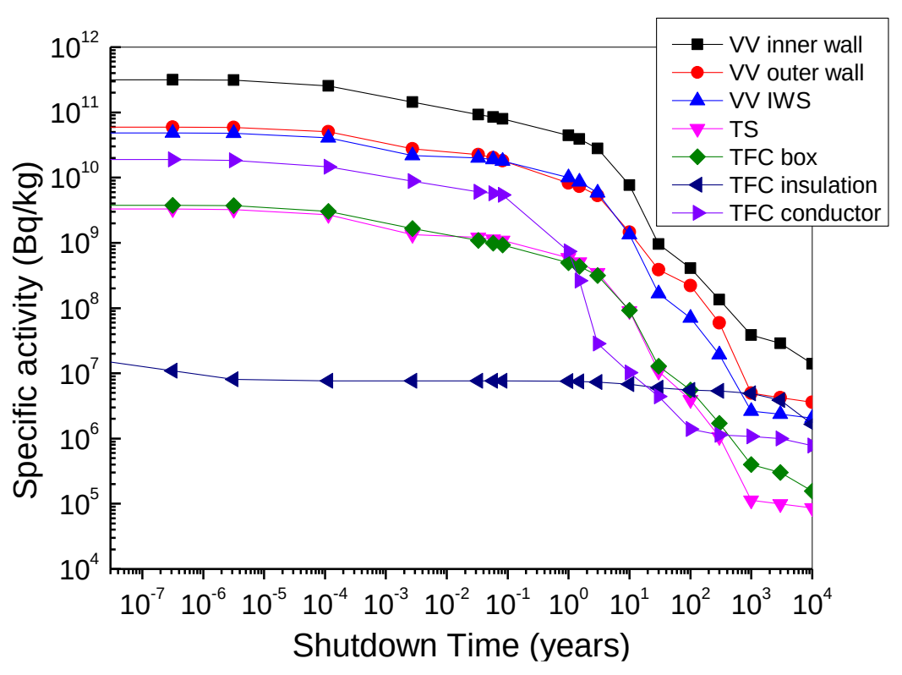
- Assumptions:
  - HCCB TBB will be replaced after 10 years of operation.
  - Divertor will be replaced after 5 years of operation.
  - VV and ex-vessel components will not be replaced during the operation.
- Analysis results:
  - At shutdown, the total activity inventory of HCCB TBB and divertor is 5.55 × $10^{19}$ Bq and 2.26 × $10^{19}$ Bq.
  - At shutdown, the total decay heat of HCCB TBB and divertor is 7.98 × $10^{3}$ kW and 2.42 × $10^{3}$ kW.
  - The decay heat production at shutdown is no more than 1% of the direct power, and drops to less than 0.1% after a few days.
  - The activation levels of VV, TS and TF coils are much lower than that of the banket and divertor.



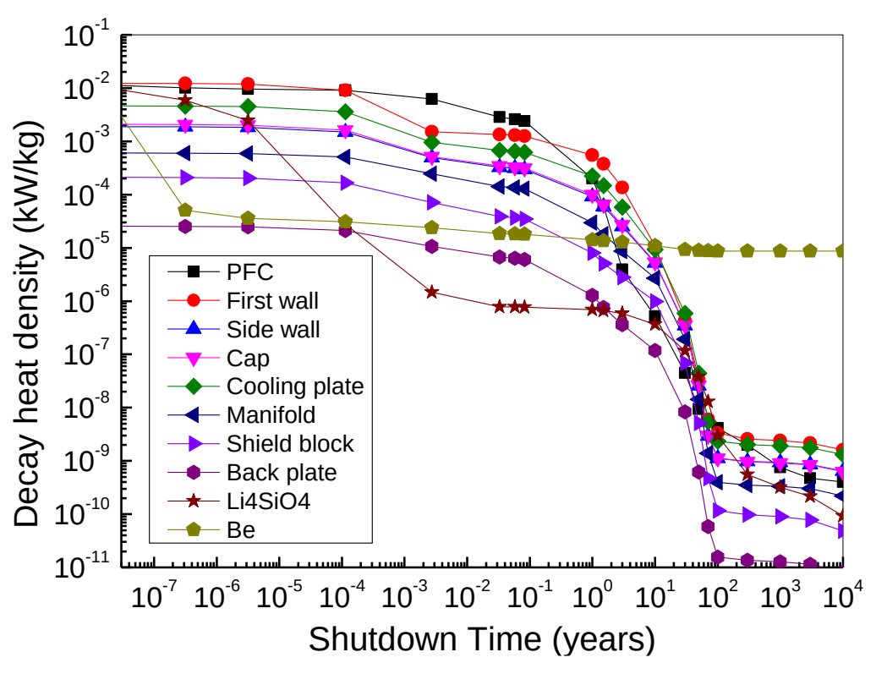
*Specific activity of HCCB TBB*



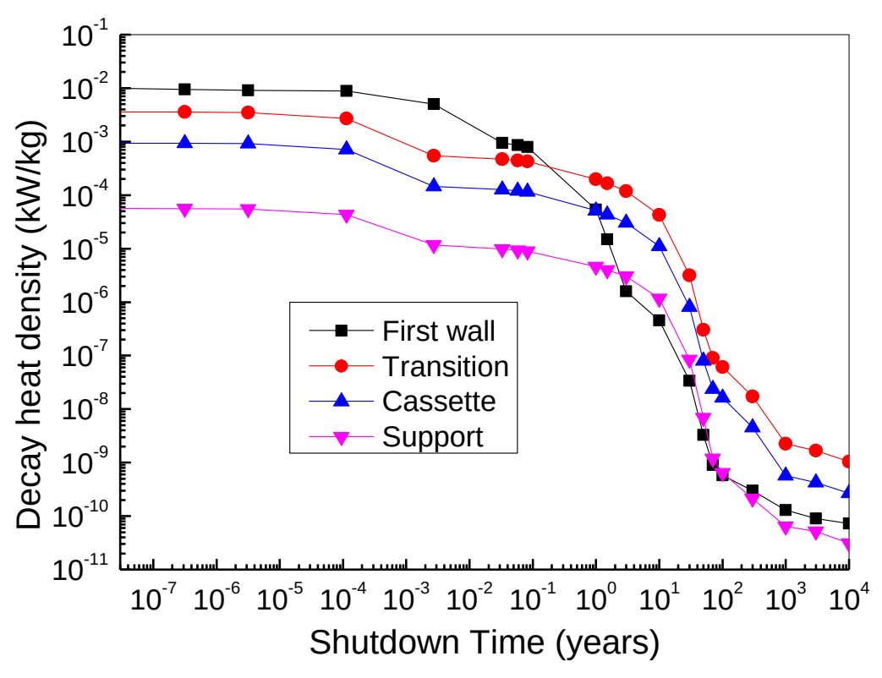
*Specific activity of divertor*



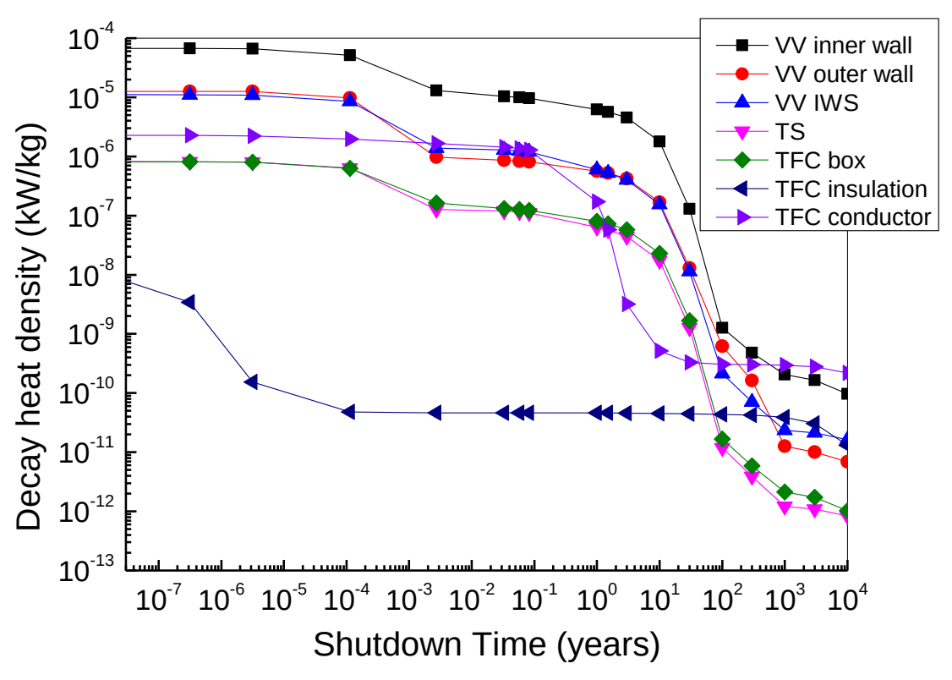
*Specific activity of VV, TS and TF coils*



*Decay heat density of HCCB TBB*



*Decay heat density of divertor*

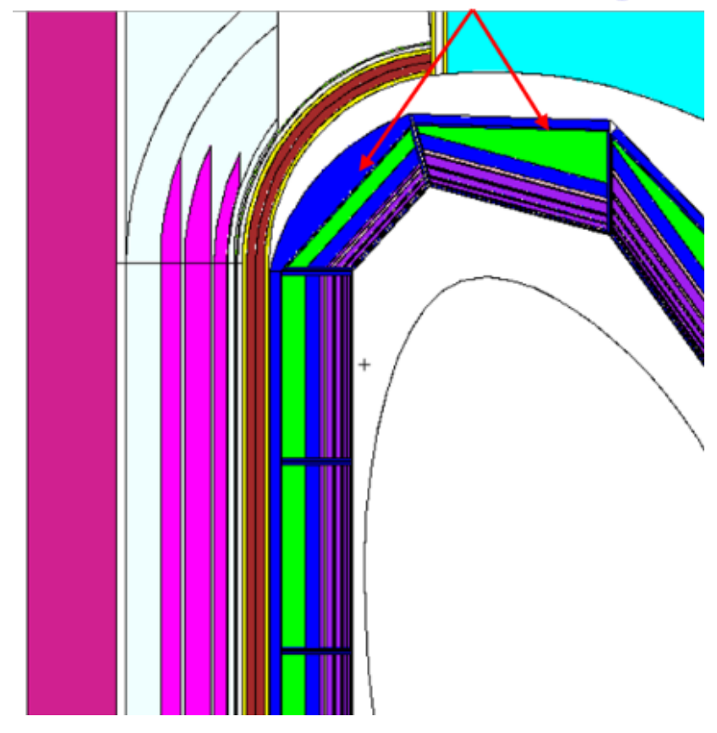


*Decay heat density of VV, TS and TF coils*

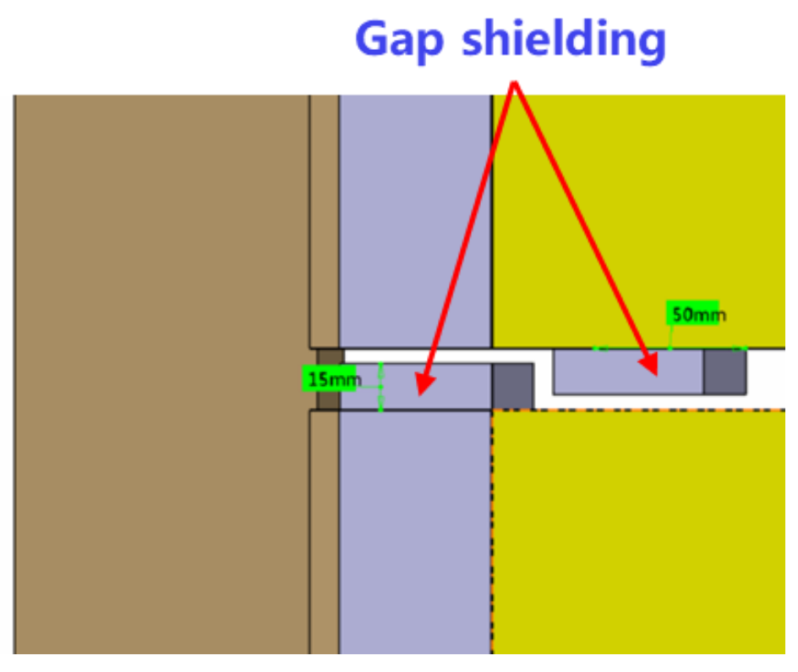
## SHIELDING ANALYSIS

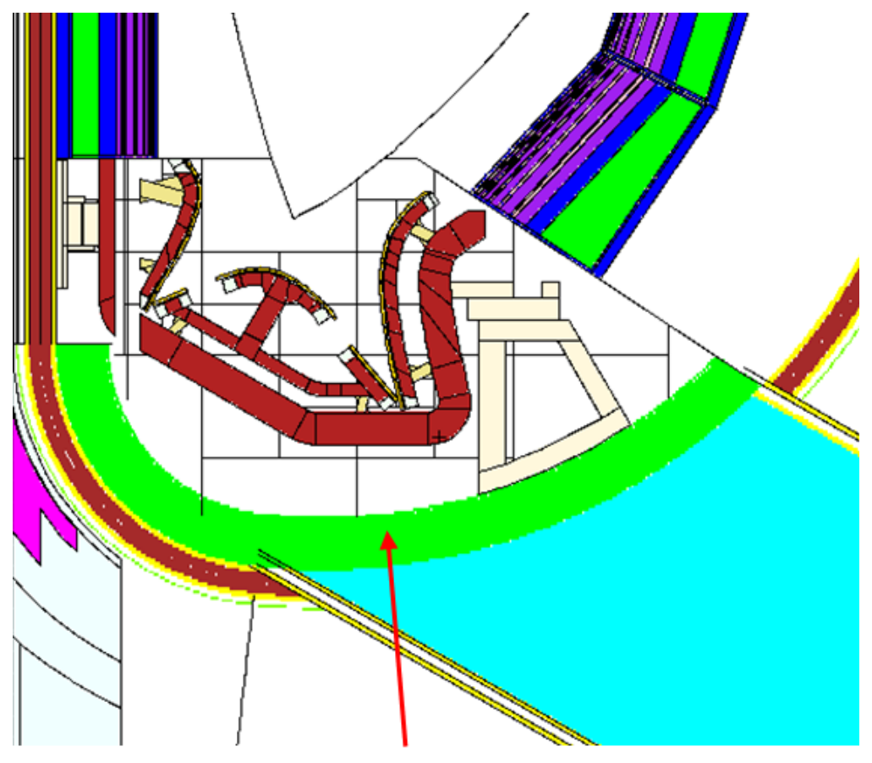
- Optimized shielding designs for CFETR:
  - Design in-wall shielding in VV
  - Add rear shielding of HCCB TBB
  - Design dogleg in the poloidal gaps among HCCB blanket modules
  - Add shielding block at the bottom of the divertor
  - Add shielding blocks around the NBI port

Rear shielding

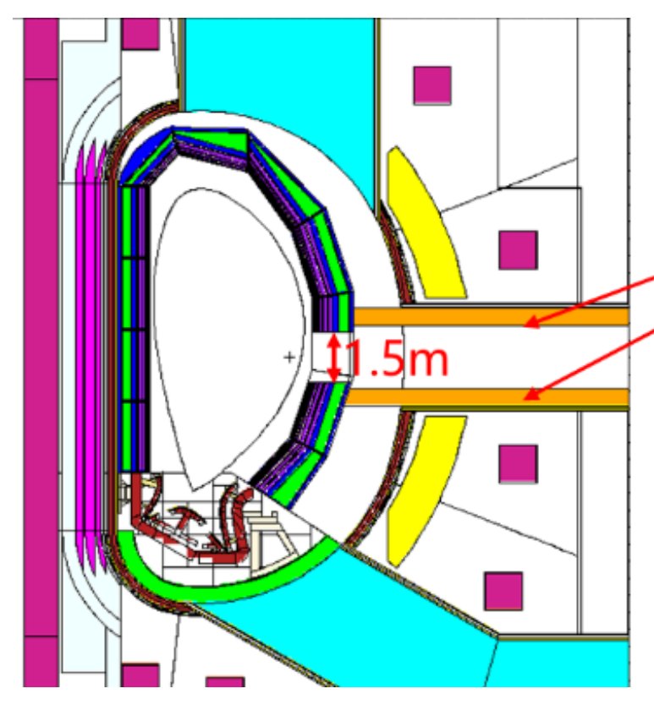


Gap shielding

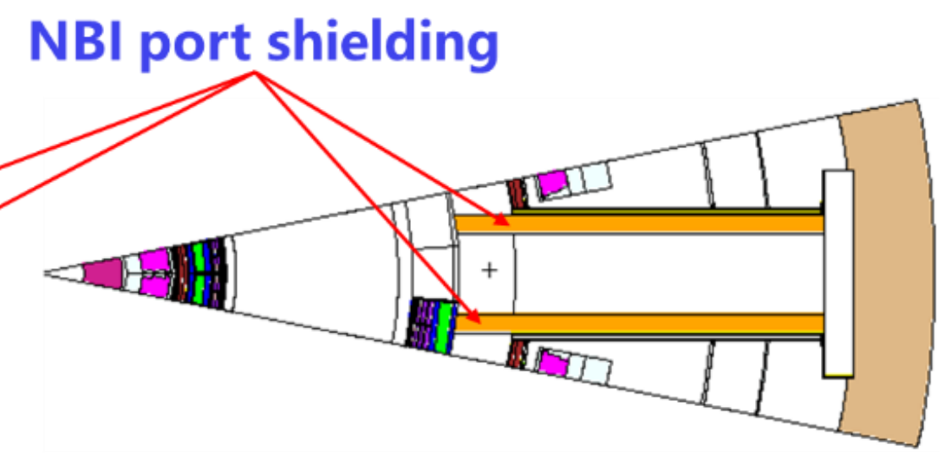


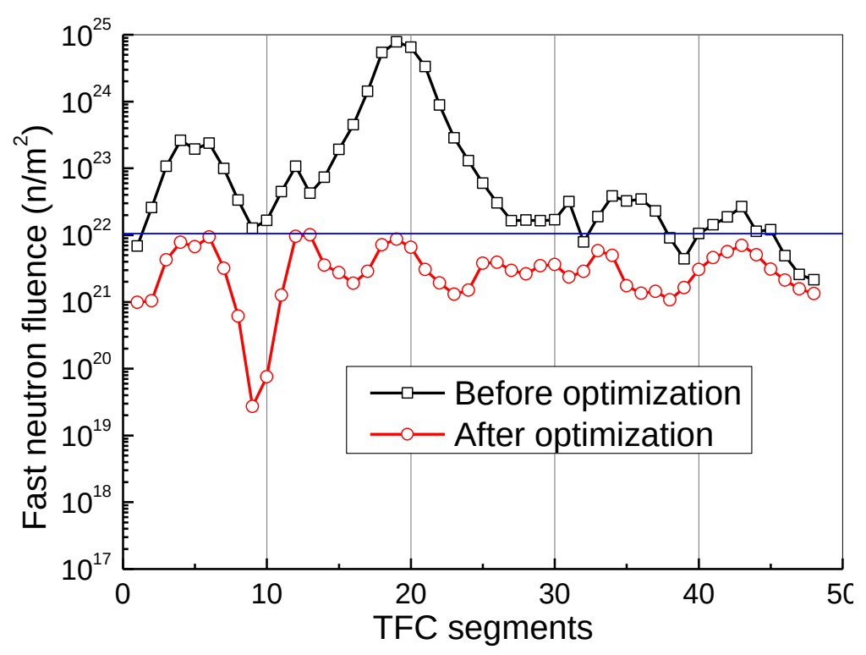


Bottom shielding

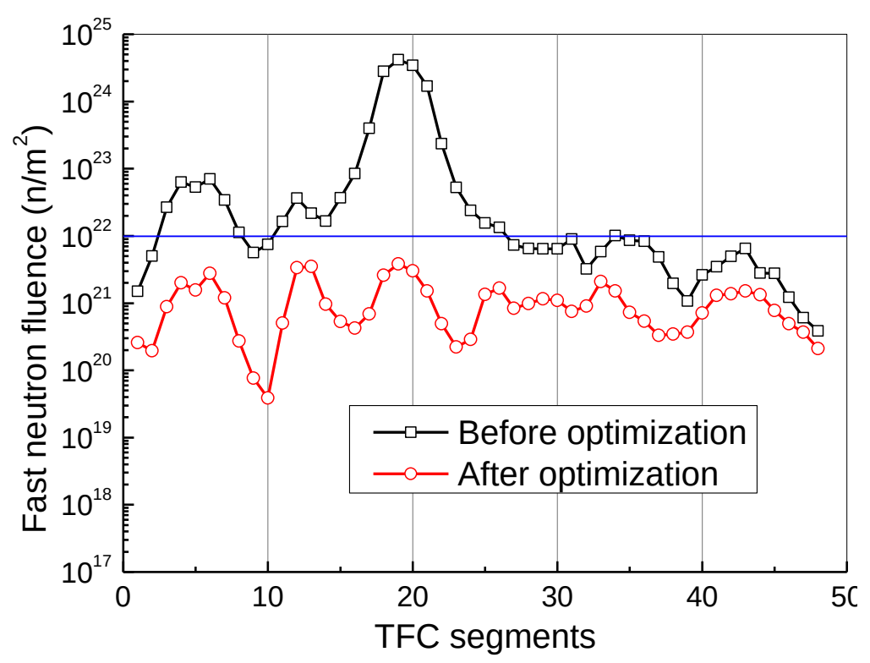


NBI port shielding

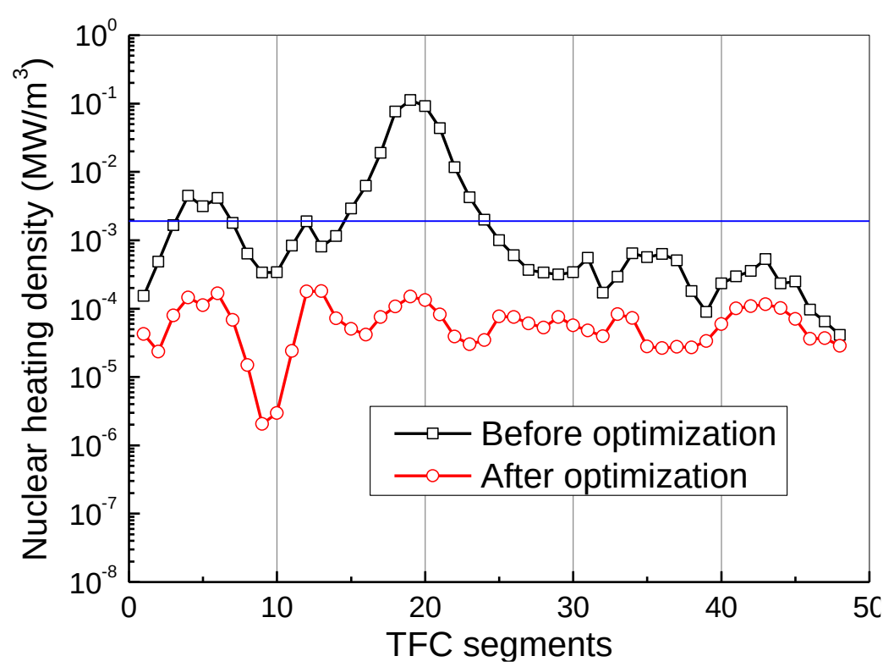




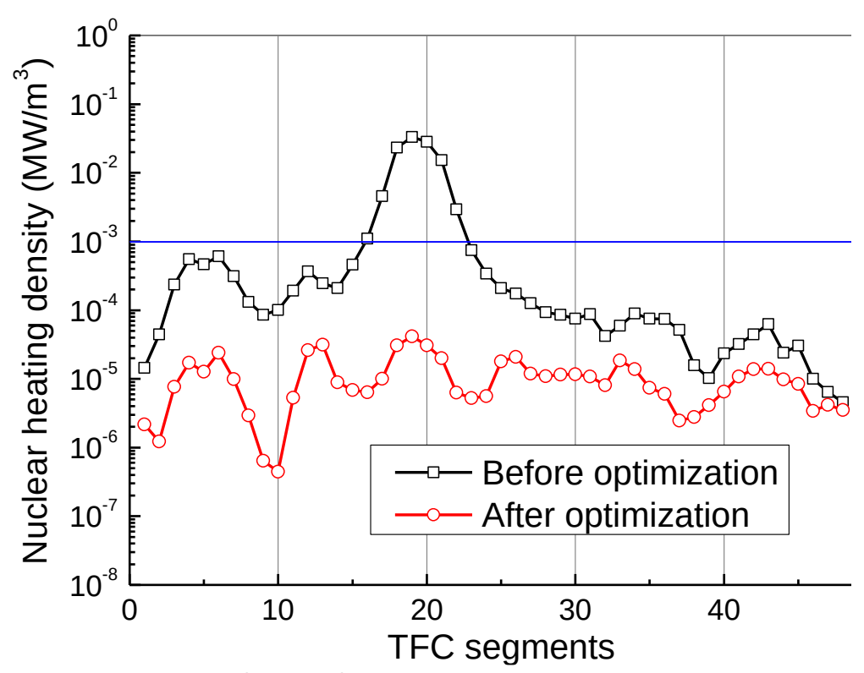
*Fast neutron fluence in insulator*



*Fast neutron fluence in conductor*



*Nuclear heating in steel case*



*Nuclear heating in conductor*

- Shielding analysis results:
  - The shielding performance of TF coils nearby divertor, NBI port and high field areas could not meet the design requirements before shielding optimization.
  - The shielding performance of NBI port is the worst, and the fast neutron fluence and nuclear heating of TF coils nearby NBI port exceed the design limit by ~2 orders of magnitude.
  - After shielding optimization, the fast neutron fluence and nuclear heating of all TF coils are below the design limit.

## CONCLUSION

- Based on the current design of CFETR, three-dimensional neutronic analysis model has been developed to be used for neutronic and shielding analyses.
- Preliminary neutron transport calculation for the major components of CFETR tokamak has been performed by using the Monte Carlo transport code MCNP4C.
- Detailed activation analysis for the major components of CFETR tokamak has been performed by using the inventory code FISPACT-2007.
- Preliminarily shielding design and optimization for TF coils of CFETR have been completed.
- Considering the engineering design update of CFETR, the further neutronic and shielding analyses will be continued in the future to obtain the more detailed results, and to improve the TBR and shielding performance.

## ACKNOWLEDGEMENTS

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