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# Nuclear Analysis of Structural Damage and Nuclear Heating on Enhanced K-DEMO Divertor Model

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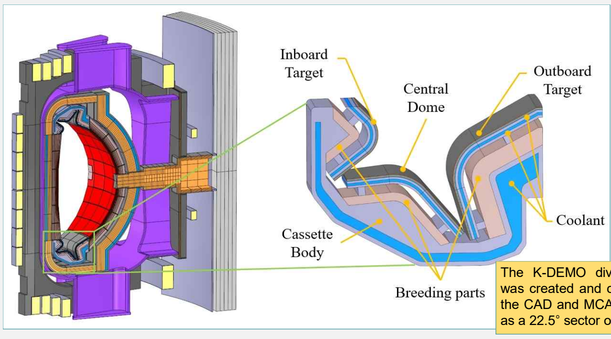
## Introduction

❑ **The K-DEMO divertor was integrated into a previously developed K-DEMO neutronic analysis model. And then, two important nuclear responses, nuclear heating, and displacement damage for the K-DEMO divertor system were examined using Monte Carlo code. Through these analyses, we estimated the overall trend of nuclear heating values and displacement damages on K-DEMO divertor system in the global model. The highest values appeared on the upper OT area, which means OT is exposed to the highest radiation conditions among the three plasma-facing parts in the divertor.**

## 2. K-DEMO Divertor Model

❑ **A configuration of 22.5° K-DEMO neutronic analysis model (left) and a concept of the divertor module (right).**




The K-DEMO divertor model was created and converted by the CAD and MCAM programs as a 22.5° sector of tokamak.

➢ K-DEMO divertor system adapts the symmetric double-null type with upper and lower 96 modules in the toroidal direction. The plasma-facing parts are made of tungsten armored high heat flux units to remove plasma radiation heat and nuclear heating. These parts are consisting of the inboard target (IT), outboard target (OT), and central dome (CD), which are supported by the water cooled RAFM steel backplate. The cassette part is made of RAFM including water coolant manifolds to cool down plasma-facing parts.

❑ **Material composition of the K-DEMO divertor**

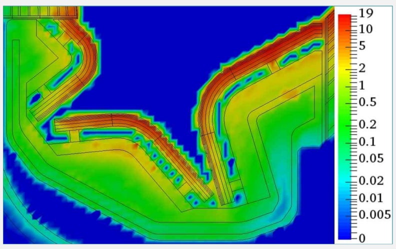
| Components | Material Composition |
|---|---|
| Monoblocks | Tungsten |
| Monoblock Backplate | RAFM |
| Coolant | Water |
| Cassette Body | RAFM |
| Breeding Zone: | Mixture of $Li_4SiO_4$ 15% and $Be_{12}Ti$ 85%, $^6Li$ enrichment: 90% |

## MCNP Calculation

➢ The MCNP code was used on the displacement damage calculation and nuclear heating calculations with FENDL-2.1 nuclear data library. The average statistical error rates on the nuclear heating and displacement damage calculations for the MCNP runs were below ~5%. The fusion neutron emission probability data were applied on the plasma region and then, 2,200 MW of K-DEMO fusion power was normalized in the following calculations.

### Nuclear Heating Calculation

❑ **Map of nuclear heating rate (W/cm³) for the divertor region in K-DEMO.**




A relatively high percentage of nuclear heating values in a single module was appeared on the upper OT area, whereas the lower part of the OT area showed relatively lower nuclear heating values than others.

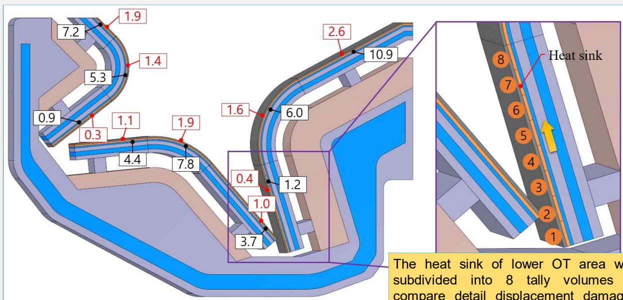
❑ **Nuclear heating on the K-DEMO divertor**

| Components | Single Module (kW) | 96 Modules (MW) |
|---|---|---|
| OT (Upper/Mid/Lower) | 1794 (1183/473/138) | 172.2 (113.6/45.4/13.2) |
| CD (Outer/Mid/Inner) | 888 (291/366/231) | 85.2 (27.9/35.1/22.2) |
| IT (Upper/Mid/Lower) | 527 (163/259/105) | 50.6 (15.6/24.9/10.1) |
| Cassette Body | 1029 | 98.8 |
| Total | 4236 | 406.7 |

➢ The total nuclear heating values on plasma-facing parts of the 96 divertor modules were 172.3, 85.2, 50.6, 98.8 MW in OT, CD, IT and Cassette Body areas, respectively. Nuclear heating values are strongly dependent on the relative locations in the divertor model to the neutron source in the plasma. A relatively high percentage of nuclear heating values (28%) in a single module was appeared on the upper OT area, whereas the lower part of the OT area showed relatively lower nuclear heating values than others.

### Nuclear Heating Calculation

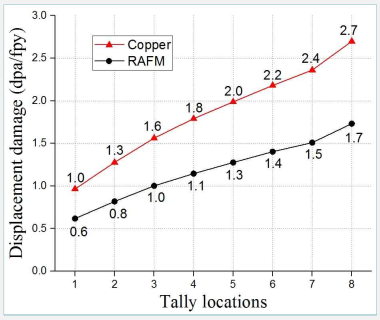
❑ **The maximum displacement damage on tungsten armors (red) and RAFM heat sinks (black) of K-DEMO divertor system (left) and a detail view of lower OT area (right).**




The heat sink of lower OT area was subdivided into 8 tally volumes to compare detail displacement damages using RAFM and copper materials.

➢ The maximum damages are indicated in the RAFM heat sink material of upper OT area with a value of 10.9 dpa/fpy. Although RAFM was further away from the plasma, the displacement damage on RAFM (10.9 dpa/fpy) was higher than tungsten (2.6 dpa/fpy). This is due to the lower threshold energy of RAFM than tungsten (RAFM ~40 eV, W 90 eV).

❑ **Comparison of calculated displacement damage rates between copper and RAFM materials in the heat sink of lower OT area.**




The copper material shows much lower displacement damage rates comparing with other parts since it is less exposed to the neutrons in the plasma.

The displacement damages in RAFM and copper materials were gradually increased in the upper direction. Also, the copper material shows ~56% higher displacement damage rates than RAFM material.

➢ In general, copper alloy materials are not considered as a heat sink for K-DEMO divertor system despite its high thermal conductivity than RAFM since they cause reusable and radioactive waste problems. However, we tried the copper material as a heat sink at the lower OT area because this area showed relatively lower displacement damage rates with RAFM material than others.

## Conclusion

◆ This study investigated that nuclear heating values and the displacement damages on the three plasma-facing parts of K-DEMO divertor.

◆ We found much lower nuclear heating and displacement damages are indicated on the lower part of OT area than others. These are important results to perform thermal-hydraulic and thermo-mechanical analyses on the divertor.

◆ It is expected that the copper alloy materials may be partially used as a heat sink only at the lower part of OT instead of RAFM material due to its high thermal conductivity.

◆ But careful attention should be paid to use copper alloy materials as the heat sink due to its activation characteristics.

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