# PHYSICAL MODEL FOR TESTING STRUCTURAL MATERIALS OF FUSION REACTORS UNDER PLASMA AND THERMAL IMPACT

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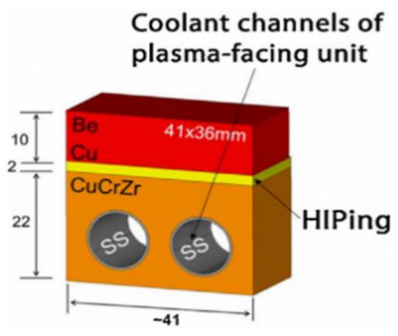
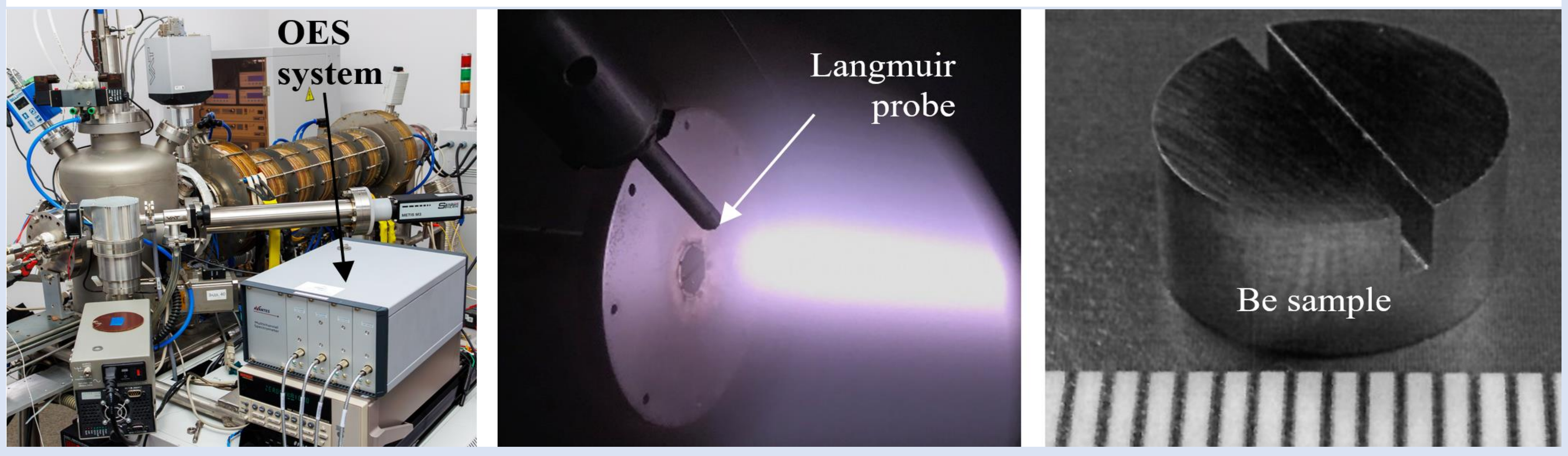
## ABSTRACT

This work presents a physical model for testing materials under the combined effects of plasma irradiation and thermal loads. Using TGP-56 beryllium as an example, the influence of hydrogen plasma was investigated at temperatures ranging from 363 to 1200 °C. The model integrates numerical simulation of thermal loads, experimental plasma-beam irradiation, and a set of advanced structural characterization techniques, including SEM, TEM, and X-ray diffraction. It was established that morphological and structural changes depend on both temperature and the number of cycles: from minor blistering at 363 °C to the formation of a porous structure at 772 °C and to severe erosion and recrystallization at 1200 °C. The proposed physical model provides a valuable tool for predicting the behavior and selecting candidate structural materials for future fusion reactors.

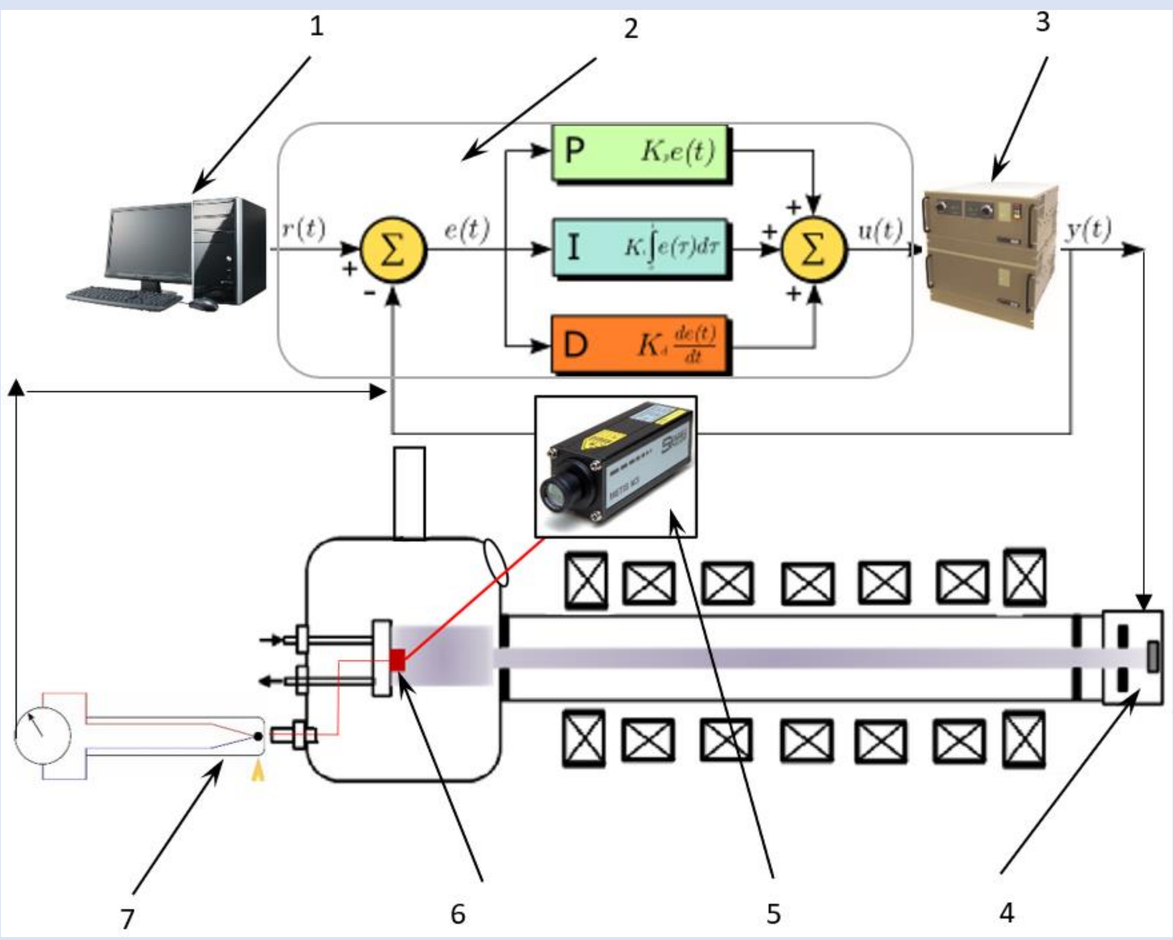
## CHALLENGES / METHODS / IMPLEMENTATION

- Mathematical modelling of the temperature distribution in the first-wall module.
- Preparation of beryllium samples for testing.
- Plasma-beam irradiation in PBI facility.
- Diagnostics: OES, Langmuir probe, mass spectrometry.
- Temperature control: pyrometry & thermocouples (PID).
- Characterization of samples: SEM, TEM, XRD, profilometry, optical microscopy.

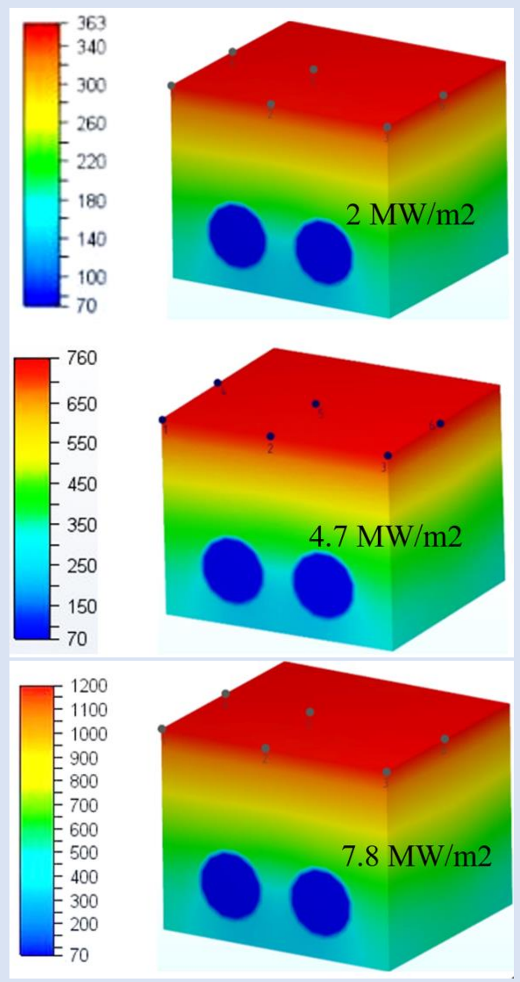



*PBI appearance and the process of the beryllium sample plasma irradiation*




*1 – control; 2 – PID-control; 3 – electron gun power; 4 – electron gun; 5 – pyrometer; 6 – target; 7 – thermocouple*

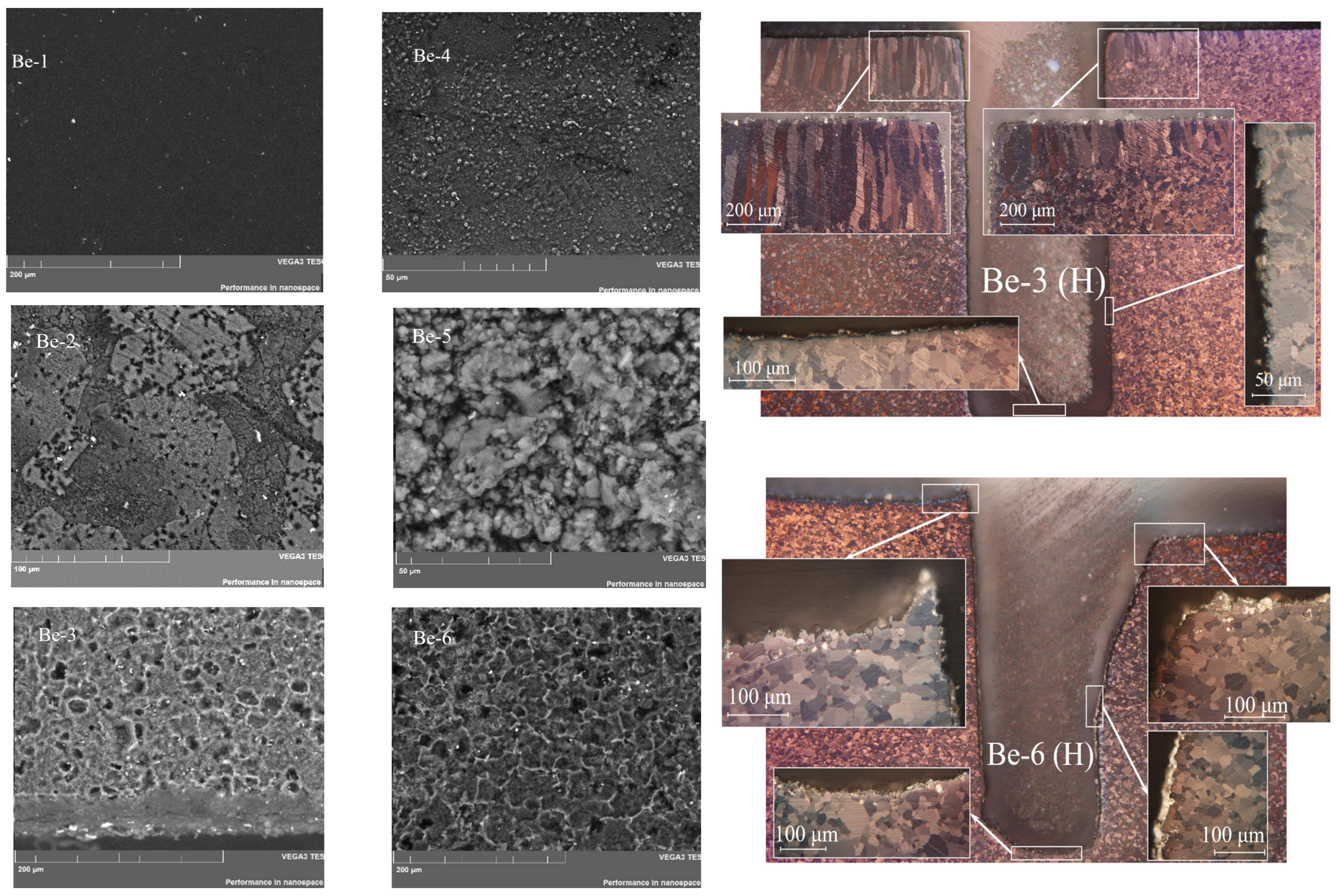



*Temperature distribution in structural materials of the FW*

*Irradiation parameters* (duration of the pulse is 500 seconds)

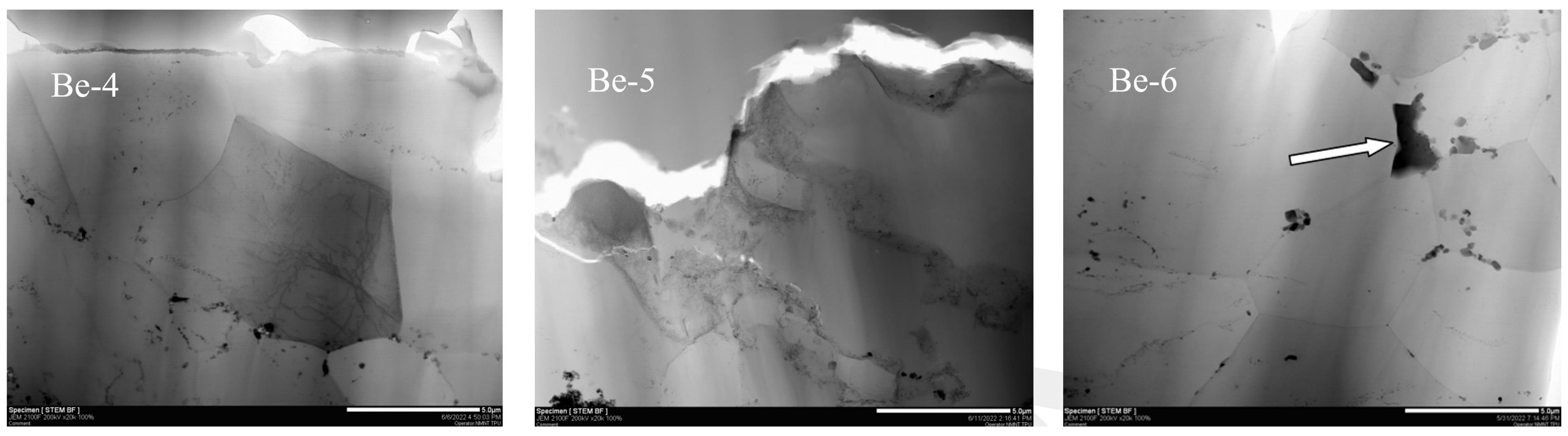
| Sample | Surface temperature, °C | Ions flux, $m^{-2}s^{-1}$ | Ions fluence, $m^{-2}$ | Number of rulses |
|---|---|---|---|---|
| Be-1 | 355÷365 | $1.47\cdot10^{21}$ | $7.34\cdot10^{24}$ | 10 |
| Be-2 | 770÷800 | $1.1\cdot10^{21}$ | $5.53\cdot10^{24}$ | 10 |
| Be-3 | 1190÷1210 | $7.12\cdot10^{21}$ | $3.56\cdot10^{25}$ | 10 |
| Be-4 | 355÷365 | $1.47\cdot10^{21}$ | $7.34\cdot10^{25}$ | 100 |
| Be-5 | 770÷800 | $1.1\cdot10^{21}$ | $5.53\cdot10^{25}$ | 100 |
| Be-6 | 1190÷1210 | $7.12\cdot10^{21}$ | $3.56\cdot10^{26}$ | 100 |

## OUTCOME



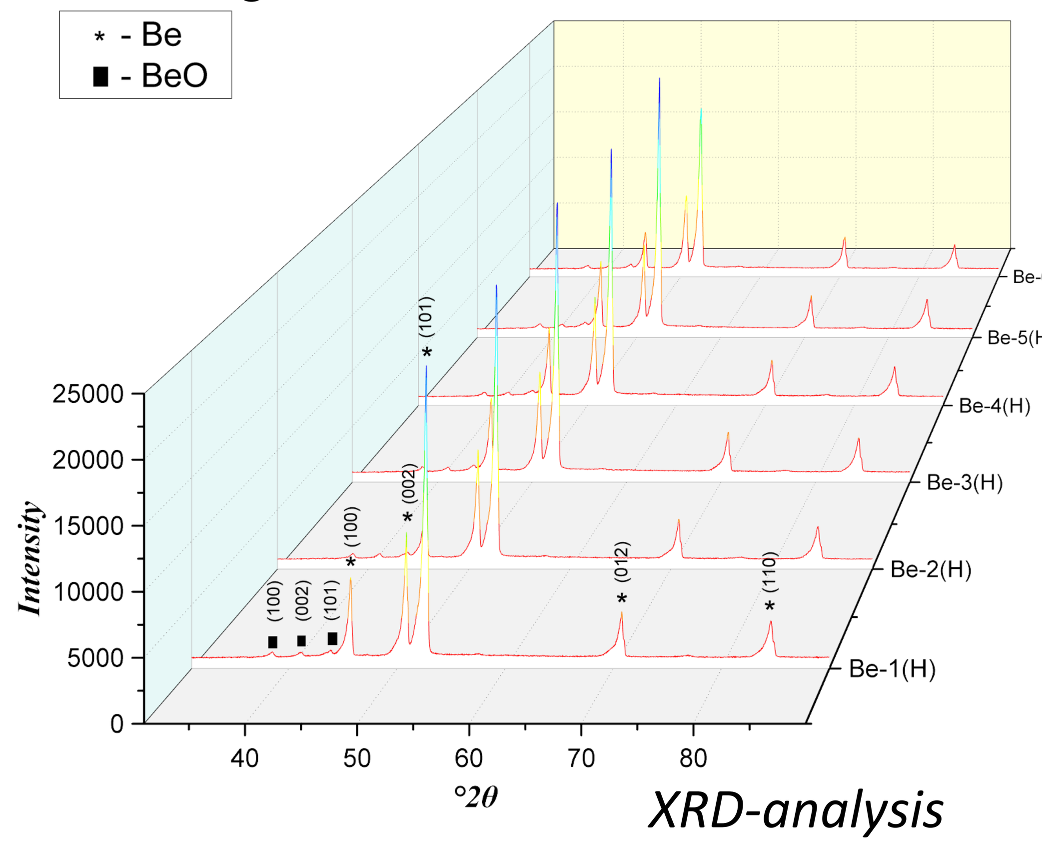

*Cross-section microstructure*

360 °C (Be-1, Be-4): minimal changes, slight blistering after 100 cycles.
772 °C (Be-2, Be-5): porous morphology, BeO inclusions, fractal-like submicron porosity after 100 cycles.
1200 °C (Be-3, Be-6): severe erosion, deep pores (~30 µm), recrystallization zones (~350 µm), mass loss ~7%.




*TEM-images*

Be-4: dislocation networks typical of plastically deformed metal.
Be-5: dense dislocation clusters, dislocation walls, subgrain nuclei.
Be-6: fully developed subgrain structure, evidence of dynamic polygonization.




*XRD-analysis*

## CONCLUSION

A physical model was developed for testing structural materials under combined plasma and thermal loads. Applied to TGP-56 Be:

- 360 °C → local blistering only.
- 780 °C → erosion, BeO inclusions, porous substructure.
- 1200 °C → severe erosion, recrystallization, deformation, mass loss. TEM: evolution from dislocation tangles, subgrain nuclei, polygonized subgrain structure. Despite morphology changes, phase composition remained constant (Be and BeO). The methodology is universal applicable for screening PFMs and structural materials for fusion reactors.

## ACKNOWLEDGEMENTS / REFERENCES

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