Beam Window Design for ADS system in JAEA

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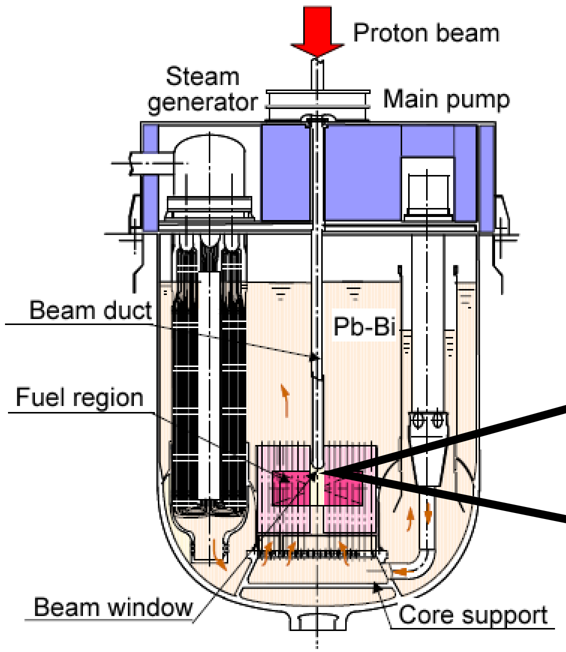
Introduction

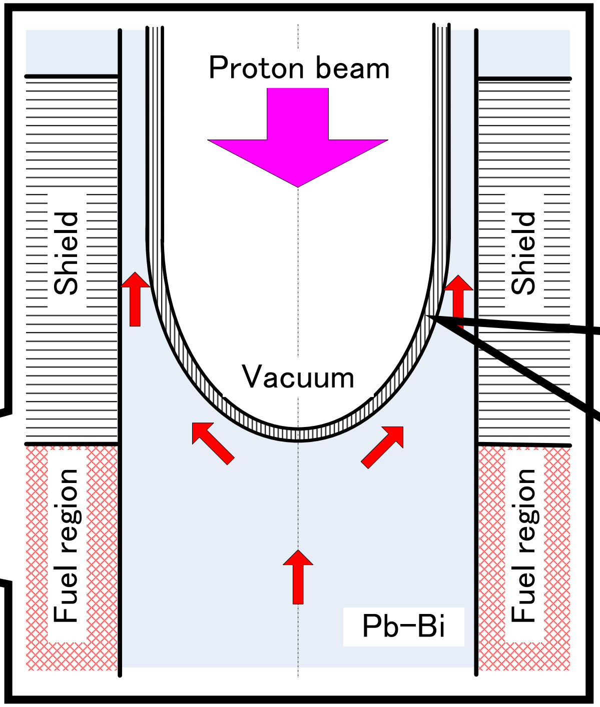
- JAEA has investigated 800MWt LBE cooled Accelerator-Driven System (ADS) to transmute minor actinides (MA).
- Many inherent issues
  - **Design of beam window**
  - Accelerator reliability
  - LBE technology
  - Reactor physics with MA fuel
  - ・・・
- Beam window will be used in the following severe condition
  - heat generation by proton beam
  - external pressure by LBE
  - creep deformation at high temperature
  - corrosion in LBE
  - irradiation damage

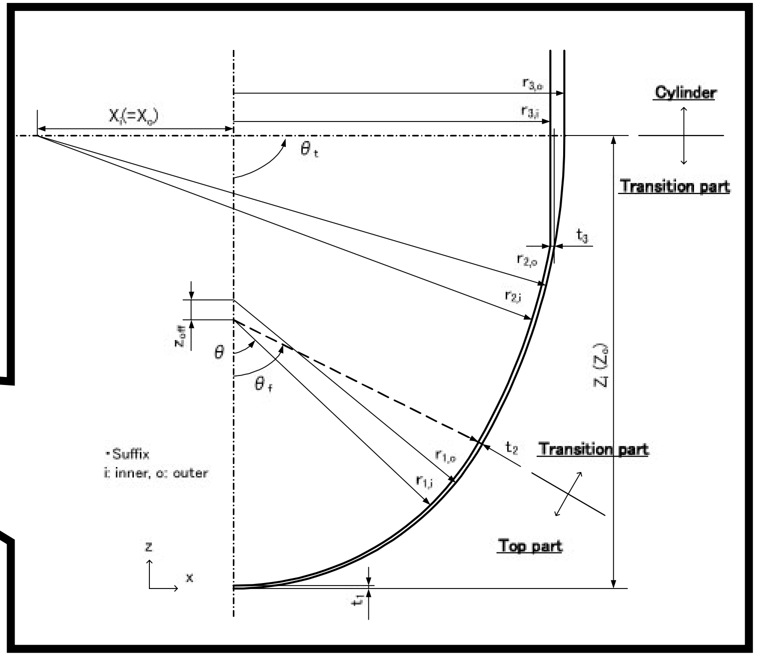
Previous study*

- Ellipse model
  - 235mm radius and 2mm thickness at the top

- It's feasible, but more feasible concept (hemisphere, thicker) is required → to mitigate the design condition

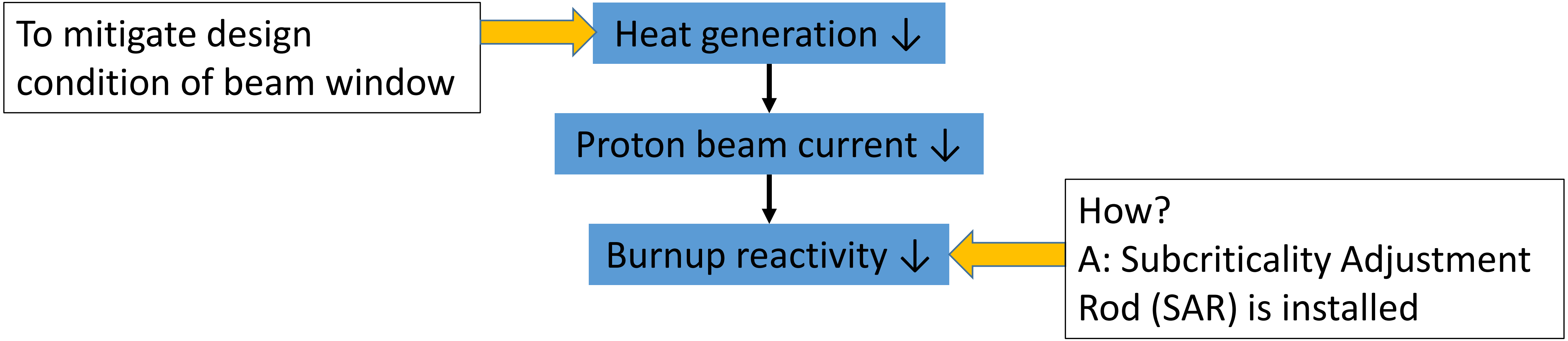






*: T. Sugawara, et al., JNST, 47 (10), 2010

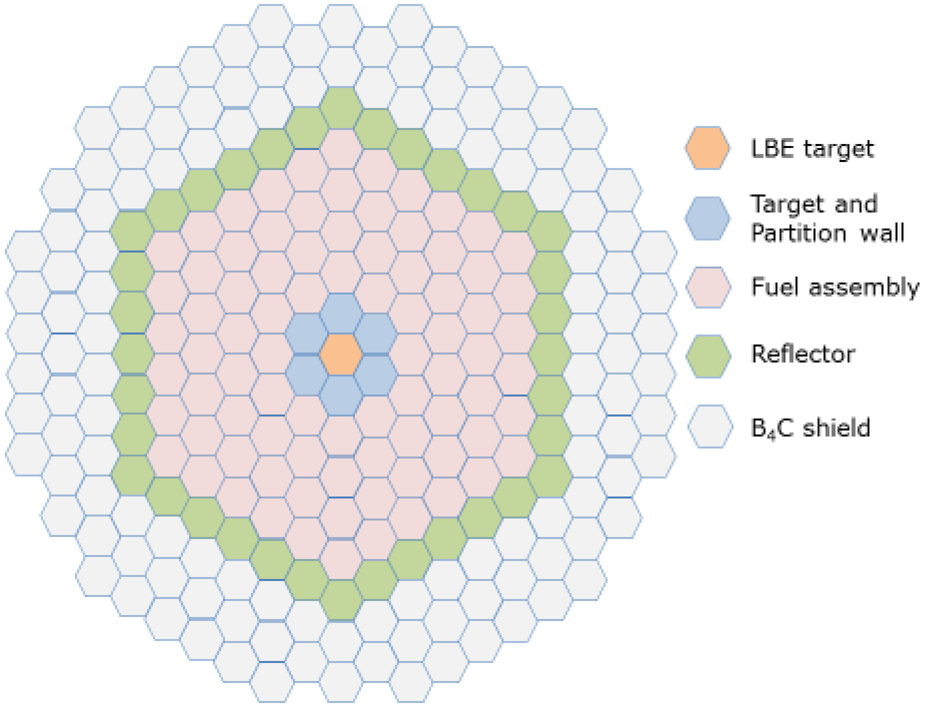
Purpose



- To realize the small burnup reactivity, subcriticality adjustment rod (SAR) is introduced to the ADS
  - Burnup analysis
  - Particle transport analysis
  - Thermal hydraulics analysis
  - Structural analysis

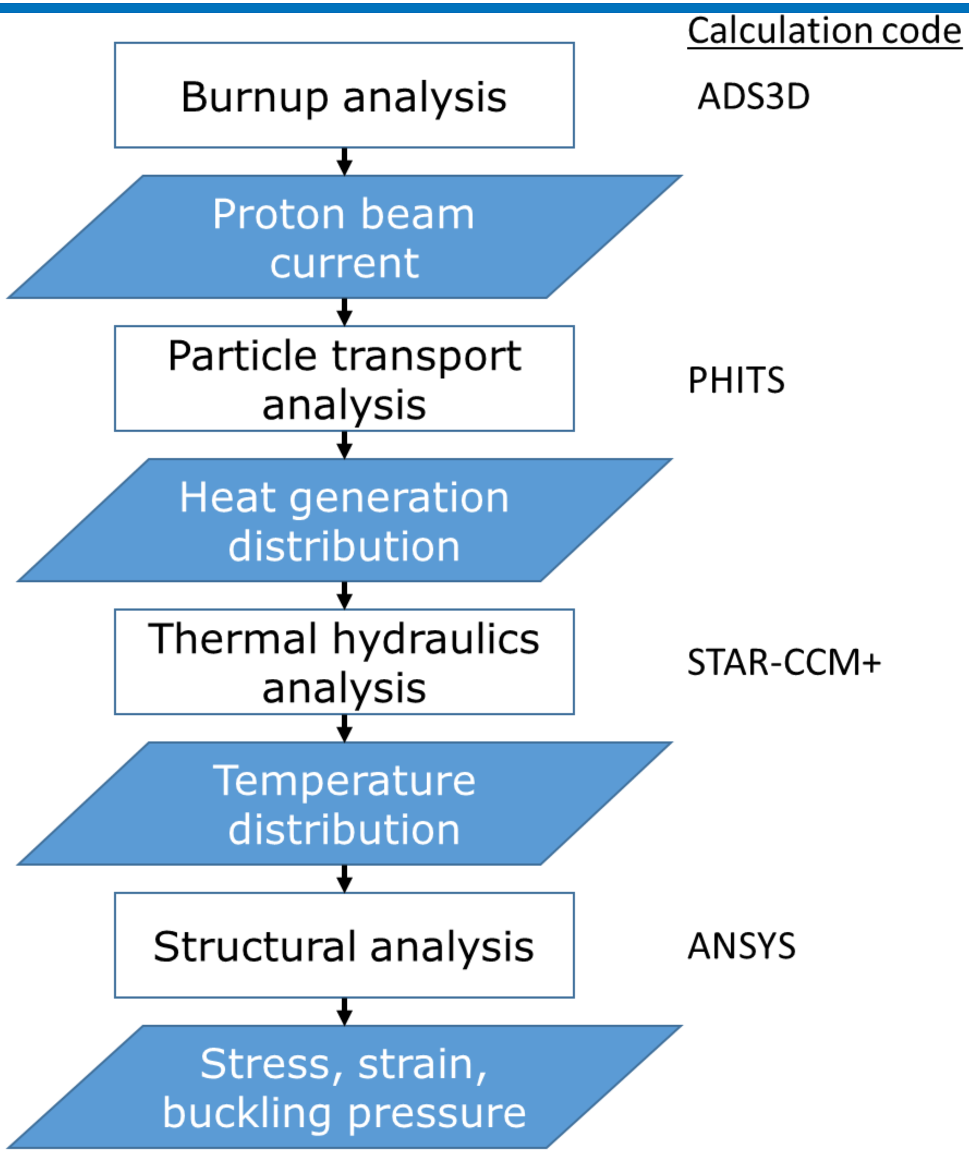
  → **More feasible beam window concept**

Calculation condition



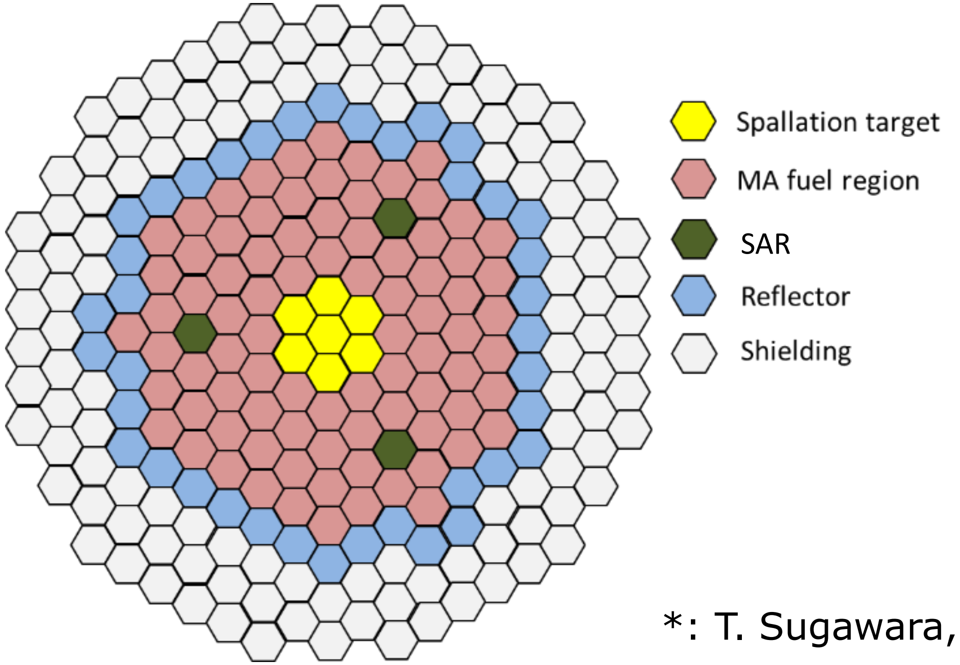
Thermal power	800 MWt
Coolant	LBE
Inlet temperature	300° C
Coolant velocity	2.0 m/sec
Upper limitation of keff	0.97
Operation period	600 EFPDs
Number of fuel assemblies	84
Pitch	233.9 mm
Width	232.9 mm
Number of fuel pins per assembly	391
Composition	(MA+Pu)N+ZrN
Pin outer diameter	7.65 mm
Thickness of cladding tube	0.5 mm
Pin pitch	11.48 mm
Active height	1000 mm

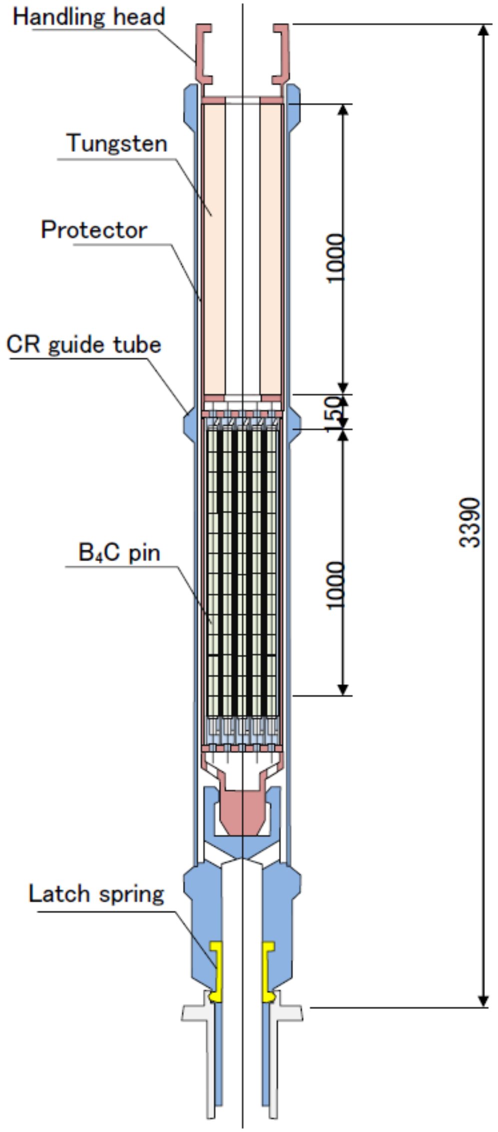
Calculation flow



Burnup analysis

- ADS3D code* was employed
  - Neutron transport in 3D geometry (deterministic method) and burn-up calculation were performed
- Calculation condition
  - 3 SARs (B_4C type) were placed in fuel region
  - To prevent the SAR drawing, tungsten block was added to the SAR.
  - All SARs were drawn 20cm by each 100days during the operation





*: T. Sugawara, et al., JNST, 53, 12, 2016

Results

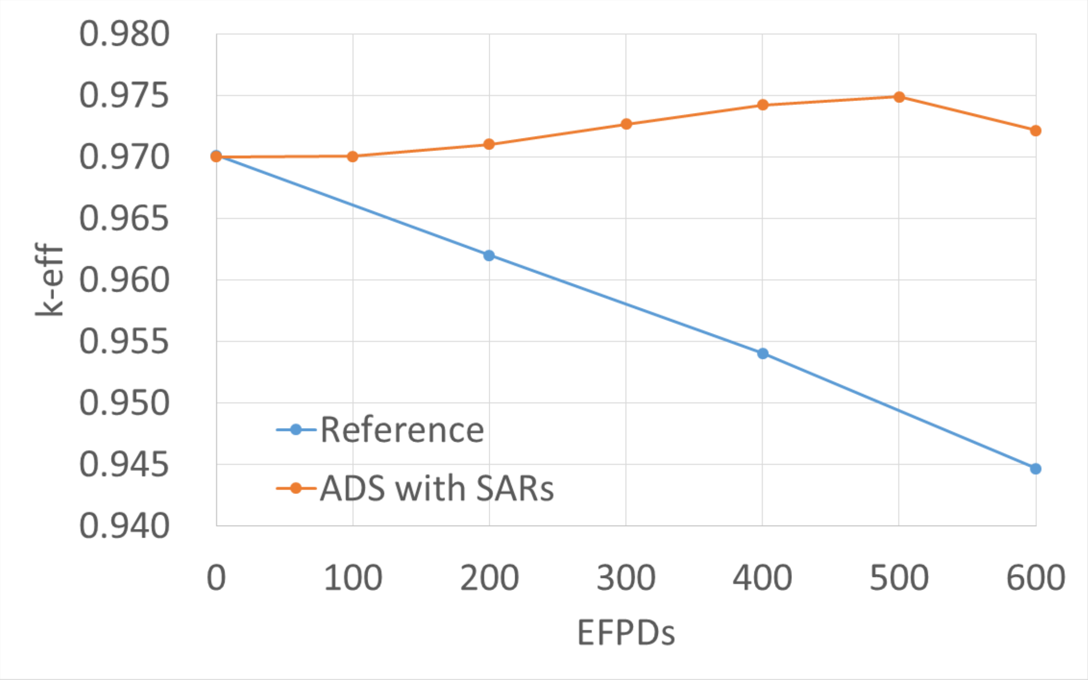


Fig. Change of the k-eff value

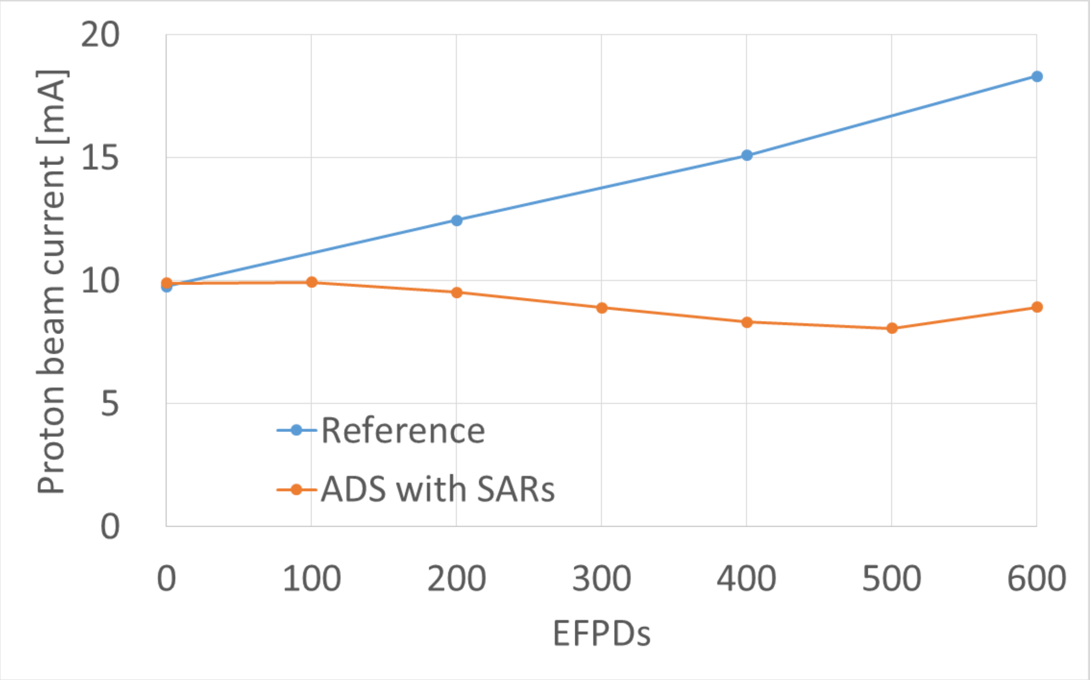


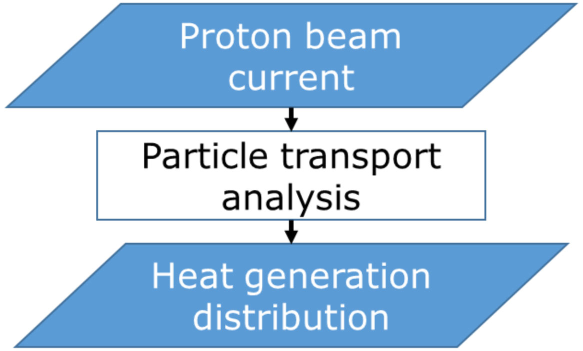
Fig. Change of the proton beam current

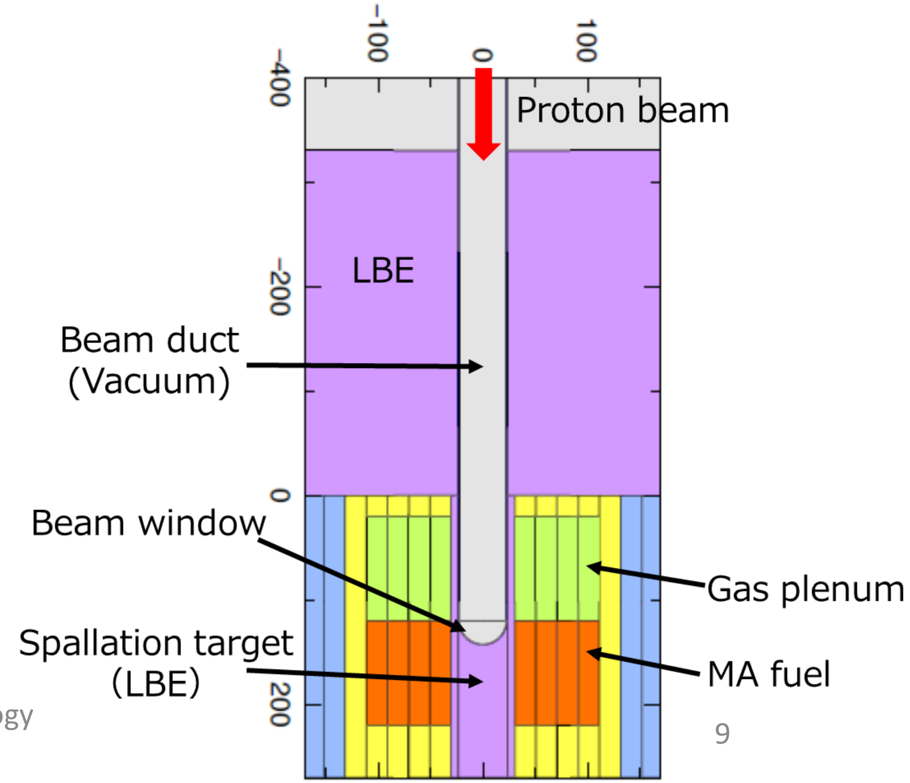
- The k-eff value would be maintained 0.97 during the cycle because it is possible to move SARs by mm/sec unit.
- This concept could maintain the proton beam current about **10mA** (20mA in the previous study)

Particle transport analysis

- PHITS code was employed.
- Gaussian profile was assumed.

	Previous study	This study
Proton beam energy [GeV]	1.5	←
Proton beam current [mA]	20	**10**
Beam duct radius [mm]	235	←
Shape of beam window	Ellipse	**Hemispherical**
Thickness of beam window at top [mm]	2.0	←
Thickness of beam duct [mm]	10.0	←
1σ of Gaussian profile for proton beam [mm]	111.6	←





Results

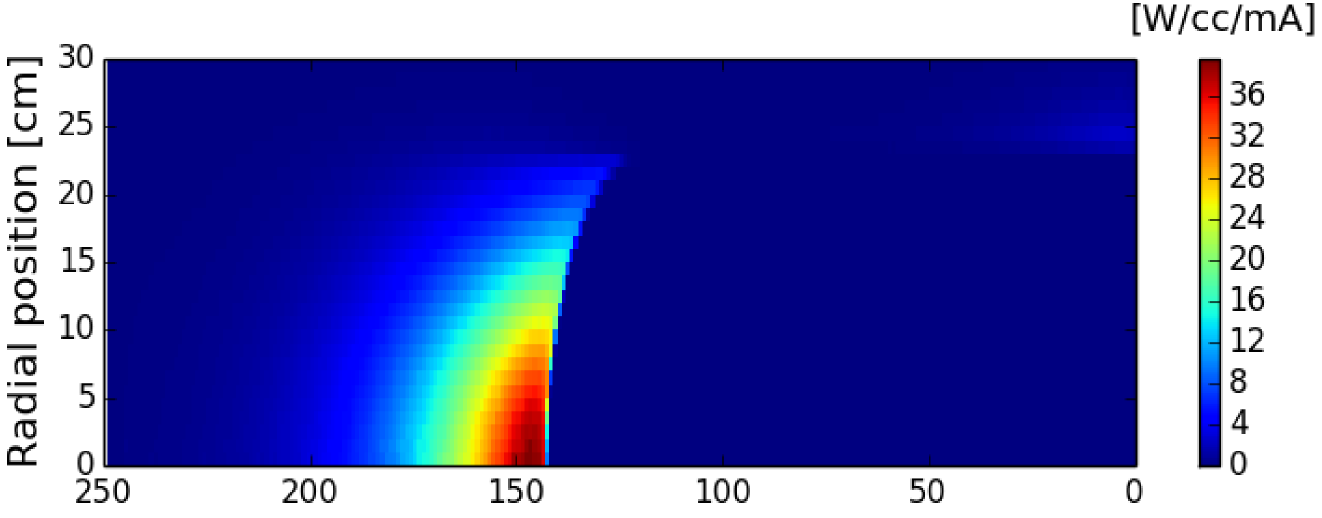


Fig. Heat generation distribution in target region

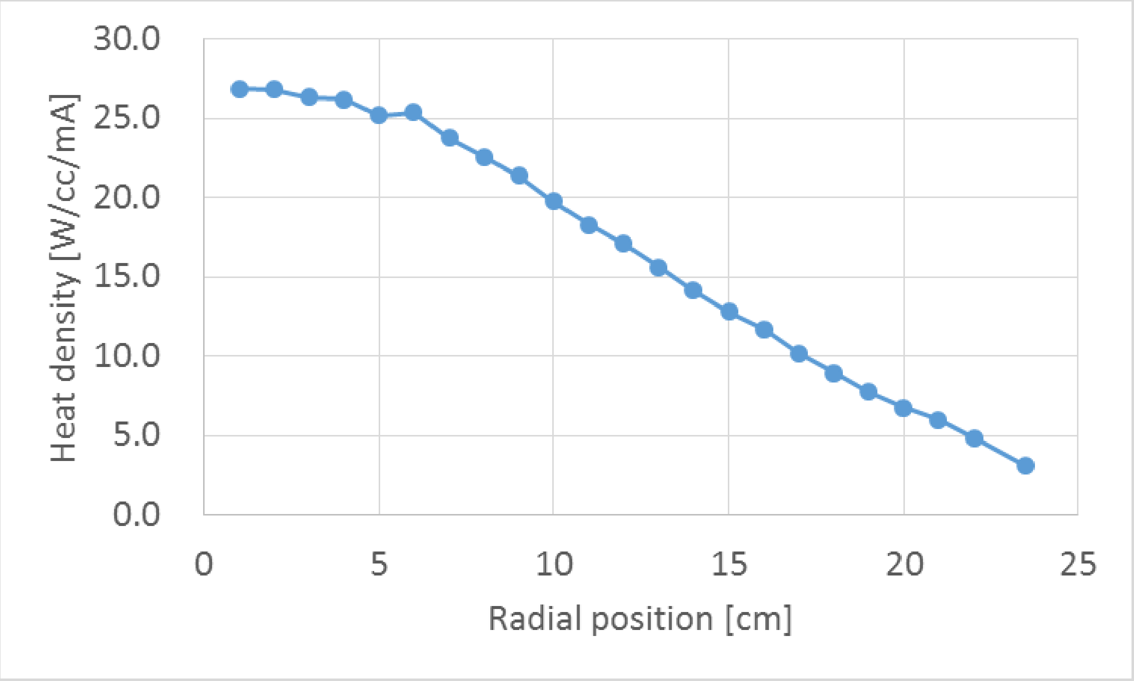
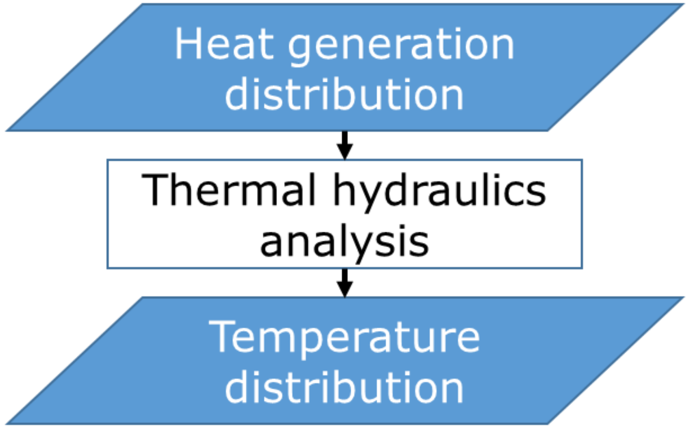


Fig. Heat generation distribution in beam window

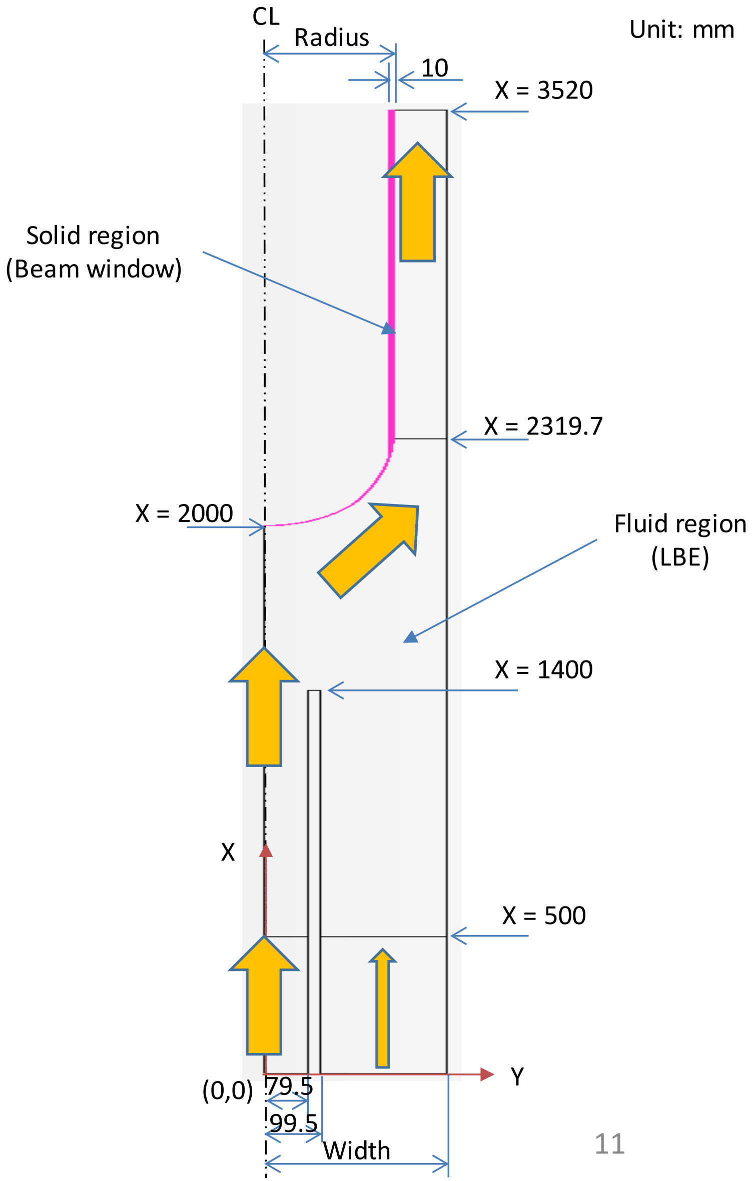
- The maximum heat density was about 40 W/cc/mA in the spallation target
- The heat density at the top of the beam window was 27 W/cc/mA

Thermal hydraulics analysis

- STAR-CCM+ code was employed



LBE velocity at the inlet	2.0 m/sec
LBE temperature at the inlet	300 ℃
Turbulence model	k-ε model
Material of beam window	T91 steel



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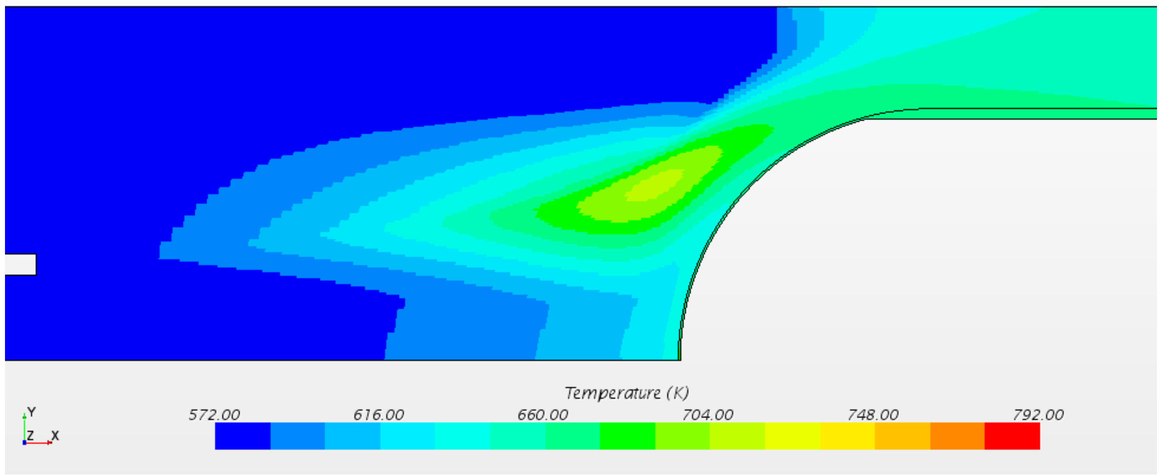


Fig. Temperature distribution in spallation target region

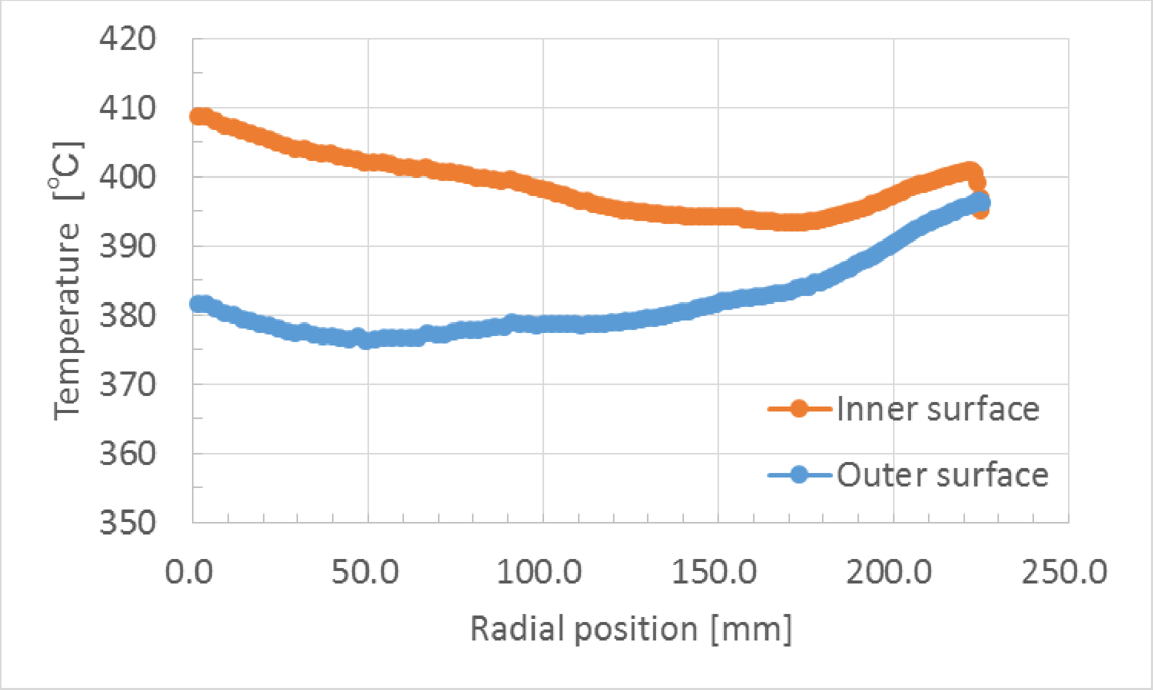


Fig. Temperature distribution in beam window

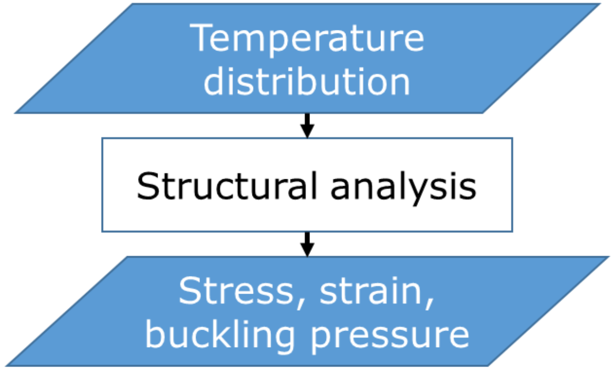
- The maximum temperature in the beam window was 409℃ (516℃ in previous study)
- The maximum difference of the temperature in the beam window was **27 ℃** (55℃ in previous study)

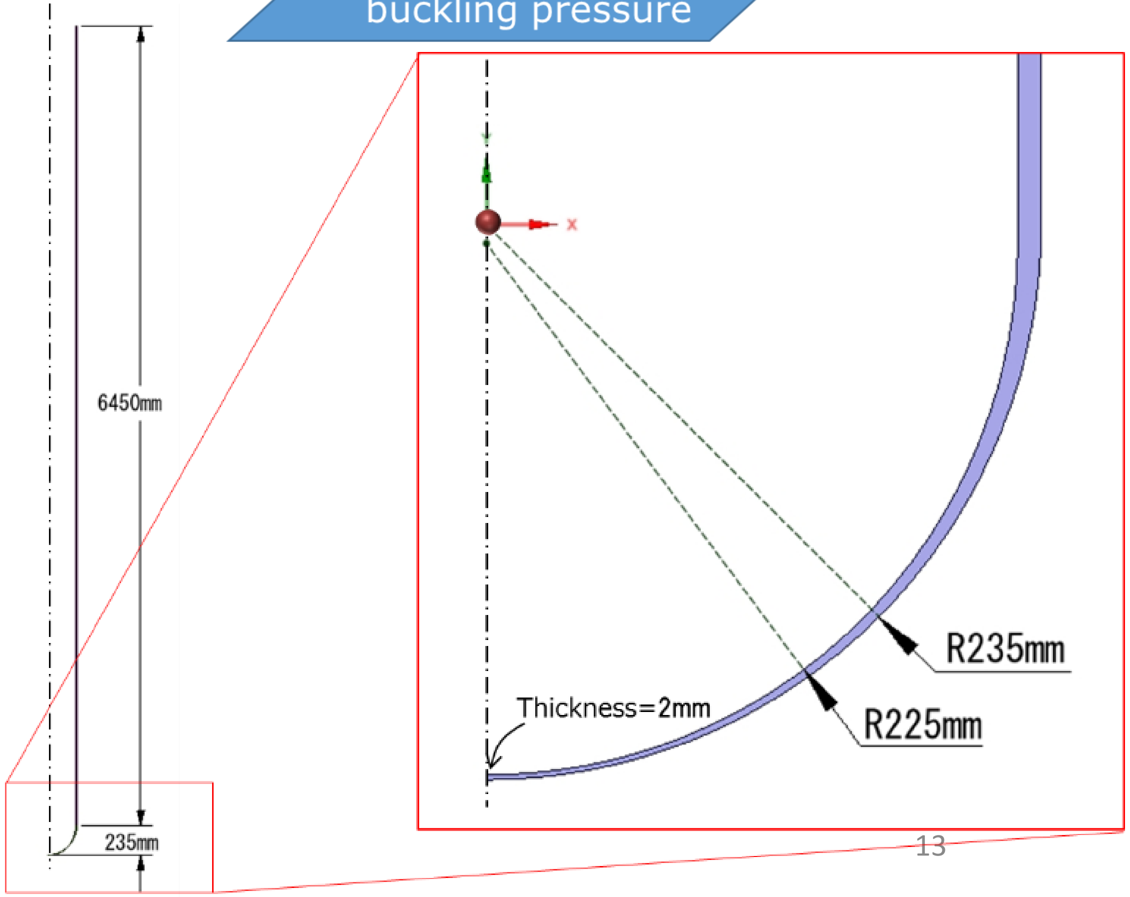
Structural analysis

- ANSYS code was employed
- Parametric survey was performed by changing the thickness (1-4 mm) of beam window.
- Approximate value derived from the following equation was used.

$$\mathrm{T(t)} = \mathrm{T}_O + Q(r)\left(\frac{t_0^2}{2}\right)\left(1-\left(\frac{t}{t_0}\right)^2\right)/\lambda$$

T: Temperature at thickness t, To: Temperature at outer surface
Q(r): Heat generation density at r, t_0: Thickness
λ: Thermal conductivity





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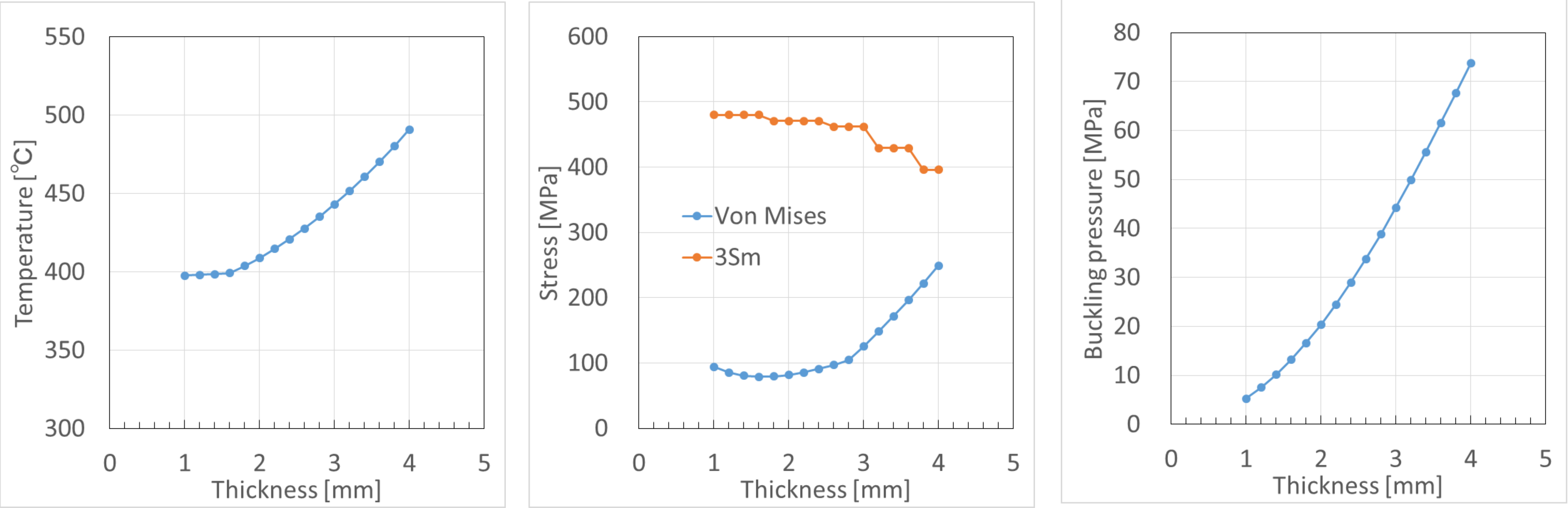

- Maximum temperature was less than 500℃ even if t=4 mm
- Von Mises stresses of all cases satisfied the criteria 3Sm
- The buckling pressure with 4 mm thickness was 3.6 times larger than the value with 2 mm thickness

  → Non-liner buckling analysis is required as the future work

Summary

	Previous study	This study
Proton beam energy [GeV]	1.5	←
Proton beam current [mA]	20	10
Number of SAR	-	3
Beam duct radius [mm]	235	←
Shape of beam window	Ellipse	Hemispherical
Thickness of beam window at top [mm]	2.0	4.0
Buckling pressure	4.1 [MPa]*	More than 3.6 times larger**

*: by non-liner buckling analysis
**: by liner buckling analysis

Concluding remarks

- To realize the small burnup reactivity, subcriticality adjustment rod (SAR) is introduced to the ADS.
- Maximum proton beam current was reduced from 20 to 10 mA by the use of 3 SARs.
- Through the coupling analyses, more feasible beam window concept (hemispherical shape, 4 mm thickness) was presented.

Acknowledgement

A part of this study is the result of "Research and development to solve the engineering issues for transmutation system using accelerator-driven system" carried out under the Innovative Nuclear Research and Development Program by the Ministry of Education, Culture, Sports, Science and Technology of Japan