The expected irradiation damage of CSNS target

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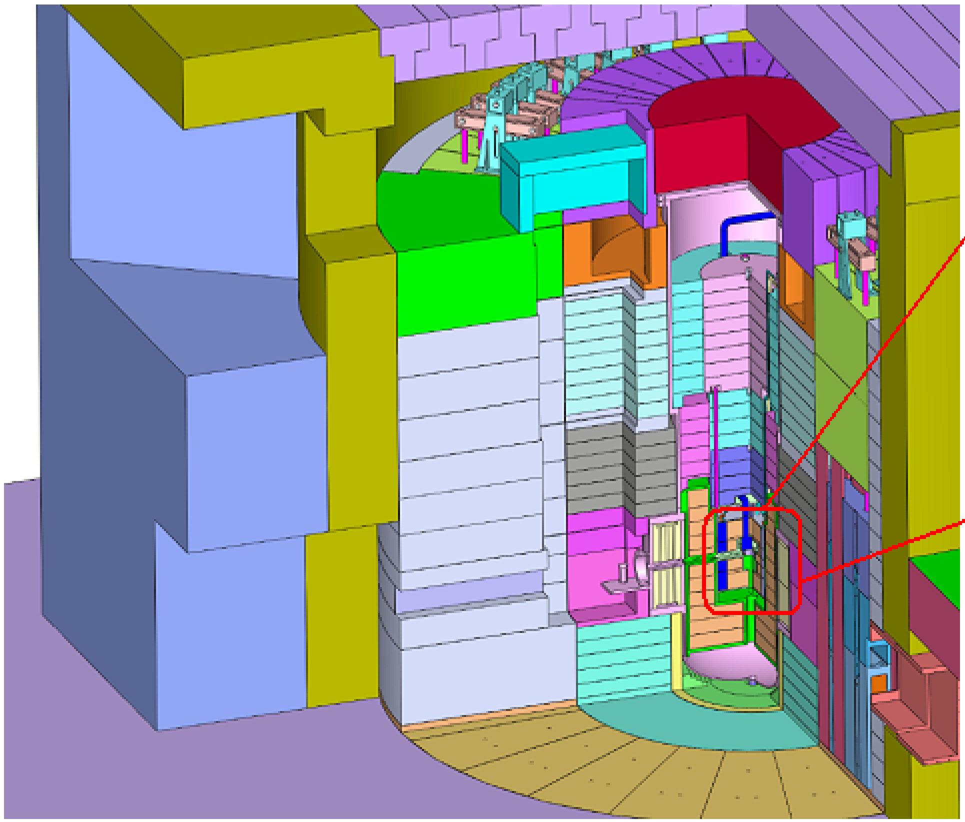
CSNS Experimental System

CSNS CHINESE ACADEMY OF SCIENCES

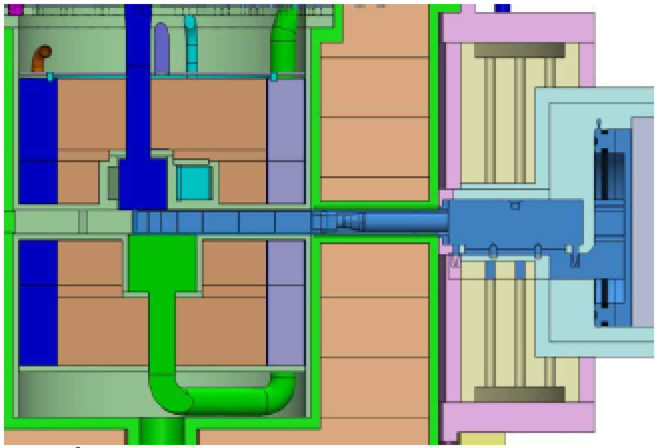
OUTLINE

- Introduction
- The irradiation damage evaluation of CSNS target
- The estimation of the lifetime of the target
- Summary

CSNS target station



The sketch of CSNS TS



CSNS TS will maintain the moderators and target separately to simplify remote handling in the hot-cell

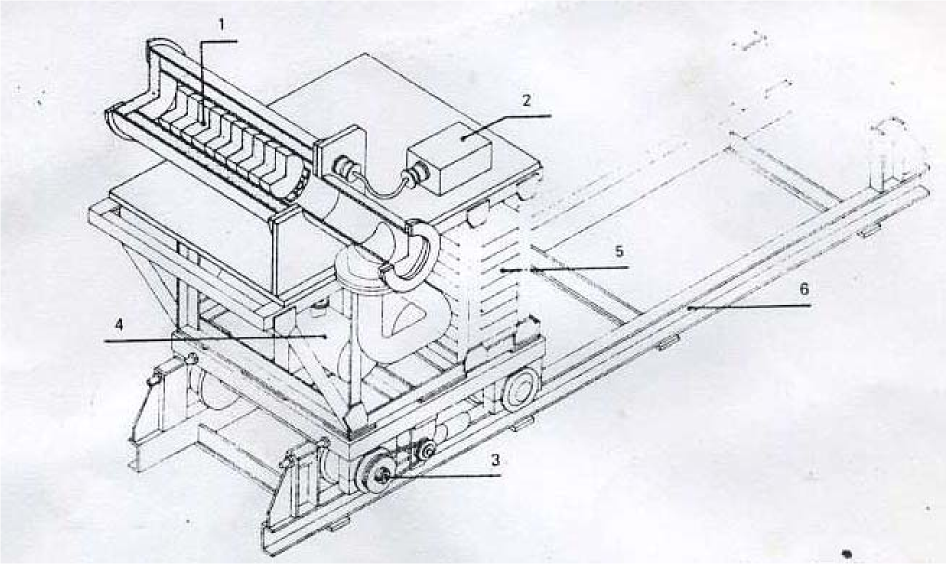
Quantities for the target damage due to irradiation

- Nuclear heating due to proton, neutron and gamma interactions with the nuclides

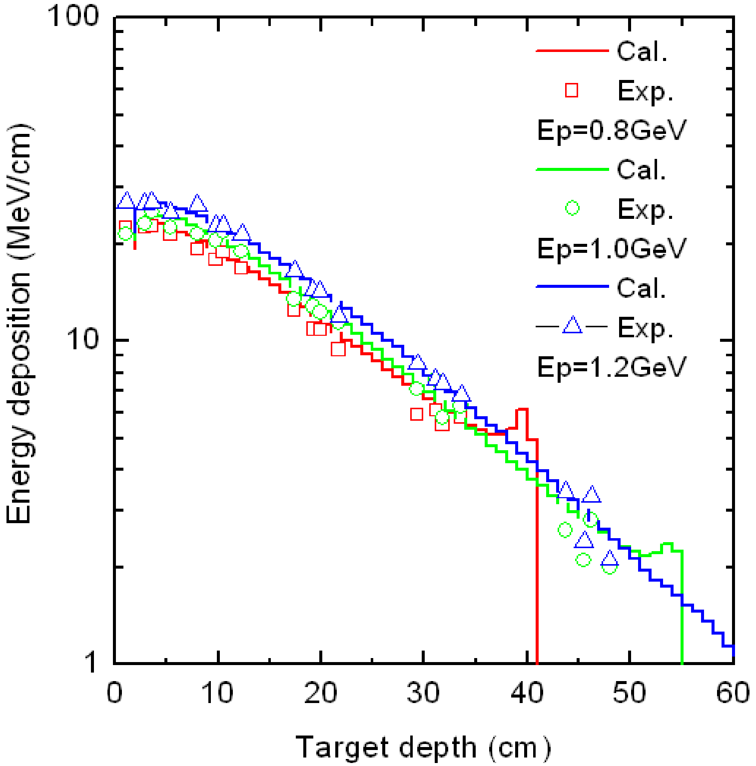
- Radiation damage in terms of the number of displacements per atom (dpa)

- The total helium and hydrogen production

Heat deposition of the target



Calorimeter measurement diagram of the facility



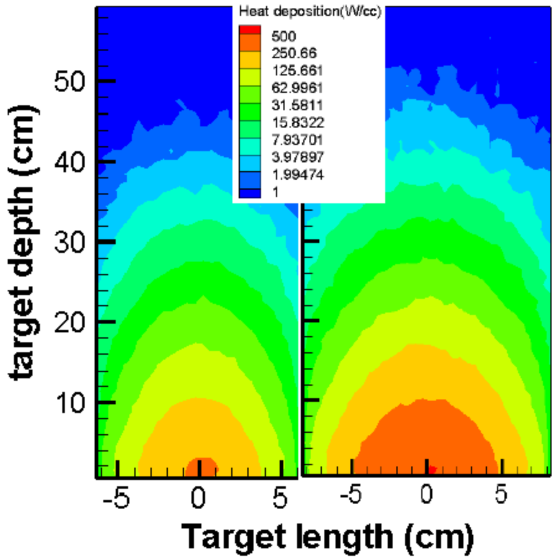
V.I.Belyakov-Bodin, V.D.Kazaritsky, et.al.

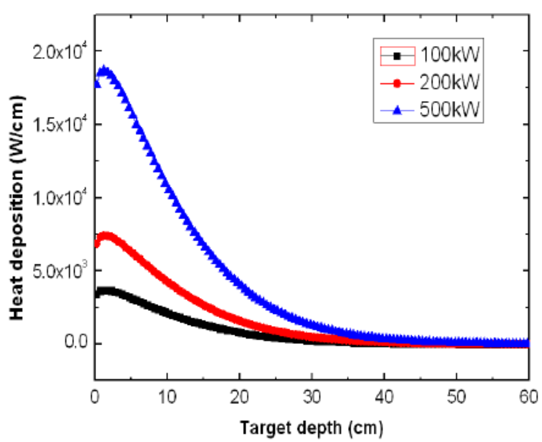
Institute of Theoretical and Experimental Physics, Russia

NIMA 295,140 343,508, 335,30

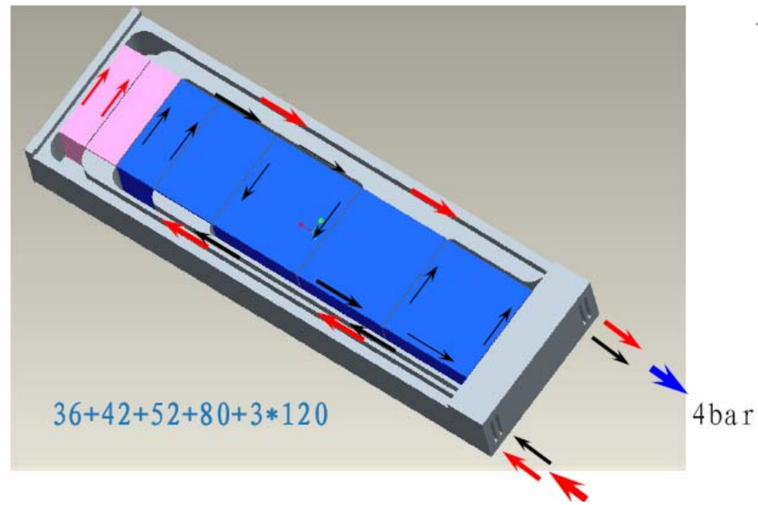
Comparison of the measured energy deposition with theoretical results (MCNPX2.5.0) in a Pb target

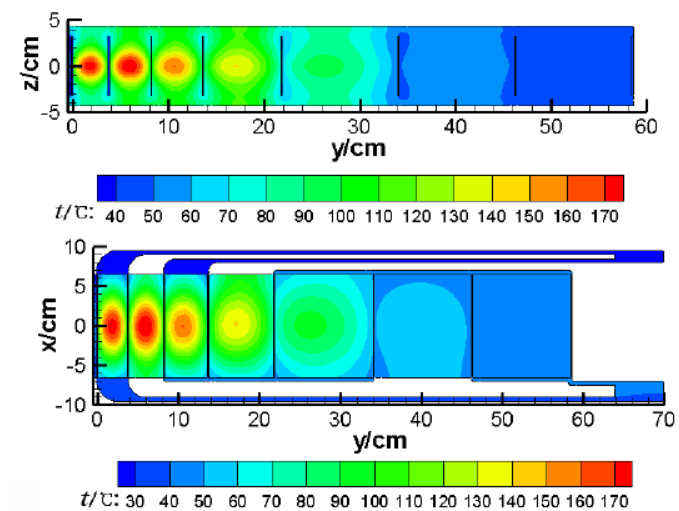
Heat deposition of the target





Heat deposition of the target





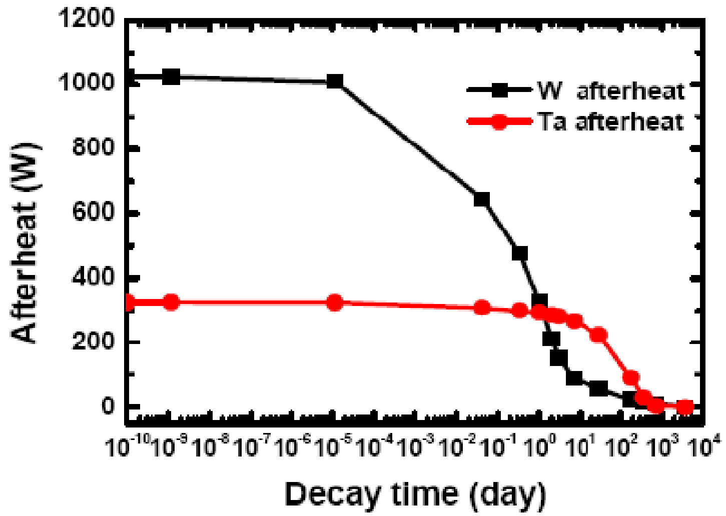
Flow rate

~130 liter/min

Pressure drop

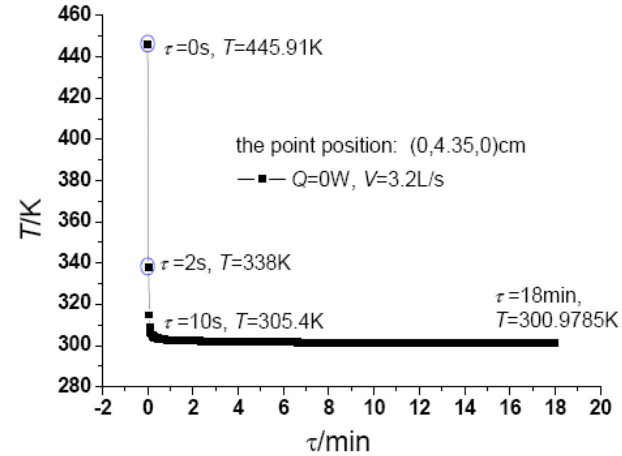
~25kPa

Afterheat of the target

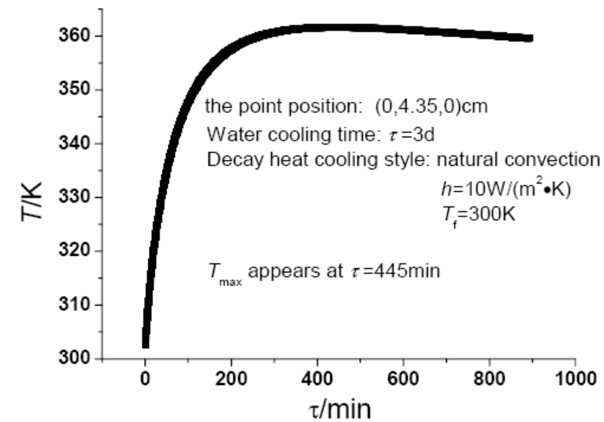


The afterheat of the target (beam power 240kW)

nuclide	λ	0s	1s	1h	8h	1d	2d	3d	7d	30d
W 187	1 d	33.5	33.5	34.0	51.7	57.2	52.3	40.0	27.3	2.9
W 185	75. 1d	2.8	2.8	4.4	6.0	8.7	13.2	18.0	30.5	37.6
Ta182	114 .4d	81.6	81.9	86.2	88.6	90.2	91.6	92.6	95.2	98.8

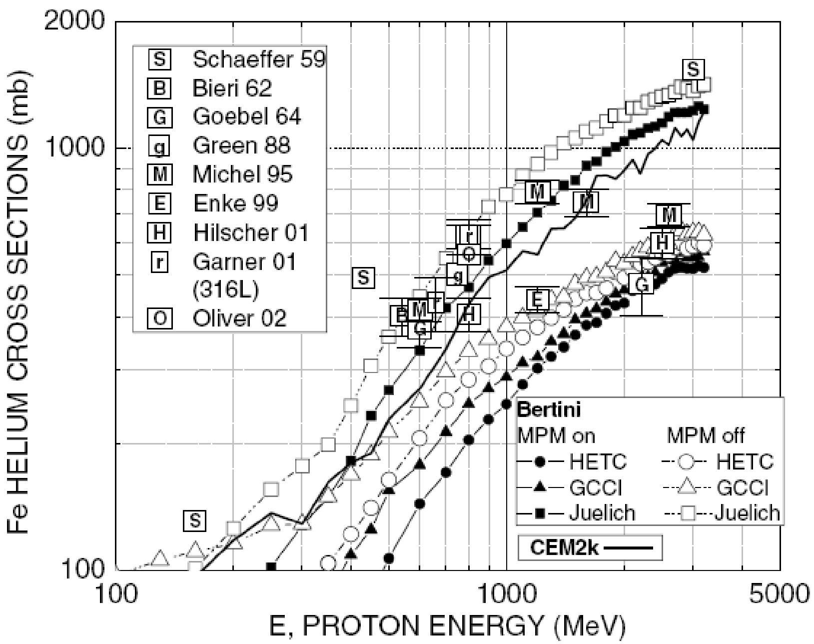


The temperature of the target when it is cooled by water after the beam stops

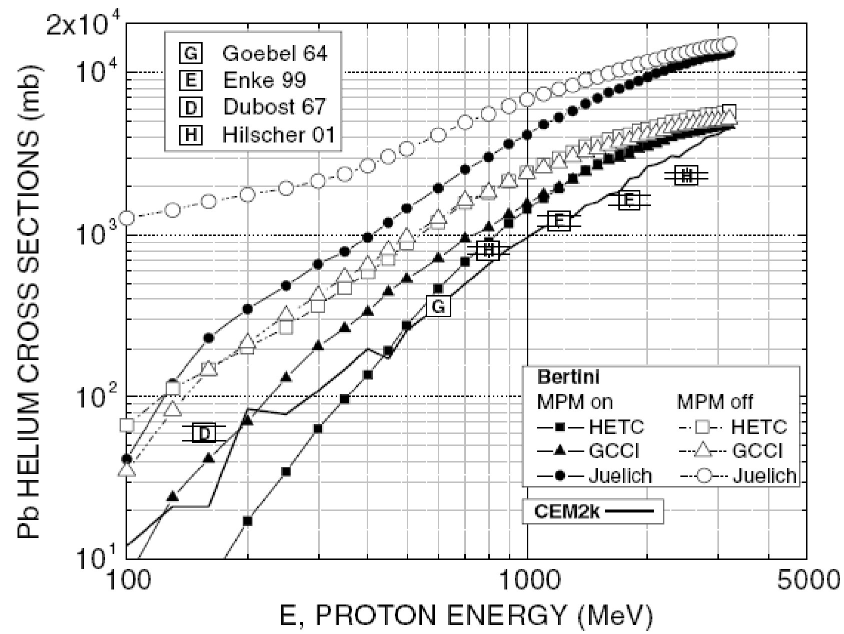


The temperature of the target when it is cooled by natural ventilation

Damage energy and gas production cross section



Helium cross section versus proton energy for Fe.



Helium cross section versus proton energy for Pb.

W.Lu, M.S.Wechsler, J.Nucl.Mater.361(2007)282

Damage energy and gas production cross section

- **Neutron transport**

  En<20 MeV ENDF/B-VI

  20MeV<En<150MeV LA150N

  En>150MeV

  CEM2K (tungsten)

  Bertini/Julich level denisty /MPM on(SS316)

- **Proton transport**

Ep<150MeV LA150H for He and H production

Ep>150MeV CEM2K (tungsten)

Bertini/Julich level denisty /MPM on(SS316)

Physics models are used for all damage energy calculation due to protons

Damage energy and displacement cross section

The calculation of Damage energy and displacement cross section

$$\sigma_e = T_{dam}/N_v x$$

σ_e = Damage cross section

T_{dam} = Mean Damage Energy per source particle (recoil energy, including elastic)

x = sample thickness

N_v = Atomic Density

$$\sigma_d = \sigma_e \beta/(2T_d) \quad \text{(Modified Kinchin-Pease model, NRT model)*}$$

σ_d = Displacement cross section

β = 0.8, deviation from a hard sphere (Kinchin & Pease). Compensates for forward scattering in the displacement cascade.

T_d = Threshold displacement energy (see table)

Factor of 2: on average the PKA (Primary Knocked-on Atom) energy is shared equally between two atoms after the first collision. Compensates for energy lost to subthreshold reactions.

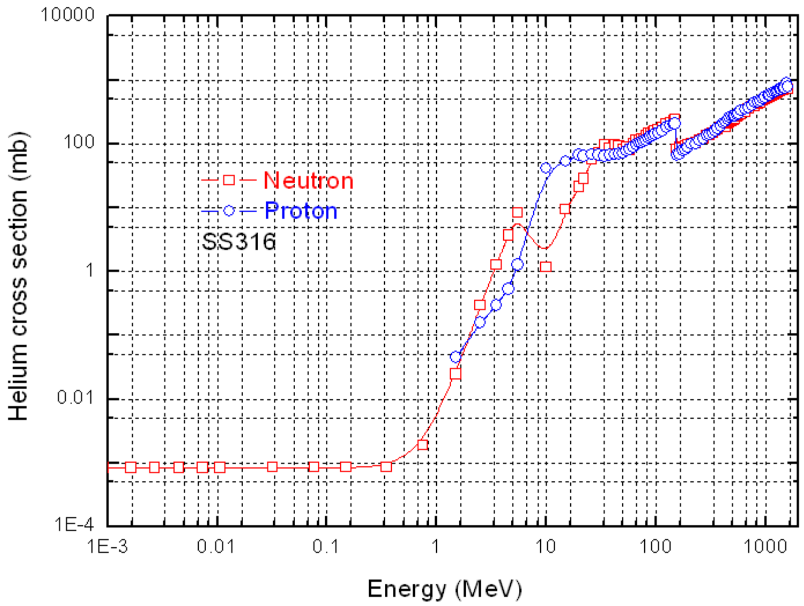
*M.J.Norgett, M.T.Robinson, and I.M.Torrens, Nucl.Eng.Des.33,50 (1975)

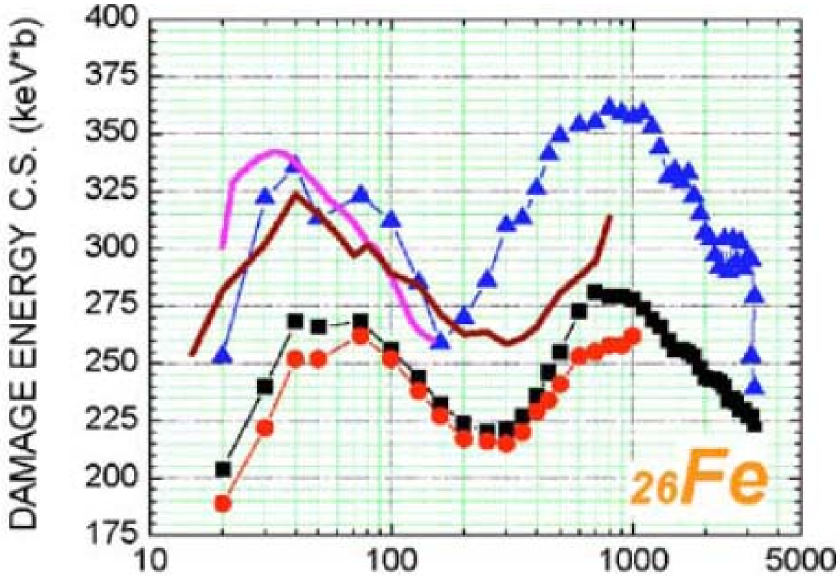
Damage energy and displacement cross section

Threshold Displacement Energies Td

Element	Td (eV)
Lithium	10
Beryllium	31
Carbon	31
Aluminum	27
Silicon	25
Chromium	40
Iron	40
Nickel	40
Copper	40
Zirconium	40
Niobium	40
Molybdenum	60
Tin	60
Tantalum	53
Tungsten	90
Lead	25

Damage energy and gas production cross section





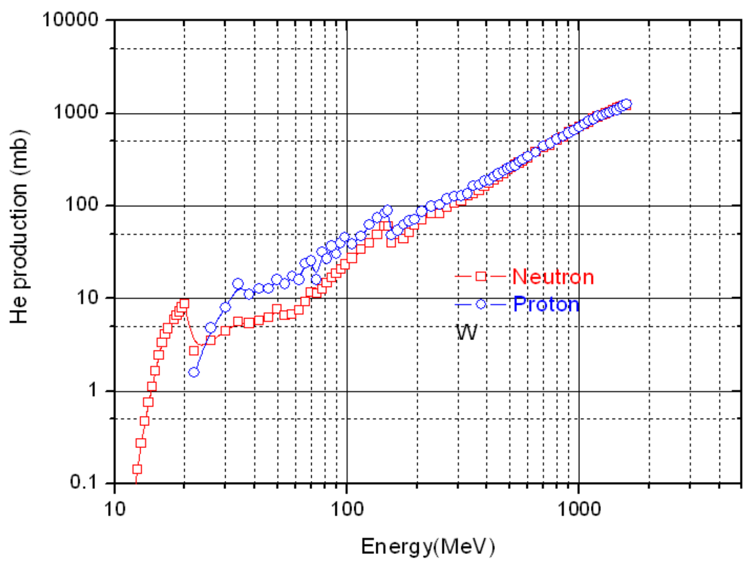
Neutron and proton induced damage energy and gas production cross sections by ENDF/B-VI (En<20MeV), LA150 (20MeV<En<150MeV), and Bertini/Julich/MPM on for SS316 (En>150MeV, Ep>1MeV).

Neutron induced damage energy cross section by Bertini (black), ISABEL (red), CEM (blue)

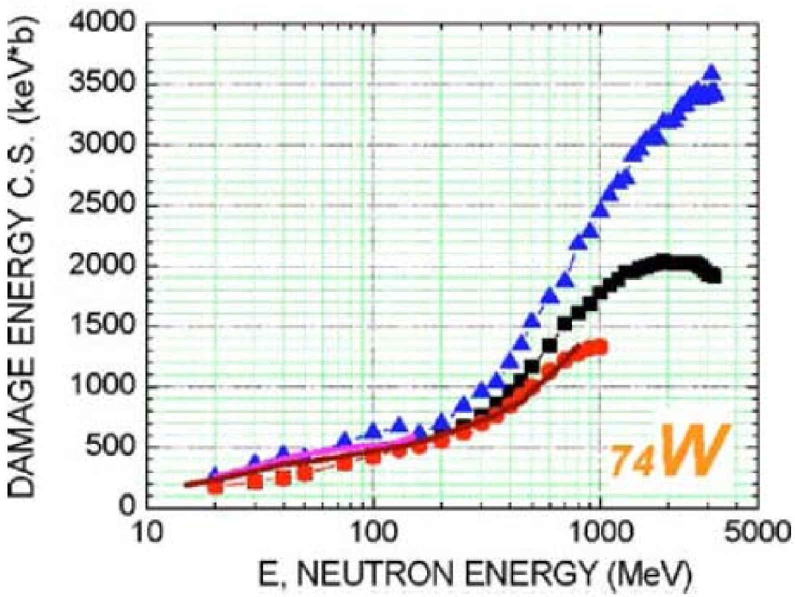
LA150 (line)

From Wei Lu et al J.ASTM International Vol.3.No.7

Damage energy and gas production cross section libraries



Neutron and proton induced damage energy and gas production cross sections by ENDF/B-VI (En<20MeV), LA150 (20MeV<En<150MeV), and CEM2K for tungsten (En>150MeV, Ep>1MeV).

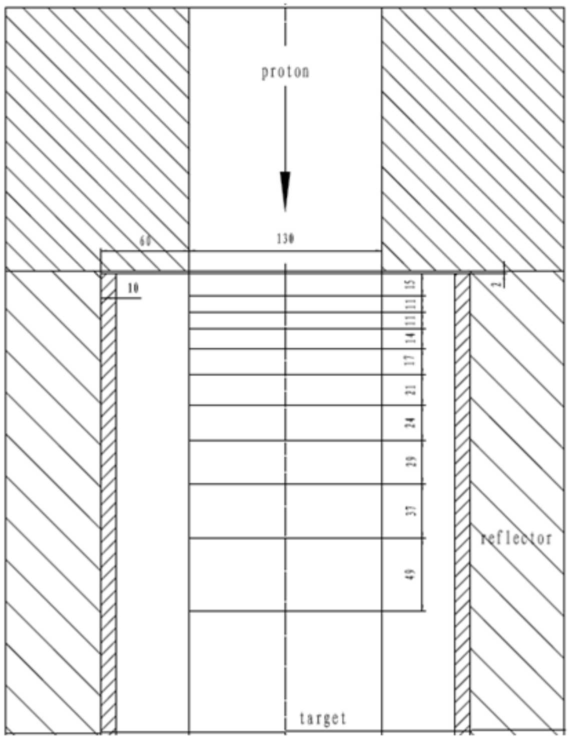


Neutron induced damage energy cross section by Bertini (black), ISABEL (red), CEM (blue)

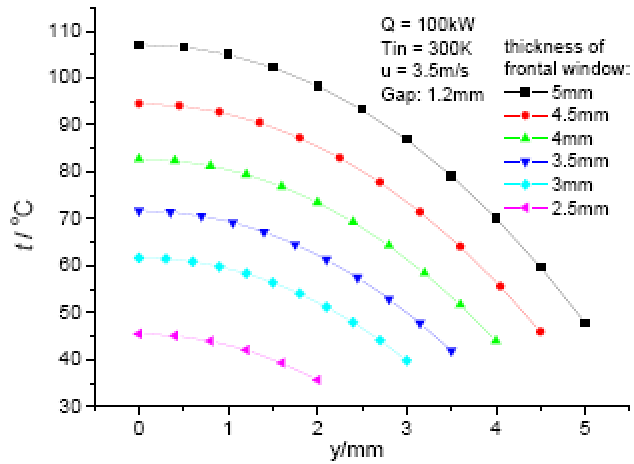
LA150 (line)

From Wei Lu et al J.ASTM International Vol.3.No.7

The calculation model of CSNS target



Horizontal cut of MCNPX model



the

center

All calculations are for 100kW and 5,000 hours (1 operating year).

Proton beam profile

Energy 1.6GeV

Gaussian

Wide FWHM 66 mm

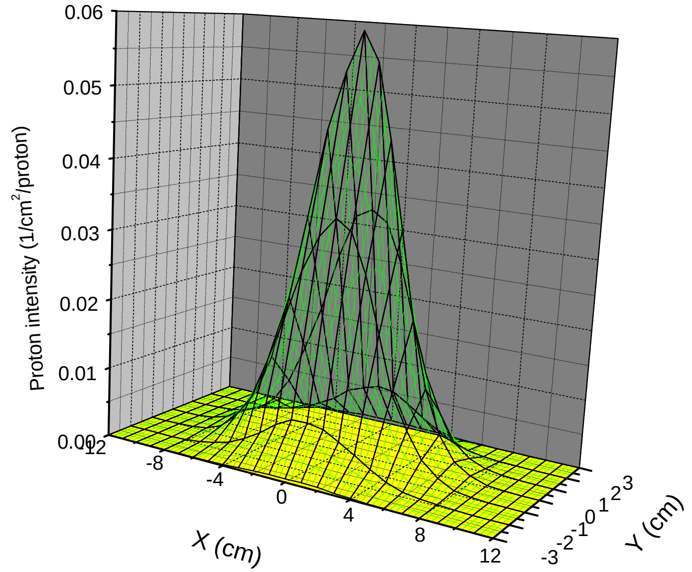
Height FWHM 22 mm

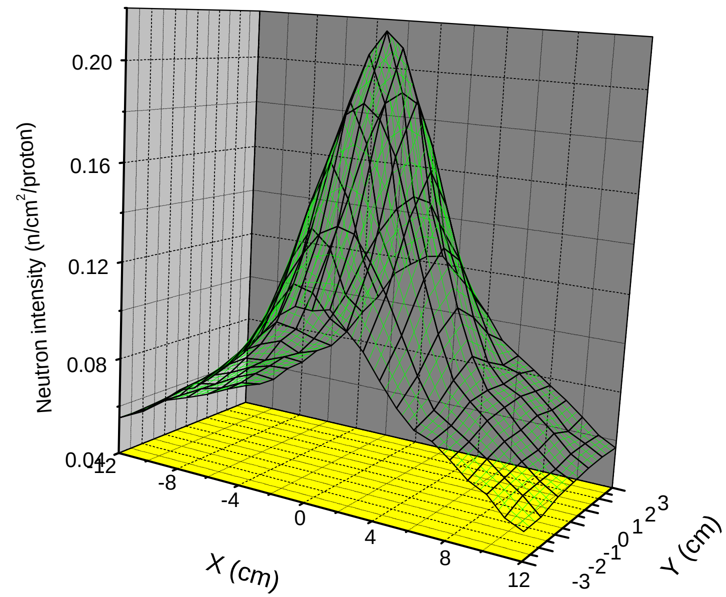
Uniform

Wide 120 mm

Height 40 mm

The proton and neutron flux of the target vessel window: Gaussian



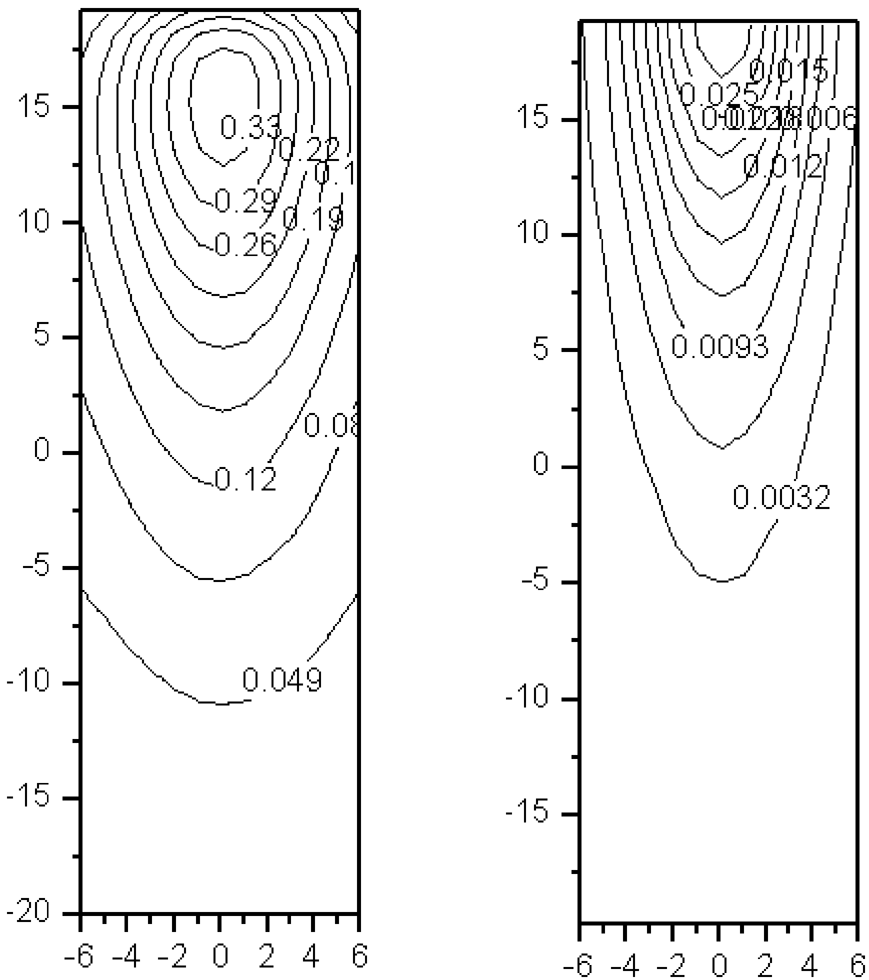


Double Gaussian distribution

Wide FWHM 66 mm Height FWHM 22 mm

Peak current density 3.86 μ A/cm^2

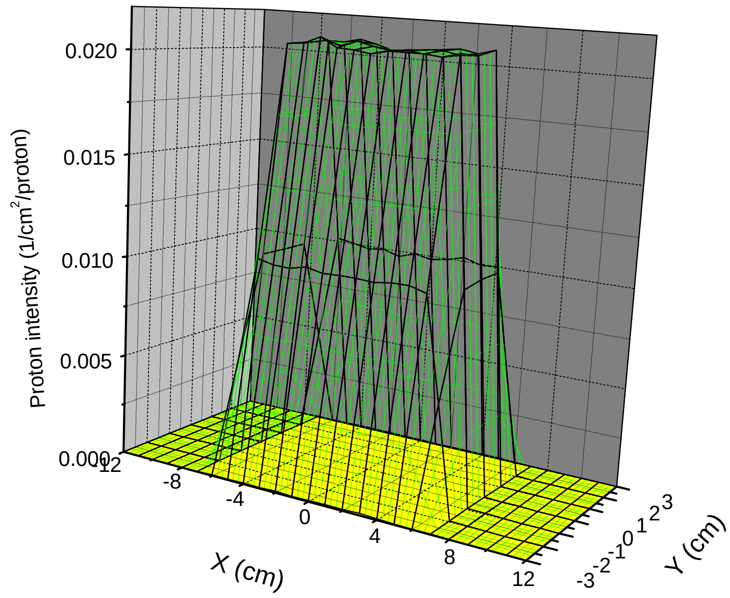
The proton and neutron flux of the target : Gaussian

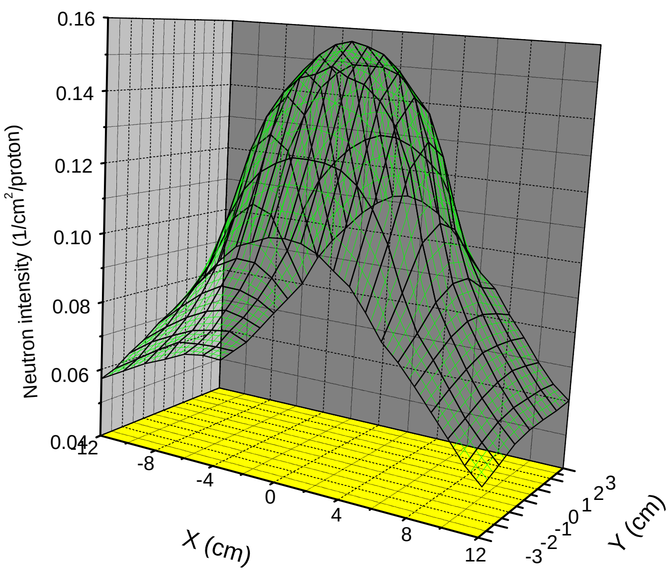


The neutron and proton fluxes of the target

The maximum neutron flux located on the fourth target plate and the maximum proton flux located on the first target plate

The proton and neutron flux of the target vessel window: uniform



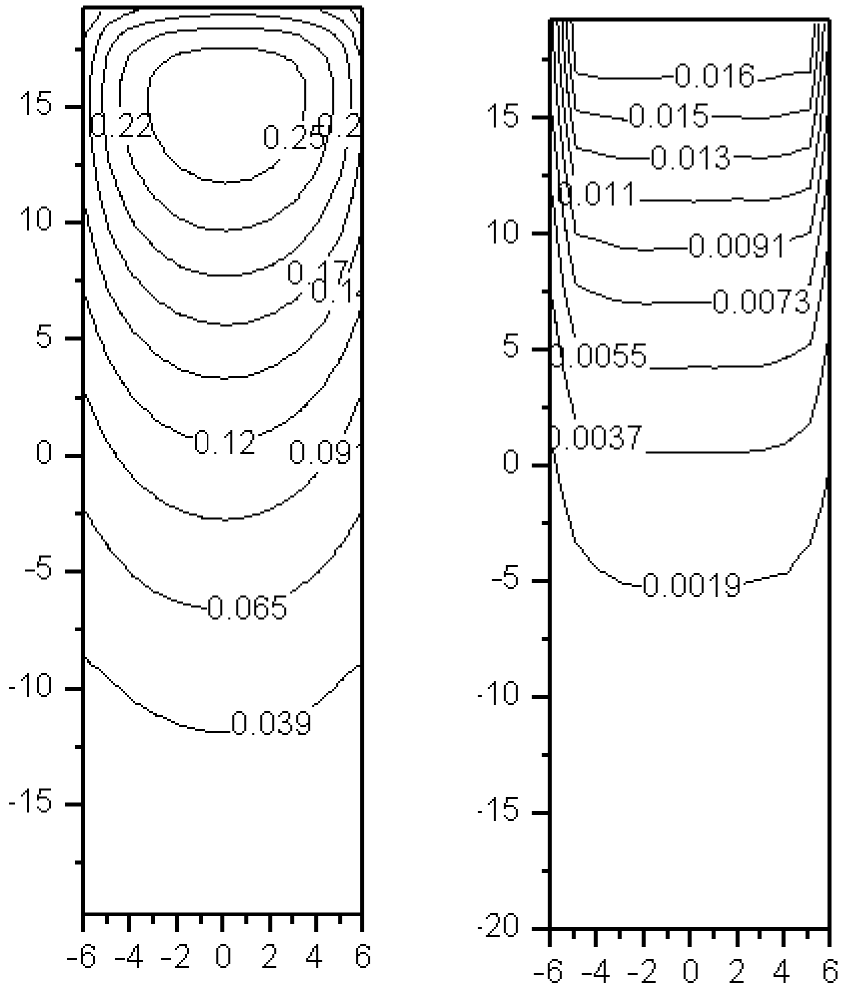


Flat distribution

Wide 120 mm Height 40 mm

Peak current density **1.30 μ A/cm²**

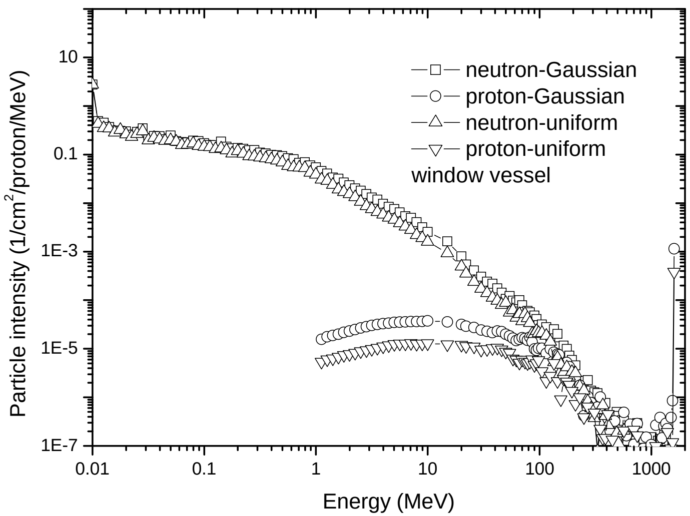
The proton and neutron flux of the target : uniform

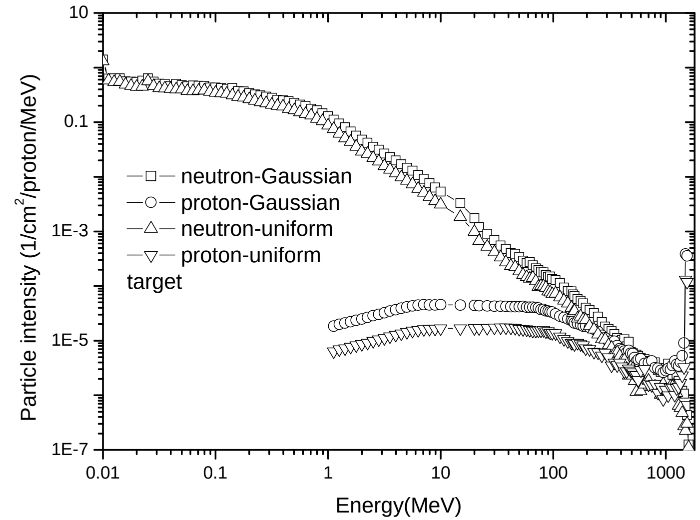


The neutron and proton fluxes of the target

The maximum neutron flux located on the fourth target plate and the maximum proton flux located on the first target plate

The damage evaluation of CSNS target





The neutron and proton fluxes under to inject proton profile (a) the vessl window (b) the forth target

Calculation the damage of dpa and gas production by folding the fluxes into the damage and gas production cross sections

The damage evaluation of CSNS target

Radiation damage rate

	Uniform	Gaussian	SNS
Displacement (dpa/yr)			
Window	1.29	2.52	21
Target	2.20	5.37	
Proton flux in tally zone* ($\times 10^{14}$ p/cm^2/s)			
	0.078	0.25	1.52
Neutron flux in tally zone* ($\times 10^{14}$n/cm^2/s)			
	0.60	0.86	8.78

* Data from M.H.Barnett J.Nuclear Materials 296 (2001) 54

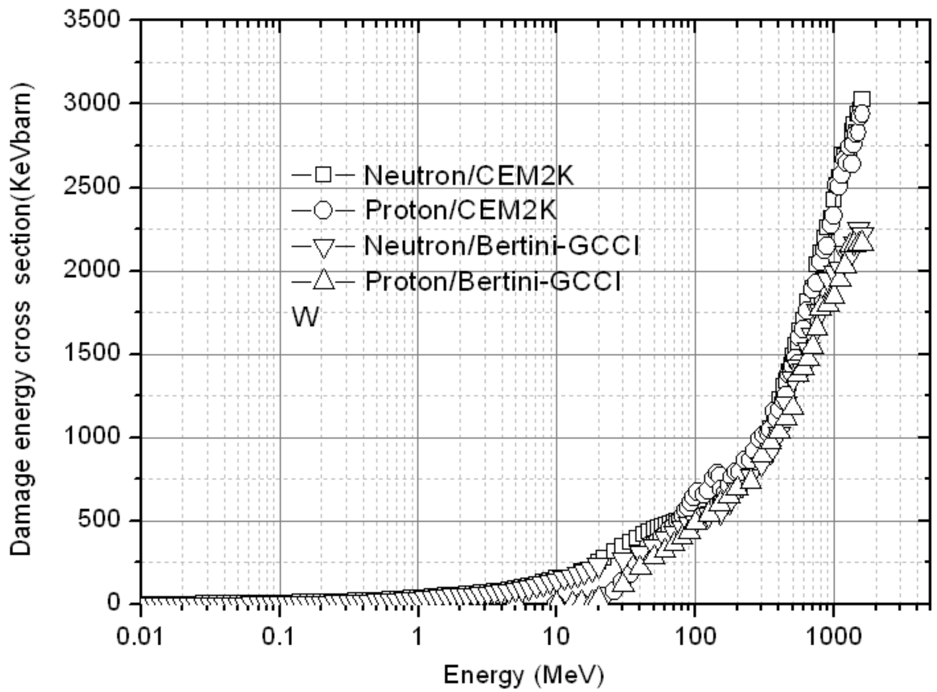
He production appm/dpa=80 , H production appm/dap=300

Estimation of the life time of the target

	Uniform	Gaussian	Allowable DPA
Lifetime			
Window	~8	~4	10
Target	~5	~2	10

Life time is dominated by the dpa of the front target

Summary



- The appropriate choose of the physics model for the different materials
- The proton beam profile especially its peak intensity is very important

The damage energy cross section under the different physics model

W.Yin, T.J.Liang, Q.Z.Yu, X.J.Jia J.Nucl.Mater. 398 (2010)100

Thank you for your attention!