Induced activity in coolant, air, soil and groundwater of CSNS target station

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Outline

- Calculation methods
- Activation calculation of coolant
- Activation calculation of airborne radionuclide
- Activation calculation of soil and groundwater
- Summary

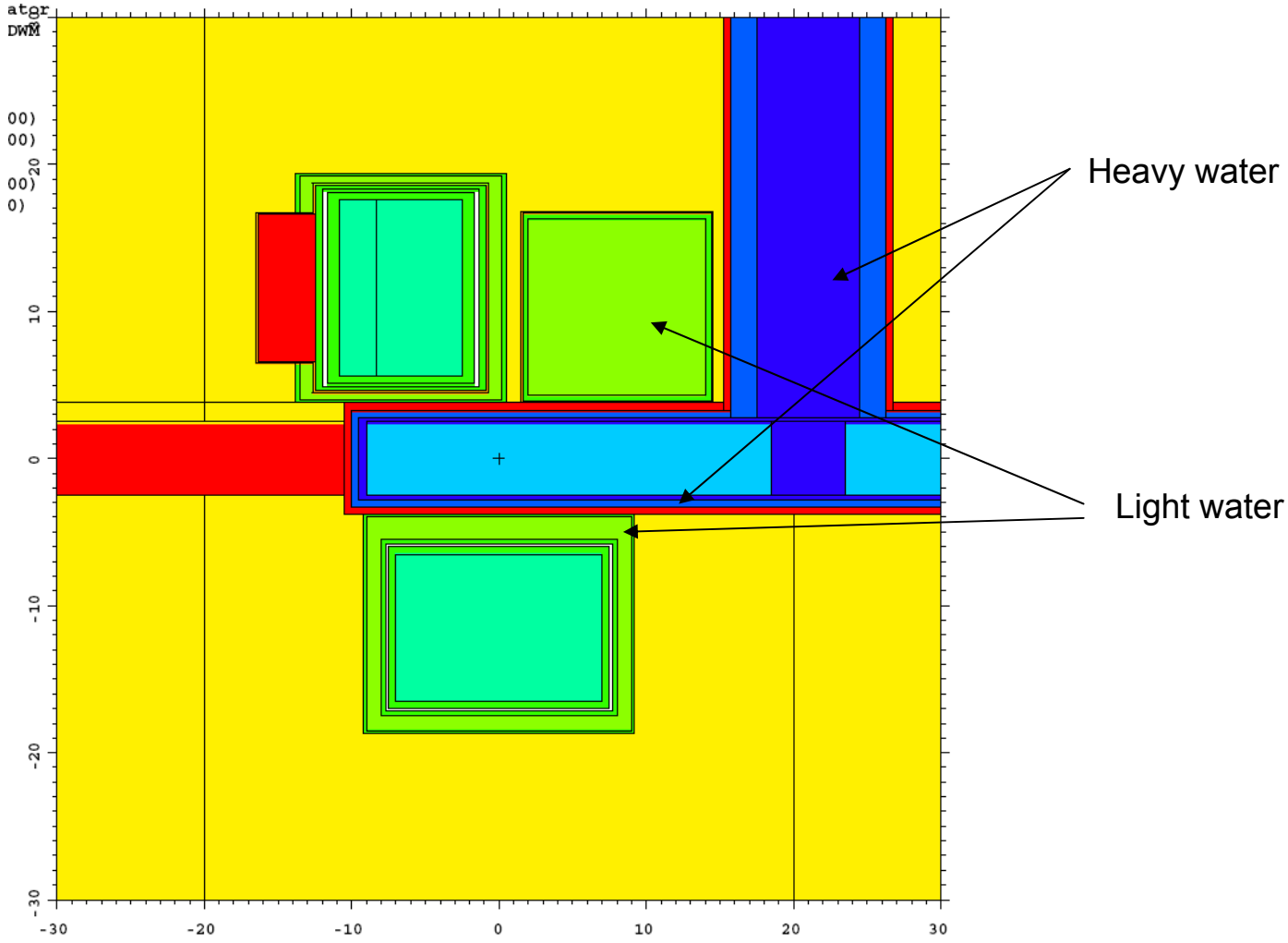
Calculation Methods

- Code system: MCNPX 2.5 + Activation Script 0.5 + Cinder90 6.2
- Flux and histp calculations were run separately, Mix-and-Match was used for flux calculation.
- Bertini model for INC
- 1.6GeV proton, 240kW (9.375E+14 proton/s)
- Gaussian beam profile (FWHM 10cm x 1.5cm)
- CSNS rotating target + three moderators configuration

Activation of Coolant in Target Station

- There are many cooling loop in CSNS target station, the coolants become highly active during operation. This leads quiet high radiation level around the pipe. We need the activity levels of these loops for design and maintenance of these loops.

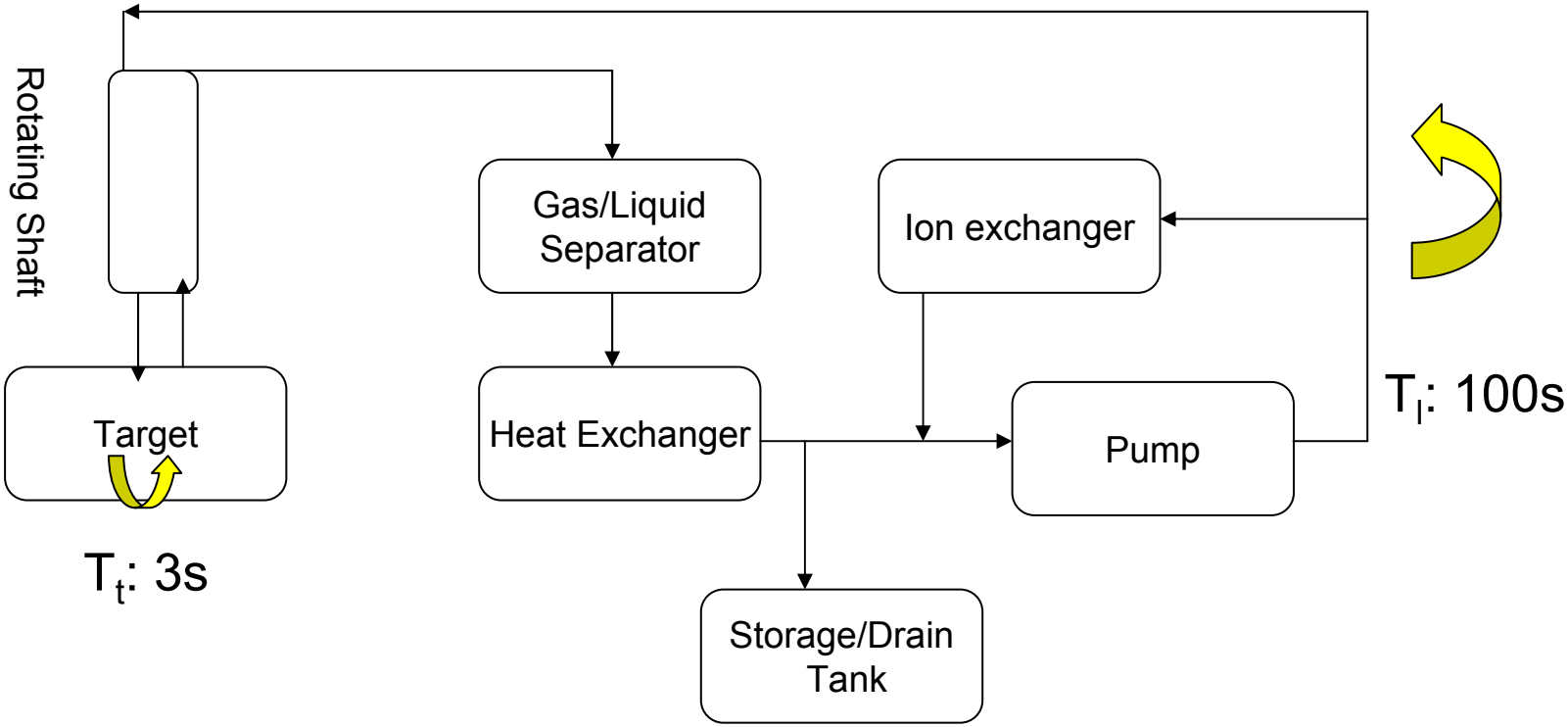
Geometry for activation calculation of coolant



Production Rate of Radionuclide in Heavy Water for Target Cooling

Radionuclide	halftime (s)	spallation production rate (/p)	Total production rate (/p)
H 3	3.89E+08	3.06E-03	3.31E-03
Be 7	4.61E+06	4.56E-04	4.56E-04
C 11	1.22E+03	8.77E-04	8.77E-04
C 15	2.45E+00	2.94E-05	2.94E-05
N 13	5.98E+02	3.12E-04	3.15E-04
N 16	7.13E+00	1.49E-05	1.80E-03
O 14	7.06E+01	9.87E-05	9.87E-05
O 15	1.22E+02	2.94E-03	2.98E-03

Flow Chart of Heavy Water Loop



Activity density for a single nuclide in target heavy water

$$C_i(t) = \frac{R(1-e^{-t_t\lambda})e^{-t_l\lambda}(1-e^{-t\lambda})}{V(1-e^{-t_l\lambda})}$$

R — production rate

λ—decay constant

t—running time

t_t—the time of volume V of heavy water pass through the target

t_l—circulation of heavy water through the loop

V—Volume of Heavy water in target

Building up of activity

nuclide	halftime (s)	Activity density (Ci/cc) at differnet irradiation time					
		1s	1m	1h	1d	7d	∞
H 3	3.89E+08	1.93E-12	1.16E-10	6.93E-09	1.66E-07	1.16E-06	1.08E-03
Be 7	4.61E+06	2.24E-11	1.34E-09	8.06E-08	1.92E-06	1.29E-05	1.49E-04
C 11	1.22E+03	1.58E-07	9.32E-06	2.42E-04	2.78E-04	2.78E-04	2.78E-04
C 15	2.45E+00	2.34E-17	9.51E-17	9.51E-17	9.51E-17	9.51E-17	9.51E-17
N 13	5.98E+02	1.12E-07	6.51E-06	9.54E-05	9.69E-05	9.69E-05	9.69E-05
N 16	7.13E+00	2.76E-08	2.97E-07	2.98E-07	2.98E-07	2.98E-07	2.98E-07
O 14	7.06E+01	1.83E-07	8.32E-06	1.87E-05	1.87E-05	1.87E-05	1.87E-05
O 15	1.22E+02	4.06E-06	2.07E-04	7.17E-04	7.17E-04	7.17E-04	7.17E-04

Result Analysis and discussion

- Tritium released from target?
- Be7 filter efficiency ?
- Dose calculation along pipe is processing.
- Estimation of radiation dose level from ISIS

Saturated Activity density (Curie/cc)

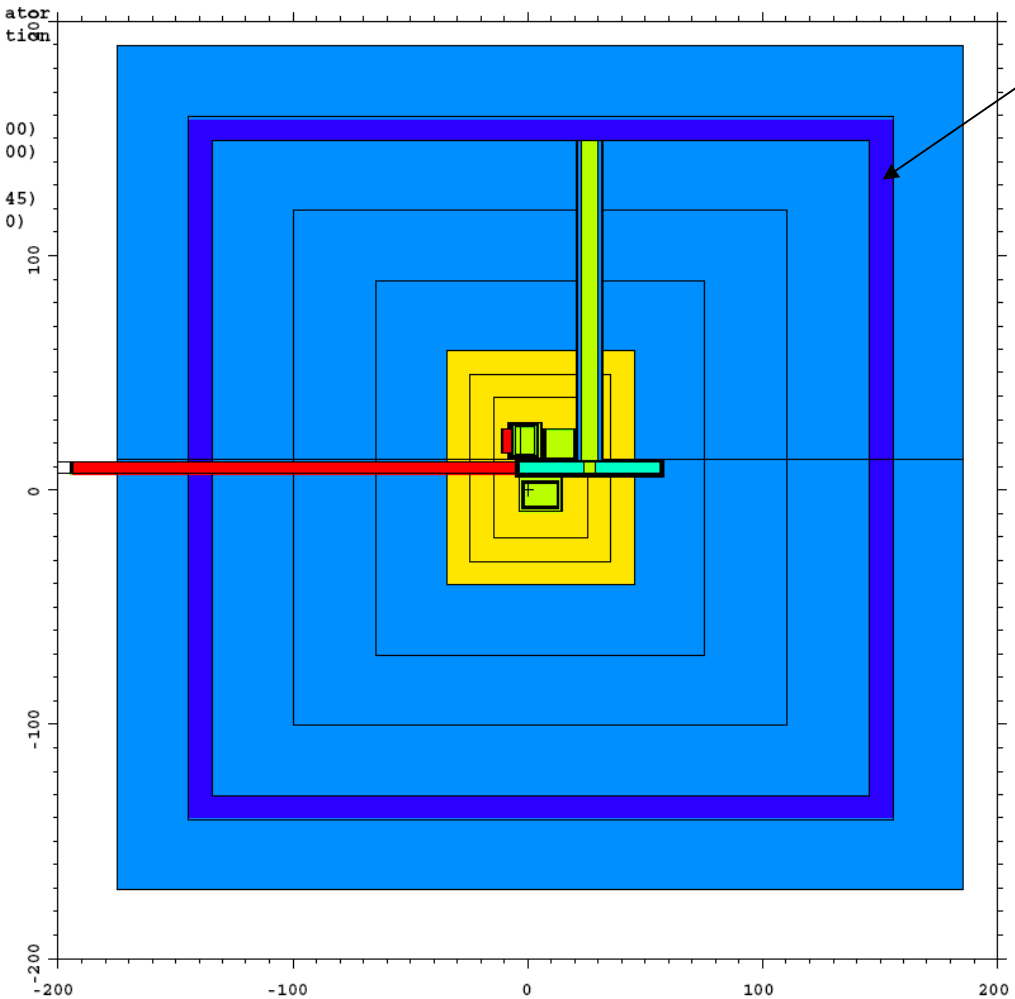
	this calculation	ISIS calculation
O 15	7.17E-04	1.69E-03
N 13	9.69E-05	4.68E-04
C 11	2.78E-04	1.98E-04
Total:	1.09E-03	2.36E-03

- The dose for ISIS Loop is about 1Sv/h, for our case, It should be several hundreds mSv/h

Production and Release of Airborne Radionuclides in Target Station

- **Estimate the activity of airborne radionuclide produced inside target station**
- **How many airborne radionuclide will be released? Source term for calculation of the dose equivalent delivered at the site boundary**
- **How large the helium vessel we need?**

Geometry for Air Activation Calculation



Air Layer 10cm

Case1: 140cm to center
volume 3.943e+06 cm3

Case2: 110cm to center
volume 2.496e+06 cm3

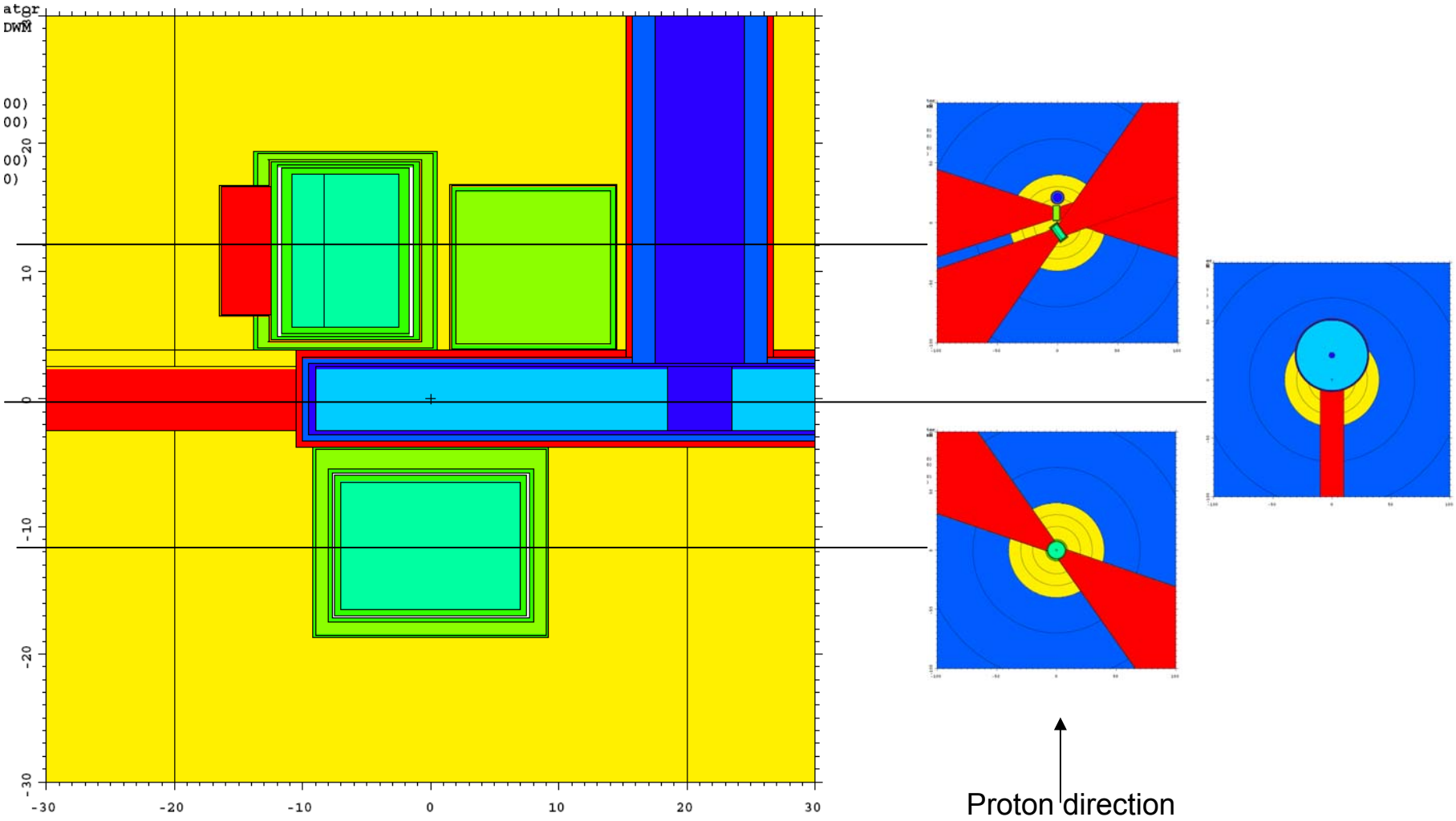
Case3: 80cm to center
volume1.361e+06 cm3

Nuclide	Atomic density (atoms/cc)
N14	4.20E+19
N15	2.15E+16
O16	1.08E+19
O18	1.26E+17
Ar40	1.56E+17

Air Activation Results

Nuclide	Halftime (s)	Saturated activity (Ci)		
		140cm	110cm	80cm
H 3	3.89E+08	1.8599E-02	2.9581E-02	9.6810E-02
Be 7	4.61E+06	1.7646E-03	2.5818E-03	9.2324E-03
C 11	1.22E+03	2.6424E-03	4.6440E-03	1.5820E-02
N 13	5.98E+02	7.4164E-03	1.3149E-02	4.8029E-02
N 16	7.13E+00	1.2726E-03	2.3634E-03	7.6573E-03
O 15	1.22E+02	2.6325E-03	5.0579E-03	1.7338E-02
Ar 41	6.58E+03	8.1284E-03	1.3707E-02	1.9657E-01
Total		4.7658E-02	9.5642E-02	5.0282E-01

Geometry for Helium Activation Calculation



Production rate of Tritium in Helium Inside the Helium Vessel

- **Only one possible radionuclide: 3H will be produced in Helium.**
- **The production of tritium is dominated by hadronic spallation reactions**

Position	Volume (cc)	Product rate (H3 atom/p)
Void around the rotating shaft	2.53E+03	5.95E-08
Void around target	3.71E+03	1.41E-06
Proton beamline	1.89E+04	8.05E-05
Neutron beamline CHM	7.98E+04	5.75E-07
Neutron beamline CHM	7.97E+04	9.71E-07
Neutron beamline DPHM	8.62E+04	1.51E-06
Neutron beamline DPHM	7.81E+04	4.37E-07
Neutron beamline DWM	5.63E+04	3.97E-07
Neutron beamline DWM	8.11E+04	8.53E-07
Total		8.67E-05

Result Analysis

- 8.47E-02 curie of tritium produced in helium during 5000h operation per year

- Main contribution from proton interaction with helium in proton beamline

- Calculation uncertainty from tritium production cross section

- Difference between neutron beamlines is due to the difference of high energy hadrons flux

Activity Density in the RTBT Tunnel due to Air Activation in Target Station

- **The Air inside target is connected to Tunnel of Ring Target Beam Transport (RTBT) and released there.**

- **Assume the tunnel is ventilated continuously, the activity density as a function of irradiation time for a single nuclide is given by:**

$$C_i(t) = \frac{R\lambda_i}{(\lambda_i + F/V)V}[1 - e^{-(\lambda_i + F/V)t}]$$

R — production rate in TS	/s
λ_i —decay constant	/s
t—running time	s
F—Ventilation rate	1.49e-01 m^3/s
V—Volume of Tunnel	3.58e+3 m^3

Activity Released per Year

- **For irradiation time > 5 V/F (1.2e5 s), the activity density will be:**

$$C_i = \frac{R\lambda_i}{(\lambda_i + F/V)V}$$

- **The activity released per year will be:**

$$\frac{R\lambda_i FT}{(\lambda_i + F/V)V}$$

T: operation time per year (5000h)

Activity of Airborne Radionuclides Released per Year

Nuclide	Halftime (s)	Activity released per year (Ci)		
		140cm	110cm	80cm
H 3	3.89E+08	7.16E-04 (8.54E-02)	1.14E-03 (8.58E-02)	3.73E-03 (8.84E-02)
Be 7	4.61E+06	5.71E-03	8.36E-03	2.99E-02
C 11	1.22E+03	2.21E+00	3.89E+00	1.33E+01
N 13	5.98E+02	6.44E+00	1.14E+01	4.17E+01
N 16	7.13E+00	1.14E+00	2.12E+00	6.88E+00
O 15	1.22E+02	2.35E+00	4.51E+00	1.55E+01
Ar 41	6.58E+03	5.24E+00	8.83E+00	1.27E+02
Total		1.74E+01	3.08E+01	2.04E+02

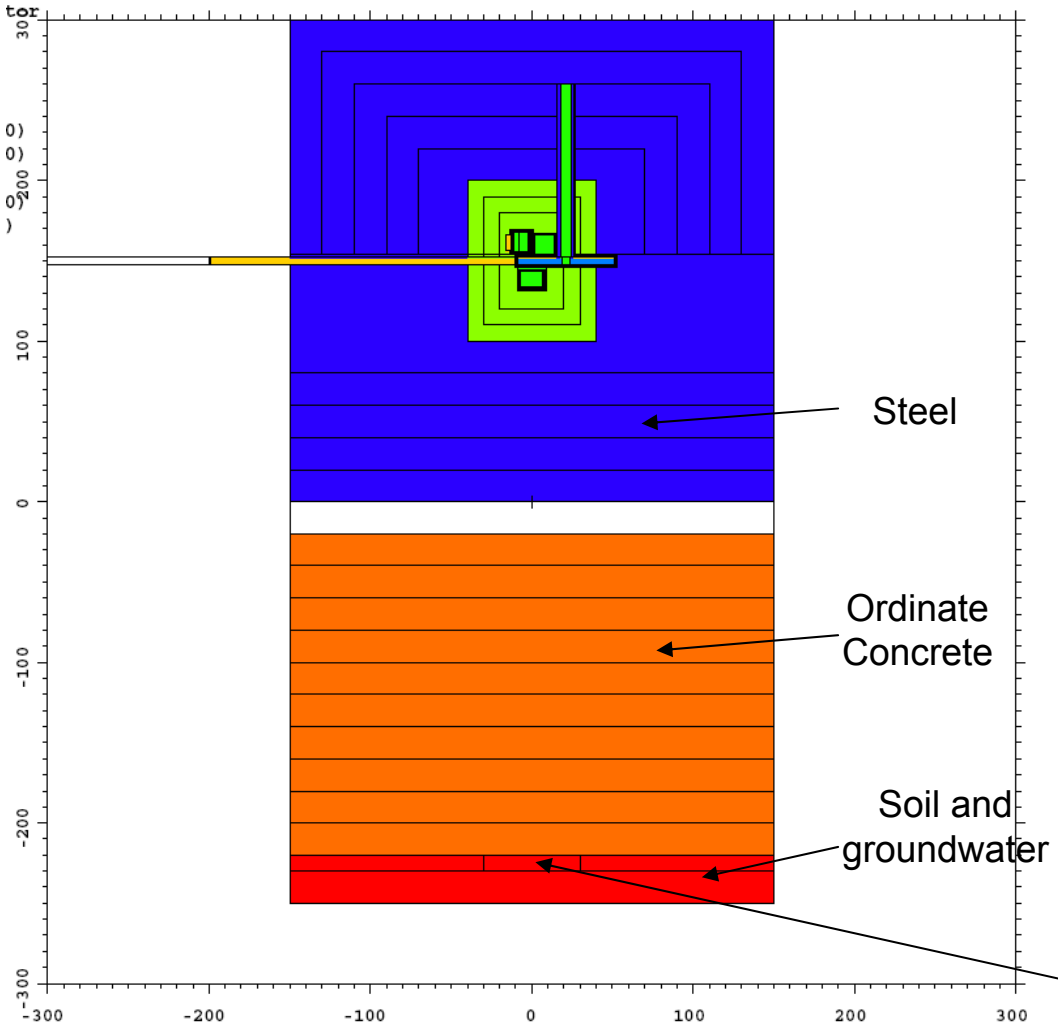
- Activity released can be reduced by ventilation discontinuously

- The dose equivalent rate at site boundary is calculating by a group of Tsinghua university using CAIRDOS code.

Activation of Soil and Groundwater Below Target Station

- The soil below the target station is hydrologically connected to groundwater.
- It's important for shielding design of target station to calculate the activity concentration levels of induced activity in soil that could be leached out and reach the public drinking water supply.
- Only H3 and Na22 contribute significantly to the activation of the underwater.

Geometry for Activation Calculation of Soil and Groundwater



Below the Be reflector

Case1:
1m steel +0.2m void
+ 2m ordinate concrete

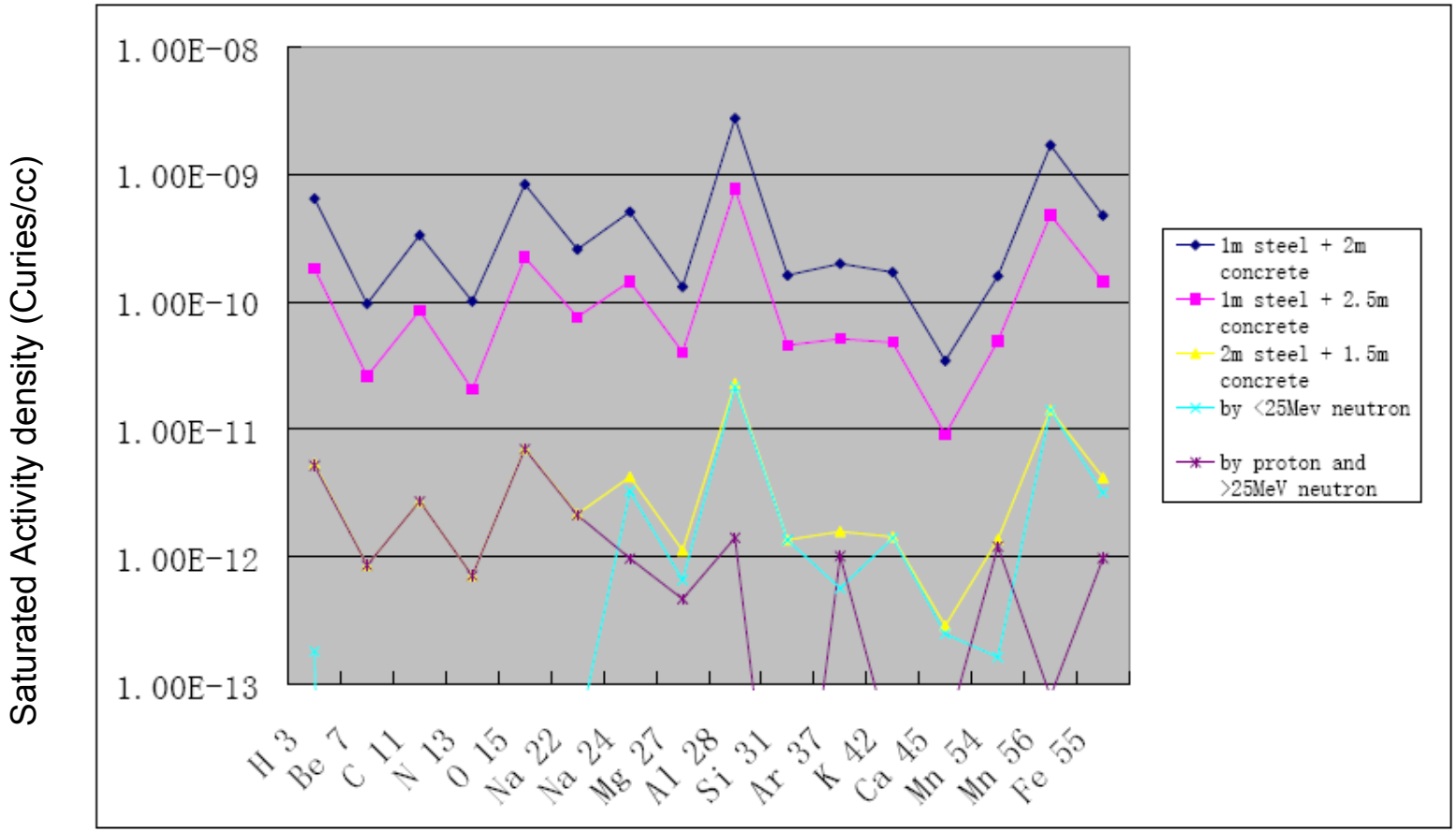
Case2:
1m steel +0.2m void
+ 2.5m ordinate concrete

Case3:
1m steel + 0.2m void
+ 1m steel + 1.5m ordinate concrete

Overall Composition of CSNS Site Soil and Groundwater

	Density□g/cm3□	Element	Weight Fraction□%□
Soil (30% volume of water)	1.91 (1*30%+ 2.3*70%)	O	46.8
		Si	33.4
		Al	6.63
		Fe	4.08
		K	1.94
		Ca	1.81
		H	1.75
		Ti	0.87
		C	0.85
		Mg	0.44
		Na	0.42
		Mn	0.20
		N	0.11
		Others	0.7

Results of Major Contributions in Soil and Groundwater



Exemption Levels for Solid waste

Nuclide	Saturated activity density (Bq/g))	Exemption level * (Bq/g)
Na 24, Ar 37	5.0e-02, 3.64e-2	0.1-1.0
Be 7, Ca 45 Mn 54, Fe 55 Mn 56	1.98e-02 6.63e-03 3.15e-02 9.61e-02 3.28e-01	$1.0\text{-}10^2$
C11, N 13 O15, Mg 27 Al 28, Si 31 K 42	6.28e-02 1.64e-02 1.63e-01 2.59e-02 5.29e-01 3.13e-02 3.30e-02	$10^3\text{-}10^4$

* From Chinese National Standard GB13367-1992

Groundwater Activation

- Assuming all H3 and Na22 is leached out of the soil and is dissolved in the groundwater
- 30% volume of water

	Saturated activity density (pCi/cc)			activity density for case 3 after 30 years operation (5000h/year) (pCi/cc)
	case1	case2	case3	
H3	5.8e+02	1.63e+02	4.83e+00	2.29e+02
Na22	2.32e+02	6.83e+01	1.95e+00	1.17e+02

Concentration Limits for Drinking Water

- No concentration limit for individual nuclide in Chinese drinking water standard
- USA EPA standard for tritium concentration in drinking water: 20pCi/cc
- USA DOE derived concentration in drinking water for Na 22: 10pCi/cc
- For 2m steel plus 1.5m concrete below the Be reflector , the activity level of groundwater is below the limits
- Consider dilution and the residence time of water , the concentration of H3 and Na 22 in water could be reduced significantly.

Summary

•The production rates of radionuclides in coolants, The airborne radionuclides produced in the air and helium inside target station and the activation of soil and underground water under target station are calculated by MCNPX + Activation Script + CINDER90 code.

•Uncertainty of results origin from the cross section, geometry models and some uncertain factors in engineering realization.

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