RADIATION PROTECTION OF CSR

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Abstract

The construction of CSR (Cooling Storage Ring) which include a main ring (CSRm) and an experimental ring (CSRe) will be started in this year. Heavy ions of carbon to uranium will be accelerated up to 900MeV/u and 400MeV/u at intensity of 10^8 pps. The HIRFL (Heavy Ion Research Facility in Lanzhou) will be used as injector.

For the shielding design of CSR, the secondary neutrons due to ion beam loss and their spectra, angular distribution were estimated based on experimental results. The dose equivalent at the shield surface and in the surrounding environment, neutron skyshine dose equivalent were also estimated in this study.

The experimental results, neutron yield, spectra and angular distributions for 400 MeV/u ^{12}C+Cu reaction, were used for estimating the source term of shielding design.

It is found that the most important environmental radiation impact component of CSR is the skyshine neutrons.

Keywords: Radiation protection CSR Neutron

1. Introduction:

CSR (Cooling Storage Ring) is a heavy ion accelerator build in Lanzhou, using the HIRFL (Heavy Ion Research Facility in Lanzhou) as injector. The designed energy of CSR was 900MeV/u for ^{12}C, and 400MeV/u for ^{238}U, and the maximum beam lost occurred at the primary target, it is: for 900MeV/u ^{12}C, 4.4×10^7 ion/s. Fig. 1gives the overall layout of HIRFL-CSR.

For radiation protection of high-energy heavy-ion accelerator, the secondary neutron produced from beam loss is the most important. But the lack of the data of neutron production make the problem more complex.

In this report, the following problems are discussed.

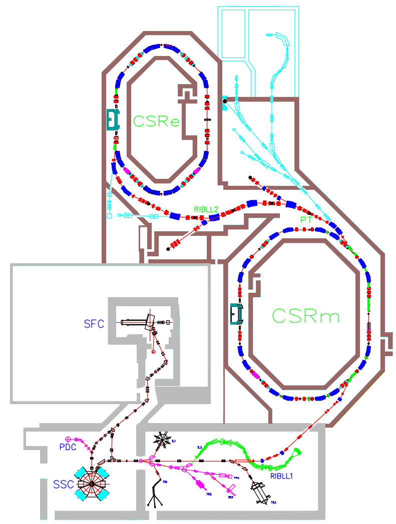

Fig 1 the overall layout of HIRFL-CSR

1. Secondary neutron production by heavy ion bombardment;
2. Dose equivalent at the thick shield surface;
3. Skyshine dose equivalent which is important to the external exposure of nearby population;

2 Neutron yields, spectra and angular distributions

The main problem of radiation protection for heavy ion accelerator is cause by secondary neutrons, which are produced from bombardment of heavy ion on thick targets. The secondary neutrons have the following characters:

1. Promptness, when the accelerator is shut down, secondary neutron will not emit immediately;

2. The secondary neutrons are obviously divided into two components: the high-energy neutrons from nuclear cascade process and the low energy neutrons from evaporation process. The high-energy neutrons are strongly peaked in the forward direction and the low energy neutrons are more isotropic;

3. Significant numbers of neutrons are emitted with

energy higher than the incident energy per nucleon and a few of them even can reach about twice of the energy;

4. The yields of secondary neutron obviously increase with the projectile energy per nucleon, when the incident energy per nucleon is the same, the yields are increased with incident particle atomic mass, and the effect of the atomic mass of target are not very important.

For low and mid-energy heavy ion reaction, the secondary neutron yields can be calculated in different projectile-target combination with the different projectile energy. But for the high-energy reaction (E>100MeV/u), the data of secondary neutron are very lack. In this report, different methods are used to estimate the secondary neutron yields and angular distributions.

2.1 Calculation from neutron multiplicity

The total neutron yields can be express by:

$$Y(T>T_0)=M(T>T_0)\times F \qquad (1)$$

Here, F is the nuclear interaction fraction, M is the neutron multiplicity, which can be calculated from Madey's report[1].

As for neutron angular distribution, M. M. Baibier gives a semi-experimental formula, which is[2]:

$$\begin{cases} (dN/d\Omega)_0 = \dfrac{10}{\pi} Y & \theta \le 10^0 \\ dN/d\Omega = \dfrac{2.5}{\pi} Y \cdot e^{-\theta/\theta_0} & 10 < \theta < 120^0 \end{cases} \qquad (2)$$

Table 1 gives the calculated results.

Table 1 Calculated neutron yields of 900MeV/u ^{12}C+Cu reaction using Barbier method (n/sr· s)

Angular / Energy	0°	30°	60°	90°
>100MeV	8.14	0.598	0.2	0.07
>50MeV	10.24	0.75	0.258	0.086

2.2 Analysis of new measurement result.

In 1998, the neutron fields of 100, 180, and 400MeV/u ^{12}C+Cu reaction were measured by Nakamura et.al[3]. with TOF method. The result shows that the neutron yields of mid-energy heavy-ion reaction are increased approximately with the increasing of the square of projectile energy per nucleon. Assume the same results while the energy rise to 900 MeV/u then, we could estimate the neutron data of 900 MeV/u ^{12}C+Cu reaction from measured results. Table 4 gives the neutron yields of 900MeV/u ^{12}C+ Cu reaction.

Table 2 calculated neutron yields of 900MeV/u ^{12}C+Cu reaction using measurement results (n/sr· s)

Angula / Energy	0°	7.5°	15°	30°	60°	90°
100MeV	46.2	13.9	5.4	2.07	0.017	4×10^{-3}
100MeV	4.88	3.3	2.38	1.82	0.78	0.55
5<En<10MeV	0.71	0.70	0.60	0.64	0.33	0.31

3. Dose estimation at thick shield surface

3.1 Shielding calculation

For a point source, neutron dose equivalent rate outside the shielding could be expressed as:

$$H = \frac{1}{r^2} \cdot J \cdot Y(\theta) \cdot C \cdot B \cdot e^{-\rho \cdot d/\lambda} \qquad (3)$$

And for a even line source, it is:

$$H = \frac{J'}{4r} Y(E_j) \cdot C \cdot B \cdot e^{-\rho \cdot d/\lambda} \qquad (4)$$

Where,

r is the distant between reference point and the neutron source;

J is the beam losses;

J' is the beam lose per unit length on the even line source;

Y(θ) is the secondary neutron yields;

C is the neutron flux-effective dose conversion factor;

ρ is the density of shielding material;

d is the shielding thickness;

λ is the neutron attenuation lengthy in shielding.

The build up factor B takes the dose contribution of low energy neutron produced in the shield into account. Fig.2 gives the neutron dose equivalent rate out side the shielding.

Assuming the beam line was a even line source, the shielding thickness could be calculated from expression (4) , it's: for CSRm, very little because of the low beam loss rate; and for the CSRe, it's 99cm.

3.2 Skyshine

Because the Skyshine neutrons are very important for public expose dose, so it must be tack into account.

In our case, because the roof shielding of CSR's target room is very thick, this problem is not very serious. Calculation[4] indicate that the maximum annual public dose equivalent caused by skyshine neutrons of CSR are no more than 1/5 of the dose limit of national standard.

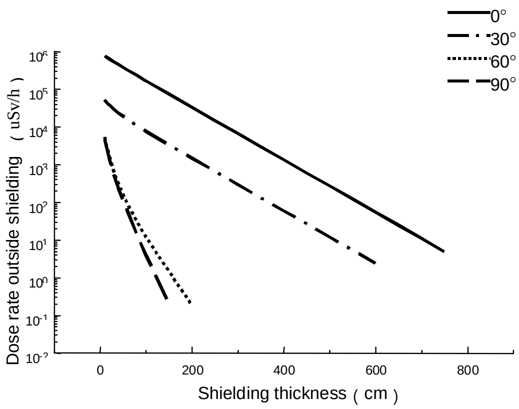

Fig. 2 Neutron dose equivalent outside the shielding （900MeV/u ^{12}C+Cu, r=600cm，beam intensity=1×10^8 ion/s）

4. Shielding configurations

Three shielding configurations are used in CSR, they are movable shield for beam tunnel, beam dumper for target room and labyrinth for people come in and out the tunnel (fig. 3, fig. 4 and fig. 5).

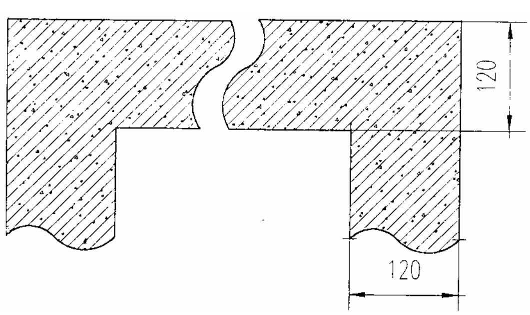

Fig.3 Movable shielding of CSR(cm) (reinforced concrete density ρ=2.5g/cm^3)

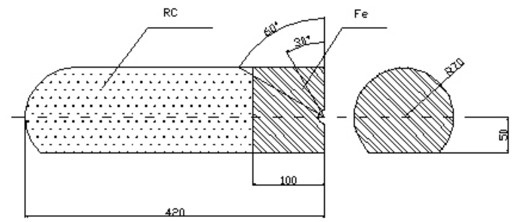

Fig.4 Beam dumper(cm)

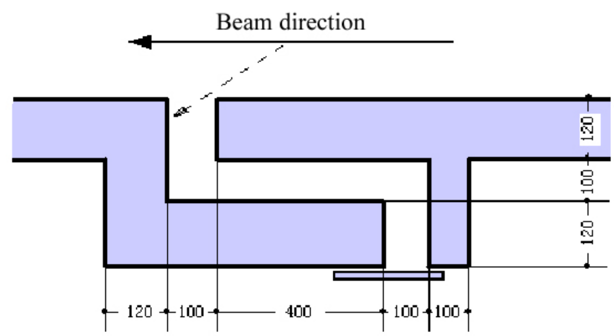

Fig. 5 labyrinth

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