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Radiation Shielding Design of CSR

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Abstract The construction of CSR (cooling storage ring) which includes a main ring (CSRm) and an experimental ring (CSRe) will be finished at the end of 2005. 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 the injector. For the shielding design of CSR, the secondary neutrons due to the ion beam loss, their spectra and angular distributions were estimated based on the experimental results. The dose equivalent outside the shielding surface and in the surrounding environment and the neutron skyshine dose equivalent were also estimated in this study. The experimental result, neutron yield, spectrum and angular distribution for 400MeV/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.

Key words radiation protection, CSR, neutron

1 Introduction

CSR is a heavy ion accelerator build in Lanzhou, using the HIRFL as the 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, 4.4×10^7ion/s. Fig. 1 gives the overall layout of HIRFL-CSR.

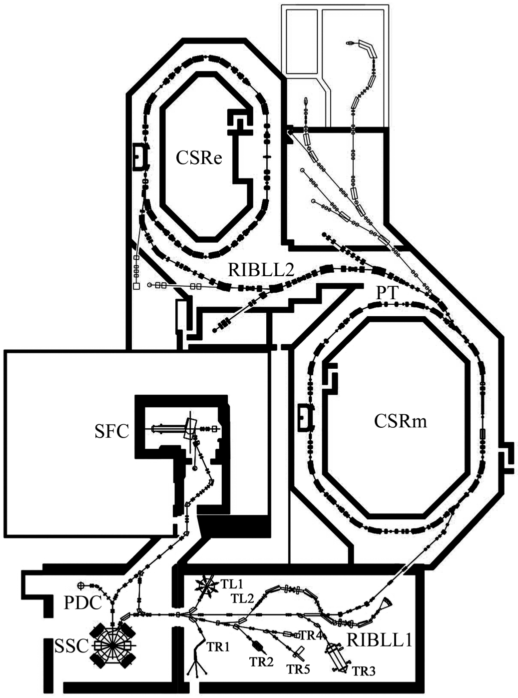

Fig. 1. Overall layout of HIRFL-CSR.

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

In this report, the following problems are discussed.

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.

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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 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 is not very important.

For low and intermediate-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 ($E > 100\mathrm{MeV/u}$), the data of secondary neutron are very insufficient. 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. Barbier gives a semi-experimental formula, which is[2]:

$$\begin{cases} (\mathrm{d}N/\mathrm{d}\Omega)_0=\dfrac{10}{\pi}\cdot Y & \theta\leqslant 10^\circ \\ \mathrm{d}N/\mathrm{d}\Omega=\dfrac{2.5}{\pi}Y\cdot \mathrm{e}^{-\theta/\theta_0} & 10^\circ<\theta<120^\circ \end{cases}\ . \qquad (2)$$

Here, Y is the total neutron yield and $\theta_0 = 28^\circ$; Table 1 gives the calculated results.

Table 1. The calculated neutron yields of 900 MeV/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 intermediate-energy heavy-ion reaction are increased approximately with the increasing of the square of projectile energy per nucleon. Assuming the results are the same while the energy rises to 900MeV/u, then we could estimate the neutron data of 900MeV/u ^{12}C+Cu reaction from the measured results. Table 2 gives the neutron yields of 900MeV/u ^{12}C+Cu reaction.

Table 2. The calculated neutron yields of 900 MeV/u ^{12}C+Cu reaction based on measured results. (n/sr·s)

angular 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
$5<E_\mathrm{n}<10$MeV	0.71	0.70	0.60	0.64	0.33	0.31

3 Dose estimation at thick shielding surface

3.1 Shielding calculation

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

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

And for a even line source, it is:

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

Where,

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

J is the beam loss;

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

$Y(\theta)$ 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 into account the dose contribution of low energy neutron produced in the shield. Fig. 2 gives the neutron dose equivalent rate outside the shielding.

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

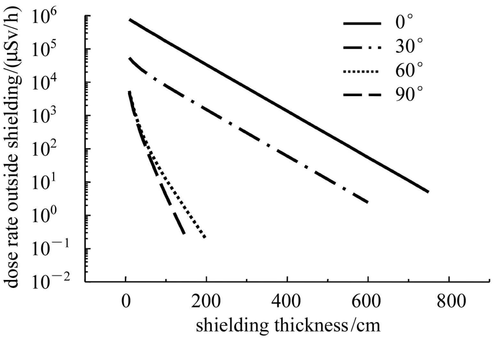

Fig. 2. Neutron dose equivalent outside the shielding. (900MeV/u ^{12}C+Cu, $r = 600$cm, beam intensity=1×10^8ion/s).

3.2 Skyshine

Because the Skyshine neutrons are very important for public expose dose, it must be taken 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] indicates that the maximum annual public dose equivalent caused by skyshine neutrons of CSR is no more than 1/5 of the dose limit of national standard.

4 Shielding configurations

Three shielding configurations are used in CSR, they are movable shield for beam tunnel, beam dumper for target room and labyrinths for people to come in and go out of the tunnel (Fig. 3, Fig. 4 and Fig. 5). In the case of beam line shielding calculation, we assume the beam line is an even line source. This is not necessarily the case however, beam loss may occur at some important parts, especially in one point totally. So 1.2m reinforced concrete shielding is used in the roof and the sideward of the beam tunnel, this thickness is the same as that of the target room, so the dose rate will not exceed the upper limit even in the most serious situation.

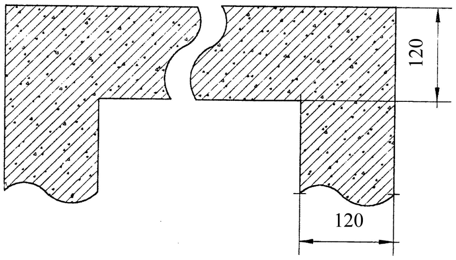

Fig. 3. Movable shielding of CSR (cm). (reinforced concrete density $\rho = 2.5\text{g/cm}^3$).

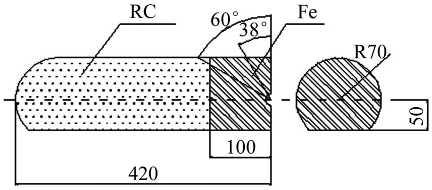

Fig. 4. Beam dumper(cm).

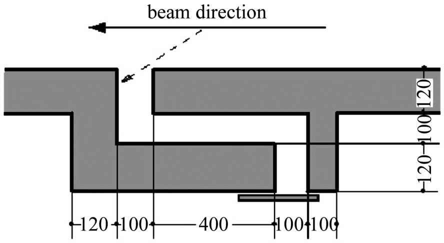

Fig. 5. Labyrinth.

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CSR的辐射屏蔽设计

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摘要　CSR(cooling storage ring)按计划将于2005年底建成调束, 届时从^{12}C到^{238}U的重离子将可以分别被加速到900和400MeV的能量. HIRFL(兰州重离子加速器Heavy Ion Research Facility in Lanzhou)将用作CSR的注入器. 为了CSR的屏蔽设计, 本文利用现有的实验数据计算了由于束流损失产生的中子及其能谱、角分布, 同时也估算了屏蔽体外表面的中子剂量、环境中子剂量及天空返照中子剂量. 在源项计算中使用了400MeV/u ^{12}C+Cu反应的中子产额、能谱、角分布的实验数据. 计算表明, CSR对环境剂量影响最大的是天空返照中子.

关键词　辐射防护　CSR　中子

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