Some neutronic calculations for KENS-II

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Introduction

Proton energies of the intense spallation neutron sources currently in operation or designed are in the range $Ep \leq 1.1$ GeV. Optimization studies of the target station have so far been performed for these proton energies.

The KENS-II project has been included in the Japanese Hadron Facility Project where we have to share the proton accelerator, a so-called "First Ring", with Meson Arena for nuclear physics and μSR experiments. The possible highest proton energy for this accelerator is 2 GeV, which is the highest among the world's spallation neutron sources. We, therefore, performed some neutronic calculations with 2 GeV protons in order to have a good knowledge of the neutronic characteristics and the optimal parameters of the target station for KENS-II.

Target model and calculation codes

First we considered cylindrical targets and then rectangular parallelepiped targets. The target was a uniform mixture of target metal with coolant and cladding[1], which was similar to the model target used in the optimization study of ISIS[2].

Source neutrons below 15 MeV produced in a target were calculated using the NMTC/JAERI code[3]. Leakage neutrons from a bare target and slow neutrons emitted from a moderator were calculated using the TOWTRAN-II[4] and MORSE-DD[5] codes, respectively, coupled with the NMTC/JAERI code.

Number of source neutrons

Figure 1 shows the number of source neutrons below 15 MeV produced in the target of various materials as a function of proton energy. Here, the length and the radius are fixed at 32 and 5 cm, respectively. The proton-beam profile was assumed to be cylindrical, 2.35 cm in radius, for simplicity. The results do not include the neutron multiplication by low energy nuclear reactions.

We chose tungsten as a reference material for the non-fissile target because of its relatively high neutron yield and the practicality. In the present study, we performed calculations only on two target materials U(uranium) and W(tungsten).

The number of source neutrons below 15 MeV produced in the target is shown in Fig. 2 as a function of target length. The number is saturated at about 16, 28, 43 and 50 cm for the proton energies 0.5, 0.8, 1.5 and 2 GeV, respectively.

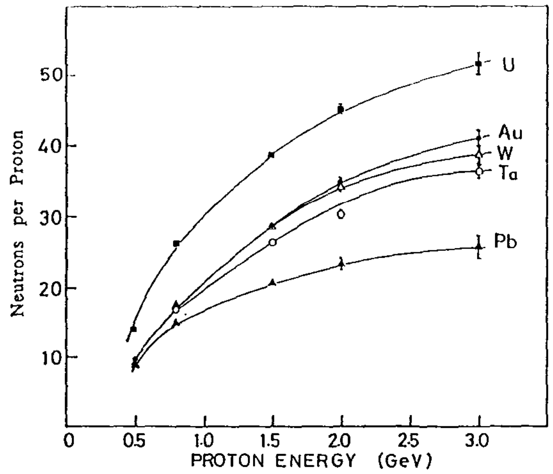

Fig. 1 Number of neutrons below 15 MeV produced in various targets per proton as a function of proton energy. Lines are guides for eye.

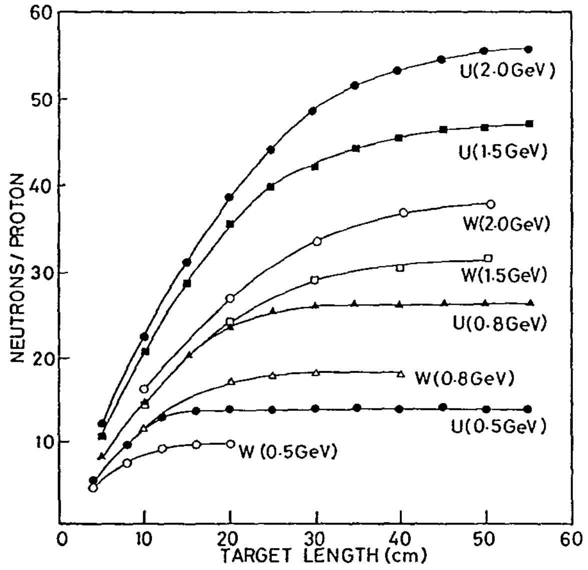

Fig. 2 Number of neutrons below 15 MeV produced in target per proton at various energies as a function of target length. Lines are guides for eye.

Leakage neutrons

The number of leakage neutrons from the cylindrical surface of the bare target is shown in Fig. 3 as a function of target radius. The target lengths used in this calculation were 16, 30, 44, 55 cm for 0.5, 0.8, 1.5, 2 GeV, respectively, which gave the saturated neutron yield as shown in Fig. 2.

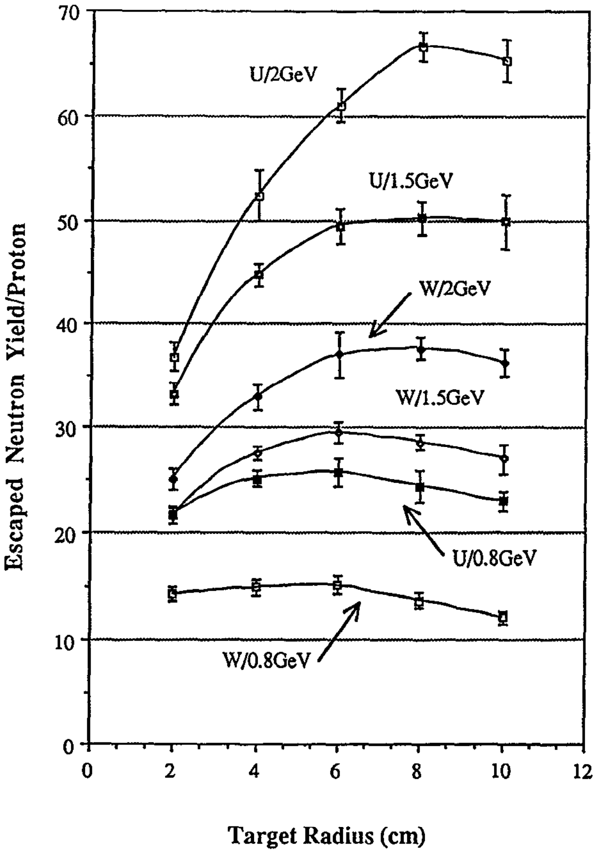

Fig. 3 Number of leakage neutrons from cylindrical surface of a target per 2 GeV proton as a function of target radius.

The number of leakage neutrons increases with increasing radius due to the neutron multiplication by low energy nuclear reactions such as (n, 2n), (n, f), etc. The relative gain of a U-target to a W-target is larger for the number of leakage neutrons than for source neutrons. The reason is that uranium has lower threshold energies for such reactions than tungsten. The number of leakage neutrons from the cylindrical surface decreases at a larger radius, because the leakage from the end surfaces becomes significant.

The number of leakage high energy neutrons above 15 MeV from the U-target is plotted in Fig. 4 as a function of target radius for various proton energies. The

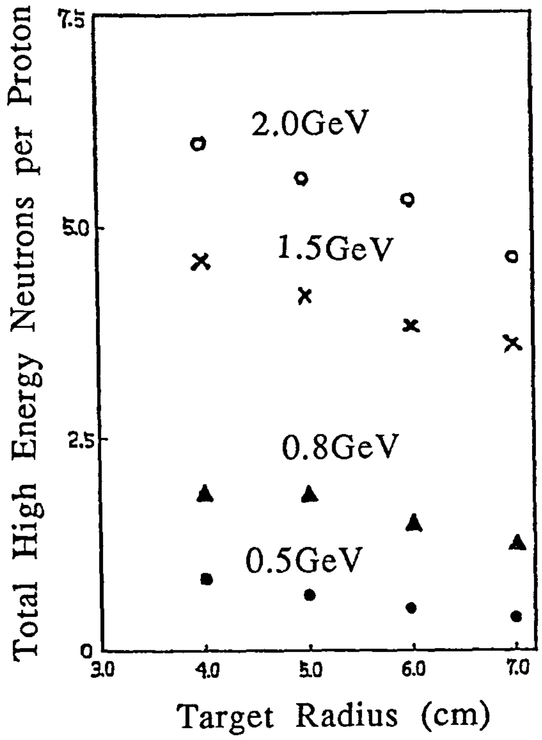

Fig. 4 Number of leakage high-energy neutrons (En > 15 MeV) per proton as a function of target radius for various proton energies.

intensities decrease with increasing target radius. This is simply explained by the attenuation length of the target material for high energy neutrons. The number increases almost proportionally to the proton energy taking into account the attenuation and the leakage from the end face.

Leakage neutron spectra from the cylindrical surface of the U-target for 2 GeV protons are shown in Fig. 5. The peak value increases and the peak energy decreases with increasing radius. The softening of the spectra at the higher energy region is due to the inelastic scattering with target nuclei, while that at the lower energy region is mainly due to the neutron moderation by the coolant D_2O in the target. The energy spectra of high energy neutrons above 15 MeV did not show a large difference between U and W.

Slow neutrons

A model of the target-moderator-reflector assembly is shown in Fig. 6, where two reference moderators are positioned above the target for simplicity. The reference moderator is rectangular parallelepiped (10 x 10 x 5 cm^3) of H_2O with a B_4C decoupler of cutoff energy 20 eV. The size of proton beam entrance was fixed at 10 cm in diameter in the calculation.

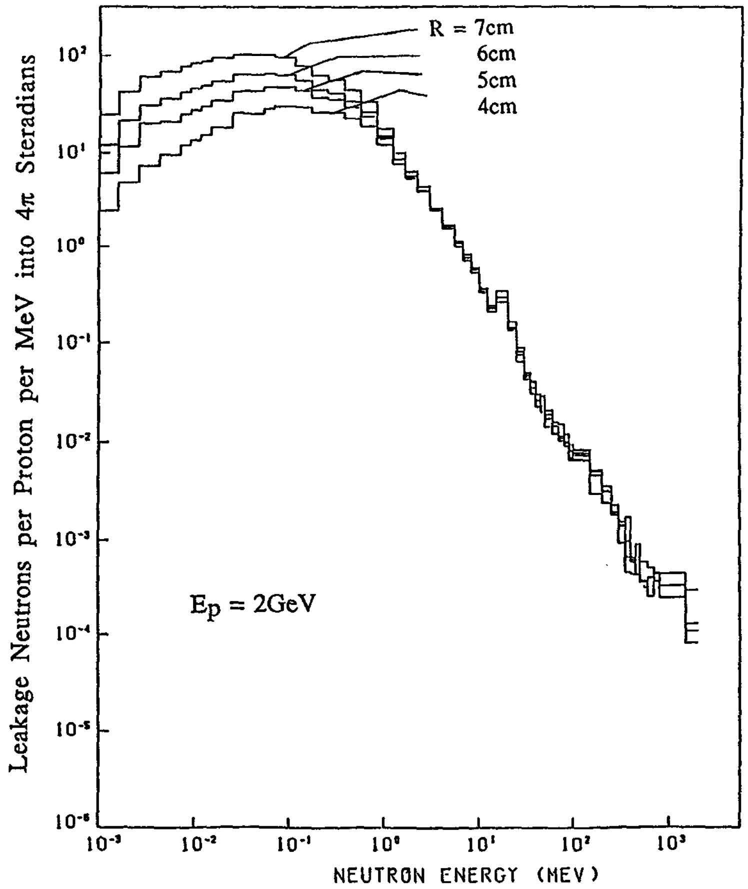

Fig. 5 Leakage neutron spectra from the cylindrical surface of a target for various target radii.

The radius is one of the most important design parameters of the target, because the coupling efficiency between the target and moderator decreases with increasing target radius. Figure 7 shows the target-radius dependence of the slow neutron intensities from the moderators for two different proton-beam sizes, 1.25 and 2.35 cm in radius. In the calculation the front face of the first moderator is aligned to the target face as shown in Fig. 6. It turned out that the optimal target radius which gives the maximum intensity is about 5 cm for both targets for the proton-beam size of 2.35 cm in radius. Present results with 2 GeV protons did not show a significant difference to those by Atchison with 0.8 GeV protons. The ratio between the maximum intensities of U- and W-targets is about 1.5, which is more or less smaller than the case for the lower proton energies. The optimal radius shifts toward smaller values for smaller proton-beam sizes. There exists appreciable gain with a smaller proton-beam size for U but not for W. This unexpected result could be attributed to the fixed size of the proton beam entrance.

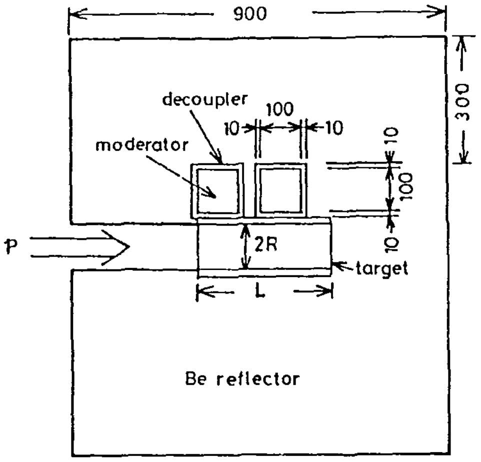

Fig. 6 Model of target-moderator-reflector assembly used for calculation.

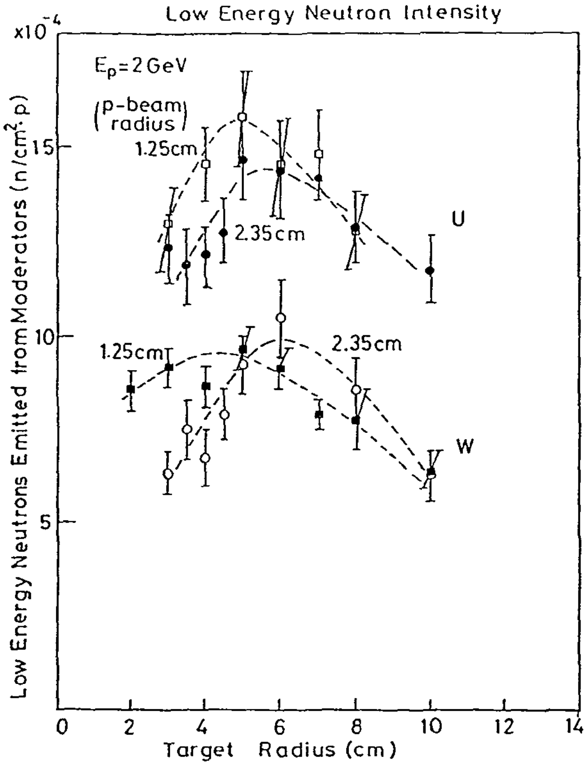

Fig. 7 Slow neutron (En < 0.9 eV) intensities per 2 GeV proton obtained from two moderators with U- and W-target as a function of target radius for two different proton-beam sizes. Lines are guides for eye.

The axial position of moderators on the target is another important parameter to be optimized. Figure 8 shows slow neutron intensities from two moderators as a function of axial moderator position for two different proton energies. The target-moderator configuration is shown in the inset of Fig. 8. Here the parameters to be optimized are x and d. However, the separation, d, between the two moderators is fixed at 5 cm from a practical point of view. The sum of the intensities from the two moderators are also shown in the figure. A maximum appears at x=0 cm for 2 GeV protons and at x=-4 cm for 0.8 GeV protons. The difference reflects the axial source neutron distribution in the target shown in Fig. 9 in which we see broader features with less increase in the maximum intensity for higher proton energies. The slow neutron intensity at the maximum point for 2 GeV protons is about twice that for 0.8 GeV protons, so that the gain factor of the intensity per energy is 0.8 for 2 GeV protons against 0.8 GeV.

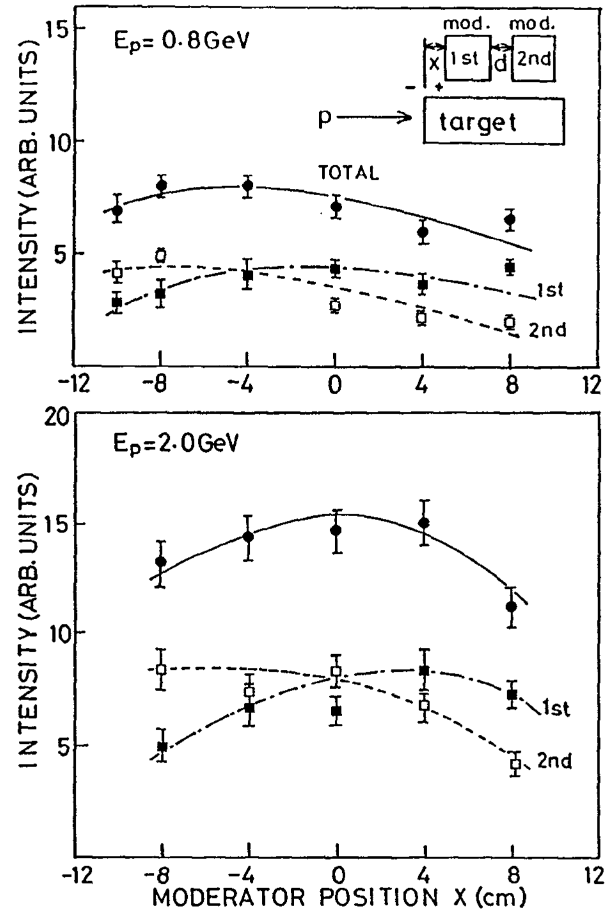

Fig. 8 Slow neutron (En < 0.9 eV) intensities per proton obtained from two moderators as a function of axial moderator position on the target. Lines are guides for eye.

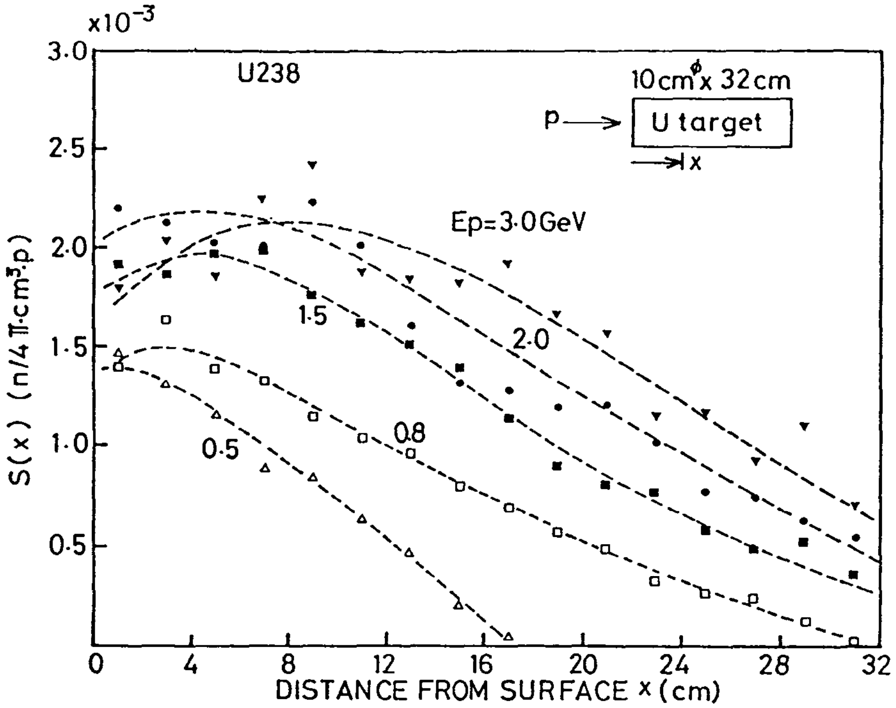

Fig. 9 Axial distributions of sub 15 MeV neutrons in target. Broken lines are guides for eye.

Rectangular target

Next, we consider rectangular parallelepiped targets. We calculated the target width dependence on the slow neutron intensity. The dimension of the target is shown in the inset of Fig. 10, where the target height is fixed at 10 cm. The sum of the slow neutron intensities obtained from the two moderators with such a target is shown in Fig. 10. The gain of neutron intensity by increasing the lateral dimension of the target is about 10% for U but there is no gain for W. The reason is that reflected neutrons cause additional fission in the U-target but not in the W-target.

Conclusion

The fraction of slow neutron intensity versus the proton energy becomes 0.8 for 2 GeV compared to that for 0.8 GeV, and this is higher than 0.67 calculated for source neutrons. The uranium target has a higher neutron productivity, 1.5 times that of the tungsten target, even for 2 GeV protons. The target radius and the moderator axial position have definite optimal values for 2 GeV protons in spite of the broader distribution of the source neutrons in target, and these are essentially similar to the results for 0.8 GeV protons[2]. The broad distribution with a little increase in the

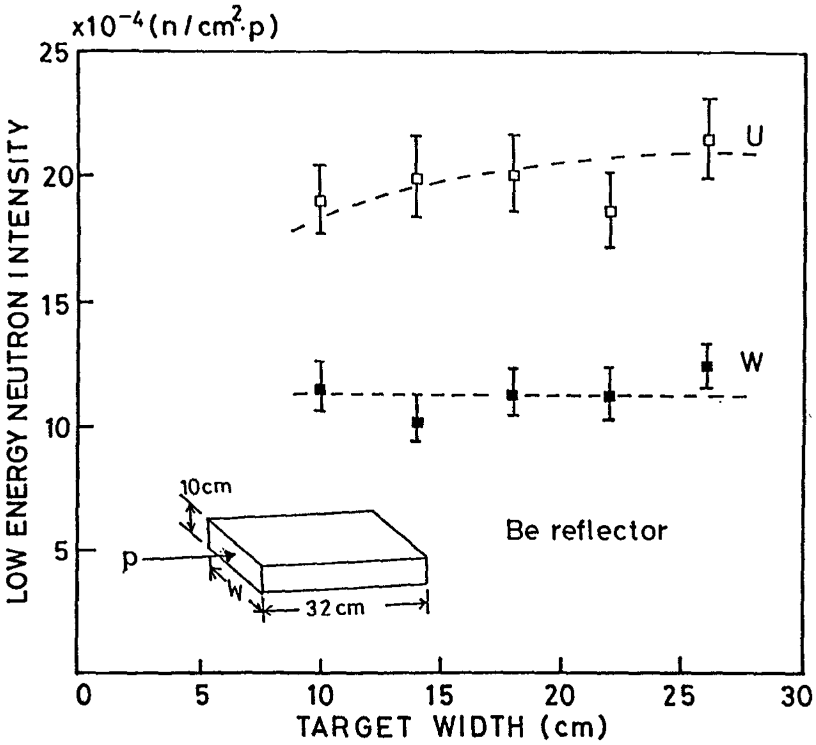

Fig. 10 Slow neutron (En < 0.9 eV) intensities per 2 GeV proton obtained with U- and W-rectangular-parallelepiped-target as a function of target width. Broken lines are guides for eye.

maximum luminosity of source neutrons for 2 GeV protons could make it easier to remove the heat load from the target than the case for the same beam-power with lower energy and higher proton current. Therefore, we could conclude that the 2 GeV protons for KENS-II do not have significant difficulties in producing slow neutrons, and that non-fissile material has higher advantages to produce neutrons for higher proton energies. Detailed neutronic calculations are now under way to design a neutron target station for KENS-II.

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