Comparison of the Slow-Neutron Intensity -0.8 GeV vs 3 GeV Protons-

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Abstract

The choice of the proton energy for an intense pulsed spallation neutron source is one of the most important topics in recent years. A high proton energy, but with a modest beam current, is more acceptable from an accelerator point of view. We calculated the slow-neutron intensities from a reference target-moderator-reflector assembly for various proton energies over the range 0.8 - 3 GeV. The result shows that the slow-neutron intensity per unit proton beam powder with 3-GeV protons is about 80% of the 0.8-GeV case. A higher proton energy is also well acceptable from a neutronic point of view.

1. Introduction

When we consider an intense "pulsed" spallation neutron source, a high-intensity proton ring accelerator, such as a compressor ring, a synchrotron or an FFAG is generally indispensable, combined with a high-current proton linac of full energy or an appropriate injection energy. A higher energy, but having a modest beam current, is more feasible from an accelerator point of view (space charge limit). The merits and demerits for using higher energies ($E_p > 0.8$ GeV) are being extensively discussed at various laboratories (e.g. for ESS :European Spallation-neutron Source, IPNS upgrade, etc.). We had a similar problem in choosing the proton energy for the Japanese Hadron Project (JHP) where KENS-II, a next-generation pulsed spallation neutron source, is to be involved. The neutron society stressed the adoption of a lower energy, say 1 GeV, while the nuclear physics society suggested a higher energy, at least 2 GeV (hopefully 3 GeV). We performed some neutronic calculations [(1)] in order to understand the proton-energy dependence of the neutron intensity using a hadron transport code NMTC/JAERI [(2)] combined with some low-energy neutron transport codes. Our results were very much unfavorable for higher proton energies. Based on these results we chose 1 GeV in the first-phase JHP.

We recently found our earlier calculation [(1)] to be some misleading. NMTC/JAERI gave smaller neutron yields at higher proton energies (above 1 GeV). After that, the code was revised and confirmed to give consistent results with those using an HETC code in some benchmark calculations, and with some measured results. [(3)] We performed re-calculations using the revised NMTC/JAERI on a target-moderator-reflector system which was the same as in the previous calculations, since the results are so important for the strategy of a new source. We briefly report on the new results, while mainly focussing on the slow-neutron intensity with 3 GeV protons compared with the 0.8 GeV case.

2. Fast Neutrons from Target

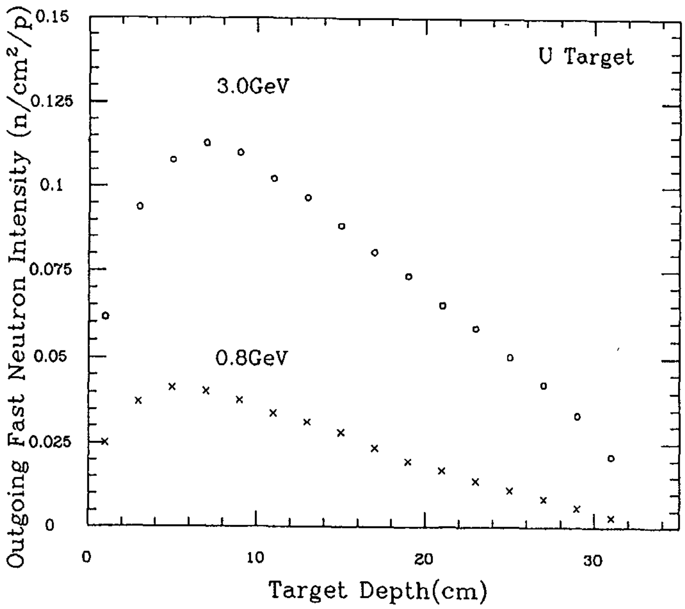

Fig. 3 Axial distributions of outgoing fast neutrons from a cylindrical surface.

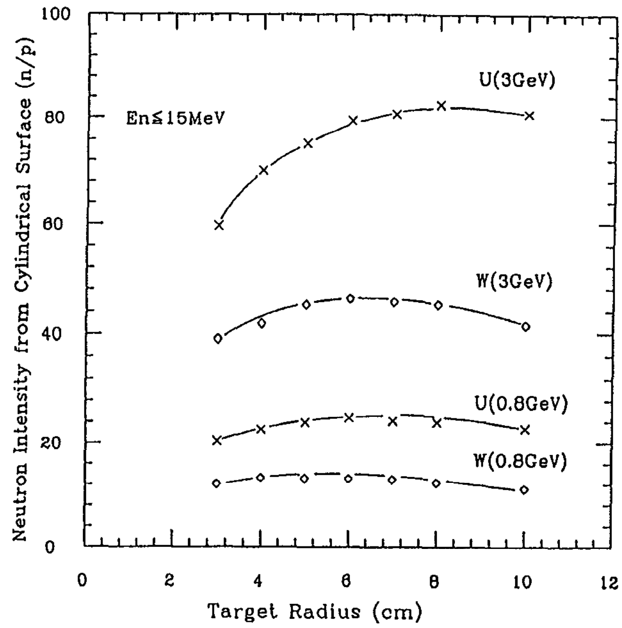

Fig. 4 Escape fast-neutron intensities from a cylindrical surface of targets as a function of the target radius.

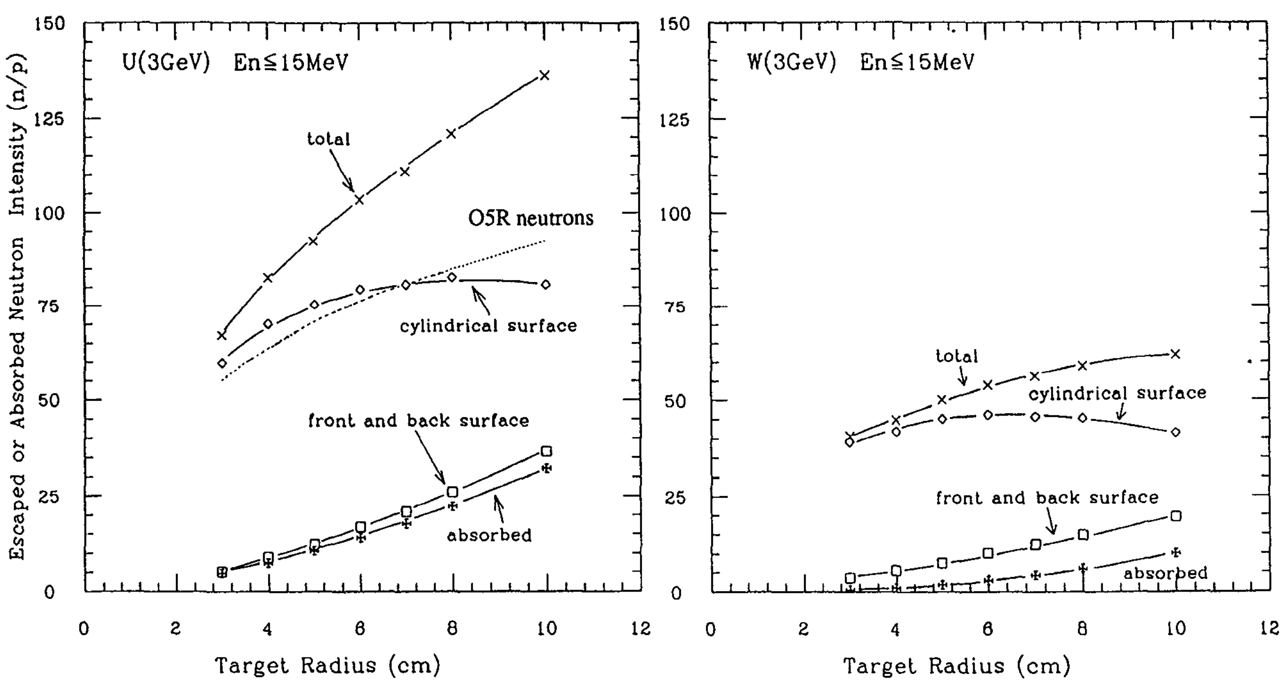

Fig. 5 Contribution of each process (escape and absorption) as a function of the target radius.

and adsorption) for U and W targets. The absorption in the U target is considerable compared to that in the W case, since the cross sections of (n, f) and (n, xn) are significant.

Figure 1 shows the calculated results of the O5R neutron intensities as a function of the proton energy for various target materials with dimensions of 32 cm long and 10 cm in diameter. Although this size is not sufficient for higher proton energies, it will be more realistic. We assumed a cylindrical proton beam profile of 4.7 cm in diameter. O5R neutrons mean those below 15 MeV directly obtained from a hadron transport calculation, which does not include neutron generation below 15 MeV. However, the O5R neutron will be a simple, but good, measure of the neutronic performance of a target (full calculations are given later). In the present results the intensities increase more linearly with the proton energy than in the previous results. The lower intensities in the lead target are due to its lower number density; i.e. the diameter of 10 cm and the length of 32 cm are not sufficient for lead.

The axial distributions of O5R neutrons (s (z)) in a uranium (depleted U) target are shown in Fig. 2 for various proton energies. In the present results, by increasing the proton energy the peak intensities increase monotonically with the peak position shifting a bit downstream, in contrast with the previous results, in which the peak intensities were almost saturated at higher energies (say above 1.5 GeV) and the shifts of the peak position were not small.

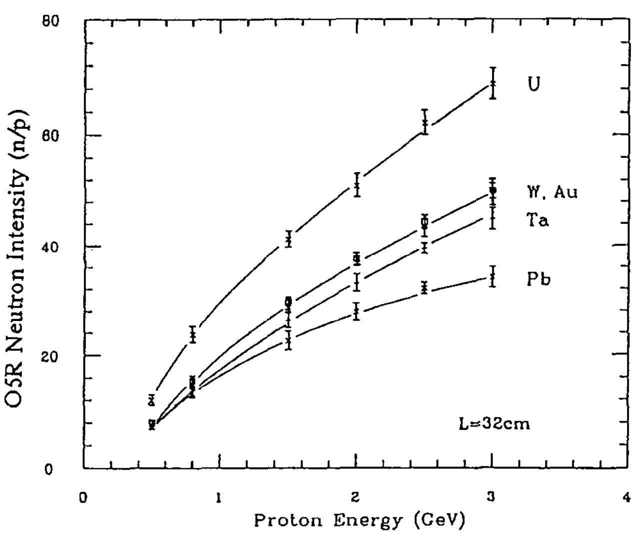

Fig. 1 O5R neutron intensities for various target materials as a function of the proton energy.

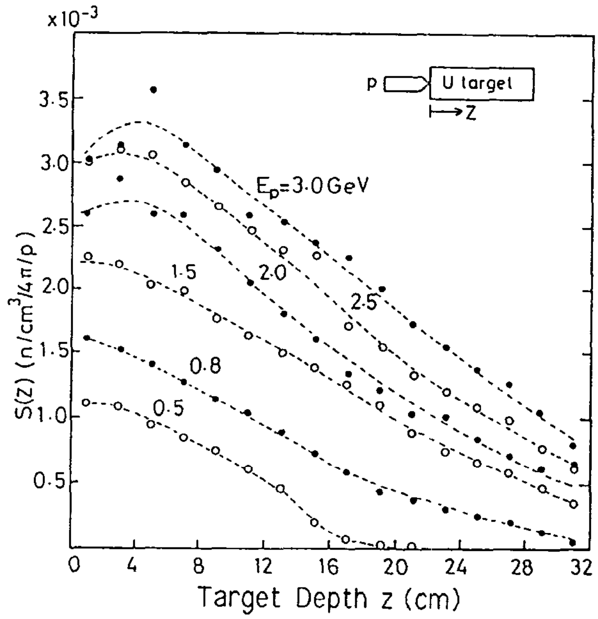

Fig. 2 Axial distributions of O5R neutrons in a U target at various proton energies.

We then calculated the intensities of escaping fast neutrons from the cylindrical surface of the targets, since the slow-neutron intensity from the moderators is directly related to those neutrons. Figure 3 shows the outgoing fast-neutron intensities from U target as a function of the axial depth of the targets for 0.8 and 3 GeV protons. In this calculation and the following neutron production below 15 MeV during neutron transport in the target was included.

Figure 4 shows the escape fast-neutron intensities as a function of the target radius. Although the total number of neutrons produced in the target increases with the target radius, the intensity of escaping neutrons from a cylindrical surface does not increase monotonically, due to escaping from both ends and absorption in the target. Figure 5 shows the contributions of each process (escape

3. Slow-Neutron Intensity

We calculated the slow-neutron intensities ($E_n < 0.9$ eV) from the moderators in the model target-moderator-reflector system shown in Fig. 6. In this model two reference light-water moderators were put on the target in a wing geometry, although in a real system it would be typical to put at least four moderators with different neutronic characteristics (2 above, other 2 below the target). This model would be sufficient to examine the slow-neutron intensities from the moderators. The intensities as a function of the target radius are shown in Fig. 7 for proton energies of 0.8 and 3 GeV. The neutron intensity increases with the target radius and then decreases. This is partly due to the fact shown in Fig. 4. However, the peak appears at a smaller radius than in Fig. 4. This is due to the fact that the coupling between the target and moderator becomes loose with increasing target radius. The proton energy dependence is rather modest. The optimal target radius is 4 - 5 cm. We chose a radius of 5 cm in the following calculations.

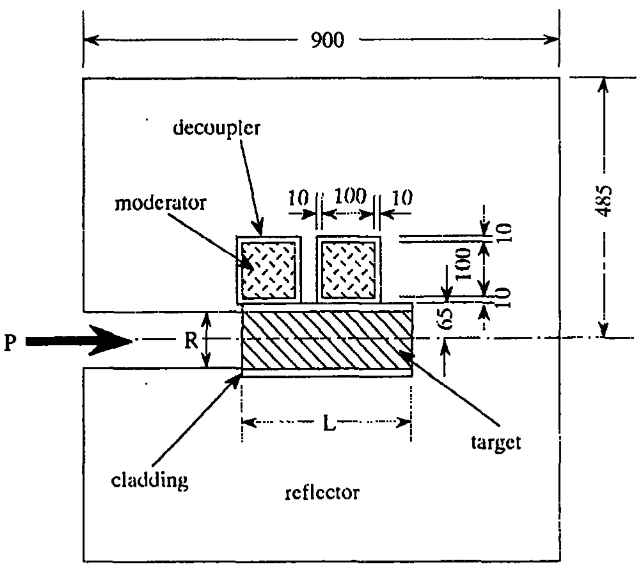

Fig. 6 Target-moderator-reflector system used for a calculation of the slow-neutron intensity.

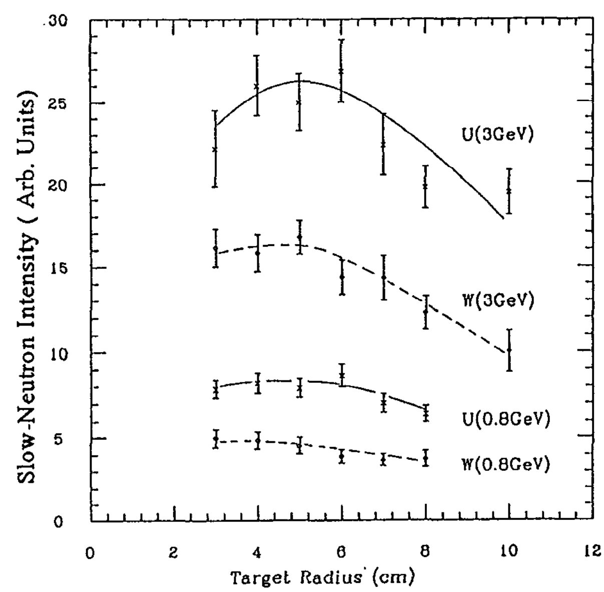

Fig. 7 Sum of the slow-neutron intensities from reference moderators as a function of the target radius.

In Fig. 8 the sum of the slow-neutron intensities from the two moderators set at the optimal positions are plotted as a function of the proton energy. The intensity increases almost linearly with proton energy, Vassil'kov (3) showed that the total neutron yield from a target $Y(E_p)$ can be expressed as

$$Y(E_p) = A + BE_p^y,$$

where A and B are constants. The value of y determined by a measurement for a lead target (20 cm in diam.) was $y = 0.75 \sim 0.85$, depending on the measuring methods. The solid curves in Fig.8 are the calculated values using the above equation with the given constants. The curves were normalized to the present data at 2 GeV. The agreement is fairly good. This means that the slow-neutron intensity is almost proportional to the total neutron yield in the proton energy range 0.8 ~ 3 GeV. In other words, the slight deviation in the slow neutron intensity from a linear line at higher energies is mainly due to the energy dependence of the total neutron yield, rather than a broadening in the axial distribution of out-going neutrons.

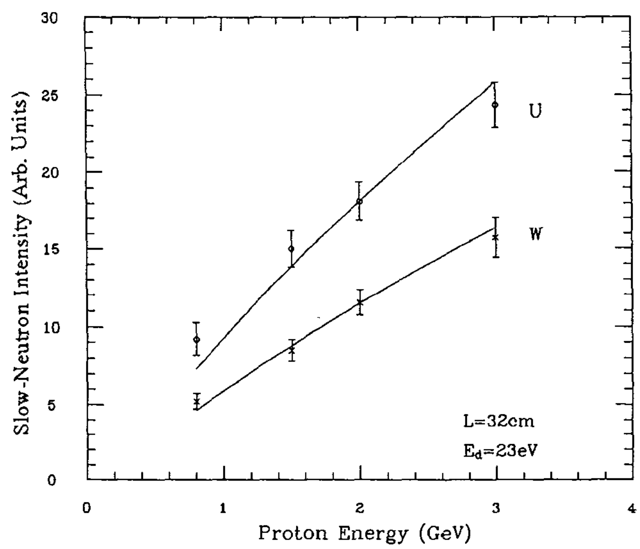

Fig. 8 Sum of the slow-neutron intensities from reference moderators optimally placed as a function of the proton energy. The solid curves are the calculated values of the total neutron yields normalized at 2 GeV.

4. Conclusion

In summarizing the results, the slow-neutron intensities per proton can be increased by about a factor of 3 when the proton energy is increased from 0.8 to 3 GeV. This number should be compared to the increase in the proton beam power (3.75 times). The slow-neutron intensity per proton beam power with 3-GeV protons is about 80% of the 0.8-GeV case. This value is quite acceptable.

References

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