# THE CHOICE OF OPTIMUM PROTON ENERGY FOR A HIGH POWER SPALLATION SOURCE - ISSUES FOR THE TARGET STATION.

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## 1. INTRODUCTION.

A debate central to the design of a new spallation source with proton beam power in excess of 1 MW is the choice of the energy of the proton beam. This paper presents a brief review of some of the effects of the proton beam energy on the design of a Target Station.

The main issue is to achieve maximum performance in terms of neutron beam characteristics within the constraint of practical engineering and material limits.

In the following discussion a constant proton beam power is assumed. Thus higher energies imply lower proton beam currents. The dimensions of the biological shield are dependant on proton beam power and are essentially independent of proton energy. The nuclear particle cascade which characterises the basic neutron production increases in physical extent as the proton energy increases which is the crucial feature as far as the Target Station is concerned.

## 2. NEUTRONIC PERFORMANCE.

The yield of fast neutrons from a spallation target varies essentially linearly with proton energy. Experimental data indicate a small fall off at energies above about 2 to 2.5 GeV but for practical purposes the basic fast neutron yield for a given proton beam power can be taken as independent of energy below 3 GeV. New data [1] confirming this have been presented at this meeting as well as new calculations [2].

Rather than considering fast neutron production the performance of the source must be judged by the neutron beam fluxes and time pulse characteristics at the experiments. These have to be matched to the requirements of the neutron scattering instruments. This implies that several moderators with different temperatures, materials and pulse shaping will be required.

At the workshop on High Power Targets at PSI [3] there was a concern that the useful neutron fluxes would be lower for the higher energy beams. This was based on calculations indicating that the fast neutron flux from the target surface, the 'brightness', is reduced for higher energy due the increased longitudinal extend of the nuclear cascade.

Studies have been reported at this meeting [4] of calculated and measured moderator fluxes for realistic configurations. With limited optimisation these show that the useful neutron fluxes per MW of beam power are essentially independent of the proton energy. This is new and important data. The work has covered both of the standard target/moderator configurations, wing and flux trap.

There is one caveat to this which concerns neutron backgrounds in the experiments. There is considerable experience to show that at, or below, 800 MeV backgrounds are acceptable. There is very little experimental evidence for energies above this. The magnitude of the background problem remains an area to be studied.

However, a general conclusion is clear. The neutron beam characteristics required by experiments can be achieved for a wide range of proton beam energies. The experimental aspects of the source specification will have only a marginal role in the consideration of the choice of proton energy for a high power source.

## 3. CALCULATIONAL METHODS

The main body of data available to validate theoretical calculations and phenomenological models is restricted to energies around 1 GeV. However, extrapolation to higher energies has been successful in several areas. In particular the work done on the design of calorimeters for high energy physics experiments give some confidence that reliable calculations of nuclear cascades can be performed up to several GeV.

## 4. ENGINEERING.

The target stations required for a high power spallation source present a formidable engineering challenge.

### 4.1 Cooling Systems

A crucial concern is cooling systems. The peak power deposition of up to 8 MW per litre for a stationary solid target is very clearly at the limit of the capabilities of pressurised water cooling. There are ways to reduce the peak power deposition.

- Decrease the longitudinal interaction density by increasing the proton energy.

The peak power deposition at 800 MeV is 8 MW/l and at 3 GeV this drops to about half this value.

- Decrease the lateral density either by moving the target or increasing the proton beam size.

Studies on neutron production have shown that increasing the beam diameter in a 'wing' geometry results in reduced neutron flux from the moderators. Calculations of the effect of increasing proton beam diameter for a 'flux trap' configuration have not yet been performed and this data will be crucial in the consideration of the optimum proton energy.

Rotating solid targets were extensively studied during the SNQ and practical solutions found to the engineering problems. A new design for a solid rotating target giving a flux trap configuration was presented at this meeting.

Detailed work is now needed to establish the practical limit for pressurised water cooling given the geometric constraints of achieving the required neutron fluxes.

A general conclusion is that cooling the target whilst maintaining neutron beam fluxes becomes progressively easier as the proton energy increases. However, while the lower energies present greater difficulties, further work is required to establish whether or not practical engineering solutions exist.

4.2 Thermal Shock

The effect of the short duration proton pulses (<3 μs) is to deposit power beyond the rate that normal thermal conduction processes can transport the heat. This results in shock wave propagation with its associated high transient stresses. This could present a serious materials problem. As the power deposited per unit volume reduces as the energy increases the effects of thermal shock will also reduce with increasing proton energy. Thermal shock is a phenomenon which will require investigation.

## 4. RADIATION DAMAGE.

A spallation source based on a 5 MW proton beam will produce irradiation of structural materials comparable to that of a high flux research reactor such as that at the Institute Laue Langevin. Experience with such reactors does not suggest that there are any insuperable problems. However, spallation sources presents some special problems. As with peak power deposition the 'density' of radiation damage will decrease as the proton beam energy increases.

4.1 Assessment.

The crucial difficulty is the reliability of the assessment of component lifetimes. There is little data available for the irradiation conditions in a spallation source although the experience at existing sources such as ISIS will be valuable. Accurate prediction of lifetimes is important as this will determine the strategy for component replacement which in turn will dominate the detailed design of theses components and the handling philosophy.

4.1 The Proton Beam Window.

Most target station designs requires a window separating the proton beam vacuum from the target. This component which requires special consideration. Experience at existing accelerators is limited to proton beam current densities below 100 $\mu A.cm^{-2}$. For a typical parabolic proton beam profile a limit of 100 $\mu A\ cm^{-2}$ would require a beam diameter of 250 mm at 800 MeV and 70 mm at 3 GeV for 5 MW beam power. Proton beam diameter has a significant effect on the possible neutron fluxes as mentioned above in the considerations of the effects of peak power deposition in the target.

Design of a window for beam current densities well above 100 $\mu A\ cm^{-2}$ with a minimum lifetime of one or two years may well be impossible. However, a window with relatively short lifetime for example three months could still be acceptable if replacement is a short operation of say one or two days. This would be a practical solution within the normal constraints of an accelerator complex.

4.3 The Target and Moderators.

For the reasons discussed above there may well be a proton energy below which a solid stationary target is impractical. Radiation damage will result in changes in material properties such as embrittlement is likely to make the design problem more rather than less difficult. However, as with the window a solution which gives relatively short lifetime with fast replacement could still be practical.

## 5. CONCLUSIONS.

In principle it would appear that, by careful optimisation, target/reflector/moderator configurations can be designed to give about the same neutron beam fluxes independent of the proton energy. Solutions to the engineering difficulties, in general, get easier as the proton energy increases.

However, the implied lower energy limit for a practical target station is not known at present. This is the main issue for the Target Station design.

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