CHOICE OF PROTON ENERGY FOR NEW SOURCES

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Abstract

Some of the accelerator design factors affecting the choice of proton energy for a future spallation source are identified and discussed.

Introduction

The final selection of the proton beam energy for a future higher intensity spallation neutron source must take into account factors from the target design and the neutron scattering instrument design as well as the accelerator design. Only accelerator design factors affecting the performance, construction cost and operating cost of a 5 MW Spallation Neutron Source are outlined in this paper as a preliminary to a discussion on these topics.

Conclusions of Prior Meetings

Initial meetings on a possible, new European Spallation Source concluded that a suitable set of parameters would be those shown in Table 1.

Beam Energy	0.8 - 3.0 GeV
Beam Power	5 MW
Proton Beam Pulse Length	< 3 μs
Target 1	4 or 5 MW @ 50 Hz
Target 2	1 MW @ 10 Hz

Table 1

It was also concluded that a future study would need to design and cost an accelerator and two target configuration consisting of the following:

1. An 800 MeV linac of 6.25 mA mean current and 100 mA or more peak current.
2. Three compressor rings.
3. A 5 MW Tantalum target and target station.
4. A 1 MW target and target station.

In addition a future study would need to assess the possible benefits that could be derived from the use of :

1. Superconducting Linacs.
2. Fixed Field Alternating Gradient Accelerators (FFAG).
3. Use of Higher Proton Energy.
4. Different Target Designs.
5. Other Types of Accelerators.

Existing Experience

Table 2 (Ref. 1) outlines the parameters of some of the accelerators used for existing pulsed, spallation neutron sources. An exception is the cyclotron at PSI where the high power spallation target is still under construction and the beam is continuous and not pulsed. It is included here because the beam power is expected to reach the 1 MW level this year.

FACILITY	ENERGY (MeV)	Repetition Rate (Hz)	Operating Beam Power (kW)	Highest Achieved Beam Power (kW)
KENS (Japan)	500	20	2	2
IPNS (US)	450	30	6	7
LANSCE (US)	800	20	40	60
ISIS (UK)	800	50	145	160
PSI (S)	570	CW	1000 (Design)	

Table 2.

Figures for beam losses at the two most powerful pulsed spallation sources currently in operation are given in Table 3. It is interesting to note that one, ISIS, is a linac and rapid cycling synchrotron and the other, LANSCE, is a linac and compressor ring.

	ISIS	**Beam Energy**	**LANSCE**	**Beam Energy**
Beam Current	190 μA	800 MeV	80 μA	800 MeV
Losses				
Injection	3 μA (c)	70 MeV	6 μA (c)	800 MeV
Trapping	28 μA (c)	70 MeV	0.5 μA	800 MeV
Acceleration	1.5 μA (c)	120 MeV	-	
Extraction	<10 nA	800 MeV	160 nA	800 MeV
Transport	<1 nA	800 MeV		

Table 3. Beam losses at ISIS and LANSCE PSR. (c) indicates that the lost beam is picked up by a beam collector.

As both these machines run reasonably close to the induced activity levels that can be tolerated for hands on maintenance it is clear that uncollected beam loss at energies above

120 MeV must be kept below 100 nA in future higher intensity machines. It is also clear that wherever possible lost beam must be captured on beam collectors specifically designed for this purpose.

New Spallation Source Proposals

Table 4 lists the main parameters of proposed designs of new spallation sources where the proton beam energies range from 800 MeV to 45 GeV. As can be seen, different accelerator options favour different proton beam energies, bearing in mind that the maximum current in a ring is likely to be limited to the levels achieved in the CERN ISR due to the instability limit.

	Linac Energy GeV	**Ring Energy GeV**	**Ring Type**	**Beam Power MW**
AUSTRON	0.07	1.6	RCS	0.1
ANL	0.4	2.2	RCS	1.0
ESS - 1	0.46	1.6	FFAG	5.0
ESS - 2	0.8	0.8	COMP X 3	5.0
ESS - 3	1.2	1.2	COMP X 2	5.0
ESS - 4	2.4	2.4	COMP X 1	5.0
ESS - 5	0.8	3.0	RCS	5.0
LANL	0.8	0.8	COMP X 1	1.0
INR	0.6	45.0	KAON FACTORY	5.0
LBL	1.0 (Ind linac)			5.0

Table 4. New spallation source proposals.

5 MW Rapid Cycling Synchrotron (RCS)

This is an extrapolation of ISIS by a factor of 30, taking the stored energy in the beam from 3 kJ to 100 kJ. The minimum final energy of the proton beam would be 3 GeV and for a 50 Hz machine the beam would need to be in the ring for at least 10 ms as compared with the 1 - 2 ms of the Compressor Ring options (CR). The required value of peak current from the 0.8 GeV Linac injector is similar to the CR options. Most of the RCS components will be technically more difficult than for the CR options with, for example, all the ring magnets having RF screens of low eddy current design inside the vacuum vessel to maintain a low impedance for the beam. It may be beneficial to consider two 25 Hz RCS to alleviate some of the design problems.

Beam loss from the injection, trapping and acceleration processes will all take place at energies well above the neutron production threshold, making beam collection considerably more difficult than on ISIS. Graphite collectors would need to be about 1 m long instead of a few centimetres.

5 MW Compressor Ring Options

Three energies have been proposed for the Compressor Ring options, namely:

3 Rings at 0.8 GeV and 1.7 MW each,
2 Rings at 1.2 GeV and 2.5 MW each,
1 Ring at 2.4 GeV and 5.0 MW.

Of these options the lower energy, three or two ring version, appears as a more favourable choice for the following reasons.

1. Cost

The cost of the rings will almost certainly scale with the beam momentum giving scale factors of 2.2, 1.3, and 1 for the 2.4, 1.2, and 0.8 GeV energies respectively. In addition there will be a much longer linac to build for 2.4 GeV energy.

2. Reliability

A multi ring version will allow continued operation at 2/3 or 1/2 intensity even if one ring fails, although it could be argued that the multi-ring version requires more components in working order if it is to operate at full intensity. However, it is likely that the 2.4 GeV version will have nearly the same number of components as the multi-ring version but they will be connected in series rather than in parallel.

Also for the 2.4 GeV linac there will be a much longer linac to maintain.

4. Buildings and Shielding

Figure 1 indicates the size of building required for achieving hands on maintenance with levels of induced radioactivity similar to those at ISIS and LANSCE. The shielding is that estimated to allow personnel occupation of the areas outside the compressor ring or beam transport line carrying the 5 MW beam. With present day prices a structure of this large cross section will cost about £400k/m. Cost savings may be made by use of tunnels but clearly the lower the energy the lower the cost of the buildings and shielding will be.

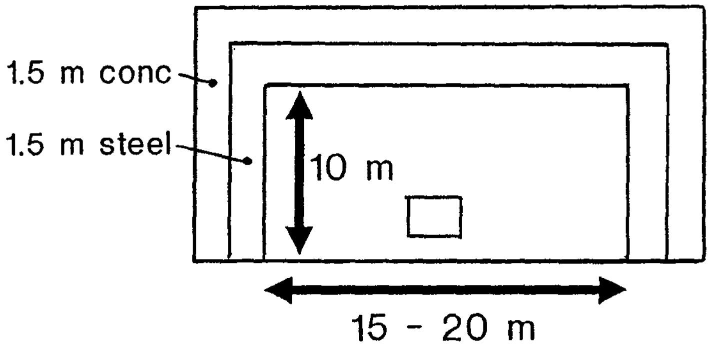

Fig 1. Shielding and building size required for hands on maintenance.

5. Lost Beam

Beam collection and collimation will be much harder at 2.4 GeV and, since the number of particles per ring is the same in all three cases, then each lower energy ring can tolerate a larger fractional loss.

6. Injection

H-minus injection becomes more difficult at 2.4 GeV where there is more uncertainty about the excited H-zero states. At the higher energy, stripping foil radiation damage will be greater, the required linac momentum ramping will be more difficult and the debunching of the linac micro bunches will be slower.

7. Extraction

For a high energy ring the aperture cannot be reduced much because of the impedance increase, thus the extraction will be more difficult.

8. Beam Transport

2.4 GeV beam transport lines will be more expensive to build and to operate than for the lower energies. On ISIS almost half the total electrical power is used by the 800 MeV beam transport line.

Conclusion

From the above considerations, it is probable that the accelerator design that will be of the lowest cost, to build and to operate with high reliability, will be that which has the lowest possible output energy and the highest achievable beam intensity. However, the final choice of energy can only be made when more detailed designs have been produced and costed.

References

1. G H Rees , Overview of Future Spallation Neutron Sources, Proc. of the US National Accelerator Conference, IEEE Trans. Nucl. Sc, 1993.