THE LINEAR ACCELERATOR FOR THE PROPOSED GERMAN SPALLATION SOURCE.

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Summary

A Study[1)] has been submitted to the German Ministry for Research and Technology on the feasibility of a spallation neutron source (SNQ). It comprises a proton linear accelerator. The basic parameters of this accelerator will be discussed, in particular those typical for the application envisaged. Particular emphasis is put on the problem of beam loss.

The neutron source should have the following properties:

1. An average thermal neutron flux comparable to that available today from high flux reactors. The neutron yield is, in a very rough approximation, proportional to the power deposited by the beam in the target. Neutronics calculations, checked by recent measurements, show that a beam power of about 5.5 MW on a Pb target is needed.

2. A time structure of the thermal neutron flux is desirable. This is reflected in a modulation of the beam with a duty cycle of about 5 %, giving a corresponding enhancement of the peak thermal neutron flux.

3. For experiments with epithermal neutrons and with neutrinos an even higher compression of the beam, by another factor of the order of 1000, is wanted.

At the present state of accelerator technology it was found that requirements 1 (and 2) can only be met by a linear accelerator. Requirement 3 necessitates the addition of an accumulator ring (a.r.). This option is part of our study, but falls outside the scope of this talk. It influences, however, the design of the linear accelerator in several respects:

1. Because of the space charge problem for the a.r., the final energy is chosen relatively high (1.1 GeV).

2. In order to facilitate the filling of the a.r., the option of accelerating H^- is kept open. This means provision for a vacuum of 2×10^{-8} mbar to avoid gas stripping and low magnetic fields to avoid Lorentz-stripping. Both sources of loss should be kept below the desired beam loss limit (see below).

The novel feature of the linac is the high average current (and power) it has to carry. It makes the problem of minimizing beam losses more urgent than for linacs operated today. It is our aim to make hands-on maintenance possible shortly after switching off the accelerator, as is the case at the LANL accelerator. From estimations of activation, it follows that beam losses per meter below 1 % at 10 MeV and below 2×10^{-7} at 1 GeV are necessary. For the case that this aim cannot be reached immediately in some locations, we make provisions for remote-handling. But we definitely want to avoid having remote-handling as a permanent feature.

Thus in describing our proposed linac I shall stress those features that are dictated by the need to cut beam losses. Table I gives the fundamental parameters of the accelerator.

Table I

Basic parameters

In brackets: options

Final energy	1,100		MeV
Particles	Protons (H^-)		
Peak current	100		mA
Average current	5	(10)	mA
Burst length	0.5	(1.0)	ms
Rep. rate	100		Hz

Ref.[1)] Realisierungsstudie zur Spallations-Neutronenquelle, 13 volumes, Arbeitsgemeinschaft SNQ Kernforschungszentrum Karlsruhe, Kernforschungsanlage Jülich 1981
English summary: KfK 3180 B, Kernforschungszentrum Karlsruhe 1981

The peak current was chosen as 100 mA, although higher peak currents have been achieved in many existing linacs. One reason is that, above 100 mA, space-charge forces start dominating and make accurate predictions about the tails of the beam populations in phase space less reliable. Also, the perturbation that the pulse beam represents for the cavity becomes more difficult to compensate. Measurements at the CERN linac have shown that these transient beam-loading effects cause beam losses. Another reason for limiting ourselves to 100 mA is economic. The additional investment in rf needed to double the peak current would increase the price of the accelerator by about 25%. One might reduce the duty cycle to reach the same average current, but this saving would be small in comparison.

The final energy is mainly given, as mentioned above, by considerations about the feasibility of the a.r. The users also favour a higher energy, which permits higher peak fluxes in spite of the restricted peak current. Finally, the heat-removal problem in the target is eased.

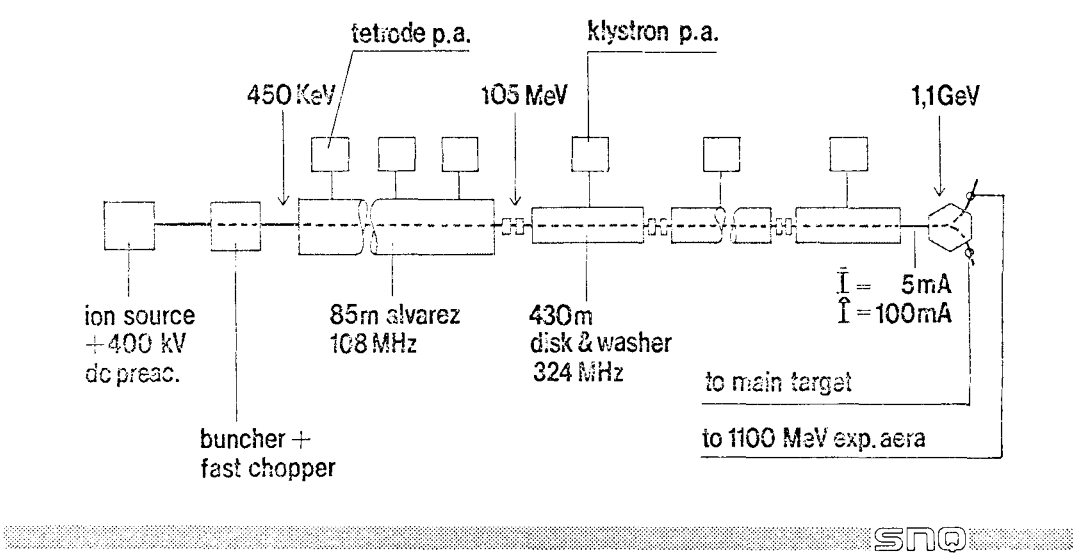
An overall layout is given in Fig. 1. We shall discuss

1. The injection energy
2. The choice of the frequency for the low-energy (Alvarez) accelerator
3. The choice of frequency for the high-energy (disk-and-washer) accelerator.

The injection energy (450 keV) was chosen lower than the usual 750 keV because the experience of other laboratories seems to indicate that for high duty cycle machines the problems of breakdown in the accelerating column is increasing with voltage and current.

The injector is followed by a buncher adapted from the one used for the new CERN linac. A capture efficiency of 90 % is expected. The corresponding beam losses occur mainly below 10 MeV and do not give rise to an activation problem.

Starting the Alvarez accelerator at an energy as low as 450 kV causes a problem. It was solved by choosing the frequency 108 MHz rather than usual 200 MHz. But this is not the only reason for choosing this low frequency. Emittance reserves both in transverse and longitudinal phase space are larger for the lower frequency. The danger of losing particles longitudinally due to space charge forces is also less at the lower frequency. We are particularly concerned about longitudinal emittance growth because there is a change of frequency in between the Alvarez and the DAW accelerator, which, of course, would give rise to losses if the longitudinal emittance is too large.



snq-linear accelerator, reference concept

Fig. 1

For the transverse motion under the influence of space charge, emittance growth is more probable at the lower frequency. Multiparticle computer simulations showed that for the parameter choice of the reference concept the transverse emittance growth is small and no instabilities are excited.

In summary we gave the preference to the lower frequency of 108 MHz. It has the additional advantage that the same frequency is used in the Alvarez of GSI at Darmstadt. So we have the transmitters and other RF components readily available.

The transition energy from the low energy to the high energy structure was chosen at 105 MeV. According to our calculations and also according to the computer simulations at this energy a jump of frequency by a factor 3 can be handled without loss of particles. The disk-and-washer structure is thus operated at the frequency of 324 MHz. A higher frequency would be favoured here from the point of view of shunt impedance, but a higher jump in frequency, e.g. by a factor 4 would leave less reserve in longitudinal acceptance.

One point needs a comment. The problems of the high voltage column and of the acceptance into the beginning of the Alvarez could be avoided by adopting the RFQ-structure that replaces preaccelerator, buncher and the first part of the Alvarez. We are often being asked, why we do not adopt the RFQ-structure. The answer is that we do not exclude the RFQ-structure for the next phase of the study. For this first phase, however, which mainly concerns the feasibility of the accelerator, we feel that we should stick to the "classical" solution for two reasons:

1. The RFQ-structure is still under development, so it would be wise to wait for some operating experience.

2. It is essential that we can punch holes of one or several micropulses into a macropulse for purposes of switching from one experimental area to another without beam loss and also later for leaving an ejection gap in the filling of the accumulator ring. In both cases no beam should be present while switching elements are in an intermediate state. These holes can be conveniently punched in behind the dc-accelerator at a 450 keV level. An RFQ-structure would start at about 50 keV and would accelerate particles up to 2 MeV. At the 50 keV level handling the beam is complicated because here it has to be neutralized to avoid blow-up due to space charge. At 2 MeV level the beam is already rather stiff, so that the deflector elements would have to be much more powerful. Breaking the RFQ-structure at an intermediate point, at 500 keV say, would mean to lose most of its advantages. It is possible that a way can be found around these difficulties. But since we could convince ourselves that the solution proposed is perfectly viable, this seems to us sufficient in this state of the project.

Coming back to the problem of beam losses, I have mentioned the following measures:

1. Choice of parameters leading to ample acceptance reserve both in longitudinal and transversal phase space.

2. Choice of a moderate peak current to keep the space charge problem under control.

3. Extensive computer simulations to check for instabilities, emittance growth and halo-formation.

Apart from these I would like to mention:

4. Use of the multipole ion source that has a low noise.

5. Very high stabilization in amplitude and phase of the accelerating rf.

6. The adoption of an adaptive forward-control-system that minimizes the transient in the rf amplitude and phase caused by the appearance of the beam in the cavity.

7. Diagnostic elements, correction elements and beam scrapers at critical positions for the detection and removal of beam halo.

As a result of our study we found that a linear accelerator of the desired performance is perfectly feasible. Its cost including buildings and including the target (that was not discussed here), is estimated to 680 MDM. Table II gives a rough breakdown of this sum.

I like to conclude giving you the names of the scientists who have contributed to the Study (Table III). Some of them will also contribute to this conference.

Table II

Breakdown of cost estimate

for the whole SNQ facility (without options)

Buildings	116	MDM
Accelerating structures and beam transport	101	
RF-System	191	
Target-block	63	
Utilities, computers	153	
	623	MDM
General engineering, licensing	56	
	679	MDM

Table III

KfK Linac Study Group

Leader	J. E. Vetter	
Beam Dynamics	K. Mittag	+
	D. Sanitz	+
	K. Bongardt	+
	M. Pabst	+
Injection	B. Pioscyk	+
Acc. Structures	G. Dammertz	
	R. Lehmann	
Beam handling	W. Kühn	
	G. Schaffer	
Diagnostics	H. Schweickert	
RF System + Controls	G. Hochschild	
	R. Hietschold	
	A. Hornung	
	D. Schulze	+
Gen. Engineering	H. Sebening	
	G. Böhme	
	B. Haferkamp	

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E. Boltezar	CERN	S.O.Schriber	CRNL
K. Goebel	CERN	M.R.Shubaly	CRNL
D. Warner	CERN	K. Crandall	LANL
M. Weiß	CERN	H. Hereward	

+These persons made contributions to the present conference.

Discussion

The government will probably make a decision on the SNQ by the end of this year: to stop, continue as a study, or decide on a site for the full project. The potential users would be fundamental researchers in neutron scattering, materials scientists, persons from the nuclear physics community interested in intermediate energies and mesons, and finally, there is considerable interest from the neutrino community because the time structure and high average flux give unique opportunities for neutrino experiments.