Advantage of Neutron Sources with Time Structure for Special Neutron Spectrometers

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Expansion of neutron scattering research requires better neutron sources, even better than the HFR Grenoble. Research reactors seem to be at the limit of development. pulsed sources, especially accelerator pulsed sources, offer a break-through to considerably better sources. For nearly all neutron scattering experiments using neutron energies larger than 100 meV the flux versus energy distribution and the pulse characteristics make accelerator pulsed neutron sources superior to reactors with continuous flux. For cold and thermal neutrons (E smaller than 109 meV) the comparison of continuous and pulsed sources - both in competition and complementarity - is very complex. It obviously depends among many other aspects on the type of sources compared. In this paper we report on some general and also on some very specific considerations to compare the HFR Grenoble (HFRG) with the German Spallation Source Project (SNQ) /1,2/.

The hybrid version of the SNQ with a lead target offers an average flux at the hydrogeneous moderator (below the target wheel) of $\Phi_t = 8\times10^{14}$ n/sec cm^2 and a perturbed flux of $\Phi_c = 5\times10^{14}$ n/sec cm^2 at the position of the cold source in the moderator (above the target wheel). The WFRG-values are $\Phi_t = 10^{15}$ n/sec cm^2 and $\Phi_c = 5\times10^{14}$ n/sec cm^2, respectively. We see, the average fluxes of HFRG and SNQ are about the same. Any gain factor obtainable from the time-structure of SNQ is a full gain compared to the HFRG.

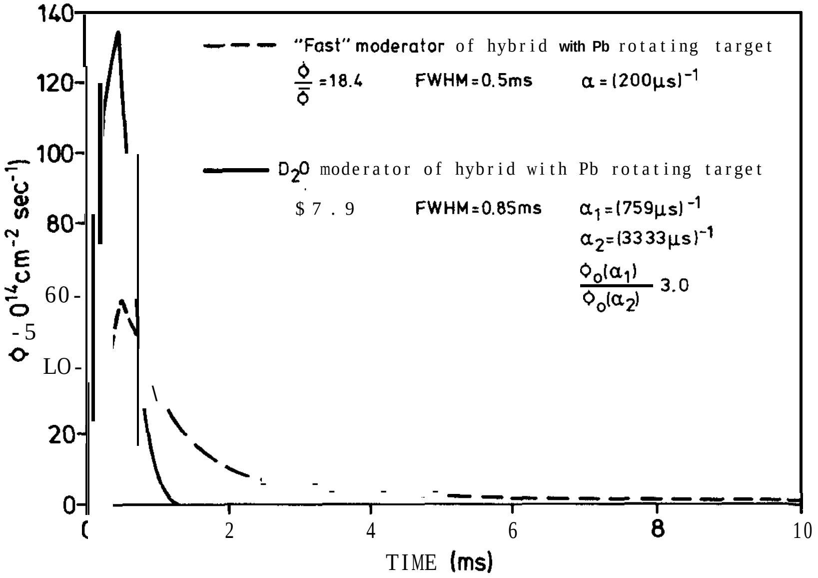
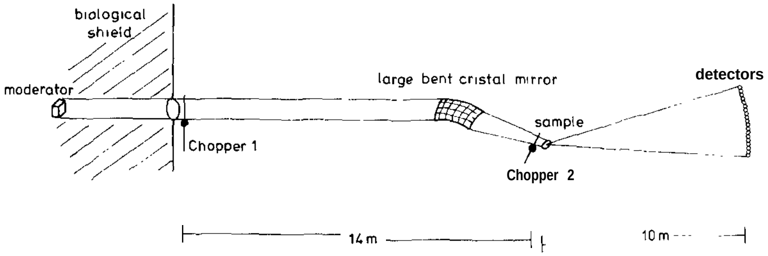


Fig. 1 Neutron pulse forms in the SMQ for H_2O and D_2O moderators /2/.

The 500 µsec proton-pulse of the SNQ is supposed to produce a peak-flux $\hat{\Phi}_H$ of $1{,}5\times10^{16}$ n/sec cm^2 at the hydrogeneous moderator and a peak-flux $\hat{\Phi}_D$ of 4×10^{15} n/sec cm^2 at the position of the cold source in the D_2O moderator (Fig. 1), thus the maximum gain for SNQ compared to HFRG is 15 and 8, respectively. Typical time-of-flight-spectrometers (tof); as IN4, IN5, IN6, and D7 at the HFRG, would fully benefit from this gain, provided the higher duty cycle normally used at reactors could be compensated by larger sample to detector distances keeping the total solid angle constant by some additional costs for detectors. There are about ten neutron diffractometers at the HFRG, all of them operating with single crystal monochronator.About two third of the activity (powder diffraction, structure analysis at single crystals with large unit cells, diffraction at biological substances) would benefit appreciably from the time- structure provided the large multidetector units are backed-up by electronics and computers able to handle data collection e.g. for 4000 detector elements and a few hundred time-of-flight-channels.

There are, however, special cases (structure analysis for single crystals with small unit cells, fine structure of bragg peaks), where discussions have not revealed full use of time-structure yet. At least a factor of two can be taken as granted for these cases taking into account that i) second order can be eliminated. ii) fast neutron background appears in definite time windows only and iii) inelastic scattering contributions can be separated. In total SNQ would be superior to HFRG for neutron diffractometry somewhere between 2 and 15, somewhat like a factor 7.

As already said in neutron spectroscopy tof-spectrometers fully gain from time-structure. At SNQ probably the fraction of tof-spectrometers would be considerably higher, including new developments like constant q-tof, a renewal of statistical chopper techniques and an adaptation of back-scattering spectrometer to the specific time structure of GSP /3/. An old technique - triple axis spectrometry (tas) - and a new technique - neutron spin echo - seem to tend more towards continuous flux. Neutron spin echo can probably be superimposed to tof as well as it is on the way to be superimposed on tas. The question remains what must be the ratio of $\hat{\Phi}$ to $\bar{\Phi}$ to convert a tas-specialist to tof-phonon-spectroscopy, having in mind that a conventional tas at SNQ already has some advantage (second order diminuation, background free time window). A ratio of 7 to 10 for $\hat{\Phi}/\bar{\Phi}$ probably is necessary to obtain this conversion. To get an idea, whether this guess is reasonable, we sketched an Eo = 100 meV phonon spectrometer (Fig. 2) and considered its efficiency:



100 meV TOF spectrometer

Fig. 2 A 100 meV TOF spectrometer.

With a 25 µsec chopper placed at the biological shielding and a second at 14 m distance just before the sample for E_0 = 100 meV the energy resolution would be 2.2%. In order to keep both the vertical and horizontal divergence comparable to normal tas-conditions a large size double-bent monochromator is placed between the choppers as a "mirror" element. The pulsing reduces the "apparent" source flux from $1{,}5\times10^{16}$ n/sec cm^2 by a factor 25 µsec/10 msec down to 4×10^{13} n/sec cm^2, which is a factor 25 below the HFRG-value. Thus, at least 25 detector-tof-channels have to carry useful information. For optical phonons and low-dispersion acoustical phonons a much higher number seems to be achievable.

A great number of experiments will be installed, at neutron guide tubes. Similar to a classical multichopper time-of-flight spectrometer (as IN5 of HFRG) the time structure of the SNQ may be used for energy selection using the long distances in the neutron guide tubes combined with high duty cycle disc choppers. We may first consider a neutron guide installed on a cold source. It should cover an energy range of about 1 meV $\leq$ E $\leq$ 15 meV and will be 50 m in length. According to the pulse width in the D_2O moderator of about 2 msec disc choppers with 30% duty cycle running at 100 Hertz will be suitable. In Fig. 3 it is shown that 4 choppers will be necessary for monochromatizing the beam. The neutron wavelength may be chosen by simply setting the phase between the choppers. The resulting resolution varies between $\Delta\lambda/\lambda = 0.026$ at 9 Å and 0.105 at 2,3 Å.

In some cases such as small angle scattering experiments poorer resolution may be of interest. This may be achieved with 40% duty cycle choppers at smaller distances. Then, at least 5 choppers are needed. A rather flexible instrument may consist of 6 disc choppers (for example at 20 m, 22 m, 25.7 m, 27.2 m, 30 m, and 50 m from the cold source). The lowest resolution of $\Delta\lambda/\lambda = 0.13$ at = 4 Å results when choppers 1 to 5 operate at 100 Hertz and chopper 6 is at rest. Running-all 6 choppers at 200 Hertz will improve the resolution to give $\Delta\lambda/\lambda = 0.04$ for typical 4 Å or $\Delta\lambda/\lambda = 0.018$ for 9 Å neutrons. If still a better resolution is wanted the phase of chopper 4 may be changed and thereby cutoff a portion of the monochromatic pulse. This will of course reduce the intensity in a higher rate.

Choppers in a thermal neutron guide looking on an hydrogeneous moderator will allow much better resolutions since the pulse length will be about 500 µsec in the SNQ or about 200 µsec with a storage ring. As an example we may consider a neutron guide 80 m in length designed for an energy range of 15 meV to 50 meV. An energy resolution of 2% at 25 meV will result for a 500 µsec pulse.

As shown for the cold neutron guide the resolution may be variable when using high duty cycle choppers. The resolution may be changed in steps from $\Delta\lambda/\lambda = 0.5\%$ to $\Delta\lambda/\lambda = 8\%$ (E = 25 meV) without losses in the wavelength center of the pulse. Still better resolution need longer guides or cutting away of monochromatic neutrons.

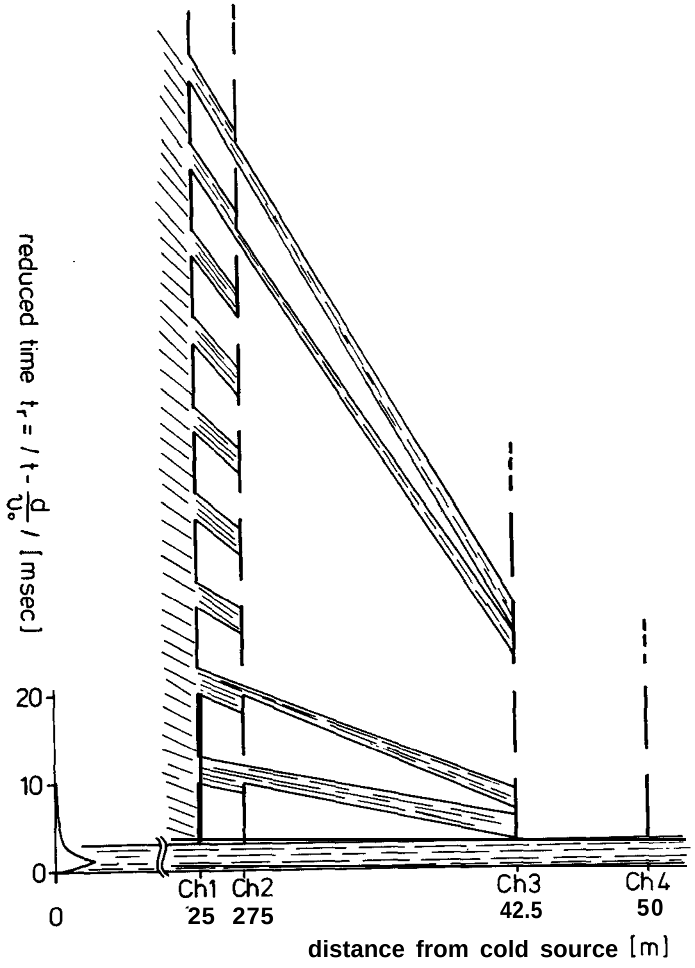


Fig. 3 Energy selection by disc choppers in neutron guides. In the reduced scale the neutrons of the selected speed v_0 follow horizontal lines. Up to the 10th order all neutrons with different speed are shielded by the chopper discs.

In total it can be expected that SNQ would be superior to HFRG in neutron spectroscopy at least a factor 7. It should be mentioned at this point that SNQ contains two options - uranium target, storage ring - which would improve the gain factor considerably. On the other hand, however, there would be some instruments, like high resolution tas, which would have no dramatic gain compared to HFRG.

References

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