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State of the SNQ Project

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The state of the SNQ project can be stated in 6 words: the SNQ will not be built.

This decision was taken only two weeks ago by the Supervisory Board of our laboratory, based on a recommendation by a commission of the federal German parliament, the commission for research and technology. The decisive paragraph of the decision reads:

> "The Supervisory Board has noted that the KFA associates do not see any possibility of realizing the project under the present circumstances in view of the high amount of funds required for the construction of the SNQ spallation neutron source. It, therefore, decides that the project be terminated by December 31, 1985 in accordance with Art. 7, para. 2a of the partnership agreement. The Supervisory Board requests the Board of Directors to complete any work still under way for the SNQ project during this period and to document the results also with a view to a potential revival of such a project at a later date. The Supervisory Board notes that the Federal Minister for Research and Technology intends to set up an advisory committee in order to clarify the question of future research opportunities for German scientists working with neutrons. The KFA is requested to support the activities of this committee by making available its expertise and the experience gained in handling the SNQ project."

The associates mentioned here are the German federal goverment which provides 90% of the laboratory budget and the government of the land Northrhine-Westfalia which contributes 10% of the budget. The decision was taken in spite of the unanimous positive votes by two scientific bodies, the SNQ Scientific Council and the German Advisory Board on Basic Research in Natural Sciences.

Now, though the SNQ is dead we decided to come to this meeting and to present our contributions, because we think that at least some of them may be of interest to the design of other spallation sources or for the utilization of spallation sources.

Thus, first I will describe briefly once more the basic concept of SNQ. Then, in the workshops, we will present some special aspects; 8 contributions related to the target, with its special features resulting from the high power density we had planned, and 2 on ideas and development work for neutron scattering instrumentation. A rather large amount of work done about instrumentation for pulsed sources has been published as a report entitled "Proceedings of the Workshop on Neutron Scattering Instrumentation for SNQ" /1/.

The Basic SNQ Concept

The primary goal of our project has been: to create a facility for neutron scattering which goes beyond a high flux reactor. I still am convinced

- in the first place, that - at least virtually - neutron scattering is the very best tool for condensed matter research, where by condensed matter I mean not only solids and liquids but also and in particular biological matter,
- secondly, that in order to apply this tool to more and more complex and interesting systems and more complex and more interesting phenomena more beam intensity is required than presently available even with high flux reactors, and
- in the third place, that the only way to make substantial progress in this direction is the development of sources based on spallation.

The advantage of spallation lies not only in the possibility it provides for an optimal time structure of the neutron beams but also in the fact that the heat produced per released neutron is considerably smaller than with fission and can be removed more easily. Yet, also for spallation sources, the final limit for attainable flux strengthes will be given not by the achievable proton beam power but again by heat, by the heat production in the target. If one considers a hybrid target, a booster, combining spallation and fission, obviously the more fission one allows for the sooner one will reach the final limit. A booster may be a sensible option for a given accelerator; the optimal solution will be a pure spallation source.

By "beyond a high flux reactor" I mean here: not only for hot and epithermal but also for thermal and subthermal neutrons and not only for time-of-flight measurements but for as many types of measurements as possible.

We had many and long discussions on what types of measurements should be performable with a spallation source. We finally agreed to distinguish 3 classes:

1. Steady state measurements (dc-measurements like with a triple axis spectrometer). For such measurements, going beyond a high flux reactor for thermal neutron beams must mean, of course:

$$\Phi_{th} > \Phi_{th}^{HFR} \tag{1}$$

   where Φ_{th} is the thermal neutron flux from the spallation source in time average.

2. Time-of-flight measurements, mostly of the type you would or could do at a reactor too. Here, going beyond a reactor must mean:

$$\nu_s \cdot \hat{\Phi}_{th} > \nu_{tof} \cdot \Phi_{th}^{HFR} \tag{2}$$

   where $\hat{\Phi}_{th}$ is the peak thermal flux, ν_s the source repetition rate and ν_{tof} the time-of-flight pulse frequency you would use for the same measurement at a reactor.

3. Multiplexing measurements.

By "multiplexing" we mean measurements for which the time structure of the source does not determine the resolution. The time structure is used only to carry out a number of scans simultaneously. - This is illustrated in fig. 1, the well-known time-distance diagram for neutron flight. The different slopes of the oblique lines correspond to different neutron velocities or neutron wavelengthes. In time intervals T, the source provides pulses of duration τ. For a multiplexing measurement, you accept in a time fraction Δt a wavelength band which is as broad as possible (the shaded area in fig. 1), much broader than the resolution you need, and you then later, in front of the sample or behind it, subdivide this band into sections corresponding to your resolution requirements so that you perform n measurements in the interval between two pulses. You can do this by time-of-flight but also by other means, by crystals for instance.

I consider the exploitation of this possibility most important for steps beyond high flux reactors. Fig. 2 illustrates the principle with the simplest example: a measurement on diffuse elastic scattering. By elastic I mean, without energy analysis; the scattering is known to be elastic. If the incident beam is open for a time interval Δt, then we have in a distance l after a time A_M a wavelength band

$$\Delta\lambda = \lambda_1 - \lambda_2 = \Delta t \cdot \frac{\lambda_M}{A_M}$$

centered around λ_M, if $A_M = l/v_M$. If a scattering number resolution δQ is required, we need a wavelength resolution

$$\frac{\delta\lambda}{\lambda} = \frac{\delta Q}{Q} - \frac{1}{2}\cot\frac{\vartheta}{2} \cdot \delta\vartheta$$

if ϑ is the scattering angle. To achieve this resolution, for instance by time-of-flight, we require

$$\frac{\delta t}{T_M} = \frac{\delta\lambda}{\lambda_M}$$

with $T_M = L/v_M$, L being the flight path. We then get an intensity

$$I_{pulsed} = \hat{\Phi}_{th} \cdot \frac{\tau}{T} \cdot P_c \cdot \delta\Omega \cdot \frac{\Delta\lambda}{\lambda} \; \frac{\delta t}{\Delta t}$$

where P_c is the transmission of the chopper placed at distance l and open at time A_M for an interval δt and $\delta\Omega$ is the solid angle element for the scattered beam. For comparison, with a similar experiment at a high flux reactor, we would obtain

$$I_{HFR} = \Phi_{th}^{HFR} \cdot P_x \cdot \delta\Omega \cdot \frac{\delta\lambda}{\lambda}$$

P_x being the reflectivity of a monochromizing crystal. Assuming $\Phi_{th}^{HFR} = \hat{\Phi}_{th} \cdot \frac{\tau}{T}$ and $P_c \simeq P_x$, we get

$$\frac{I_{pulsed}}{I_{HFR}} = \frac{\Delta\lambda}{\delta\lambda} \cdot \frac{\delta t}{\Delta t} = \frac{L}{l}$$

which may be 10 or 20, depending on overlap conditions. We performed 10 to 20 measurements at the same time. There are many other examples for multiplexing: a multi-crystal back scattering spectrometer, time-of-flight small angle scattering, a time-of-flight spin echo instrument, etc.

For the multiplexing type of measurements, going beyond a HFR means:

$$\Delta t \quad \cdot \Phi_{th} > \delta t \cdot \Phi_{th}^{HFR} \tag{3}$$

where the fullfillment of this requirement will be constrained by considerations on the avoidance of overlap of beams from different pulses, just as the fullfillment of requirement (2) must be limited by such considerations which are specific to each measurement, of course.

The requirement (1) was specified for SNQ to be:

$$\Phi_{th} = 1.2\ \Phi_{th}^{HFR} = 1.2 \times 10^{15}\ cm^{-2}s^{-1} \tag{1a}$$

With protons as primary particles and U^{238} as spallation material this means a beam power of 5.5 MW. The energy was chosen to be 1.1 GeV, because at this energy the heat produced per released neutron has a minimum. Then a time-average current

$$\bar{I}_p = 5\ mA \tag{1b}$$

is required. For the repetition rate, ν_s, we got requests between 25 and 400 Hz from different users,

$$\nu_s = 100\ s^{-1} \tag{2a}$$

appeared as a reasonable compromise. The requirements (1b) and (2a) can be fullfilled with a linear accelerator or, possibly, with a FFAG synchrotron only.

With a linear accelerator of the high frequency type

$$\hat{I}_p = 200\ mA \tag{2b}$$

is feasible with present-day technology without too large beam losses. This yields

$$\hat{\Phi}_{th} = 4.5 \times 10^{16} \text{ cm}^{-2} \text{ s}^{-1} \qquad (2c)$$

$$\nu_s \cdot \hat{\Phi}_{th} = 4.5 \times 10^{18} \text{ cm}^{-2} \text{ s}^{-2}$$

From (1a), (2a) and (2b) it then follows that the pulse width must be $\tau_p = 250$ µs.

The values for $\bar{\Phi}_{th}$, equ. (1a), and for $\hat{\Phi}_{th}$, equ. (2c), refer to a H_2O moderator without poison and fully coupled to the target. With τ_p = 250 µs the neutron pulse width is

$$\tau_{th} = 280 \text{ µs}. \qquad (3a)$$

To make the pulses shorter would require not only shorter proton pulses but also poisoning and decoupling of the moderators which in turn would reduce $\bar{\Phi}_{th}$ by more than an order of magnitude and $\hat{\Phi}_{th}$ by about factor 2. And, moreover, a Δt_{th} of 280 µs is a good value for many kinds of multiplexing instruments. Other instruments, of course, need shorter pulses. They then must use individual pulse shapers, to be placed in the beam ports as close as possible to the moderators, balancing for each individual measurement resolution against intensity. Considerable effort has been spent to develop such choppers. We are confident that this can be accomplished with the help of magnetic bearings.

Many studies, in some cases very elaborate ones, have been carried out last year to optimize existing instruments and to conceive and develop entirely novel ones with regard to a pulsed source of the SNQ type. For 15 kinds of measurements the gain to be expected with such instruments in comparison to similar measurements at the ILL has been calculated on the basis of the source specifications (1a), (2a), (2c) and (3a). The results are summarized in table 1. The numbers for the gain actually ought to be multiplied by 1.2 as all calculations were done with $\bar{\Phi}_{th} = \Phi_{th}^{HFR}$ rather than with (1a).

As an option for shorter pulses - of about 200 ns duration - a compressor ring has been conceived as has been done with LAMPF. It has been proposed as an option only because:

i) for funding reasons, we wished to build the facility in two steps;

ii) we wished to await the development of demand for very short pulses as it may arise from operation of the SNS,

iii) we did not have the time or the manpower to design the ring in sufficient detail and to develop a solution to the problems arising from the short-pulsed heat generation in the target.

Reference:

(1) Proceedings of the Workshop on Neutron Scattering Instrumentation for SNQ, Jül-1954, Oct. 1984

Type of Measurement	Gain with SNQ	Reference
Time-of-Flight Powder Diffractometer with 2×10^{-4} resolution	35	(1)
Time-of-Flight Single Crystal Diffractometer a) small unit cell ($LiSO_4 \cdot H_20$)	6	(10)
b) large unit cell	9-35	(2)
c) magnetic structures	10	(10)
Small Angle Diffraction	4-6	(3)
Small Angle Scattering a) with 10 mm beam diameter, 10 % resolution	1-2	(4)
b) with 10 mm beam diameter, 1 % resolution	20	(4)
c) with 1 mm beam diameter, 10 % resolution	14	(5)
Triple Axis Spectrometer	1	
Time-of-Flight a) at thermal moderator with $v = 250$ Hz	14	
b) at cold moderator with $v = 100$ Hz	17	
Inverted Time-of-Flight with Multi-Arm-Crystal Analyser (MAX)	10	(6)
Inverted Time-of-Flight Back Scattering (IRIS) for 10-50μeV res.	12 - 15	(7)
Multi-Crystal Backscattering for 0.1 to 1 μeV resolution	12	(7), (8)
Spin Echo for 20 neV resolution	3-6	(9)

Table 1: Intensity gain for various types of measurement at the SNQ in comparison to the ILL high flux reactor. The references for the detailed calculations are to be found in /1/.

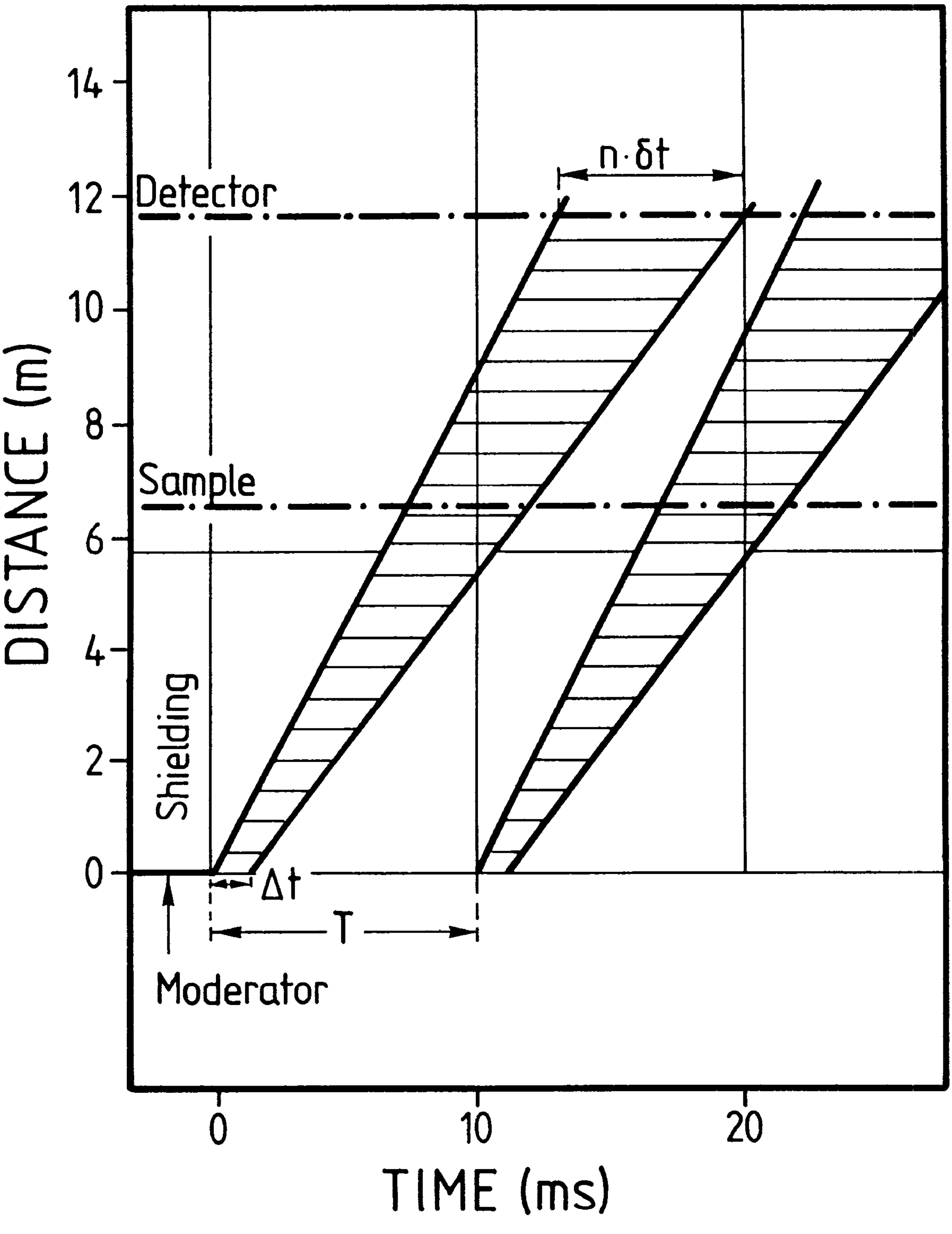

Fig. 1: The source provides pulses of duration τ in intervals T. A fraction Δt of τ is accepted to the measurement. Δt contains a neutron velocity band $\Delta v = v_1 - v_2$ which subsequently is subdivided into n elements δt, each containing a velocity band δv as required for resolution.

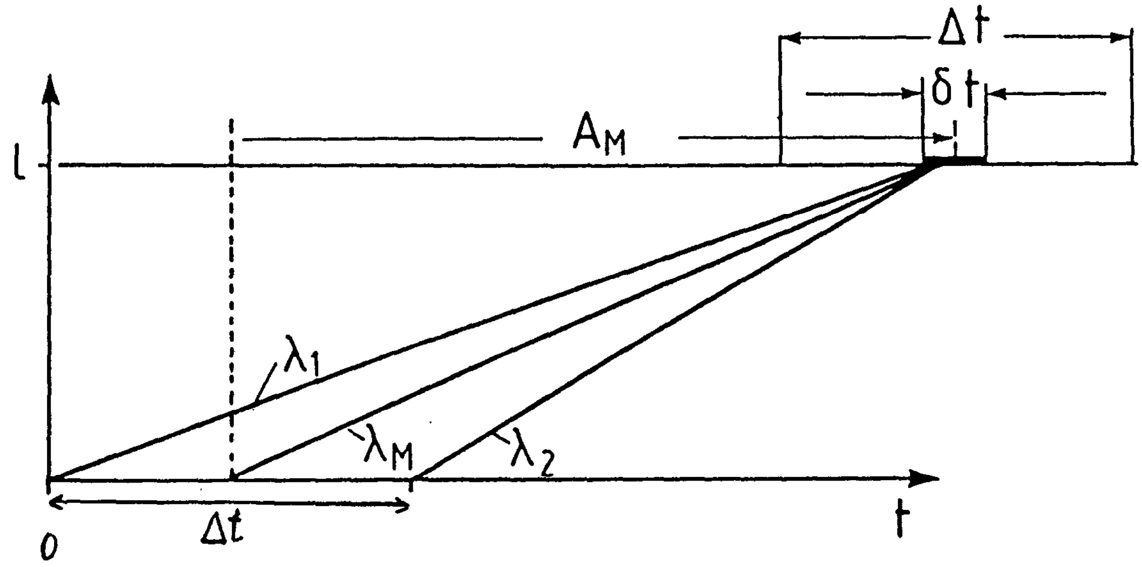

Fig. 2: Distance l between the moderator and a chopper to be open at time A_M for an interval δt in a measurement of elastic diffuse scattering (see text).