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Innovative Approach toward New Generation Sources

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Abstract

The world neutron community needs more neutrons and more opportunities at a much less expense. A worldwide neutron net work proposed here would be a future dream of the community. A neutron source being able to satisfy such requirements is the innovative neutron source. A new FFAG synchrotron will be the best candidate to realize such a network consisting of various spallation sources ranging from kW to MW in beam power. There would be many advantages with this accelerator. The next are the target issues: how to accept a higher beam-power beyond 5 MW. Some thoughts are discussed here. Various moderators are discussed in connection with the requirements from the instruments proposed for JSNS, mainly focussed on the performance and utilization of a coupled hydrogen moderator with optimized premoderator, aiming at more efficient use of neutrons. A new idea for pulse shaping, "mechanical poisoning" is proposed. At an existing spallation source the number of instruments is much smaller than at a reactor. In order to install as many instruments as possible, the beam extraction and branching methods become very important. However, even at a reactor, where mainly monochromatic neutrons are used, the neutron-intensity losses due to beam multiplexing uses are significant This problem becomes more serious in case of a pulsed source, where in many cases polychromatic beams are required. This issue is also discussed.

1. Introduction

The world neutron community needs more neutrons at much higher intensity and efficiency with much more opportunities but at much lower costs. An innovative neutron-source must satisfy such requirements. The proton beam powers in intense pulsed spallation sources recently projected or under construction are in a range of 1- 5 MW. When we consider next generation sources beyond this level, what power level could be expected in future technically and financially? Tentatively assuming a level of 5-10 MW, what major difficulties would exist and how we could solve them from accelerator and target technical points of view?

Next important issue would be "more efficient use of neutrons". Neutrons produced at a target and its vicinity must be converted to useful neutrons for experiments more efficiently. Those neutrons must be extracted and delivered to various instruments more efficiently. When we look around the existing sources and scattering facilities, still we could find a room for improvements.

The number of neutron users is rapidly increasing, especially including industrial applications. It is well recognized that the number of operating small and medium power neutron sources (reactors) is quickly decreasing, the so-called "neutron gap", which is bringing about much less opportunities for R&D of neutron techniques, educational uses, RI production, etc. We are convinced that the important mission of such sources is not only for the purposes mentioned above but also to make the neutron scattering technique more useful in various fields of research, condensed matter science, life science and basic technology R&D in industries.

Figure 1 shows the author's dream of the worldwide neutron opportunities in future. The existing reactors, of course, are important constituents of the neutron sources and ranked as equivalent spallation sources of the same neutron flux in effectiveness. Intense and super intense sources at national and world centers are very important, but small-medium power ones at regional/local centers, respective universities, laboratories and industries are indispensably important. By forming such a world neutron network the neutron scattering research could contribute for a wide range of sciences, eventually to the welfare of the mankind. In order to make such network realistic, neutron sources must be much less expensive than the presently operational or projected ones. In a spallation source the most expensive component is the accelerator system. An accelerator system consisting of a full energy linac with compressor rings is adopted in SNS and ESS, while in JSNS in phase-1 a synchrotron with a lower energy injector linac is adopted. Such systems would be orthodox and technically sure but very expensive, although we are really supporting such a system in the present project. What breakthroughs could be considered for a future accelerator system? That is one important issue in the present paper.

The next issue is whether a higher proton beam power as 5-10 MW could be acceptable at a target in near future? Prior to discussing this problem we would consider what proton energy is optimal, not only from the neutronic point of view but also from other view points. We also consider what pulse repetition rate is more useful for each experiment or how is the efficiency of a measurement as a function of repetition rate. It is also important to know how much relaxed proton-pulse-duration could be acceptable for each experiment, since the pressure wave effect on a target container strongly depends on the proton-pulse-duration.

How efficiently the neutrons produced at the target and its vicinity can be converted to useful neutrons for experiments? A new approach toward a high-efficiency target-moderator-reflector system becomes important. A high-efficiency coupled-hydrogen- moderator has already been proposed. We discuss how to use neutrons from such a moderator more efficiently.

For "more efficient use of neutrons" an efficient beam-extraction and delivery method becomes very important. The number of instruments in a pulsed spallation source is much smaller than in a reactor. In order to install as many instruments as possible, various beam multiplexing methods have so far been adopted in reactors. However, beam-intensity losses due to such multiplexing uses are significant. In a pulsed spallation source, in which polychromatic beams are mostly utilized, such losses would become more serious than in a reactor. Such issues will be discussed here.

The present paper discusses some technical aspects toward innovative-neutron sources.

2. Toward innovative accelerator for neutron scattering

We have been looking for an accelerator system suitable for future pulsed spallation neutron sources. Such an accelerator type must satisfy the following requirements; (1) much less expensive in the construction and the operation; (2) a wide coverage in the beam power ranging from small to super intense; (3) more flexibility in the pulse repetition rate and duration; (4) easy operation and maintenance; (5) simple and compact for high reliability, etc. We found that a new type of FFAG (Fixed Field Alternating Gradient) synchrotron recently proposed by Mori, et al. [1] could be a promising candidate. Generally, for an FFAG synchrotron a high-voltage and wide-band RF cavity capable of a high-speed frequency modulation is indispensable.. However, it has so far been difficult to develop such an RF cavity.

Recently, Mori and his collaborators have developed a new RF cavity, which could satisfy above requirements, using a new metal having a high magnetic permeability, as known by commercial names of FINMET, METGLAS, etc. A 1 MeV prototype FFAG synchrotron has already been built and successfully operational at KEK. Furthermore, the budget for the construction of a 200 MeV machine has already been authorized and the construction will be completed within 2 years. The construction costs for those FFAG synchrotrons were unbelievably cheap. Mori is convinced that a 10 MW FFAG synchrotron aiming at the application for ADS (Accelerator Driven nuclear energy System) will be feasible in near future. For this application a CW or quasi-CW beam is more important than a pulsed one. The repetition rate of the proposed FFAG for this purpose is 700-1000 Hz. Such a high repetition rate is essential for this accelerator to realize a higher beam power and not to give thermal shocks to ADS. We discussed about the possibility for applying a new FFAG synchrotron to an accelerator system for a future intense pulsed spallation source. If there exists a useful way to reduce the repetition rate keeping the time-average proton-beam-power, an FFAG synchrotron could be the best candidate. We found a very positive answer to this question. A bunched beam accelerated up to the final energy circulates the outer orbit (accumulating orbit). By stacking succeeding bunches on the circulating one in the accumulating orbit, a lower repetition rate as 10-20 Hz would become feasible. Of course, various R&D would be necessary for this purpose. The minimum repetition rate in a high-power FFAG will be determined by a space charge limit in the accumulating orbit. This limit is much higher than in a conventional synchrotron, since the final energy in FFAG is much higher than the injection energy in the latter. Even compared to a compressor ring it will be higher due to a longer bunch length in FFAG. With an orthodox accelerator system a lower repetition rate is only possible under the condition that the beam power per pulse is constant, while with an FFAG it would be possible to realize a lower repetition rate keeping the time-average power.

For an FFAG synchrotron the choice of the final proton energy is quite flexible: Of course, 1-1.5 GeV, where the energy cost for the neutron production exhibits the minimum, is feasible, but a higher energy, say about 3 GeV, is more feasible from the accelerator technical point of view. We studied the proton energy dependence of slow neutron intensities from various moderators designed for JSNS [2]. The result is shown in Fig. 2. It is found that up to about 3 GeV the penalty in the slow neutron intensities is acceptable, i.e., slow neutron intensities are almost unchanged up to about this energy. Thus, 3 GeV is quite acceptable also from the neutronic point of view.

What pulse repetition rate, f, is more useful? Of course, it depends on the experiments. It is believed that a lower f as 10 Hz is much useful than a higher f as 50 Hz in most cold neutron experiments and high-resolution powder diffraction experiments. This is due to the reason that the useful band-width of incoming neutrons is proportional to $1/(L_1 f)$, where L_1 is the incident flight path length, which is usually large for high-resolution experiments. Here, one question arises: Are the neutrons far from the peak value in the phase space density (at much longer wavelengths than the peak) equally useful as those in peak region? In powder diffraction experiments, those neutrons are equally useful, since the diffraction intensity is proportional not to incident neutron spectrum $I(\lambda)$ but to $I(\lambda)\ \lambda^4$. How are for other experiments? Generally, in a scattering experiment the data rate for a given resolution is proportional to the phase space density. If we choose the best k-range such that the integration of the phase space density over the k-range gives the maximum value, we have a result as shown in Fig. 4. The k-range for this integration can be determined from the useful band-width. In case of a longer L_1 (say, 100 m), a higher f than about 10 Hz does not give any merit, but for a shorter L_1 (say, 20 m) a higher f is still useful. If a relatively small q-ω space is more important, a higher f is useful even in case of a longer L_1, including powder diffraction experiments. This means that even for cold neutron experiments a lower repetition rate as 10 Hz is not always better than the higher rate. High-resolution powder diffraction is only one exception being able to take full advantage of a lower repetition rate. Taking into account the above discussions, we think that the optimal repetition rate would be in a range of 15-25 Hz when a dedicated FFAG synchrotron is allocated for these experiments.

The size of an FFAG synchrotron is fairly small compared with a conventional synchrotron or a compressor ring of the same energy and the same power. A typical size of a 10 MW FFAG synchrotron proposed for ADS is about 70 m in diameter, which could be reduced to about 25 m by adopting superconducting magnet [1]. It could be possible to install an FFAG at the same building with a target station and an experimental hall. In the experimental hall for JSNS illustrated in Fig. 4 we tried to insert the simple drawing of 10 MW FFAD synchrotron mention above, just to show the approximate size of this accelerator..

Important advantages of FFAG are as followings;

(1) No proton (H^-) linac is necessary with its building, resulting in a large cost saving;
(2) A dedicated FFAG synchrotron for each target station could be considered as shown in Fig. 2, provided that the accelerator is much less expensive.
(3) Thus, expensive proton-beam-transport-line with associated tunnel becomes no longer necessary, resulting in another cost saving;
(4) The electric power required for accelerator operation would be much lower than for the conventional accelerator system due to a higher RF to beam-power conversion-efficiency in FFAG synchrotron, resulting in a lower operation cost;
(5) The structure of an FFAG synchrotron is simple, resulting in a higher reliability;
(6) A full remote handling in accelerator maintenance might become possible due to a very compact accelerator size.

Thus, a dream towards a neutron network depicted in Fig. 1 would become more realistic. We would propose a strategy for constructing a neutron network starting from small/medium power neutron sources based on FFAG synchrotrons, of course, considering a future possibility for super high-power sources.

3. Target issues

If we assume the maximum beam power in a range of 5-10 MW for future sources, the most important issue for the target engineering would be the pressure wave effect on a target container, especially on an incident beam window. Intensive R&D efforts for finding useful methods to mitigate the pressure wave are most important. In addition to such efforts a combination of following approach would also, more or less, be useful.

(1) A longer proton-pulse-duration for a low-repetition target-station dedicated for cold neutron experiments;
(2) A higher repetition rate for a high-repetition target station dedicated for epithermal neutron experiments;
1. A larger beam footprint to reduce the beam-current-density; if the penalty in the slow-neutron intensities is acceptable.

Firstly, let's consider the approach (1). We studied the stress level on a Hg target container as a function of proton-pulse duration assuming a beam power of 100 kJ per pulse, which corresponds to 5 MW at 50Hz. The calculated result is shown in Fig. 5 with a target model used for this calculation [3]. The maximum peak to peak stress appears at the inner surface of the beam window center. With increasing pulse duration the maximum stress level decreases slowly. If we assume a proton-pulse duration equal to the cold neutron pulse width (about 230 μs for a coupled hydrogen moderator with optimized premoderator) is acceptable, the maximum stress level can be reduced by a factor of about 2.5, although it is not so drastic.

Let's consider the approach (2). For most epithermal neutron experiments, a higher repetition rate as 200 Hz could be acceptable, if a dedicated target station for such experiments can be considered, provided that the accelerator is much less expensive. Thus, we can expect a lower stress level by a factor 4 due to a lower energy deposition per pulse compared to the 50 Hz case.

Let's consider the approach (3). The issue is whether the increase in the beam footprint, accordingly the reduction in the maximum beam-current-density could mitigate the stress level to some extents. This issue is still not clear and we have to continue the measurements using AGS accelerator in BNL under the international collaboration ASTE. Prior to having an answer to this question we studied the effect of proton beam size on slow neutron intensities. The calculated result tells us that the penalty in the intensity with increasing beam size is rather modest as shown in Fig. 6 [4], suggesting the increase of the beam size to some extent might be acceptable from the neutronic point of view. Therefore, If we have a positive answer from the pressure wave experiment, this approach would also be useful..

4. Moderator issues

Figure 7 shows spectral intensities from five different moderators listed in Table 1. The moderator layout assumed is the same as for JSNS, where one coupled H_2 moderator with two viewed surfaces is located above the target and two decoupled moderators of any kinds, each has two viewed surfaces, below the target.

The coupled one, (A), gives the highest time-integrated intensities, I_{int}, in the entire energy range shown in the figure; in cold and sub-thermal energy region, approximately 20 and 100 times higher intensities compared with the decoupled poisoned H_2 moderators, (C) and (D), respectively. The result suggests that if one could take full advantage of higher I_{int}, and peak intensities, I_{peak}, from the moderator (A), a large breakthrough might be expected for certain class of experiments.

Pulse shapes from those moderators are compared in Fig. 8 at three different energies, 2, 50 and 100 meV. Pulse widths and I_{peak} are also plotted in Fig. 7 as a function of neutron energy. Figure 9 shows I_{int}, I_{peak} and pulse widths in full width at half maximum (FWHM) at 2 meV from a decoupled moderator as a function of a Gd poison position (distance from the viewed surface). The poison position of 5 cm means a simple decoupled H_2 moderator without poison. Some years ago we (Kiyanagi and Watanabe) studied various H_2 moderators experimentally and found that a wide variety of pulse widths could be obtained by adjusting the premoderator thickness, adopting decouplied premoderator (decoupler outside the premoderator) and poisoning premoderator, as reproduced in Fig. 10 [5]. The results in Fig's 9 and 10 tell us that the pulse width of cold neutrons could be controlled over a wide range of pulse widths, by trading off, more or less, I_{int} and. I_{peak}. Thus, the most important issue becomes the choice of the moderators to be installed within the maximum acceptable number of moderators. This will be the user-oriented task. For user's reference with respect to the Japanese project, we arranged Fig.11, where the cold neutron pulses at 2 meV from various H_2 moderators listed in Table 1 are compared in linear and semi-logarithmic scales as a function of reduced emission time t*. Here, t* is defined as,

$$t^* = t\, L_{10} / L_1,$$

where t is the real emission time from a given moderator, L_1 is the required path length which satisfies a required incident-neutron time-resolution with this moderator and L_{10} is that with a reference moderator. Here, we assumed a decoupled H_2 moderator poisoned at the center, moderator (C), as a reference moderator and a required time-resolution of 0.1%. The values of L_1 required for respective moderators are listed in Fig. 11. It will be interesting to see that all pulses from a wide variety of moderators (from the coupled H_2 to the decoupled and heavily poisoned one) exhibit similar shapes in the t* space. The pulse widths in FWHM are the same due to the definition of t*, but the decay characteristics are also very similar. This means that the decay time is almost proportional to the pulse width in spite of the large difference in the moderator type.

Generally, the data rate is proportional to I_{peak} in direct-geometry instruments as a chopper spectrometer. While it is proportional to I_{int} in inverted-geometry instruments, utilizing the pulse width as a resolution element, as a crystal-analyzer-type spectrometer, although the useful band width is inversely proportional to the required path length satisfying the required resolution. Therefore, in case that a wider band-width is not so important, the use of the type (A) moderator gives a great advantage for the high data rate capability, as if the pulse shapes and peak intensities are the same as shown in Fig.11. If a wider band-width is more important than the data rate, the use of another moderator of an appropriate pulse width becomes important. For those instruments not using the time structure as a resolution element directly as spin echo machine, MUSICAL type, etc., the use of the type (A) is essential. Also for those instruments not requiring a higher time (wave-length) resolution as SANS instruments, reflectometers, single crystal diffractometers for protein structure analyses, etc., the type (A) moderator is the best.

For JSNS we designed a target-moderator-reflector system, assuming that the number of neutron beams which view the moderators of types (A), (B) or (C)/(D) (originally the third one was a 3 cm thick decoupled H_2O moderator) were even. In other ward, the beam extraction angles allocated for each moderator were even. At the user's meeting recently held at JAERI to discuss instrument suite for JSNS, the moderators required for those instruments were intensively discussed. The selected moderators are summarized in Table 2. It was quite surprising that among 38 proposed instruments in class A (the highest priority), about 58% (22 instruments) selected the moderator (A).

The present result is quite different from those at other projects. We think that careful comparisons on the instrumental performances between similar instruments but with different moderators selected at the other projects are indispensable. Such efforts with extensive computer simulations are under progress..

Pulse widths of cold and thermal neutrons from a decoupled moderator are controllable by moderator poisoning at a penalty in I_{int} and I_{peak}, but at higher energies approaching the cut-off energy, the effect of poisoning is gradually diminishing. On the other hand, the decay characteristics of long-time pulse tails can be controlled by the choice of the reflector material and the decupling energy. In MW-class spallation sources one important technical issue is that the use of a B_4C decpupler becomes difficult due to the serious radiation damage. If cadmium (Gd) is only one material for a decoupler at intense spallation sources, the pulse characteristics at higher energies are not adequate. In order to solve this problem we are considering a composite material. The use of a mercury reflector is another solution [6].

5. Toward efficient neutron use

As already mentioned in the previous section, if one could take full advantage of the moderator (A), the highest I_{int} and I_{peak}, will bring about a breakthrough for "more efficient use of neutrons ". Some instruments on this end have been discussed in the previous section but no useful approach for white neutron uses. A poisoned moderator can satisfy a required time-resolution but at a large penalty in intensities, especially in I_{int}. On the other hand the use of the moderator (A) with a pulse-shaping chopper can provide a much narrower pulse, especially at a longer wavelength region, but the useful band width becomes much narrower due to a finite pulse width from the moderator. In order to solve this problem we propose to use a special disc chopper having mulch slots. With two discs rotating to the counter directions each other at a peripheral speed of about 400 m/s, a chopper burst width of about 20 μs in FWHM could be obtained with a slot aperture of about 1.6 cm and more ambitiously about 10 μs with 0.8 cm. The slot spacing on the first disc is approximately same as the moderator pulse width at corresponding energies. The idea is illustrated in Fig's 12 and 13. The first multi-slot disc-chopper (pulse shaping chopper) is installed at a distance of about 7 m from the source and another disc chopper, which rotate phased to the first one, is located in front of sample to define the band width of each chopped beam. At the sample position a train of beam-on and beam-off can be obtained as shown in a time-space diagram shown in Fig. 13. To cover a complete band-width a separate run with a different phasing, just to fill up the beam-off portions, becomes necessary. The lengths of the beam-on time are to be adjusted to have an appropriate overlap with adjacent beam-on times of the separate run. The pulse widths from various moderators listed in Table 1 are shown in Fig. 14 as a function of neutron energy by smooth curves. The pulse widths from the moderator (A) could be shortened as (A') (for the case of the chopper burst width of 10 μs) with this technique. At higher energies where natural pulse widths from the moderator are shorter than the copper burst width, the disc has a longer aperture so that the neutron beam can pass through the chopper. The effective values of I_{peak}, which are obtained by multiplying I_{peak} labeled (A) by a factor of 1/2, is shown in the lower figure compared with other moderators. The factor of 1/2 comes from the fact that two independent runs are indispensable to cover an entire band-width, assuming that there is no intensity loss in the conversing and diverging beam transmission across the choppers by super mirror guides. This technique is under development at JAERI. If the technique for a low loss beam transmission through the chopper is established, it becomes possible to obtain narrower pules than a poisoned moderator but with a higher I_{peak} at lower energies. We named this technique "*mechanical poisoning*"

This technique will especially be useful for low energy instruments utilizing polychromatic beam and pulse width as a resolution element, such as a back scattering spectrometer. Even for high-resolution powder diffraction in some applications, in which data at very small d-range are not so important as residual strain analyses, the mechanical poisoning method will provide a large advantage.

6. Neutron beam extraction

Neutron beams are very valuable but very expensive. In most neutron facilities all neutron-beams have eventually been filled up by instruments. In order to install as many instruments as possible various efforts have so far been devoted. The best example can be seen at the high-flux reactor in ILL, Grenoble, where about 60 instruments are installed, mostly on the cold neutron guides. At JRR-3M in JAERI the situation is similar, although the total number of instruments is not as many as at ILL. The number of instruments at any pulsed-spallation-neutron facility is much smaller than at a reactor, suggesting that there still exists a large room for the former to improve the situation. After ILL it has traditionally been adopted to share the same beam from one guide by several instruments. Here, one question arises, how is the beam intensity at each instrument compared to the case of only one instrument.

In order to answer this question we obtained interesting data on the real situation at JRR-3M guide hall as shown in Fig. 15 [7]. The neutron beam intensity at the instrument T1-4 decreased as listed in the attached table with the installation of other instruments at the upstream. The result is very shocking: The intensity losses are significant. The reasons are due to the scattering and absorption of neutrons by inserted monochromators , super mirror guides with a relatively high bending angle for beam splitting for other instrument, etc. Generally, in time-of-flight experiments using a pules source, most instruments need white (polychromatic) beams rather than monochromatic ones, making such beam line multiplxing as adopted at reactors more difficult. An effective approach to solve this problem is strongly desired.

We are considering a following approach for JSN, although it may be too much straightforward. The point is to install as many neutron guides as possible at the source. For example, if a beam extraction angle of 1 radian is available, at least, 10 (hopefully more) guides could be installed to view one emission surface of a moderator, corresponding to an average angular separation of 0.1 radian between adjacent instruments. Figure 16 shows an example of such a guide layout. The angular separation shown in the present example may be acceptable for those instruments having relatively long incident flight-path-lengths, especially viewing the moderator (A): The separation between adjacent guides is about 3 m at 30 m position from the source. Beam shutters couldn't be installed inside the bulk shield, but could be located in the bank for guide shield outside the bulk shield, if necessary with T_0 choppers.

7. Discussions and conclusions

For the future world neutron community, a neutron network consisting of small to super intense sources is essentially important. The neutron network discussed here could provide much more opportunities to a wide range neutron users and make the neutron scattering technique more useful in various fields of research from basic sciences to industrial technologies, eventually contributing to the welfare of the mankind. A realistic path to this goal is "innovative approach". In order to realize such an innovation, neutrons must be much less expensive. A new FFAG synchrotron is considered to be the most promising candidate for this end. If accelerators become very cheep in future, the concept of accelerator-target station may drastically change; one dedicated accelerator for one target station. Since the repetition rate and pulse width become more flexible, the optimal parameters should be reconsidered only from the neutron point of view, being free from accelerator technical constraints. More efficient use of neutrons is also very important. Some ideas are presented here for this end. Finally, we would stress that there still exists a large room to improve the present situation of the world neutron community toward much better, or hopefully "innovative" opportunities.

References

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Table 1 Moderator description used for calculation

Moderator type	main moderator size	premoderator	Interleave poison (position from viewed surface)
(A) Coupled H_2	12 x 12 x 5 cm^3	Optimized* H_2O	None
(B) Decoupled H_2	12 x 12 x 5 cm^3	Optimized* D_2O	None
(C) Decoupled H_2	12 x 12 x 5 cm^3	Optimized* D_2O	Gd (2.5 cm)
(D) Decoupled H_2	12 x 12 x 5 cm^3	Optimized* D_2O	Gd (1 cm)
(E) Decoupled H_2O	10 x 10 x 3 cm^3	None	None

*Optimized" means of optimal thickness and optimally extended for respective moderators.

Table 2. List of moderators selected for instruments for JSNS

Type of instrument	Selected moderator type	Number of Instrument
Powder diffractometer	(C) or (D)	5
Single crystal diffractometer	(A)	1
Total scattering	(B)	3
SANS	(A)	5
Biology	(A)	2
Reflectometer	(A)	4
Copper spectrometer	(A)	1
	(B)	2
Non-chopper spectrometer	(A)	4
	(B)	4
Spin echo	(A)	3
Radiography	(A)	1
Prompt gamma	(A)	1
Total	(A)	22
	(B)	11
	(C) or (D)	5

Neutron World (Nework or High way)

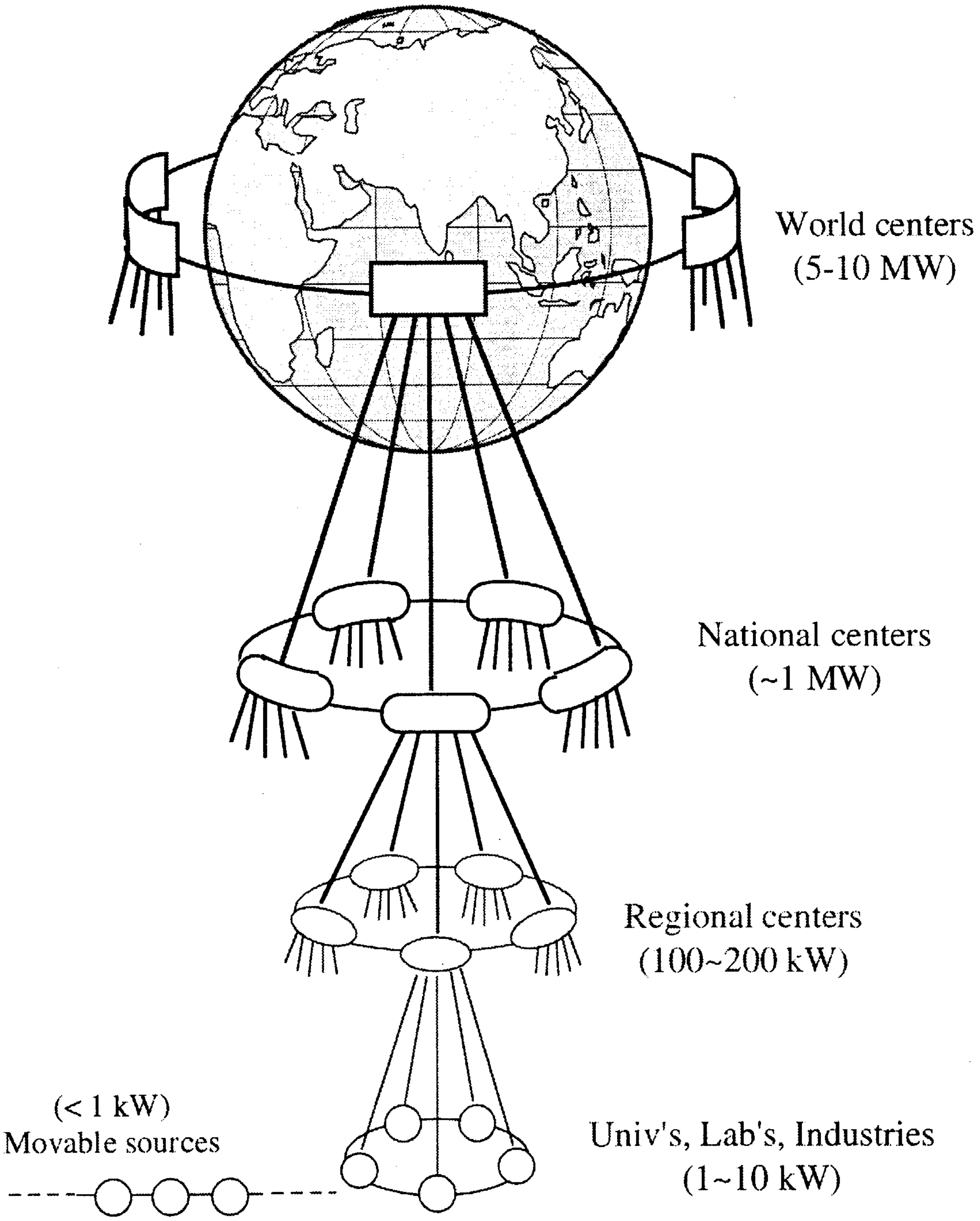


Fig. 1 A future neutron network worldwide mainly consisting of FFAG synchrotron based neutron sources of various beam powers (the author's dream).

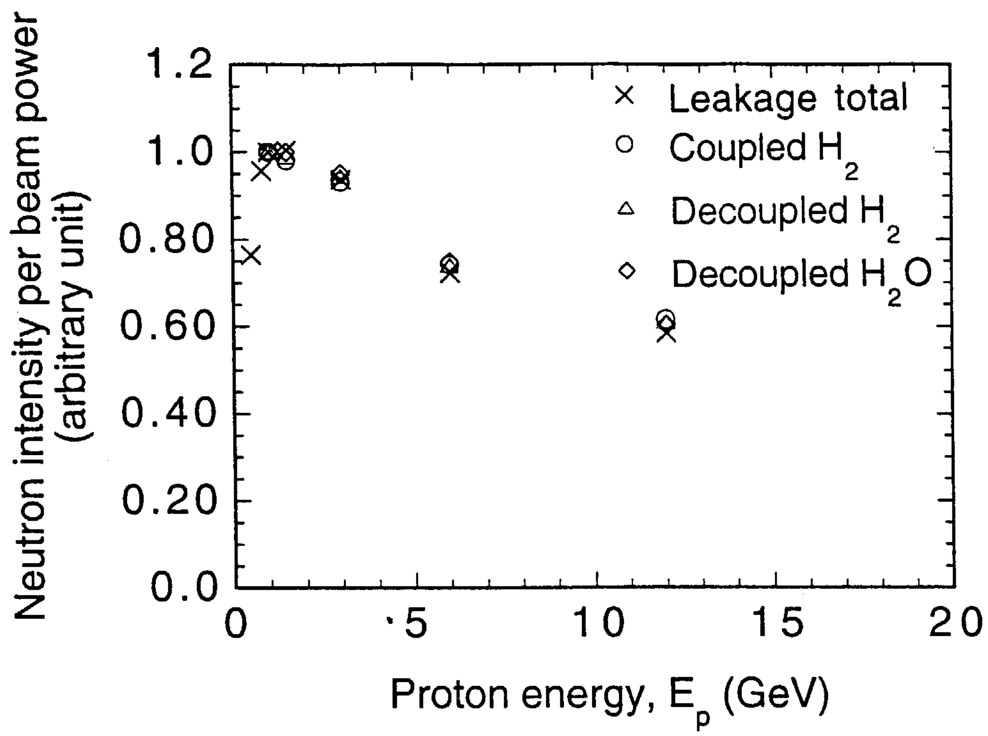


Fig. 2 . Slow neutron intensities per unit proton beam power from various moderators considered for JSNS as a function of proton energy.

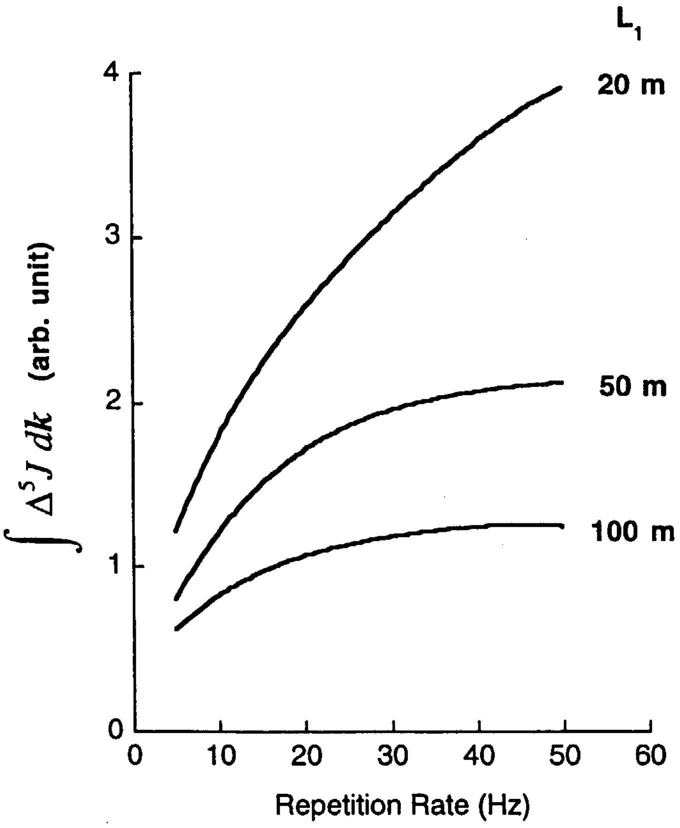


Fig. 3 Integrated values of phase space density as a function of repetition rate and incident flight path length for a fixed neutron intensity per pulse.

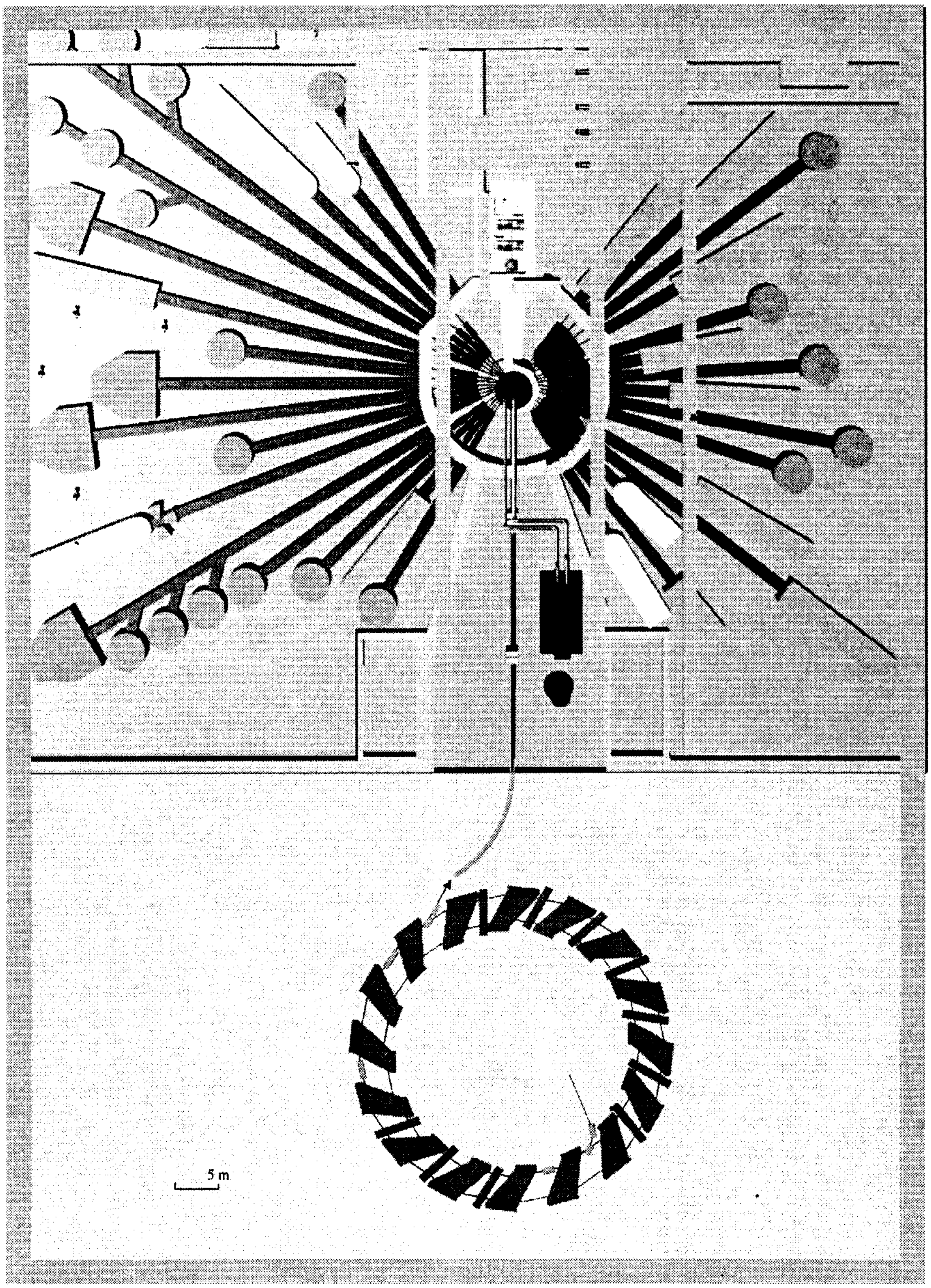


Fig. 4 Illustration of a 10 MW FFAG installed at a neutron experimental hall, just for giving an image of a dedicated accelerator for one target station.

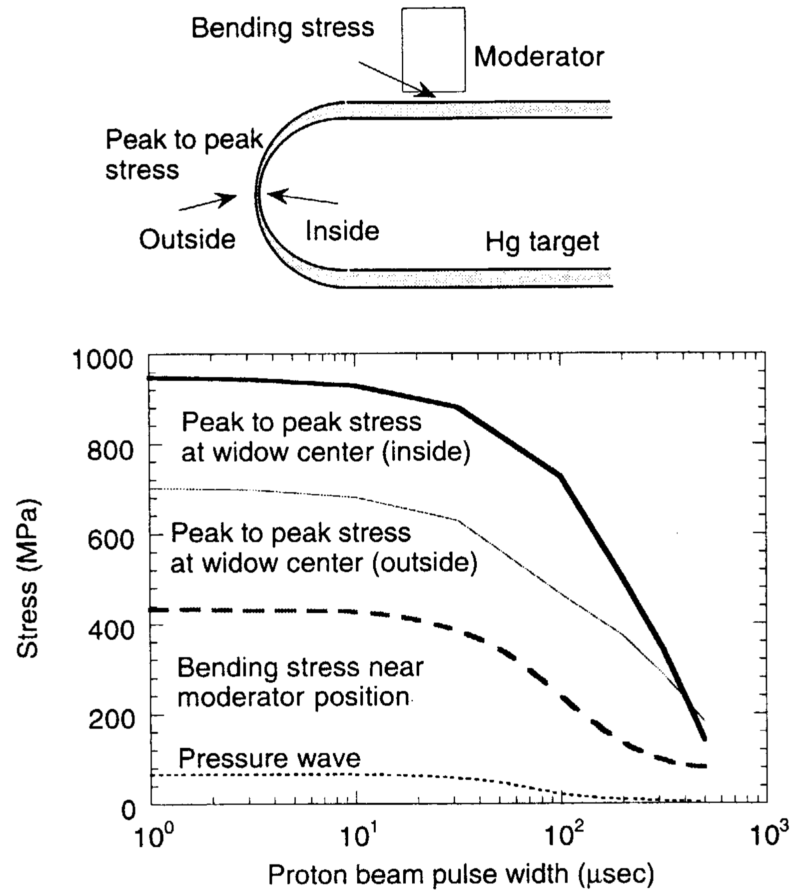


Fig. 5 Stress level in a Hg target container as a function of proton pulse duration for a proton beam power of 100 kW per pulse.

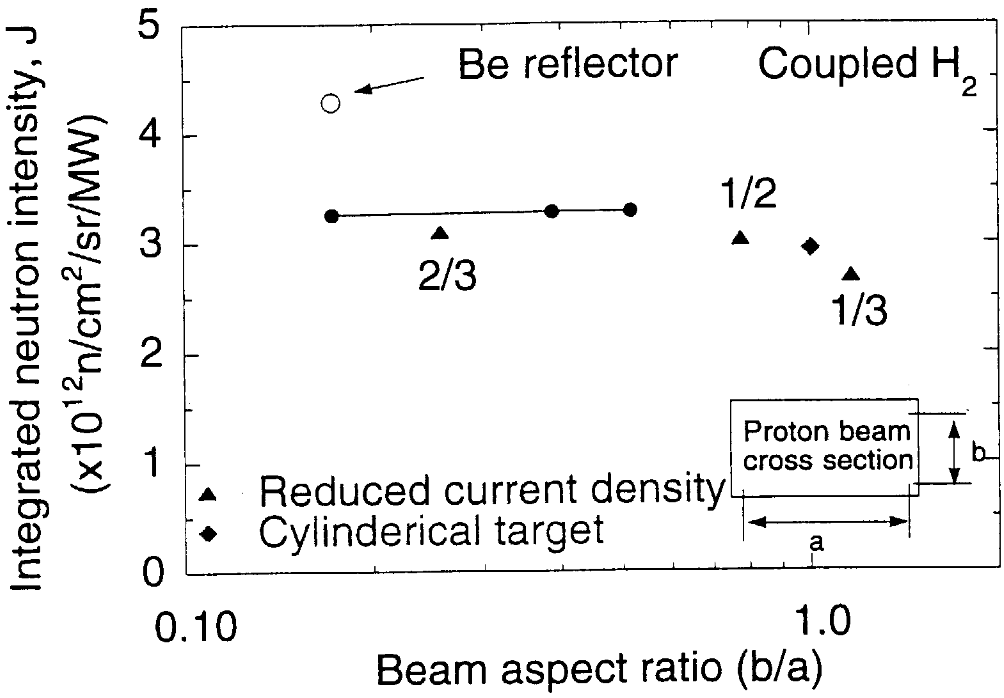


Fig. 6 Slow neutron intensity from a coupled H_2 moderator for reduced beam current densities of 1/2 and 1/3,for a given beam power, accordingly larger target sizes.

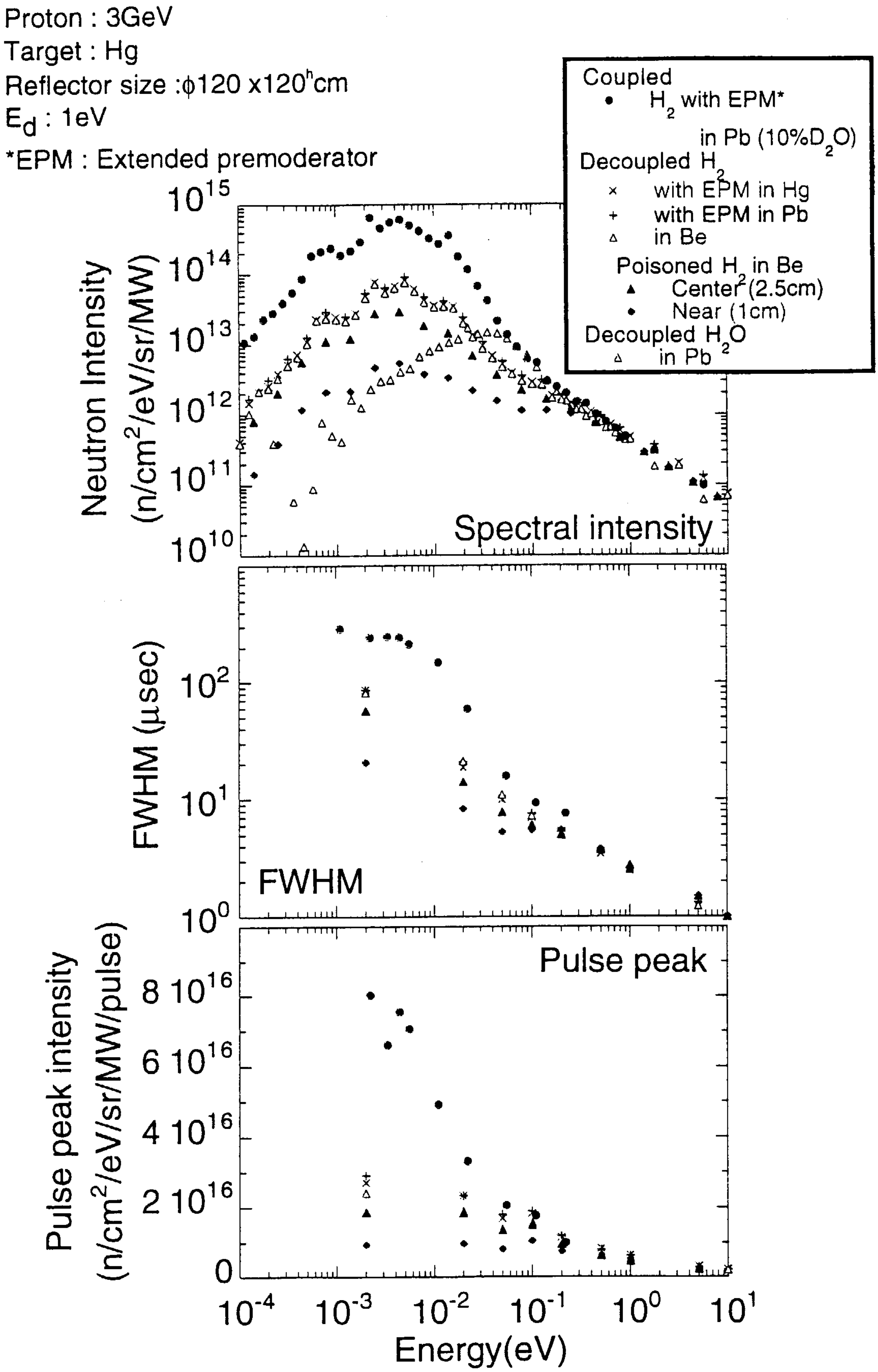


Fig. 7 Spectral intensities, pulse widths in FWHM and I_{peak} from five different moderators listed in Table 1.

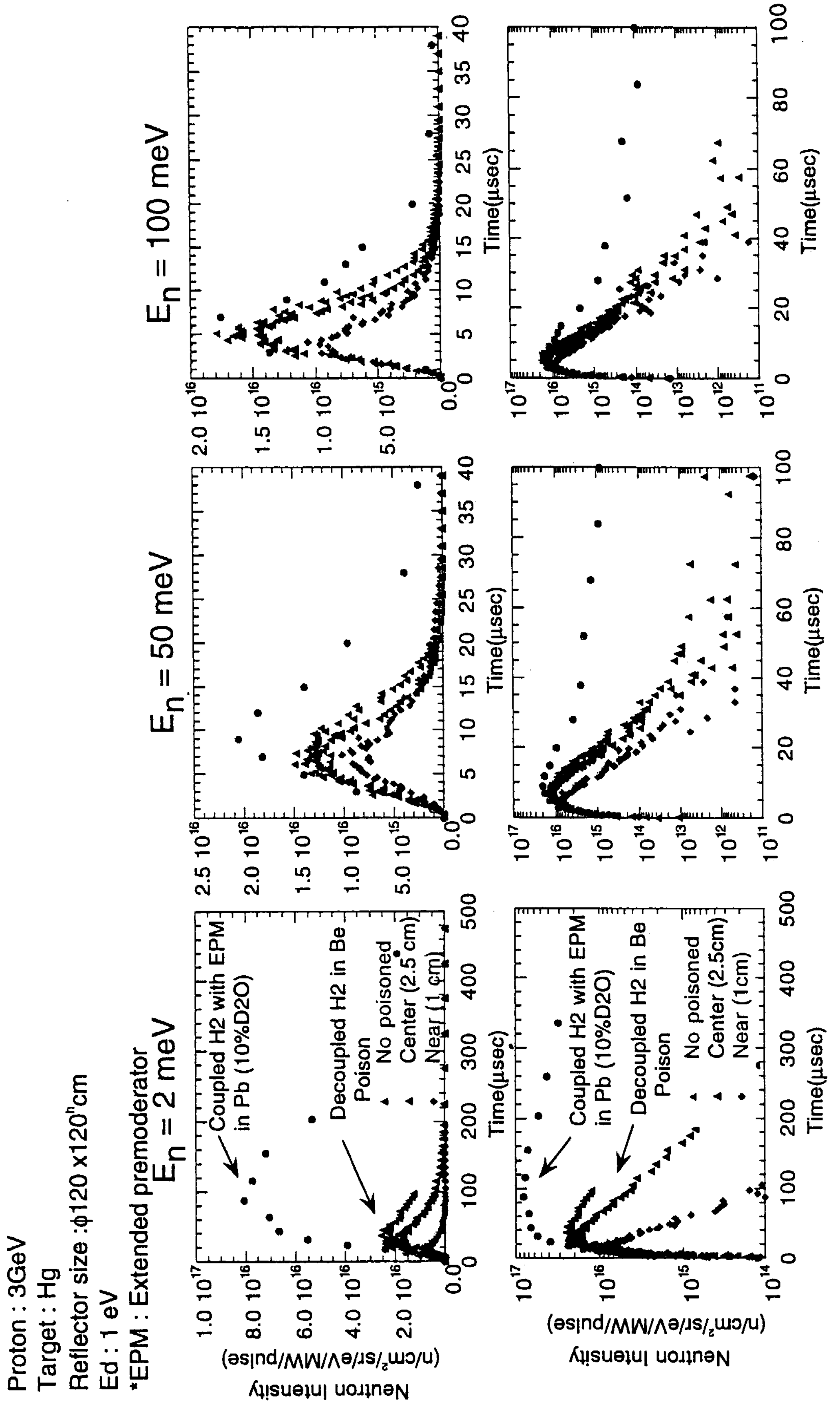


Fig. 8 Pulse shapes from various moderators at 2, 50 and 100 meV.

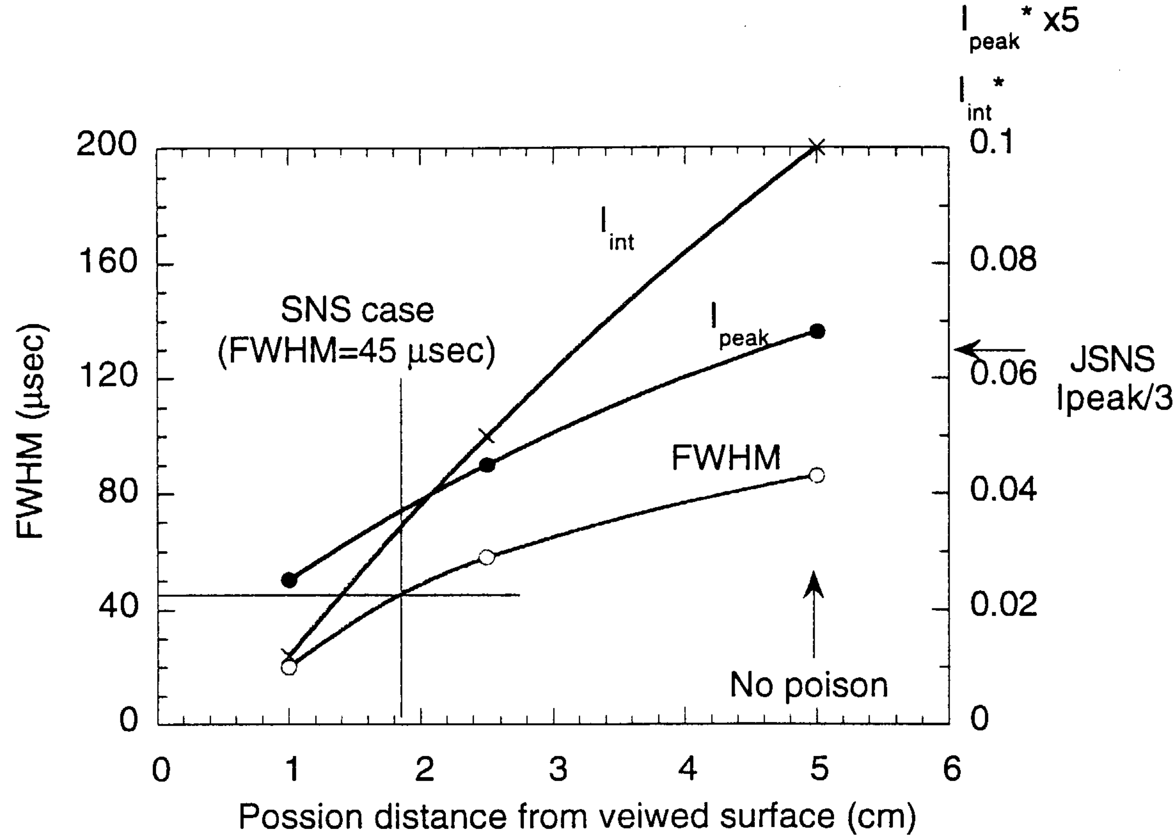


Fig. 9 Relative values of I_{int}, I_{peak} to the moderator (A) and pulse widths in FWHM of cold neutrons at 2 meV from decoupled moderators as a function of poison position.

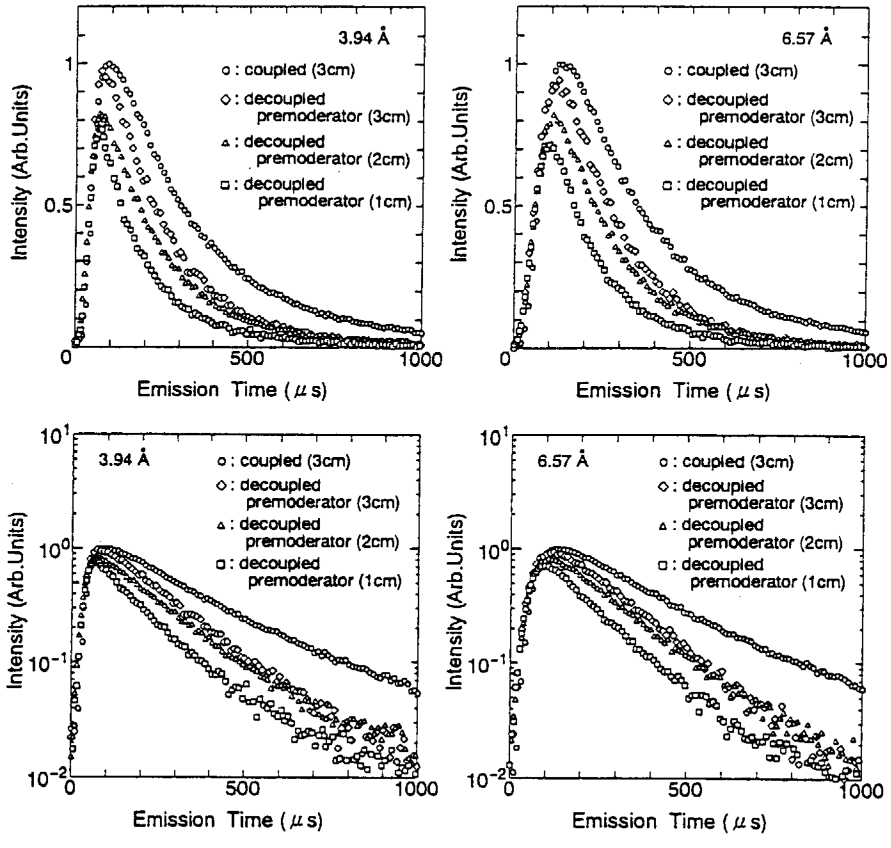


Fig. 10 Pulse shapes of cold neutrons from various H_2 moderators with decoupled premoderator, poisoned premoderator, etc. (reproduced from ref.[5]).

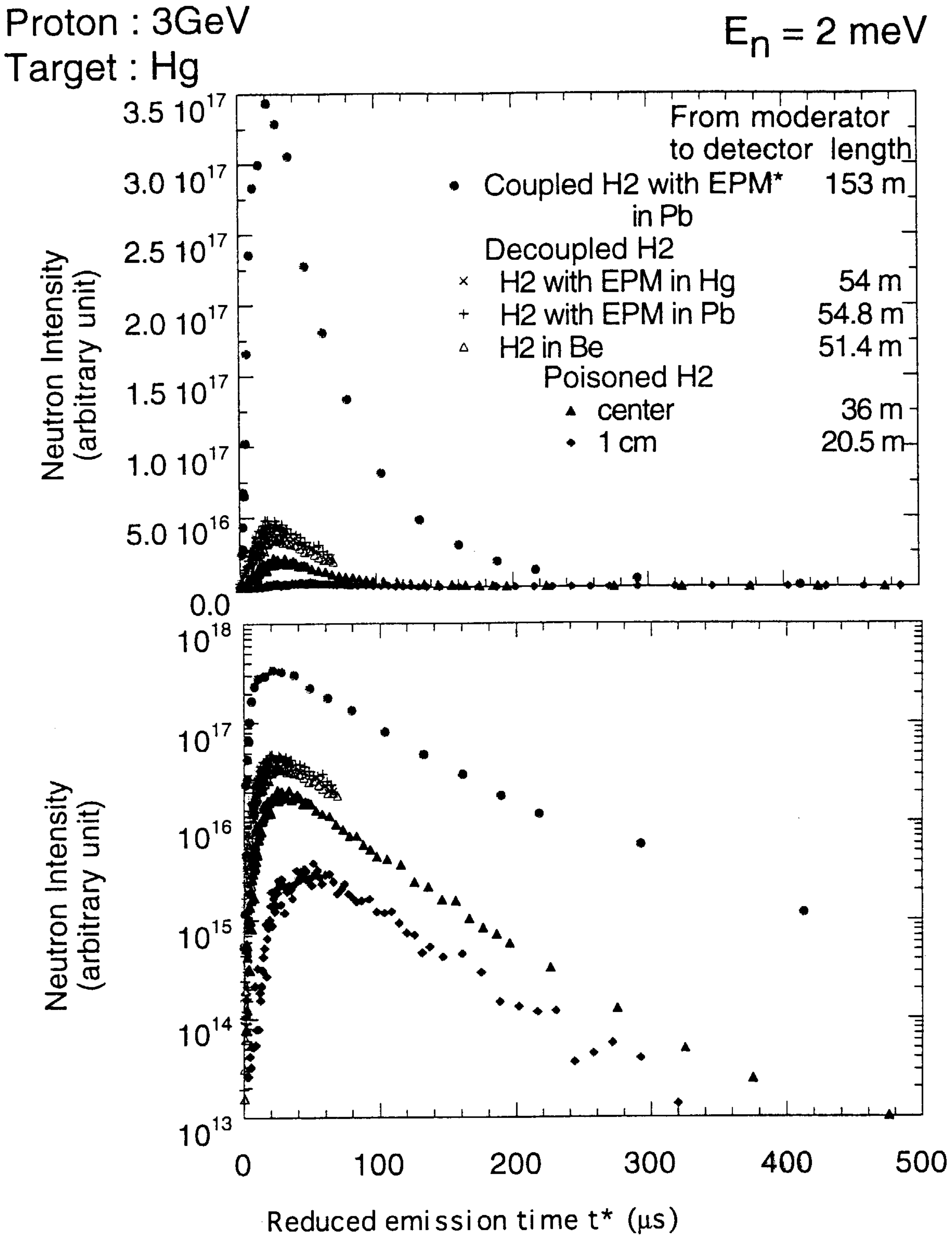


Fig. 11 Pulse shapes from various H_2 moderators in reduced emission time t* (upper: linear scale; lower: semi-logarithmic scale). For a given time–resolution of 0.1%, required incident flight path lengths are listed in the upper figure.

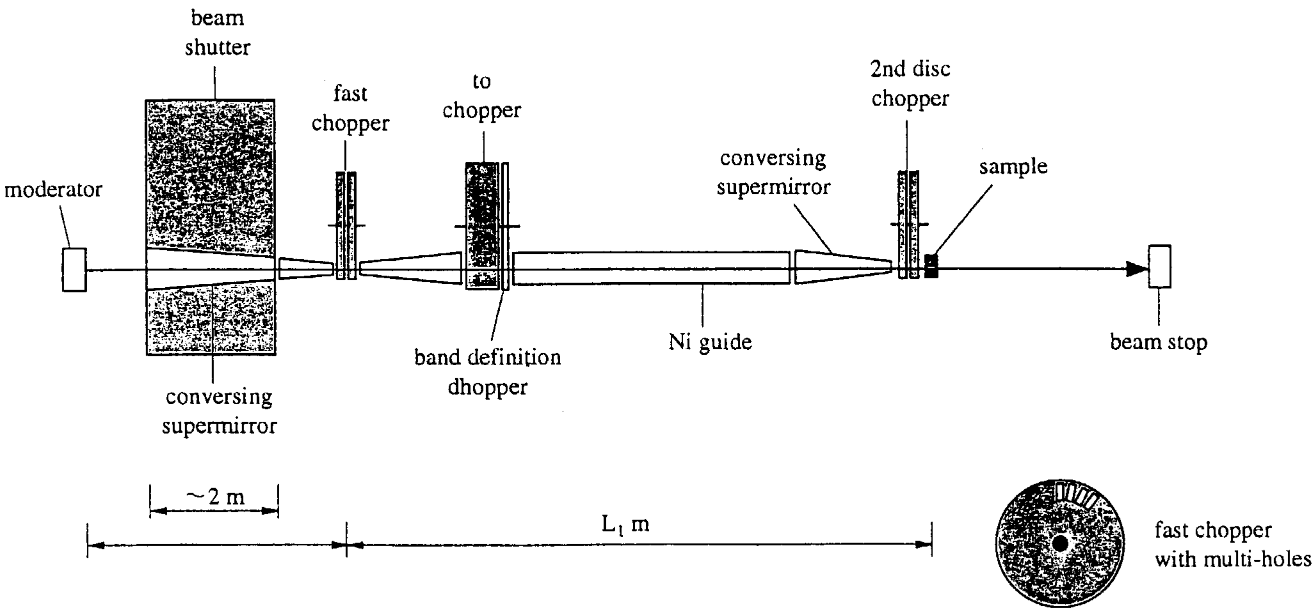
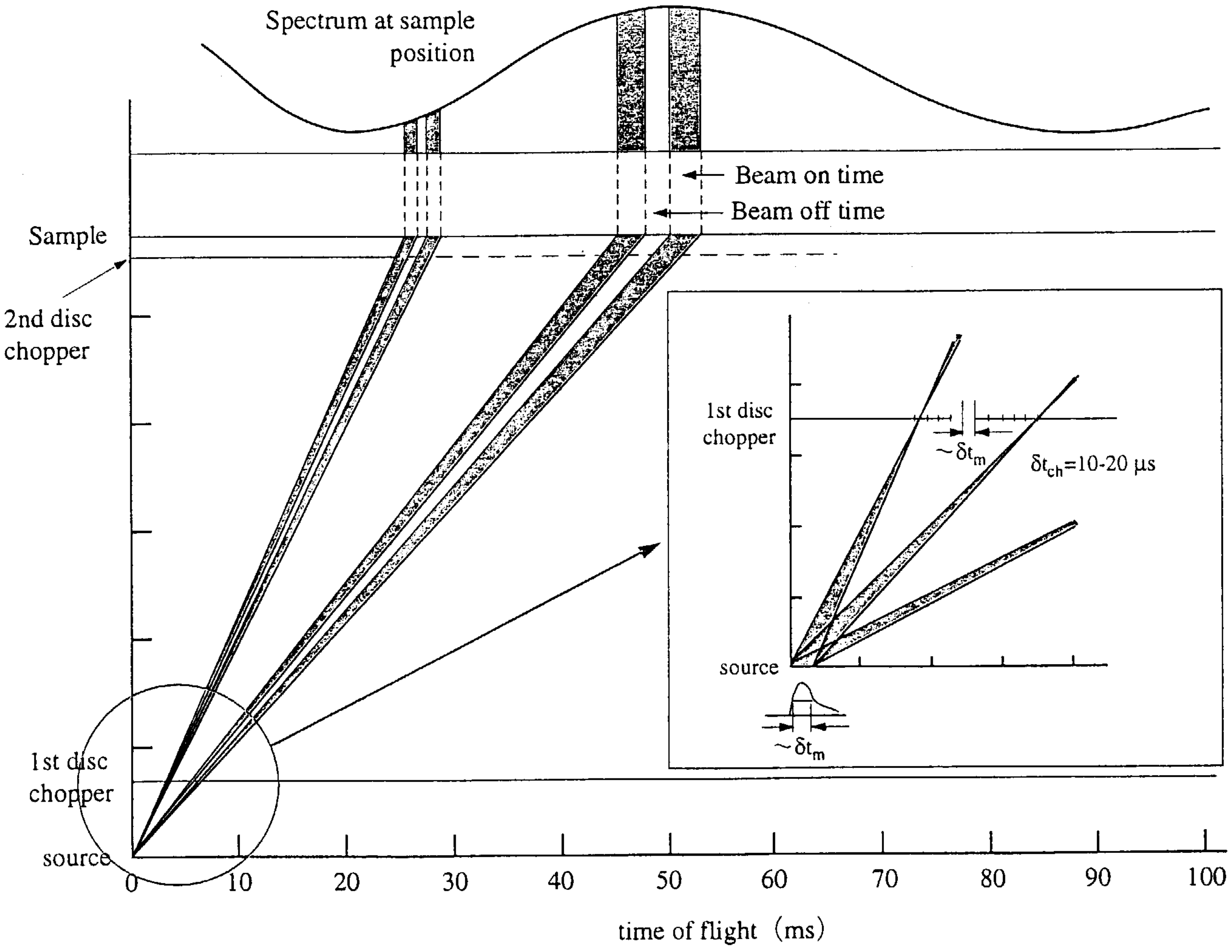


Fig. 12 A schematic diagram of "mechanical poisoning".



.Fig. 13 Time-space diagram of "mechanical poisoning"

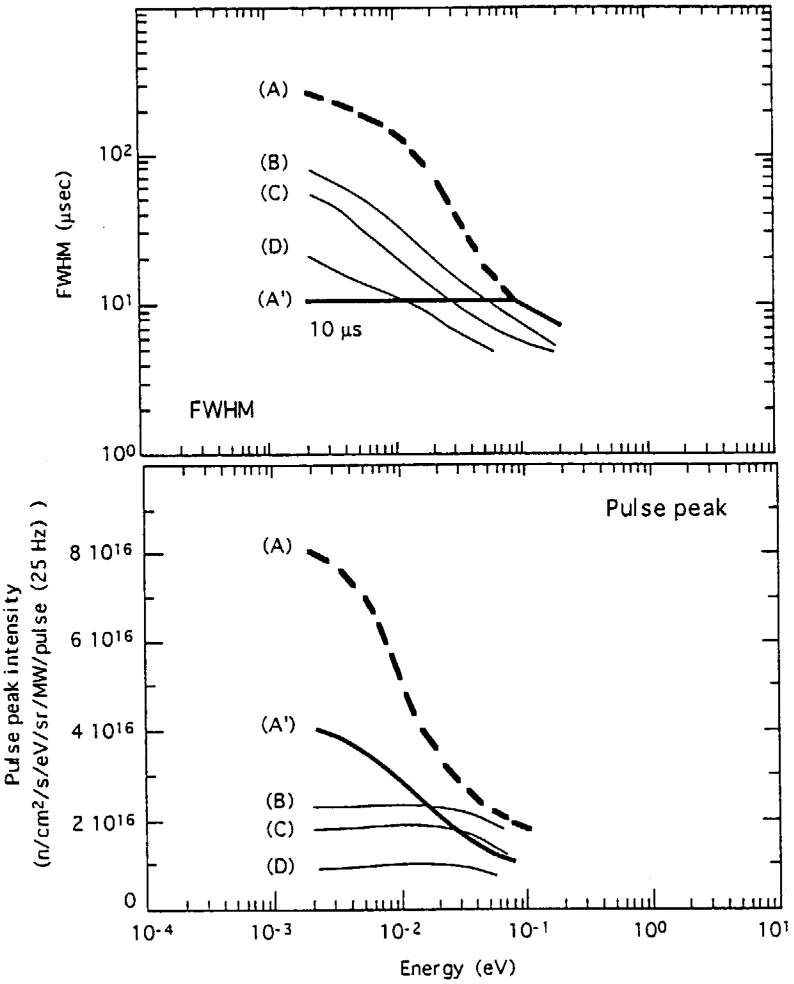
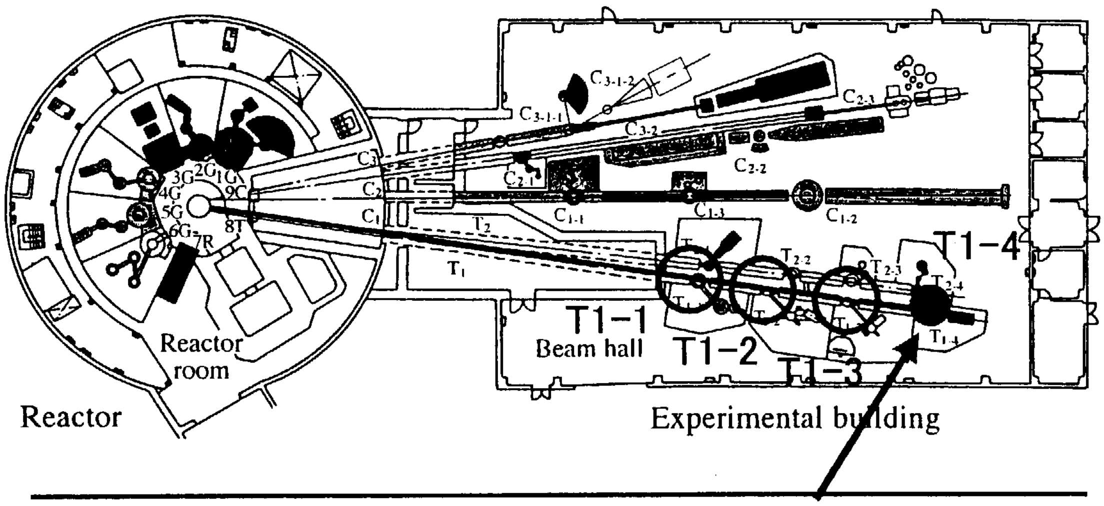


Fig. 14 Pulse widths and peak intensities obtained by “mechanical poisoning”.



	Neutron Flux
After Commissioning	$1.0 \times 10^{+8}$ n/cm²/sec
After installation of T1-1、T1-2	$2.5 \times 10^{+7}$ n/cm²/sec
After installation of T1-3	$1.0 \times 10^{+7}$ n/cm²/sec

Fig. 15 Typical neutron beam losses in some instruments at JRR-3M reactor. by multiplexing use of one beam.

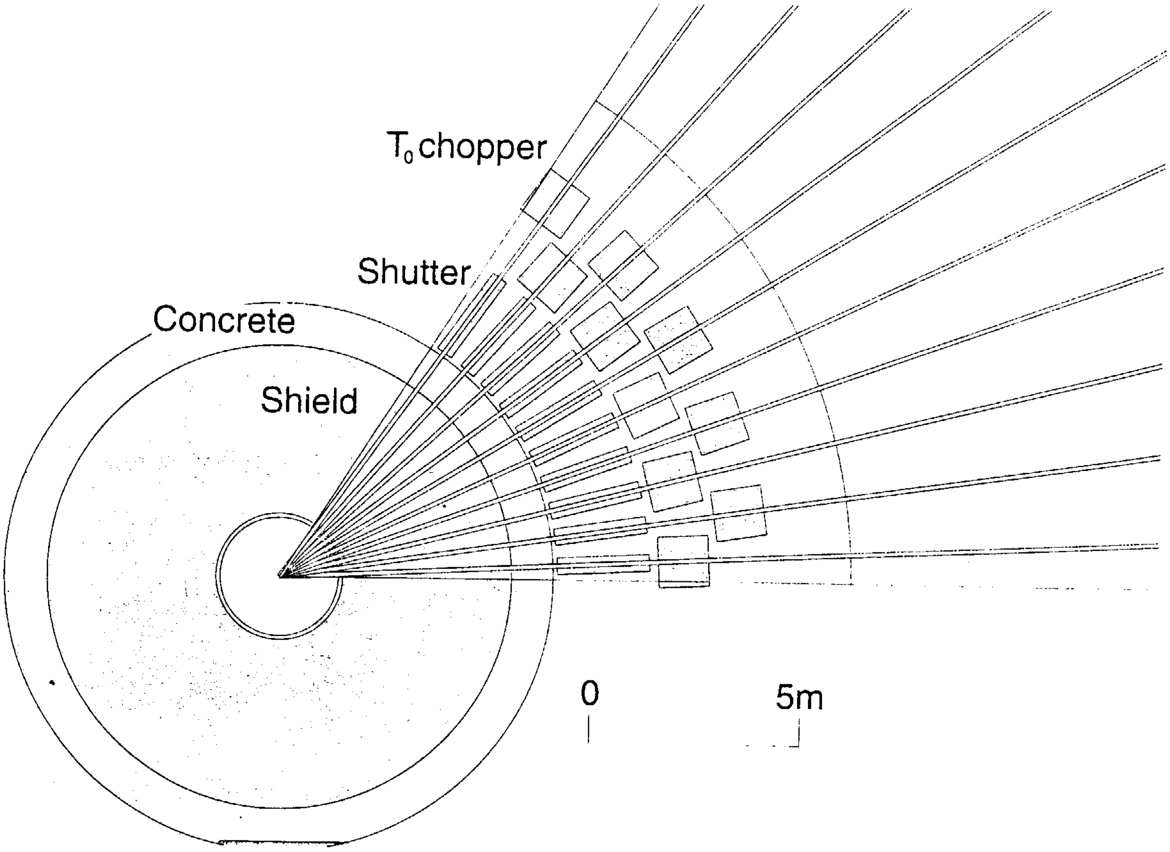


Fig.16 One example to increase the number of guides (a straight forward method).