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**SNS MODERATOR DESIGN**

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# SNS Moderator Design

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## I. Introduction

The pulsed-neutron source SNS facility will start operation at 1 MW. A later upgrade to 5 MW is planned. The facility consists of a linear accelerator, an accumulator ring, and a target station. The protons from the accumulator ring will be injected into the target station at 1 GeV. The subsequent spallation process will then produce low-energy thermal neutrons that may be used for a wide variety of experiments. In this paper we discuss neutronic calculations which address various aspects of the moderator design.

The computer codes HETC<sup>1</sup> and MCNP<sup>2</sup> were used for these calculations with the former code performing the high-energy transport. Neutrons which fell in energy to 20 MeV or less were then passed to MCNP for further transport.

## II. Moderator Position Study

For the study of moderator position, a model geometry was used in which two 12 cm x 5 cm x 15 cm cryogenic H<sub>2</sub> moderators were placed above a 12 cm x 30 cm x 60 cm Hg target and two ambient H<sub>2</sub>O moderators were placed below. Following the current SNS plans the upstream H<sub>2</sub> moderator was decoupled and poisoned and the downstream coupled. Both H<sub>2</sub>O moderators were decoupled and poisoned. The protons (with an elliptic-parabolic profile with major and minor radii of 12 cm and 30 cm) entered the 12 cm x 30 cm Hg face. A Be reflector with dimensions 96 cm x 90 cm x 90 cm was used with the upstream face of the target 36 cm from the front of the 90 cm x 90 cm face of the Be reflector. For the basic model the upstream edge of the upstream (downstream) moderators were located 4 cm (25.5 cm) from the front of the Hg. Vacuum neutron channels were included to exactly accommodate the moderator faces. A 12 cm by 30 cm vacuum-proton channel was excluded from the upstream part of the reflector. When the moderators were decoupled the moderator and the neutron channels were surrounded by a 1 mm Cd sheet. The moderator was poisoned by a 50  $\mu$ m Gd sheet placed in the center of the moderator parallel to the viewed moderator face. All neutron currents presented in this section and the next were measured by counting neutrons whose direction of travel was within 25° of normal to the moderator face.

In Fig. 1 the neutron current from the upstream moderators is shown as a function of the distance ( $L$ ) of the moderator center from the front of the Hg target. The current peaks when the upstream edge of the moderator is at the upstream edge of the target ( $L = 6$  cm). The current in the H<sub>2</sub>O moderator is greater since the neutrons are moderated through a smaller range in energy and losses are thus less. The current in the downstream moderators is shown in Fig. 2 as their location is varied. The current from the H<sub>2</sub> moderator is larger since the increase due to the coupling is greater than the decreases caused by the downstream location and the moderator material. With the above separation between

moderators (21.5 cm), the current is approximately the same (at a given L) from an upstream as from a downstream moderator if both have the same moderating material and coupling/poisoning. The large decrease in the current with poisoning and decoupling is tolerated since there is a large decrease in the tail of the pulse. The current reduction caused by moving a moderator downstream is approximately uniform with wavelength. That is, the current at all wavelengths is reduced by about the same fractional amount as the full thermal current.

### III. Moderator Interaction

The neutron current dependence on the moderator location can be modified by the interaction between upstream and downstream moderators. The upstream moderators lose neutron current ( $\leq 10\%$ ) when they are held fixed and the downstream moderators are moved upstream. If the downstream moderators are held fixed and the upstream moved downstream, the current in the downstream moderators increases if they are decoupled and poisoned and decreases if they are coupled. A possible explanation for the above variation is as follows. The loss of current in the upstream moderators is due to the loss of reflector. The current in the downstream moderators increases, due to interaction effects, if they are decoupled and poisoned, since the neutrons which were reflected into the upstream moderators are now available to the downstream moderators. If the downstream is coupled (as is the case for the  $H_2$  moderators here), the current decreases since the upstream moderator acts as a partial forward decoupler. Interaction effects between the upstream and downstream moderators are shown in Fig. 3. The upstream moderator is decoupled/poisoned  $H_2O$  at  $L = 6$  cm. The current from the downstream coupled  $H_2$  moderator is shown as it is moved upstream with the upstream moderator present and with it removed. Interaction effects reduce the current in the downstream moderator but are not large enough to offset the increase caused by moving the moderator upstream.

### IV. Reflector Materials

The model used for the reflector study is similar to that described above except only the upstream set of moderators is included and the reflector is replaced with an inner reflector (a cylinder of radius 32.5 cm and height of 90 cm whose axis is parallel to the proton beam) and an outer reflector (also a cylinder but with a radius of 100 cm and a height of 200 cm whose axis is parallel to the proton beam). The center of the cylinders is at a point 10 cm downstream from the front of the Hg target but at the center in the other two dimensions. The volume occupied by the target moderator assembly is, of course, excluded from the inner reflector and the volume occupied by the target moderator assembly and the inner reflector is excluded from the outer reflector. The composition of the reflectors is varied. All neutron currents presented in this section were measured by counting neutrons whose direction of travel was within  $90^\circ$  of normal to the moderator face.

In Table 1, the neutron current from decoupled poisoned moderators is shown for various inner and outer reflector compositions. The thermal neutron currents depend very weakly on reflector material or on the use of an outer reflector. The spectra for all cases is also virtually identical. In Fig. 4 the thermal pulses are shown. The pulse peak is independent of the reflector material. Including an outer reflector causes a decrease in the pulse width for currents  $< 10^{-3}$  of the peak.

In Table 2, the time-averaged neutron output from coupled moderators is shown for various reflector materials. It is less for a Pb inner reflector than for Be and less for both inner reflector materials when a outer reflector is used. Pb is a better outer reflector than Ni. The pulses that result when the various reflector materials are used are shown in Fig. 5. The peaks are again the same. The reduction in thermal neutron output when Pb is used instead of Be or when a Ni or Pb outer reflector is used comes mostly from the pulse tail resulting in a sharper thermal pulse. Spectra for neutrons from the moderator face are shown in Fig. 6. As may be seen the sharper thermal pulse comes at the expense of the lower energy neutrons. The difference in neutron intensity at  $\sim 3$  meV ( $\sim 5$  Å) differs by almost a factor of three between a Pb-Ni (inner-outer) and a Be-Be reflector. The largest number of low energy ( $\lambda > 1.2$  Å) neutrons result from a simple Be-Be reflector.

A question raised by the above is: why is the peak neutron current the same for all the differing reflector configurations (Fig 5) but yet the spectra show the intensity of low-energy ( $\leq 5$  Å) neutrons can differ by large factors (Fig. 6). This question is addressed in Fig. 7 where a sample of pulses for Be-Be and a Pb-Pb reflectors are shown for various wavelengths (if the pulses at all thermal wavelengths were added they would, of course, give the thermal pulses of Fig. 5 which are also plotted). At the pulse peak the neutrons are almost completely high energy (such as the  $\lambda = .8$  Å shown). The reduction in the tail of the thermal pulse when Pb is used as a reflector instead of Be is almost uniform with wavelength. The larger decrease in the totals for the low-energy neutrons is because a larger proportion of the low-energy neutrons are "tail" neutrons. Thus, if the top priority for a neutron experiment is an intense  $\lambda = 9.0$  Å neutron current, a narrower thermal pulse is undesirable.

## V. Composite Moderators

The composite moderator study reported here is similar to and was suggested by the earlier LANL work<sup>3</sup>. The model geometry used is identical to that described in Section II except: a) the front and rear moderators are fixed at  $L = 10$  cm and 31.5 cm. and b) the front moderator is divided into two sections by a plane parallel to the moderator neutron output face (the currents quoted in this section are all from the front moderator). The section on one side of the plane is filled with  $H_2O$  (and neutrons from this side are "from the  $H_2O$  face"). The section on the other side is filled with  $H_2$  (and neutrons from this side are "from the  $H_2$  face"). All neutron currents presented in this section were measured by counting neutrons whose direction of travel was within  $25^\circ$  of normal to the moderator face. The spectra for neutrons coming from the  $H_2O$  face were very similar to those from a  $H_2O$  moderator of varying widths. Those from the  $H_2$  side show an admixture behavior where the spectra look like a superposition of  $H_2O$  and  $H_2$ . It is thus possible to obtain spectra which look very different from  $H_2O$  or  $H_2$  from the  $H_2$  side but not from the  $H_2O$  side. In Fig. 8, a spectrum resulting from a  $1/4 H_2$  and  $3/4 H_2O$  configuration is compared to spectra from  $H_2O$ , L- $H_2$  and to L- $CH_4$ . A spectrum closely resembling L- $CH_4$  is seen. Thus by combining materials, both of which are commonly used for moderators one can find a material whose spectrum closely resembles that of a material whose behavior at high power (1 MW as in SNS) may be a problem. In the next figure (Fig. 9), the thermal pulse from a L- $CH_4$  is compared to that from the  $H_2O/H_2$  admixture shown in Fig. 8. The combination material gave a narrower pulse width than the pure L- $CH_4$  moderator.

## VI. Summary

Several studies were done to help optimize the moderator performance in SNS. The variation in the neutron output was studied as a function of moderator position, moderator interaction, and reflector material. The use of a composite moderator was also considered.

The neutron output from each moderator is maximized if the upstream edge is placed as far toward the upstream edge of the target as possible but not past the front of the target. The interaction between moderators causes a small decrease in the current from the upstream moderators and a decrease in the downstream moderators if these moderators are coupled but an increase if they are decoupled and poisoned.

The effect of various reflector materials depends on whether the neutron output from a decoupled or a coupled moderator is being considered. For a decoupled-poisoned moderator, the use of Pb or Be as an inner reflector material or Ni as an outer reflector makes little difference except for a reduction in the neutron tail starting at  $\sim 10^{-3}$  of the peak value.

For a coupled moderator, Pb as an inner reflector material makes a substantial reduction in the neutron tail relative to Be and the use of an outer reflector causes a reduction in the tail for both inner reflector materials. Reducing the neutron tail however causes a selective decrease in low energy neutrons.

A composite moderator in which 1/4 of the volume contains  $H_2$  and 3/4 of the volume contains  $H_2O$  can give a spectrum very similar to that from  $L-CH_4$ . The "L- $CH_4$  like" moderator has a narrower thermal pulse than the  $L-CH_4$  moderator.

## REFERENCES

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2. Briesmeister, Ed. "MCNP-A General Purpose Monte Carlo Code for Neutron and Photon Transport," LASL Report LA-7396-M, Rev. 2 (Sept. 1986)
3. D. Baker, A. Bridge, T. O. Brun, L. L. Daeman, E. J. Pitcher, and G. J. Russell, "Moderator Neutronics Design for a Next-Generation (1 MW) Pulsed Spallation Neutron Source," LANL private communication.

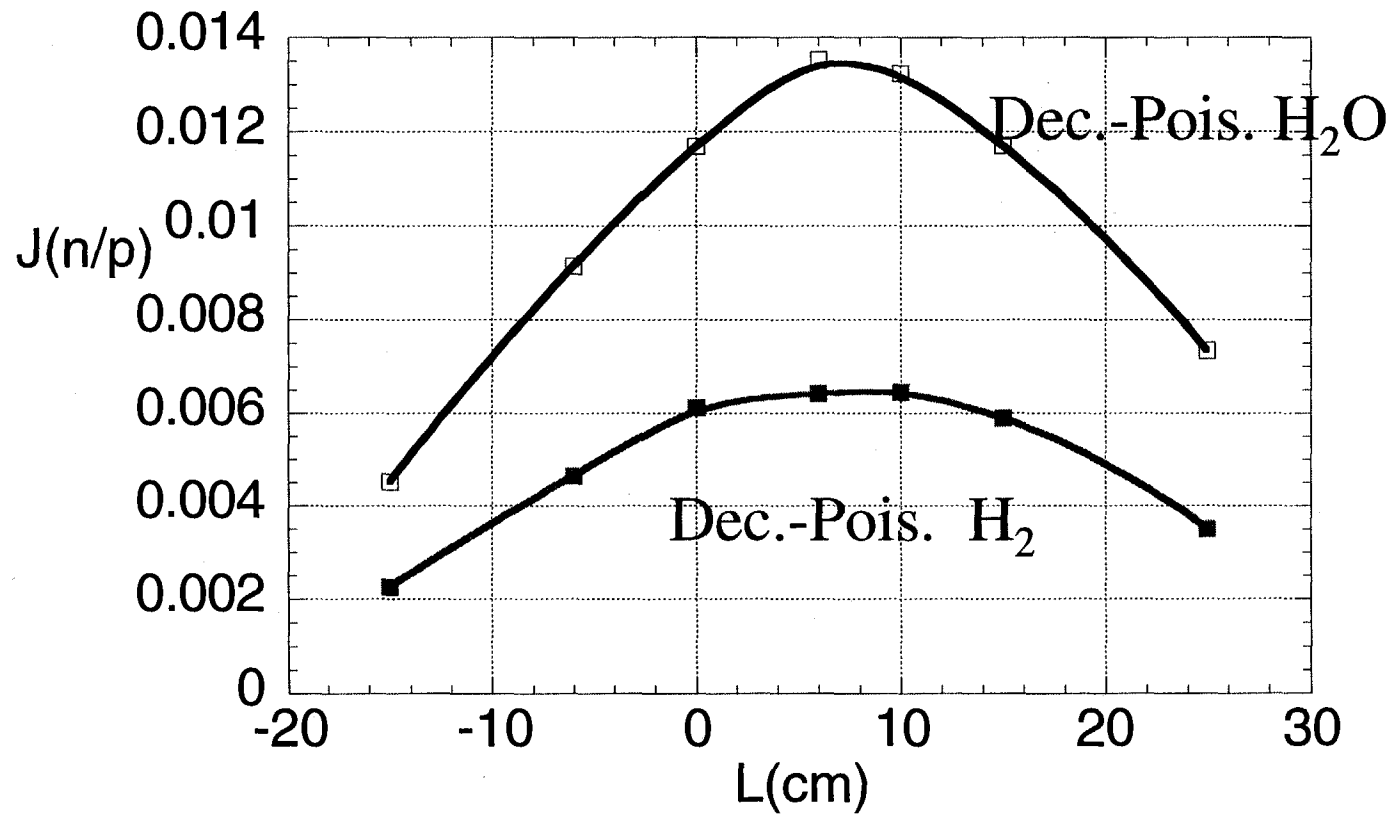


Fig. 1. Thermal neutron current from upstream moderators.



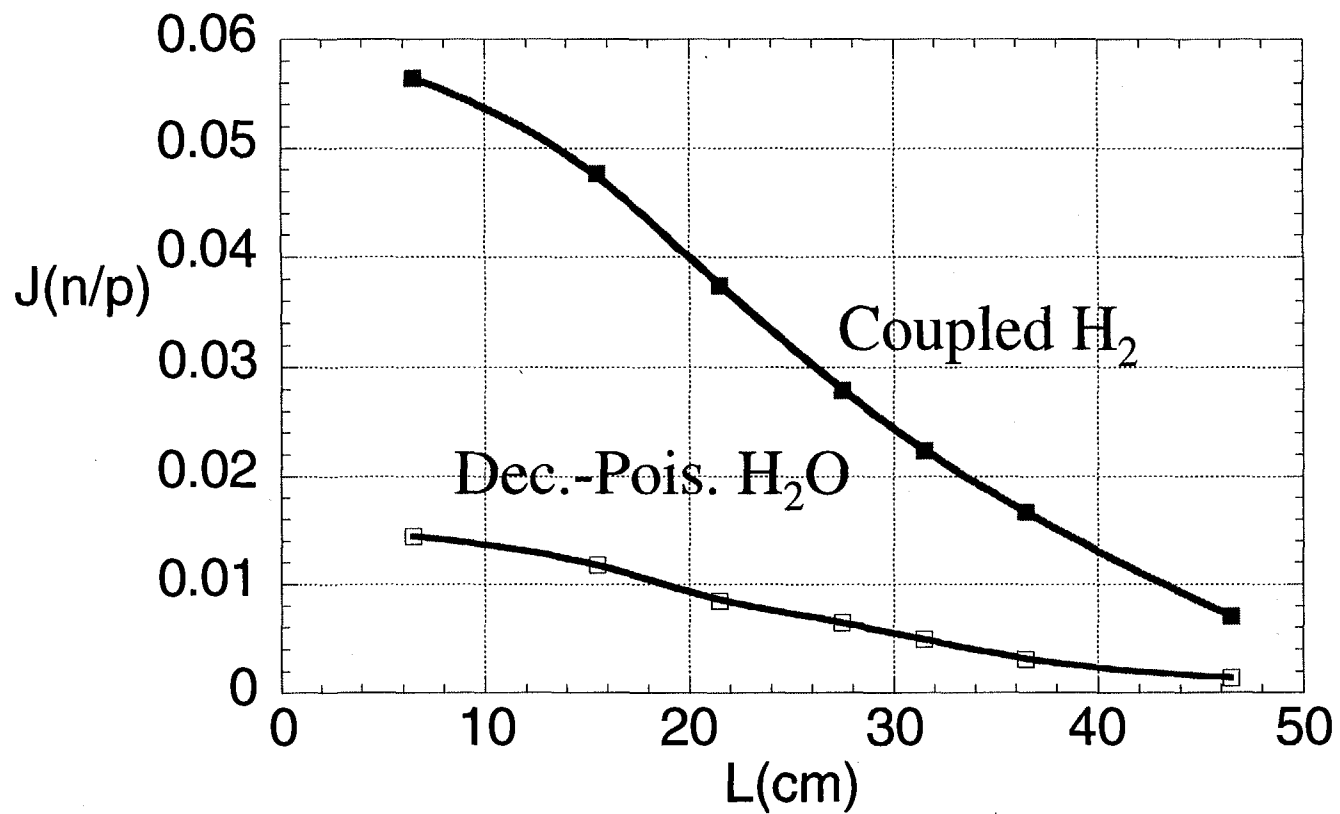


Fig. 2. Thermal neutron current from downstream moderators.

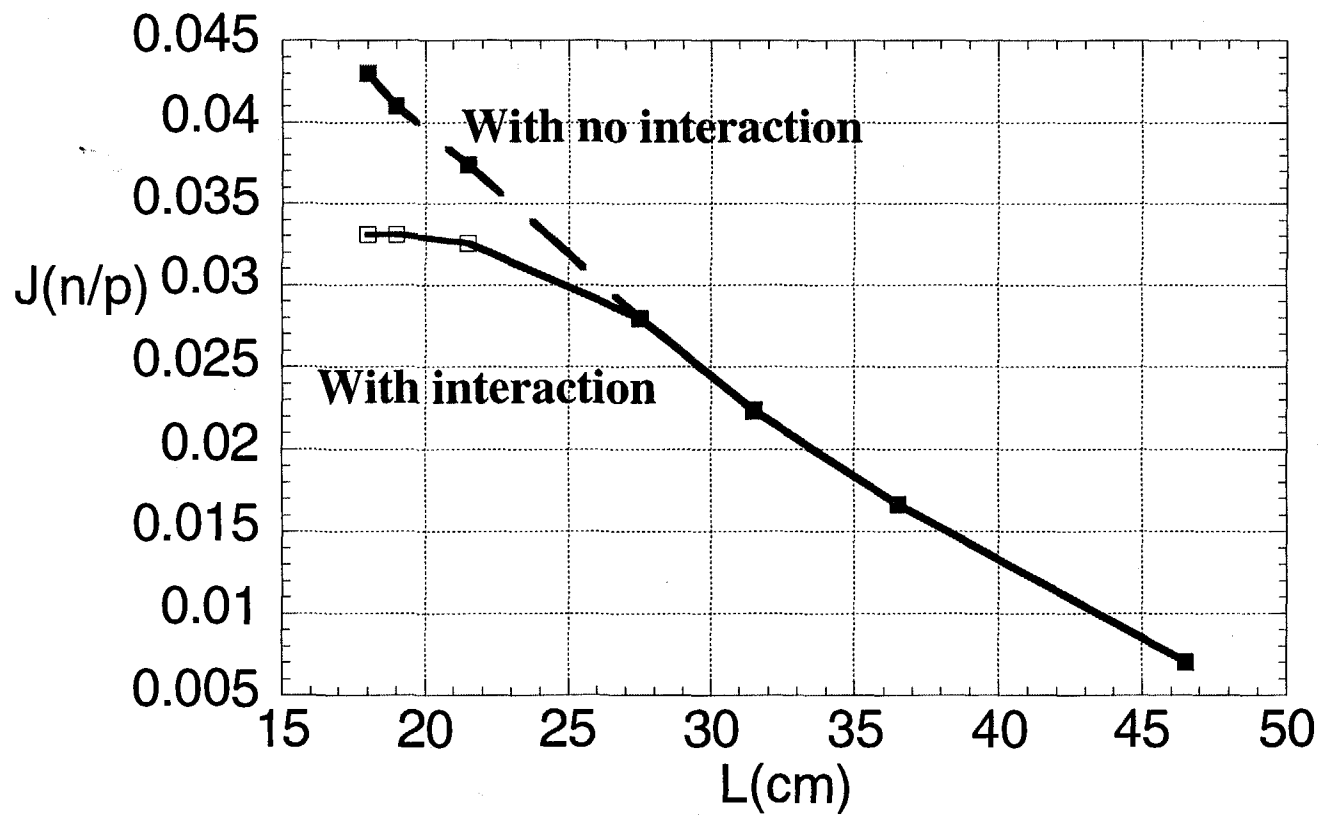


Fig. 3. Effect of moderator interaction on downstream coupled H<sub>2</sub> moderator output.

### Dec.-Pois. Moderators

Inner Refector	Be		Pb	
Outer Refector	Be	Ni	Pb	Ni
J(n/p)-H <sub>2</sub> Mod.	.0615	.0615	.0644	.0643
J(n/p)-H <sub>2</sub> O Mod.	.116	.117	.125	.124

Table 1. Comparison: Thermal neutron output for differing reflector materials and geometry.

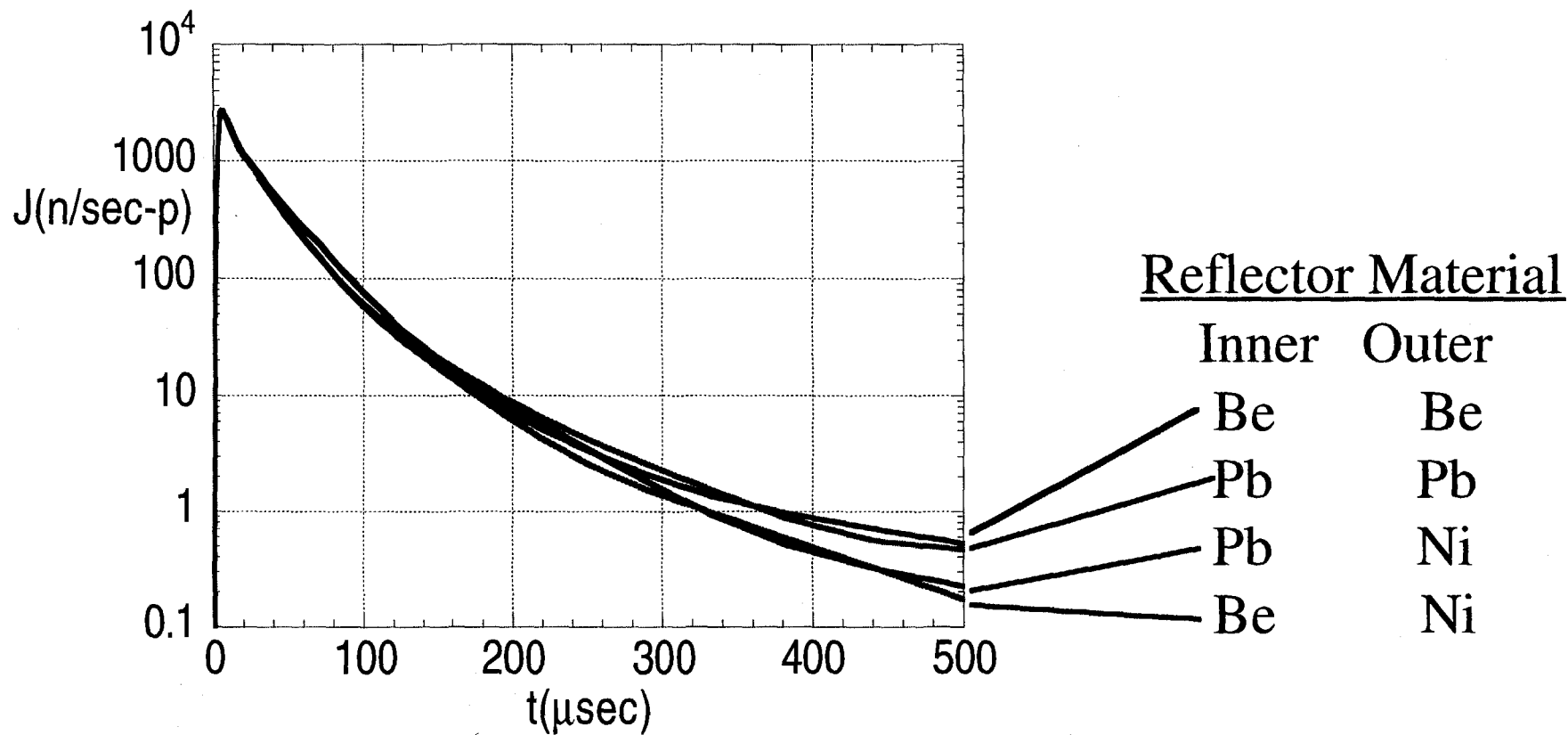


Fig. 4. Thermal neutron pulse from a decoupled poisoned  $H_2$  moderator for differing reflector materials and geometry (similar result for  $H_2O$ ).

## Coupled Moderators

Inner Refector	Be			Pb	
Outer Refector	Be	Pb	Ni	Pb	Ni
J(n/p)-H <sub>2</sub> Mod.	.414	.336	.267	.234	.182
J(n/p)-H <sub>2</sub> O Mod.	.466	.403	.344	.321	.272

Table 2. Comparison: Thermal neutron output for differing reflector materials and geometry.

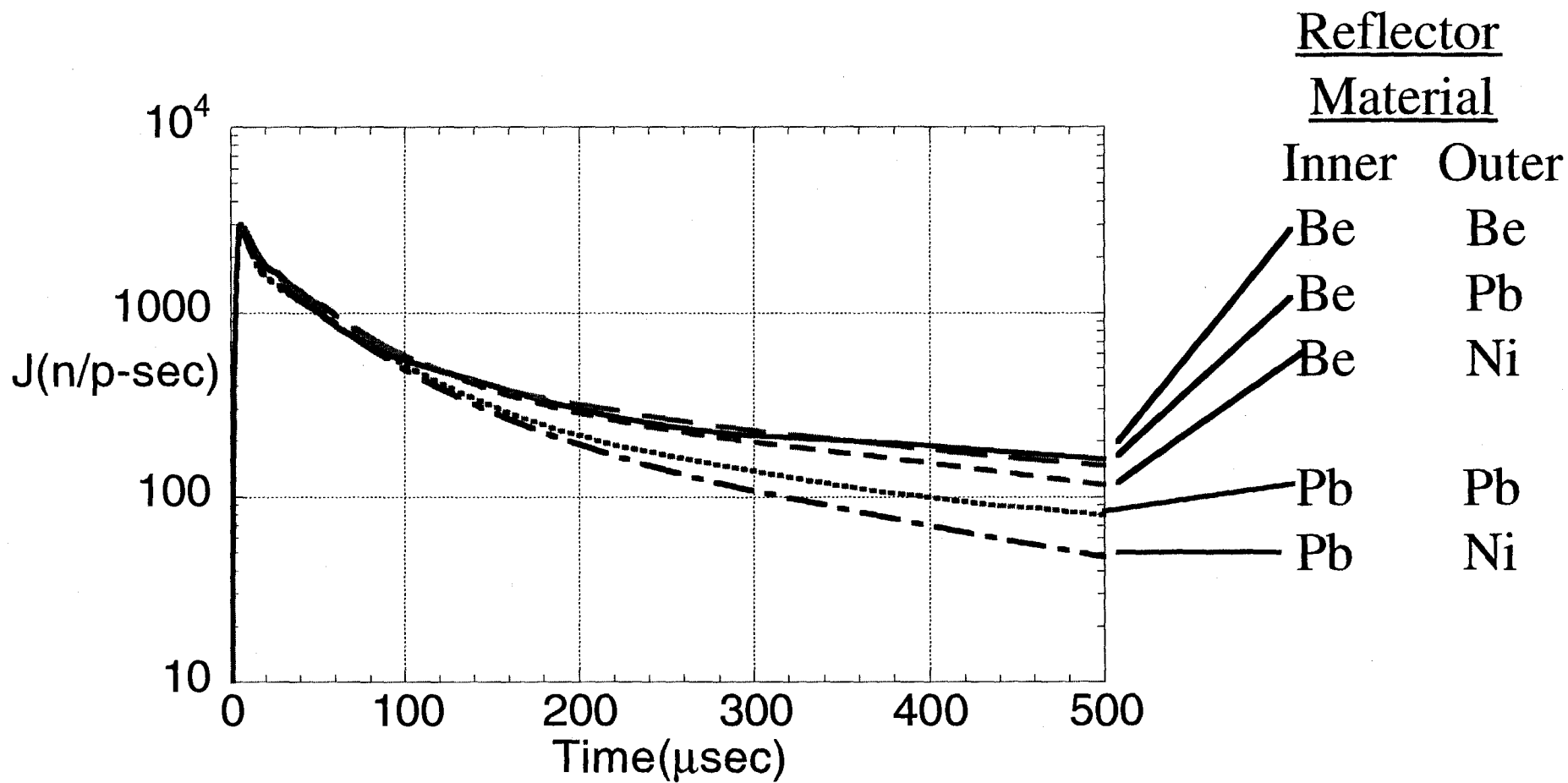


Fig. 5. Thermal neutron pulse from a coupled H<sub>2</sub> moderator for differing reflector materials and geometry.

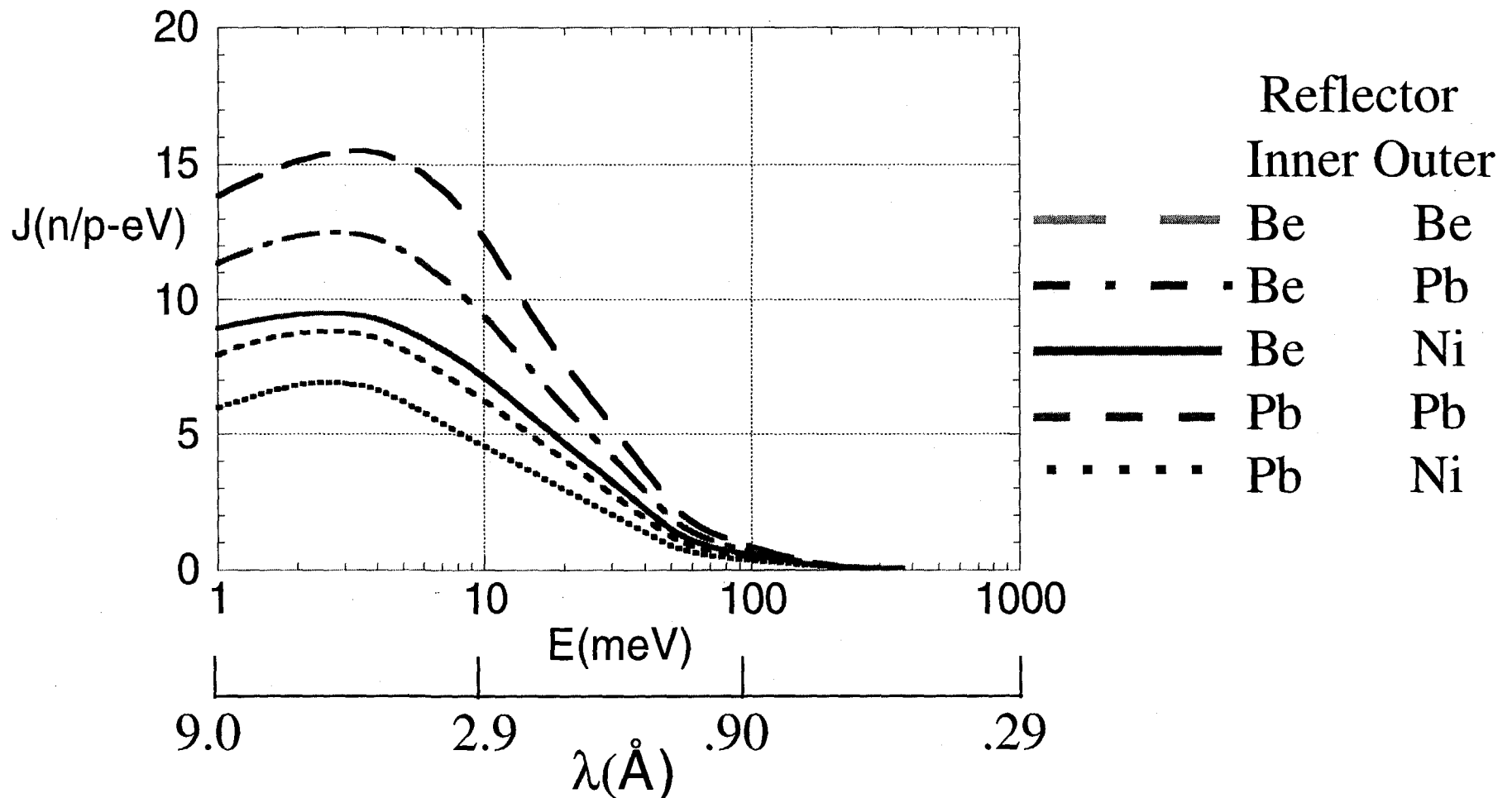


Fig. 6. Spectra from a coupled H<sub>2</sub> moderator for differing reflector materials and geometry (similar result for H<sub>2</sub>O).

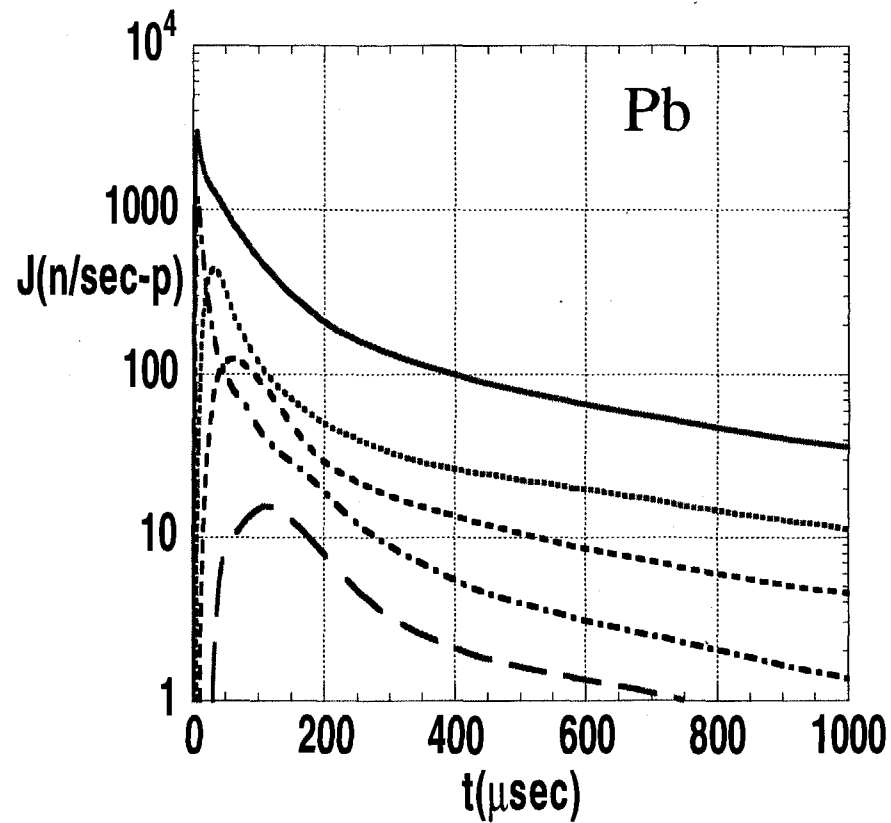
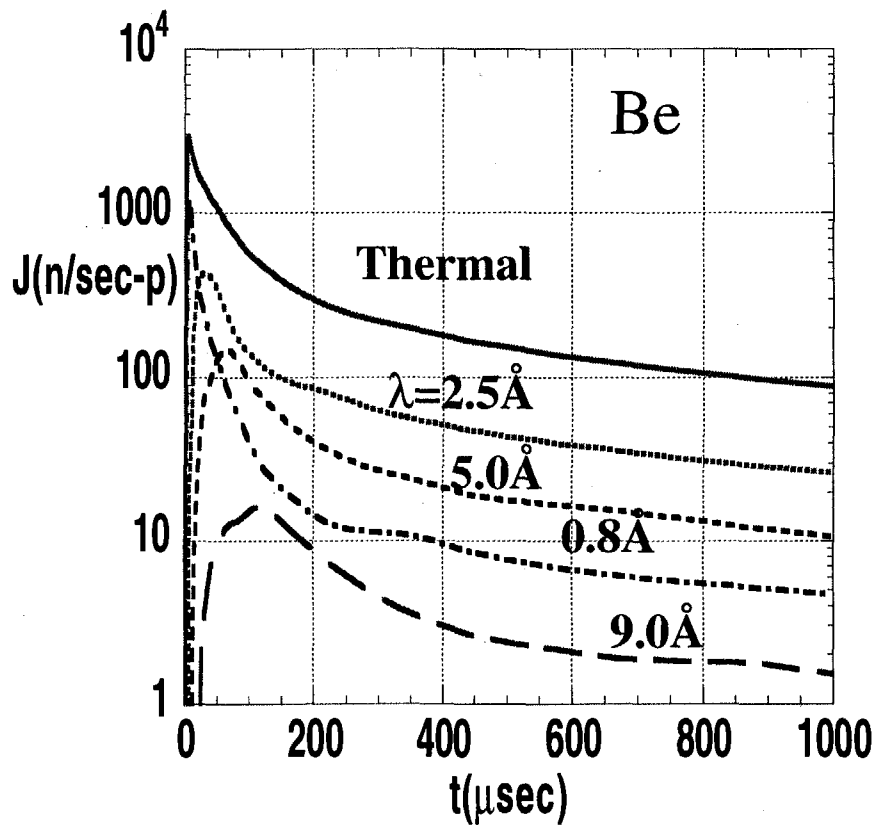


Fig. 7. Thermal neutron pulse from a coupled  $\text{H}_2$  moderator for a Be (left) and a Pb (right) reflector.



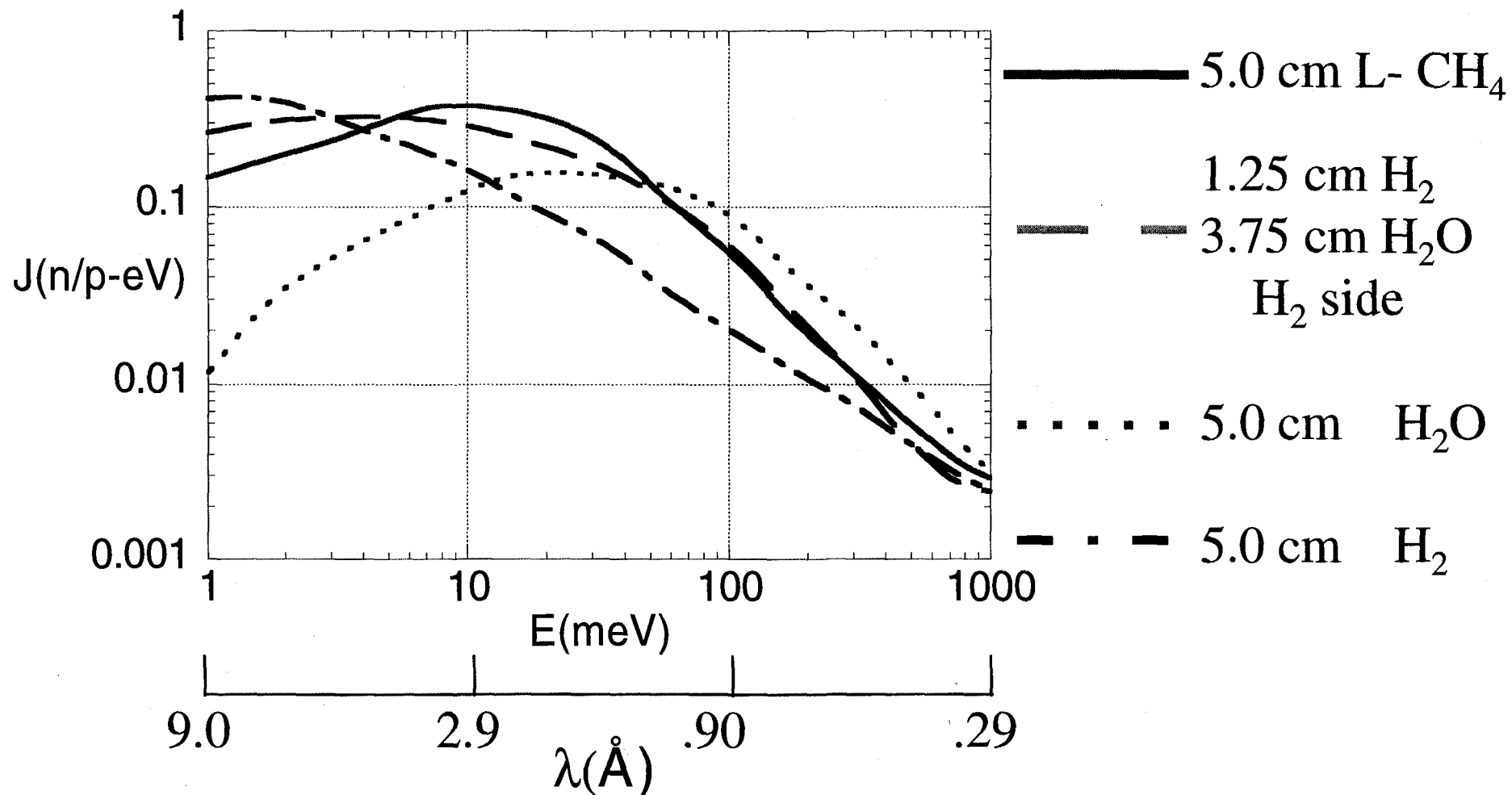


Fig. 8. Spectra from a composite decoupled moderator (total width 5 cm) with different mixtures of  $H_2O$  and  $H_2$  compared to the spectra from a  $L-CH_4/H_2O$  and  $H_2$  Moderator

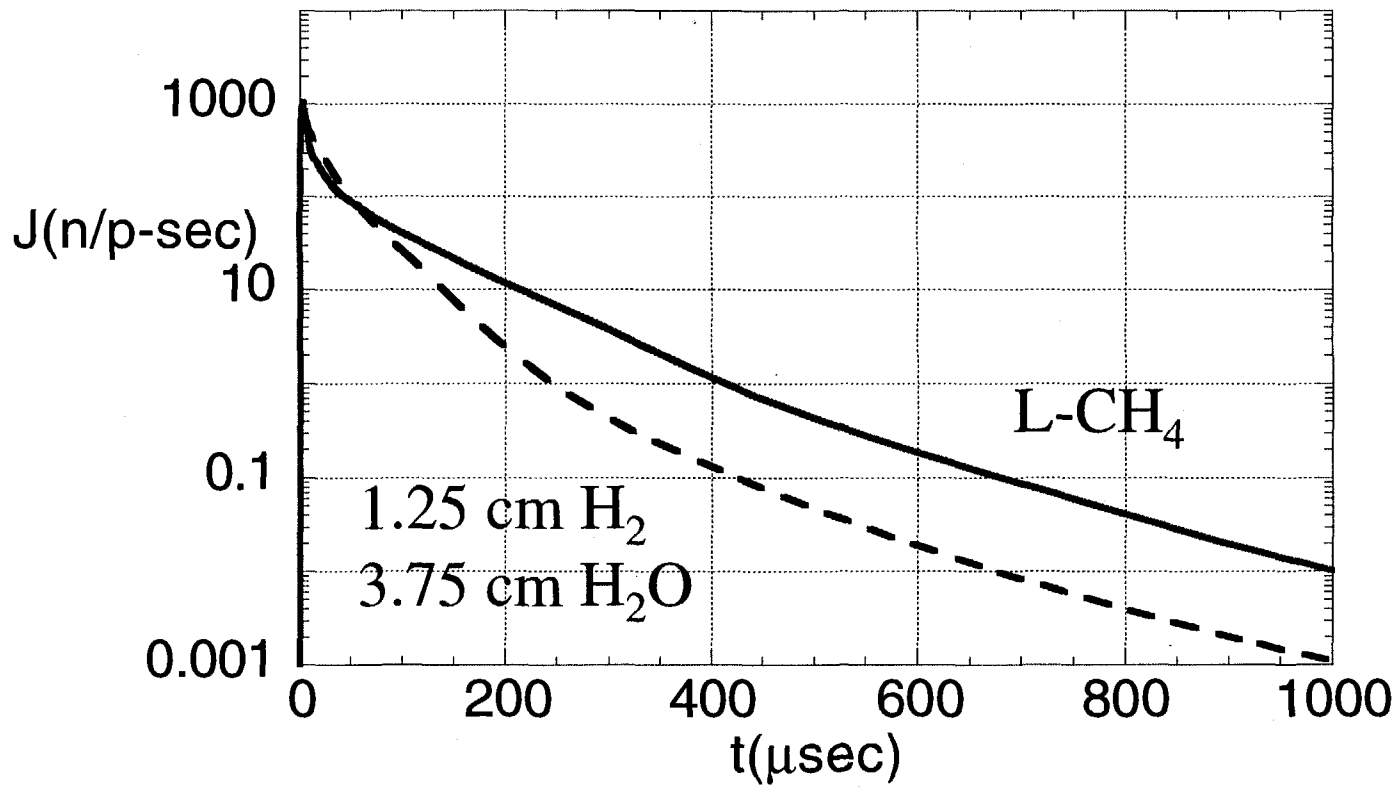


Fig. 9. Thermal pulse comparison: L-CH<sub>4</sub> and H<sub>2</sub>/H<sub>2</sub>O viewed from the H<sub>2</sub> side.