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# Development of Polarized Epithermal Neutron Spectrometer PEN at KENS

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## Abstract

The recent progress of the Polarized Epithermal Neutron Spectrometer (PEN) at KENS is described. A great improvement of the quality factor of the dynamically polarized proton filter (DPPF) has been achieved by employing a $^4$He-$^3$He heat exchanger for the cooling of the filter which realizes the complete removal of liquid $^3$He from neutron beam path. This cooling system is considered to be the most promising one in the practical use of the DPPF for polarized neutron scattering experiments.

## 1. Introduction

The Polarized Epithermal Neutron Spectrometer (PEN) at KENS[1,2] is designed to utilize the polarized white epithermal neutrons for the studies of nuclear polarization dependent scattering, magnetic scattering, nuclear parity dependent scattering, etc.. The neutron polarization is achieved by passage through a dynamically polarized proton filter (DPPF).[3,4] Since 1983, after the construction of main parts of the spectrometer, our efforts have been concentrated on the improvement of its performance, especially on getting an intense polarized neutron beam. We present here the recent progress of this point.

## 2. Improvement of dynamically polarized proton filter

The most difficult point for production of intense polarized white neutrons by use of the dynamically polarized proton filter (DPPF) is to remove $^3$He liquid from the neutron beam path as much as possible ensuring the enough cooling power for the filter material which is heated up by microwave absorption. This is because the $^3$He liquid is the coolant of the cooling system which cools the filter material down to ca. 0.5k, and, on the other hand, it is the highly neutron absorbing material. In the course of the efforts to overcome this difficulty, we have developed several types of the DPPF systems so far.[2,5] In this section Two types of them, which have recently be developed, are described.

### a) Type I filter

The first type of the DPPF is shown in Fig.1. The filter material was a mixture of ethylene glycol and ethylene glycol Cr(v) complex, which was filled in four separated cells of 2.4mm width x 20mm height x 15mm thickness. The filter thickness was decided by the optimization of the produced neutron polarization and the transmitted beam intensity. The filter cells were immersed in a liquid $^3$He container which was also a part of a microwave cavity. Spaces of 2.4mm width were left between the cells for good coolant convection around the filter material. The filter was inserted into a $^3$He cryostat, set in the center of a superconducting magnet of 25KG, and cooled down to ca, 0.5k. By use of this filter configuration, maximum proton polarization of 67% was realized. This result is satisfactory in the condition of the magnetic field and the coolant temperature. The neutron polarization was determined by the transmission through the filter and the 200 Bragg scattering from a $Fe_8Co_{92}$ single crystal. Neutron transmission through the filter was also used to monitor the liquid $^3$He level in the container. If the liquid $^3$He level is within the neutron beam path, unpolarized beam mixes with the polarized beam. The lowering of the liquid $^3$He level ,however, causes an anomalous increase in the neutron counting for the transmission measurement, and therefore it is easily detectable. During this experiment the level was found to be always above the neutron beam path. The results of the neutron polarization are shown in Fig.2. The close circles in the figure are polarizations determined by the transmission measurement. Solid curve is a calculated value by use of the cross section data by Lushchikov et al.$^{3)}$ and the proton poralization of 67%. A good agreement is seen between these results. These values are found to be the highest polarization that have ever been achieved for epithermal white neutron beam, and are sufficient for neutron scattering experiments. The open circles are the polarization determined by the $Fe_8Co_{\underset{9}{\cancel{8}}2}$ Bragg scattering. They are systematically smaller than the value determined by the transmission measurement. Most of the deference is considered to come from the depolarization of neutrons in the beam path after the filter. Further tuning of the magnetic field along the neutron beam path is necessary in order to increase the neutron polarization at the sample position for the scattering experiments up to the value obtained by the transmission measurement.

b) <u>Type II filter</u>

Although, by use of type I filter, the high enough polarization of the epithermal white neutrons could be achieved, the effective beam size is still limited one since the layers of liquid $^3He$ obstruct partly the neutron beam path. In order to enlarge the beam size, a new type of filter, which utilizes the super liquid $^4He$ as the first stage coolant , has been developed. The configuration of this type of filter is shown schematically in Fig.3. The filter material was same as the case of type I filter, but it was formed into beads of about 1.5mm in diameter. The beads filled a Cu mesh box of $3x4x1.5cm^3$ which was set in the microwave cavity filled with liquid $^4He$. The bottom of the cavity, on both inside and outside of which Ag fine powder of about 1$\mu$m in diameter was sintered, was immersed in a liquid $^3He$ pool which was cooled to ca. 0.5K by pumping. Since the thermal resistance of the super liquid $^4He$ is negligibly small, the heat produced inside the cavity can be effectively transfered to the liquid $^3He$ pool through the heat exchanger composed of the sintered Ag fine powder layers. By this configuration we can achieve the complete removal of liquid $^3$He from the neutron beam path.

A test experiment to see the cooling efficiency of this type of filter system was carried out. In order to simulate the heating up by microwave, a manganine heater winded around a Cu frame of 4x1.5cm$^2$ was immersed in the cavity filled with liquid $^4$He. The temperature of the liquid $^3$He in the pool and liquid $^4$He inside the cavity were measured with calibrated Ge thermometers. The pressure of $^3$He gas at the surface of liquid $^3$He pool was also measured to check the temperature of the liquid $^3$He. The input power were monitored by the supplied current and voltage to the heater. The results are shown in Fig.4. The fact that a difference between the temperatures of the liquid $^3$He and $^4$He exists and increases with increasing input power indicates that there is some amount of thermal resistance of the heat exchanger between the inside and outside of the cavity, as expected. The dynamical polarization of protons using this type of filter system was performed. The amount of the filter material was about 14cc. The microwave of 20-30mW was irradiated on the filter material. The temperature of liquid $^4$He on that time was about 0.5K. The maximum proton polarization obtained in this condition was 50%. This value is rather low than the case of type I filter, 67%. We guess that this difference mainly comes from the difference of sample amount. In fact, The sample amount of this type filter was 4.7 times as much as the case of type I (3cc). In spite of this fact, we could obtain a great improvement of the performance by this filter system. This point is discussed in the following section.

c) comparison of the performance

The quality factor of a neutron polarizing filter is defined as $Q=P^2T$ , where P and T are neutron polarization and transmittance through the filter, respectively. Since the neutron counting statistics in the usual experimental condition is proportional to the incident neutron beam size, it is reasonable to define the total quality factor, which represent the performance, as $Q=AP^2T$, where A is the area of the filter. We plotted the quality factors for our typical DPPFs developed so far in Fig.5 by closed marks. The abcissa shows the years when the development was performed. The quality factors are calculated at the neutron energies of 0.1 and 1eV by using the experimentally obtained neutron polarization and transmittance. The data noted as Pre-PEN in the figure are results of a test experiment for PEN using a horizontal field cryostat5). The quality factors of the type II filter are estimated from the proton polarization determined by the NMR enhacement since neutron beam experiment was not available because of the long shutdown of KENS in 1984 fiscal year. We have recently started neutron beam experiments to confirm this results. It can be seen from the figure that a great improvement of the performance has been achieved step by step. The open marks in the figure show the estimated value for the type II filter supposing the proton polarization to be 80%. Since the beam size of $3x4cm^2$ obtained by this filter is large enough for usual scattering experiments, we regard these value as our goal value. From the discussion given in the preceding section, it is clear that, in order to reach the goal, we should make further efforts on the improvements of the total cooling power of the system, microwave input power and also the efficiency of the $^4$He-$^3$He type heat exchanger.

## 3. Summary

We have achieved a great improvement of the quality factor of the DPPF by employing a $^4$He-$^3$He heat exchanger for the cooling system of the filter. It realized the complete removal of liquid $^3$He from the neutron beam path. This cooling system is considered to be the most promising one in the practical use of the DPPF for polarized neutron scattering experiments.

## references

1) M. Kohgi, Proceedings of the Sixth Meeting of the International Collaboration on Advanced Neutron Sources, ANL-82-80(1983)172.

2) M. Ishida, Y. Masuda, M. Kohgi, Y. Kanno, S. Hiramats, Y. Ishikawa, A. Masaike and K. Morimoto, KENS REPORT-V, KEK Progress Report 84-2(1984)207 ;
M. Ishida, Y. Masuda, Y. Kanno, M. Kohgi, Y. Ishikawa and A. Masaike, ibid. (1984)211.

3) V. I. Lushchikov, Yu. V. Taran and F. L. Shapiro, Soviet J. Nucl. Phys. 10(1970)669.

4) S. Hiramatsu, S. Isagawa, S. Ishimoto, A. Masaike, K. Morimoto, S. Funahashi, Y. Hamaguchi, N. Minakawa and Y. Yamaguchi, J. Phys. Soc. Jpn., 45(1978)949.

5) J. M. Newsam, M. Ishida, S. Isagawa, Y. Ishikawa, S. Ishimoto, M. Kohgi, A. Masaike, Y. Masuda, K. Morimoto and T. Nakajima, KENS REPORT-III, KEK Internal 82-5(1982)123.

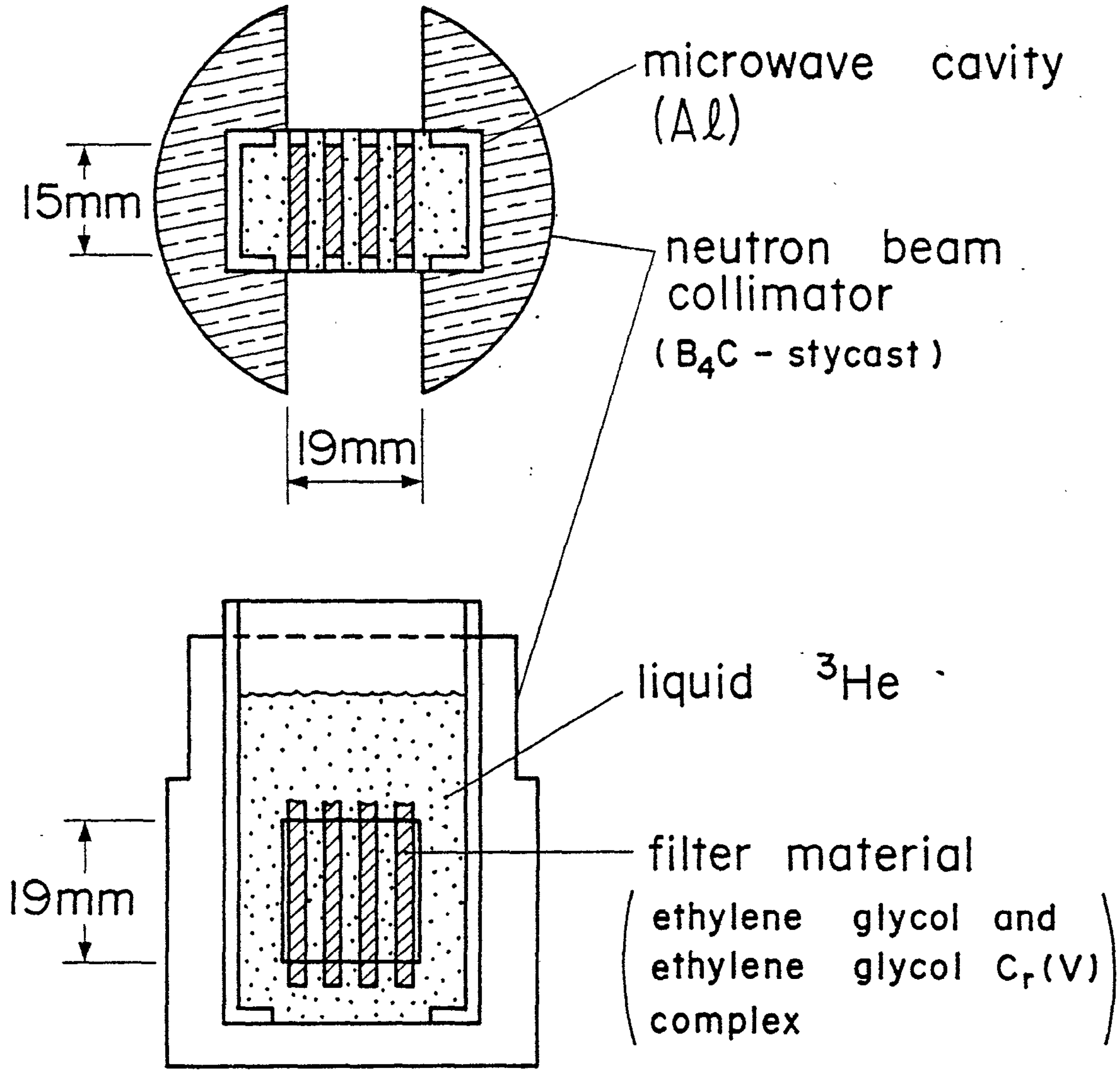

Fig.1 Type I filter. Filter cells are immersed in the liquid $^3$He container which is also used as a microwave cavity. The cavity is set in the neutron beam collimator which has windows of 19x19mm$^2$ in the center of the beam.

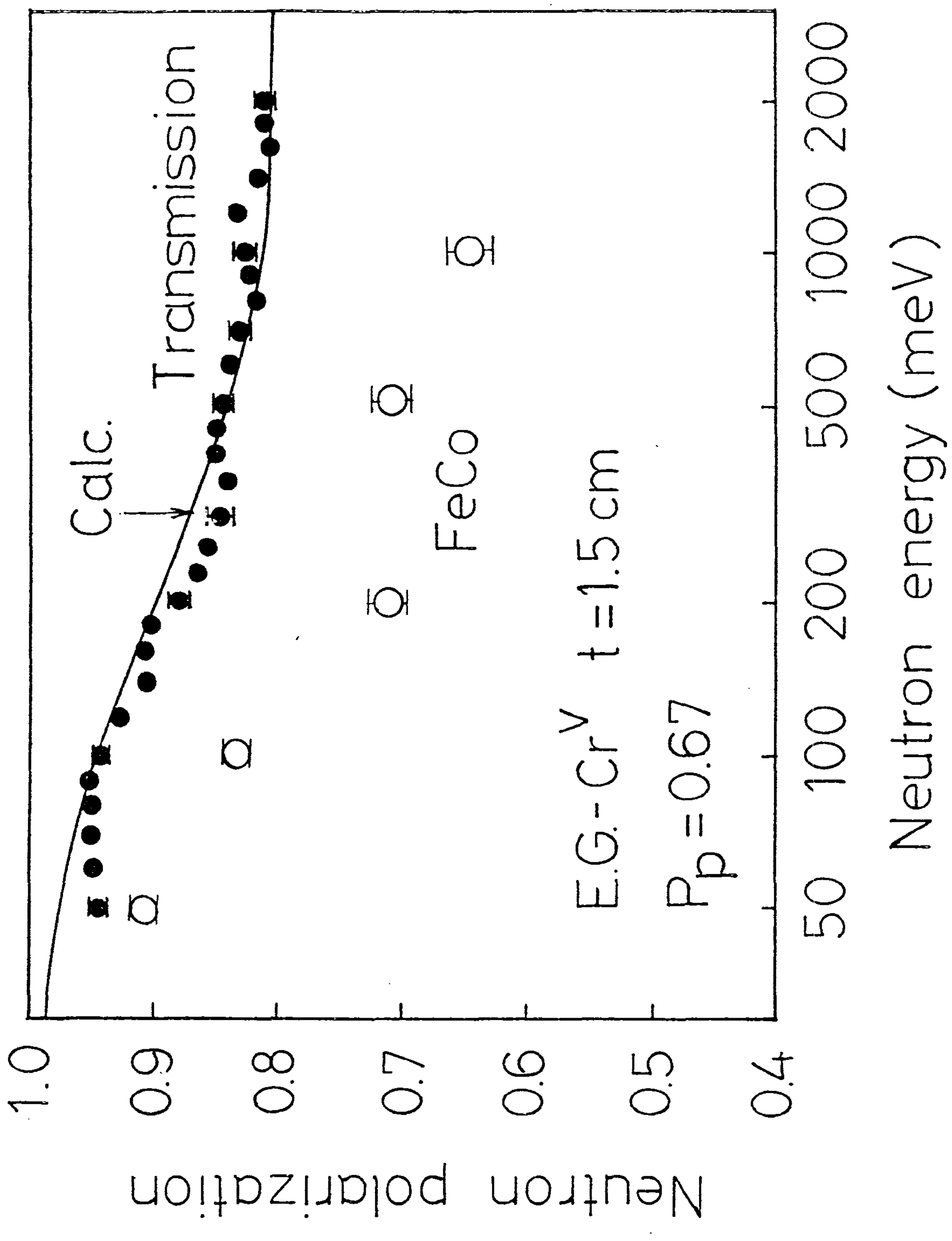

Fig.2 Polarization of the neutron beam obtained by the type I filter. Closed circles are the polarization determined from the transmission measurement. Solid line is the calculated polarization with the proton polarization of 67%. Open circles are the polarization determined by the (200) Bragg scattering from $Fe_8Co_{92}$ single crystal.

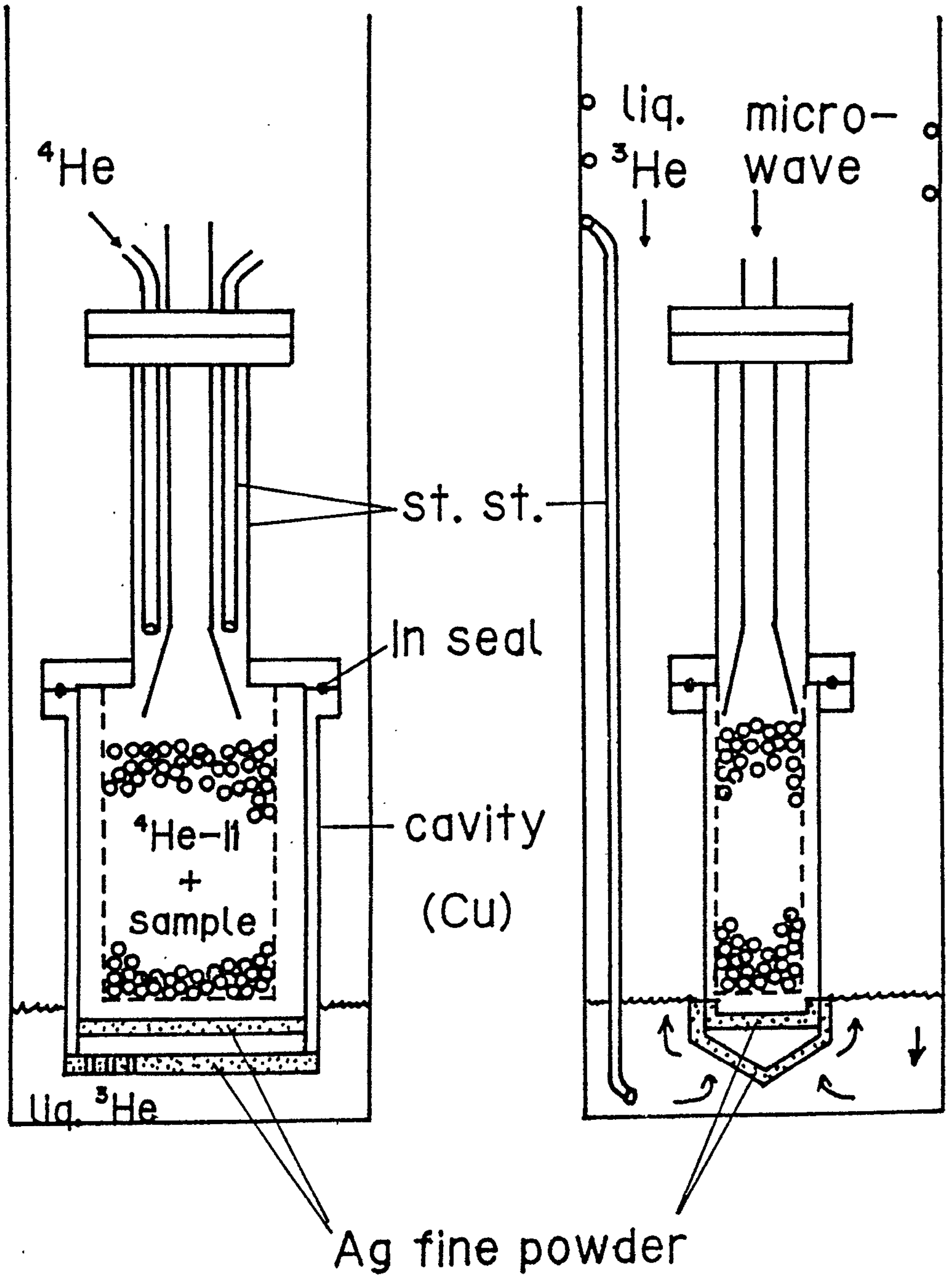

Fig.3 Type II filter. Beads of filter material fill a Cu mesh box which is set in the microwave cavity filled with liquid $^4$He. The bottom of the cavity is immesed in the liquid $^3$He pool. Ag fine powder is sintered on the both sides of the bottom of the cavity for the effective heat exchange.

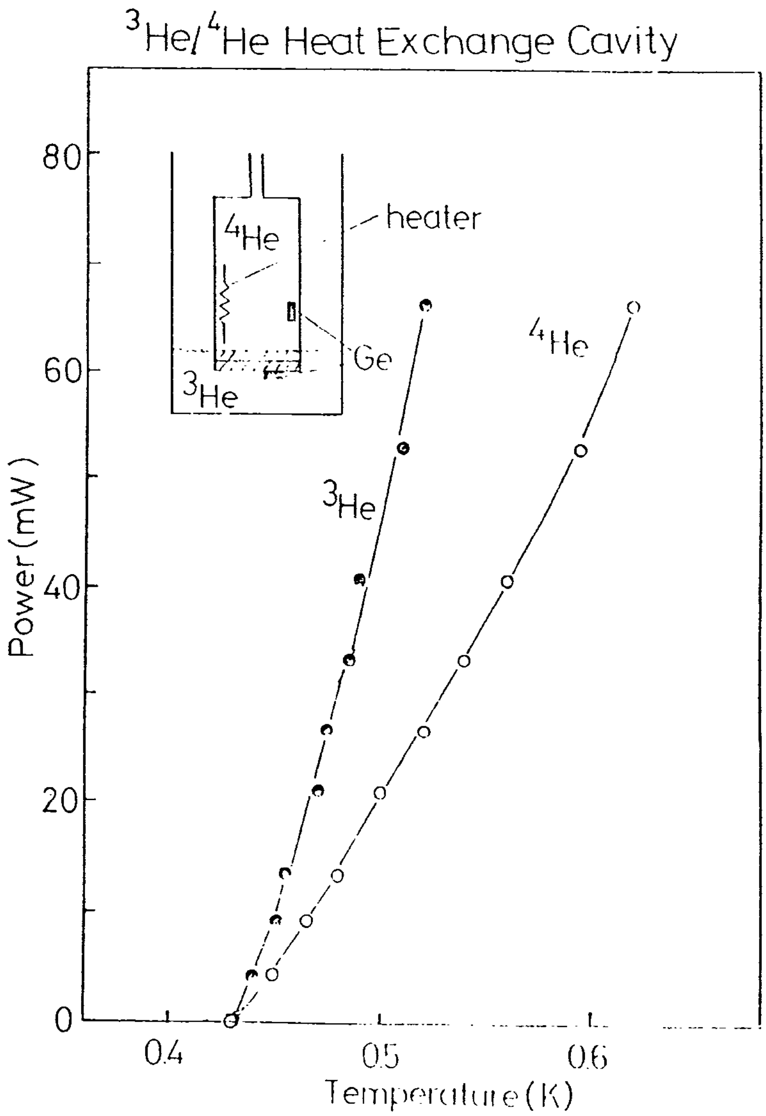

Fig.4 Cooling power of type II filter. Open circles are temperatures inside the microwave cavity. Closed circles are temperatures in the $^3$He pool. Ordinate shows applied power.

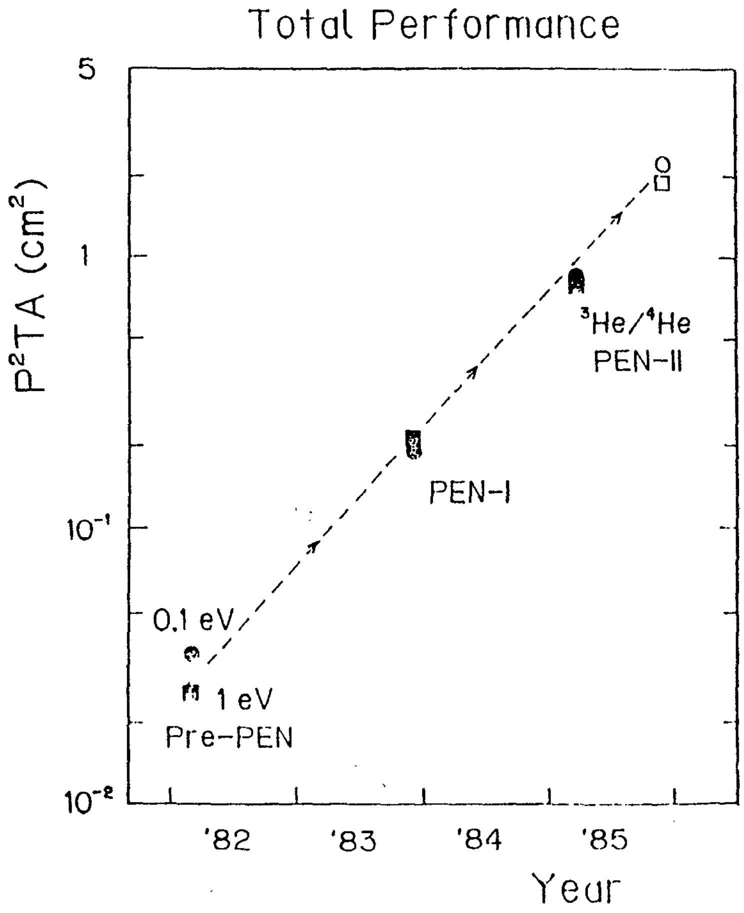

Fig.5 Performance of the dynamically polarized proton filters developed on PEN. Data noted as Pre-PEN are the results of test experiments performed prior to PEN. Data noted as PEN-I and PEN-2 show the results of experiments by using the type I and typeII filters described in the text, respectively. Open marks show the estimated quality factor by using the type II filter supposing the proton polarization to be 80%.