Experimental density of states and the UCN loss coefficient of fluoropolymers at low temperatures.

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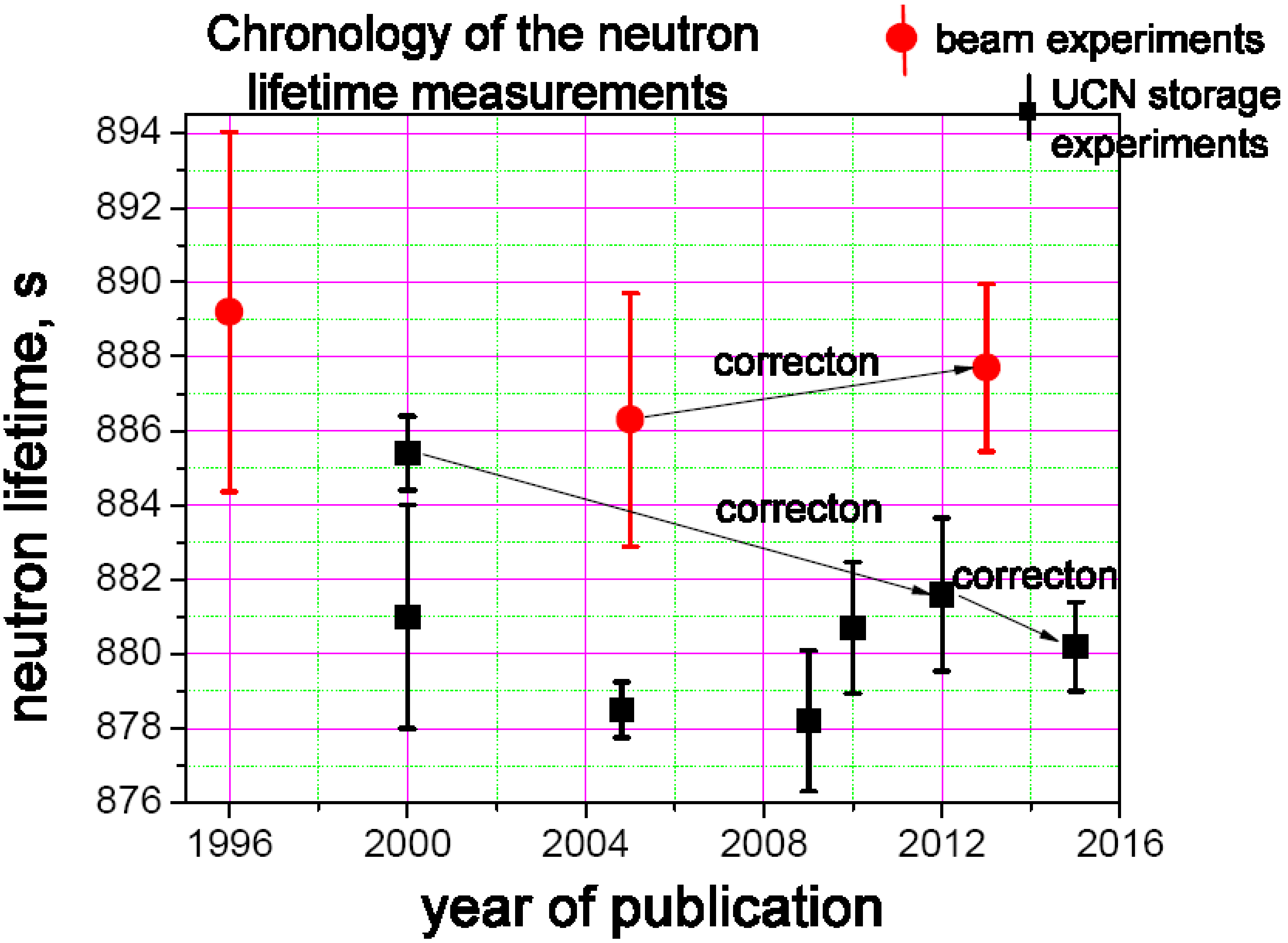
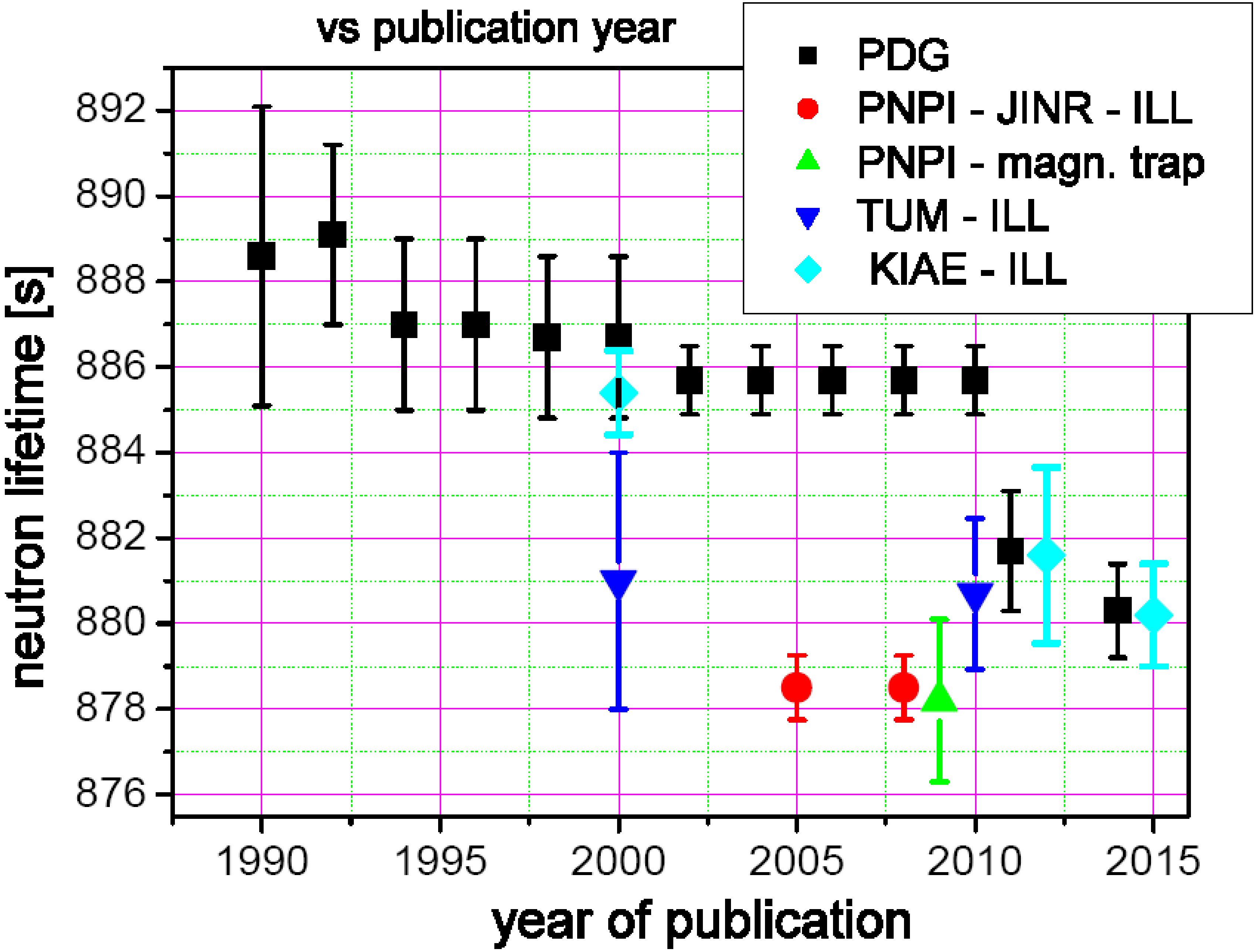
We report the inelastic neutron scattering measurement of the density of vibrational states $G(\omega)$ of four fluoropolymers which differ by chemical composition, molecular weight and solidification temperatures. These polymers are promising for the storage of ultra cold neutrons in closed volumes covered with polymer film. From inferred $G(\omega)$ we calculate the expected UCN loss coefficients and compare them with the existing experimental data.

Chronology of the neutron lifetime measurements



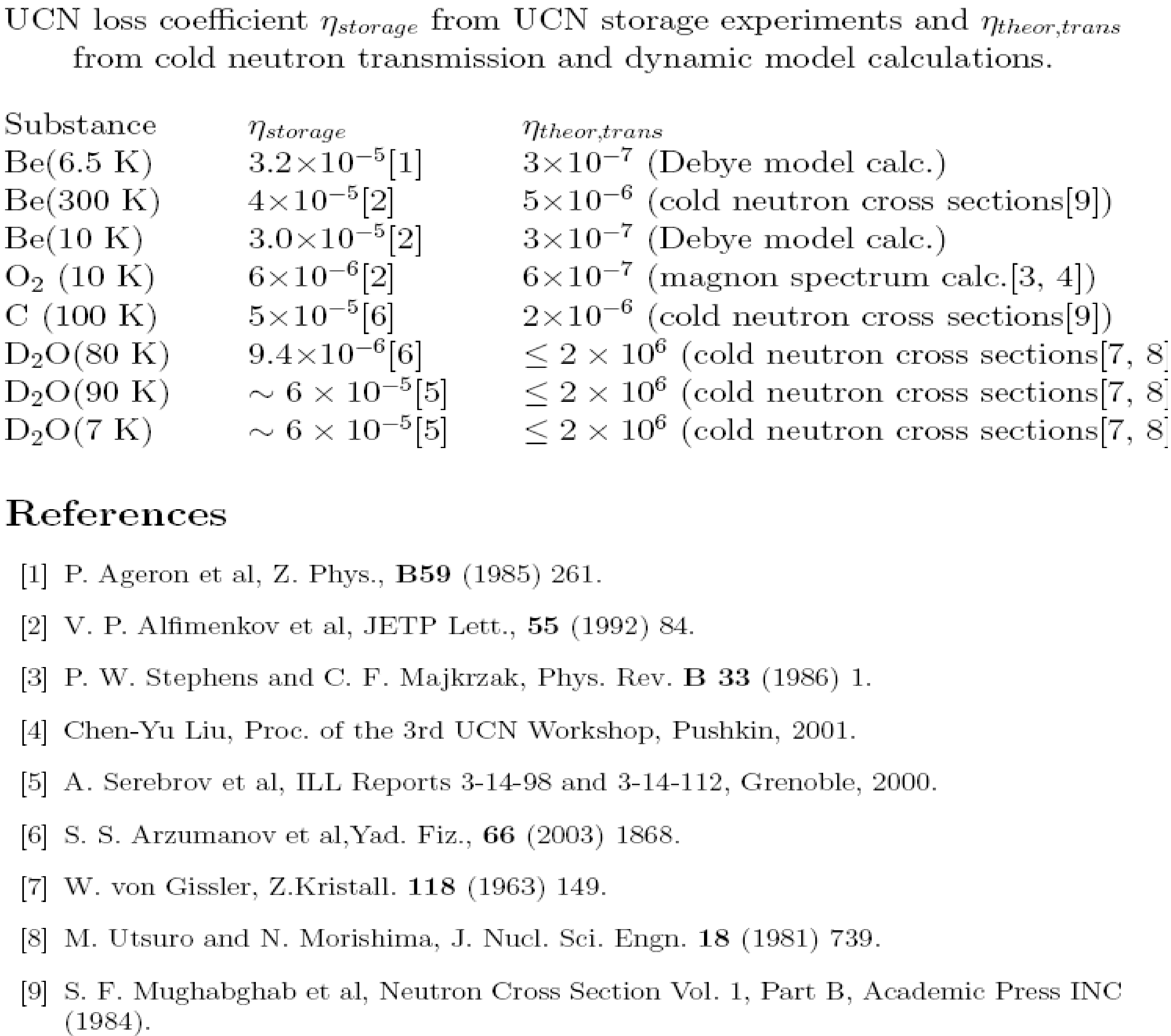


UCN-experiments & PDG neutron lifetime vs publication year

$$\tau_{\text{st}}^{-1} = \tau_{\text{decay}}^{-1} + \tau_{\text{loss}}^{-1}$$

$$\tau_{\text{st},i}^{-1} = \tau_{\text{decay}}^{-1} + \eta\gamma_i$$

From Yu. Pokotilovski, NIM A554 (2005) 356



UCN loss coefficient $\eta_{storage}$ from UCN storage experiments and $\eta_{theor,trans}$ from cold neutron transmission and dynamic model calculations.

Substance	$\eta_{storage}$	$\eta_{theor,trans}$
Be(6.5 K)	3.2×10^{-5}[1]	3×10^{-7} (Debye model calc.)
Be(300 K)	4×10^{-5}[2]	5×10^{-6} (cold neutron cross sections[9])
Be(10 K)	3.0×10^{-5}[2]	3×10^{-7} (Debye model calc.)
O_2 (10 K)	6×10^{-6}[2]	6×10^{-7} (magnon spectrum calc.[3, 4])
C (100 K)	5×10^{-5}[6]	2×10^{-6} (cold neutron cross sections[9])
D_2O(80 K)	9.4×10^{-6}[6]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8
D_2O(90 K)	$\sim 6 \times 10^{-5}$[5]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8
D_2O(7 K)	$\sim 6 \times 10^{-5}$[5]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8

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ULTRACOLD NEUTRON STORAGE IN A FLUID-WALLED BOTTLE

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Revised manuscript received 1 February 1982

Theoretically possible wall-loss probabilities for ultracold neutrons stored in solid-walled bottles have not been achieved in practice, but preliminary measurements with a fluid-walled bottle seem promising.

Nuclear Instruments and Methods in Physics Research A284 (1989) 111–115
North-Holland, Amsterdam

NEUTRON LIFETIME FROM A LIQUID WALLED BOTTLE

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The neutron lifetime has been measured in a storage experiment by counting the ultra-cold neutrons remaining in a fluid walled bottle as a function of the duration of storage. Wall losses are eliminated by varying the bottle volume to surface ratio. Our result is $\tau_\beta = (887.6 \pm 3)$ s.

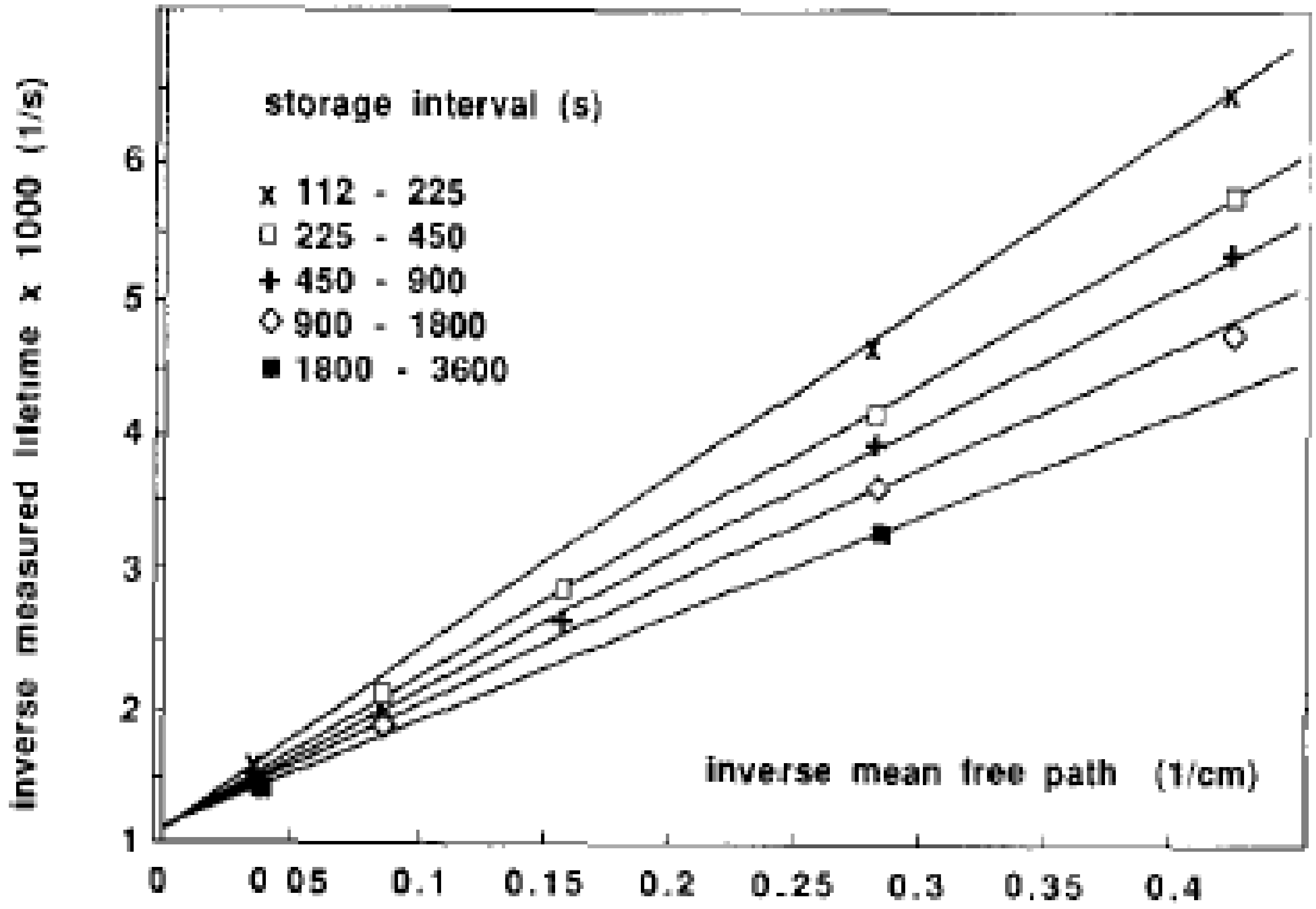

Fig. 2. Measured inverse bottle lifetimes as a function of the bottle inverse mean free path and for different storage intervals. The data are from a one week running period. Almost all the error bars are smaller than the data points.

Journal of Experimental and Theoretical Physics, Vol. 96, No. 2, 2003, pp. 172–179.
From Zhurnal Eksperimental'noĭ i Teoreticheskoĭ Fiziki, Vol. 123, No. 2, 2003, pp. 203–210.

**NUCLEI, PARTICLES,
AND THEIR INTERACTION**

Investigation of Liquid Fluoropolymers as Possible Materials for Low-Temperature Liquid-Wall Chambers for Ultracold Neutron Storage¶

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Received April 27, 2002

Abstract—Several hydrogen-free liquid low-temperature fluoropolymers are investigated from the point of view of their possible use as the material for walls of ultracold neutron traps with low losses. Viscosity was measured in the temperature range 150–300 K, and neutron scattering cross sections were measured in the temperature range 10–300 K and in the neutron wavelength range 1–20 Å. Some conclusions are made for their possible ultracold neutron bottle properties. Quasi-elastic neutron reflection from the surface of a viscous liquid is considered in the framework of the Maxwell dynamic model. © *2003 MAIK "Nauka/Interperiodica".*

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Measurement of the neutron lifetime using a gravitational trap and a low-temperature Fomblin coating

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A. Serebrov et al.,Phys. Lett. B605 (2005) 72

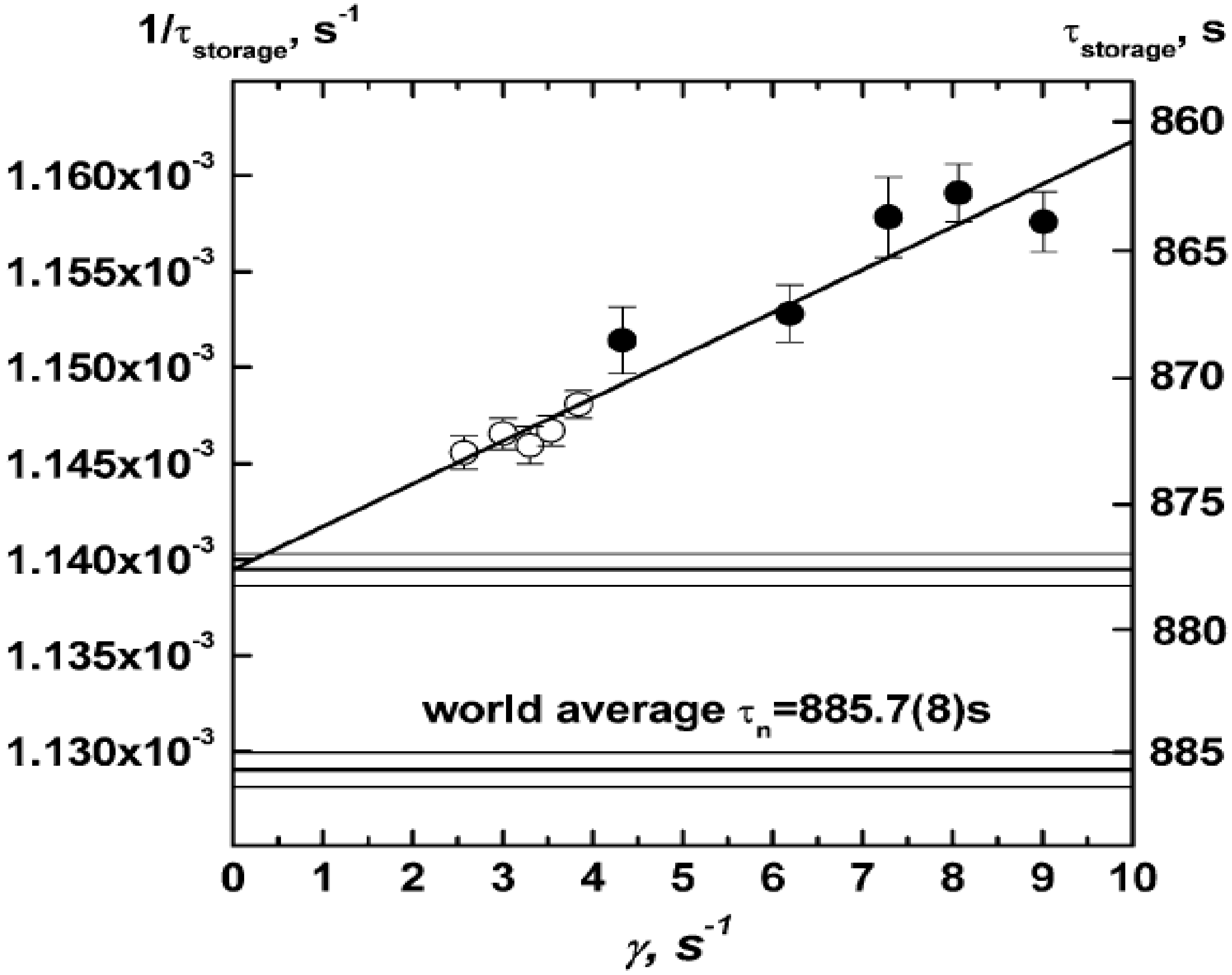
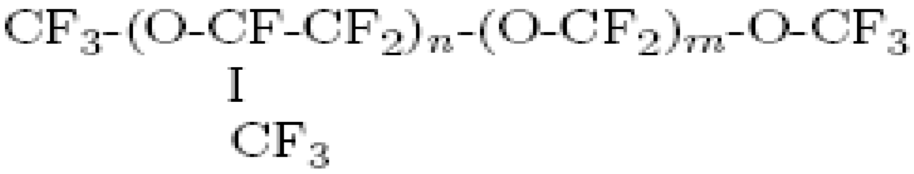


Fig. 3. Result of extrapolation to the neutron lifetime using joint energy and the size extrapolation method. Measurements made with a spherical (open circles) and cylindrical (filled circles) traps.

”Fomblin Y”



$$CF_3\text{-}(O\text{-}\underset{\substack{|\\ CF_3}}{CF}\text{-}CF_2)_n\text{-}(O\text{-}CF_2)_m\text{-}O\text{-}CF_3$$

n/m=20-40, ($\approx C_3OF_6$), molecular weight $\sim$3000

Perfluoropolyethers (or fluoropolyoximethilenes)

$CF_3O(CF_2O)_{m_1}(CF_2CF_2O)_n(CF_2O)_{m_2}\,CF_3$

with $m_1 + m_2$ $\approx$60.5, n$\approx$3.14 and molecular weight 4500.

These substances have much lower pour point ($\sim$ -90 ^{o}C) in comparison to Fomblin, that permitted to use in the UCN storage experiments much lower wall temperatures - down to -160 ^{o}

J. Am. Chem. Soc. **1995,** *117,* 4276−4278

Synthesis and Physical Properties of Novel Perfluorinated Methylene Oxide Oligomers. The Ultimate Low Temperature Fluids

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Contribution from the Department of Chemistry and Biochemistry, The University of Texas at Austin, Austin, Texas 78712−1167

Received August 18, 1994®

Abstract: Perfluorinated polyethers are a class of substances which are extremely inert and have both extraordinary high temperature stability and low temperature properties. The synthesis of perfluorinated polyformaldehydes with the highest oxygen content was designed to give the maximum liquid range and low temperature properties. Novel low molecular weight perfluorinated polyformaldehydes with stable and unreactive perfluoro-*n*-butyl end groups were prepared by liquid-phase direct fluorination. The boiling point of these compounds increases by approximately 20 °C with the addition of each difluoromethylene oxide unit. This trend does not continue for longer chain lengths ($n > 4$) where the increase in boiling point per CF_2O unit diminishes. The average increase of melting temperature is ~1−2 °C as the perfluorinated polyformaldehyde chain increases one difluoromethylene oxide unit. The new perfluoropolyether fluids produced have melting points ranging from −145 to −152 °C.

Ind. Eng. Chem. Prod. Res. Dev. **1982**, *21*, 520–522

A New Perfluorinated Grease for High-Vacuum Technology

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Montefluos SpA, Montedison, Research Development Center, Milano, Italy

A. Rolando

ROL, Lubricant Research Laboratories, Viguzzolo, Italy

Advances on fluorinated materials allowed the development of a new grease, compounded by low vapor tension perfluoropolyether liquid and special PTFE. Chemical composition, physical, rheological, and antiwear properties, and chemical and thermooxidative stability compared with other conventional lubricants resulted in attractive properties to utilize the new grease for high-vacuum technologies where residue pressures of aggressive chemical agents or energetic particles or radiations are involved. A brief account on topical high-vacuum application of the new lubricant is summarized.

Dynamics of Molecules and Materials-II IOP Publishing
Journal of Physics: Conference Series **554** (2014) 012002 doi:10.1088/1742-6596/554/1/012002

Parameters of the NERA spectrometer for cold and thermal moderators of the IBR-2 pulsed reactor

I Natkaniec[1,2], D Chudoba[1,2], Ł Hetmańczyk[1,3], V Yu Kazimirov[1], J Krawczyk[1,4], I L Sashin[1] and S Zalewski[1,5]

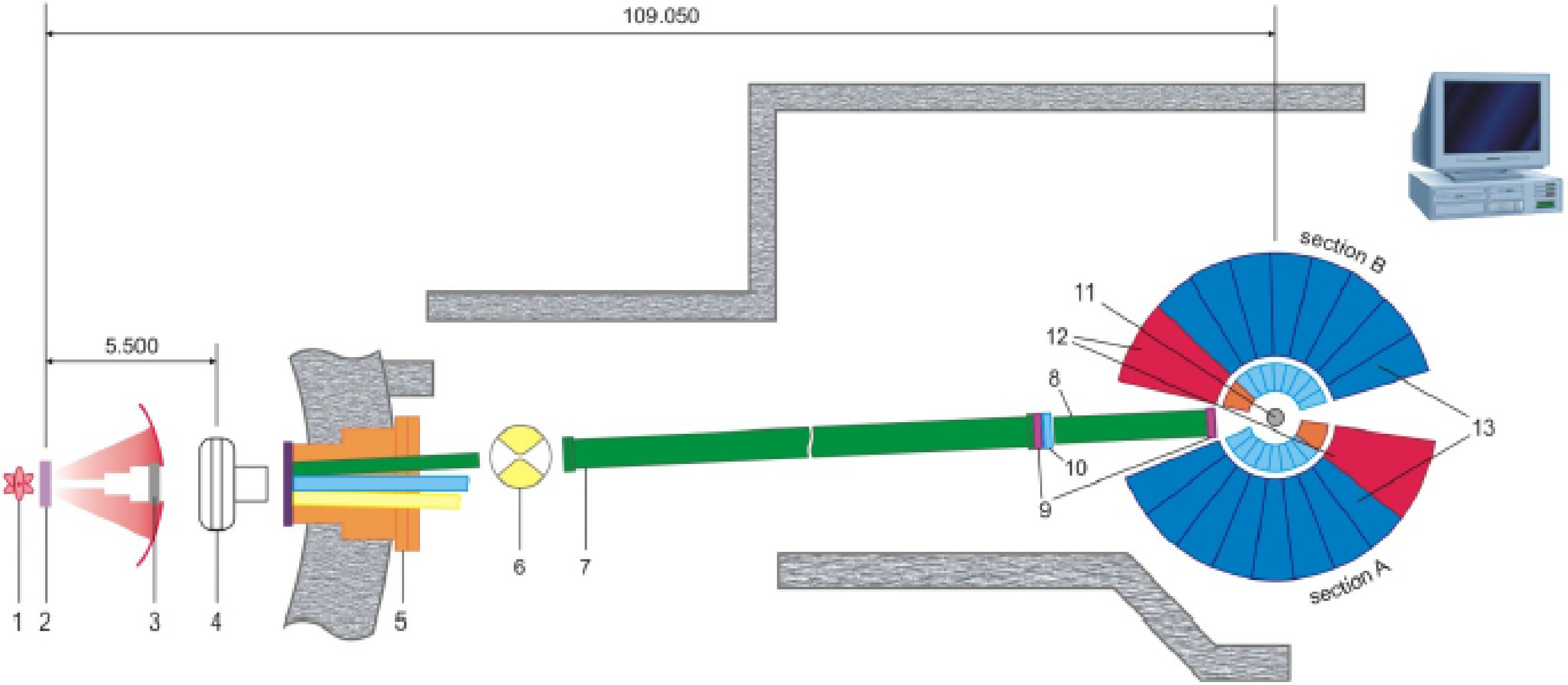


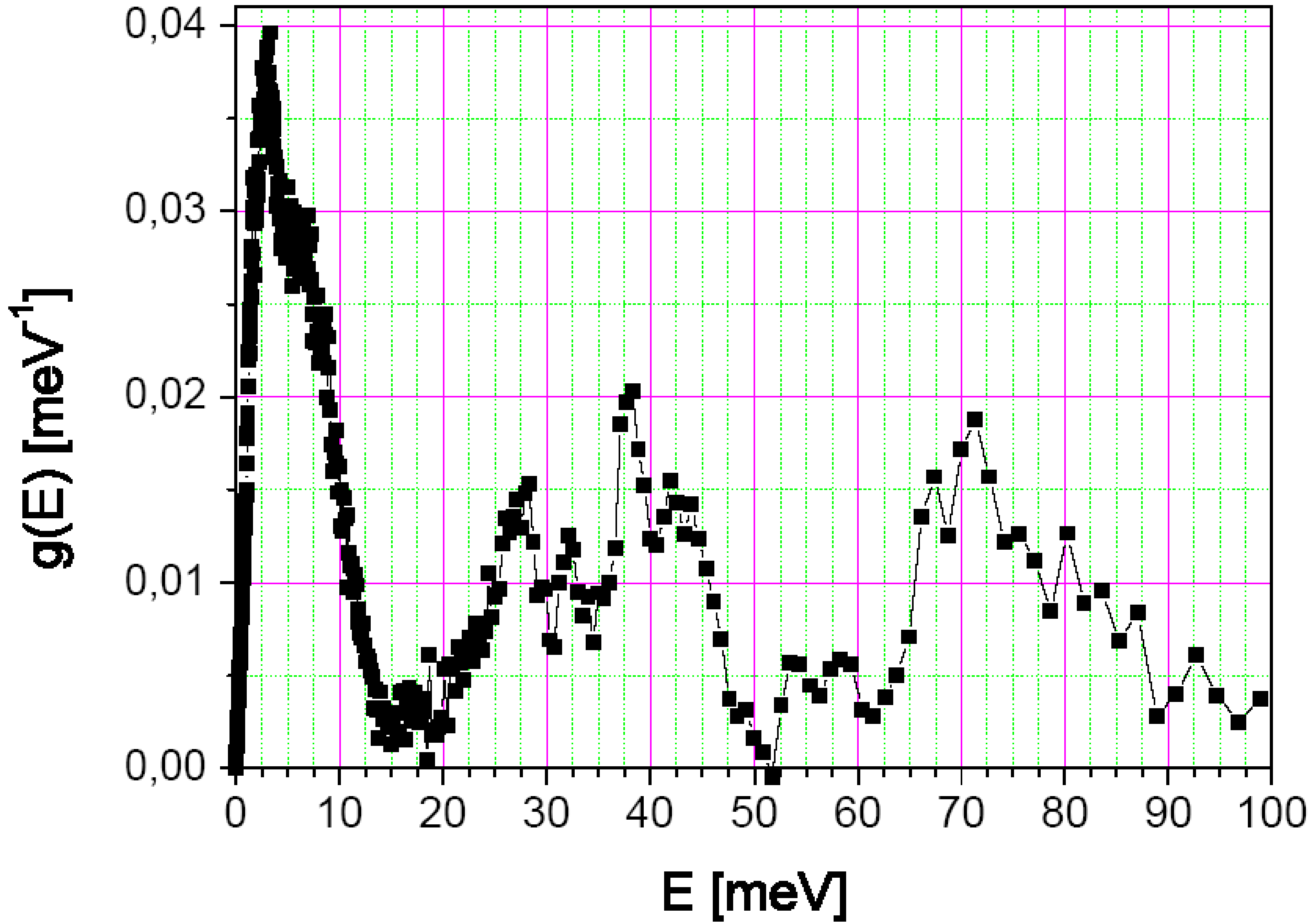
Figure 1. The layout of the NERA spectrometer: 1 – IBR-2 reactor core, 2 – thermal and cold moderators of radial horizontal channels 7-11 and tangential channels 1–9, 3 – beam shutter, 4 – fast neutron background chopper, 5 – common vacuum splitter of three Ni-mirrors neutron guides, 6 – λ-chopper of beam 7b, 7 – vacuum Ni–mirrors guide tube of neutron beam 7b, 8 – vacuum sections of beam 7b, 9 - diaphragms of incident beam, 10 –monitor, 11 – sample position, 12 – NPD sections, 13 – INS and QENS sections.

$$I(t,\theta,T)\Delta t = \Delta t \iiint \sigma(E_{\mathrm{i}},E_{\mathrm{f}},\theta,T)\Phi(E_{\mathrm{i}})R(E_{\mathrm{i}},E_{\mathrm{f}},t_0,t)$$
$$\times\, \mathrm{d}E_{\mathrm{i}}\,\mathrm{d}E_{\mathrm{f}}\,\mathrm{d}t_0,$$

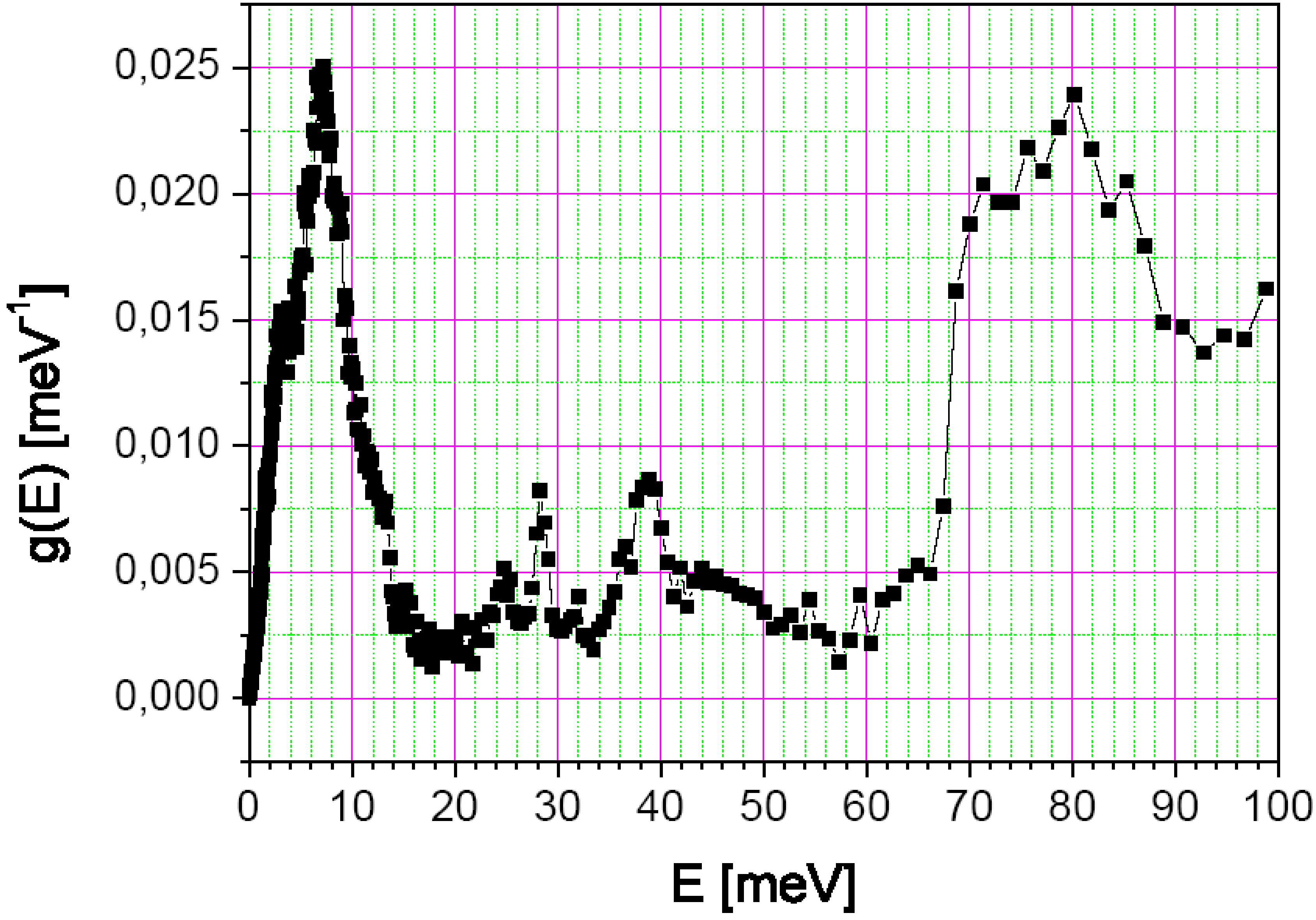
$$\sigma_1^{\mathrm{inc}}(E_{\mathrm{i}},E_{\mathrm{f}},\theta,T) \approx \sqrt{\frac{E_{\mathrm{f}}}{E_{\mathrm{i}}}}\frac{\hbar|Q(E_{\mathrm{i}},E_{\mathrm{f}},\theta)|^2}{\omega}\sum_n \frac{(b_n^{\mathrm{inc}})^2}{M_n}$$
$$\times \frac{\exp(-2W_n)}{1-\exp(-\hbar\omega/k_{\mathrm{B}}T)}G(\omega),$$

$$G(\omega) = \sum_n \sum_j \int \mathrm{d}^3q[A_j^n(q)]^2\delta[\omega-\omega_j(q)],$$

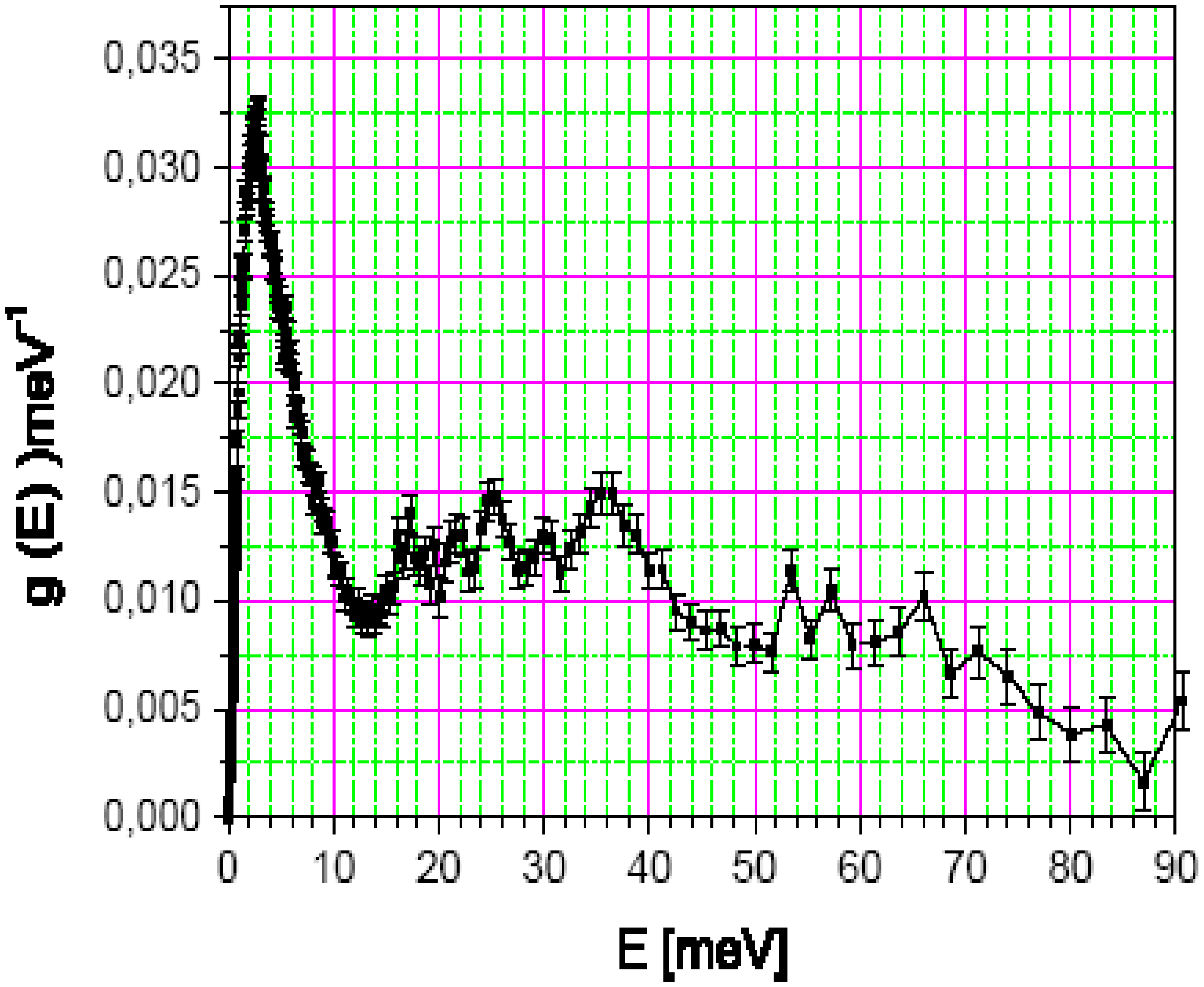
Fomblin $CF_3\text{-}(O\text{-}CF(CF_3)\text{-}CF_2)_n\text{-}(OCF_2)_m\text{-}O\text{-}CF_3$



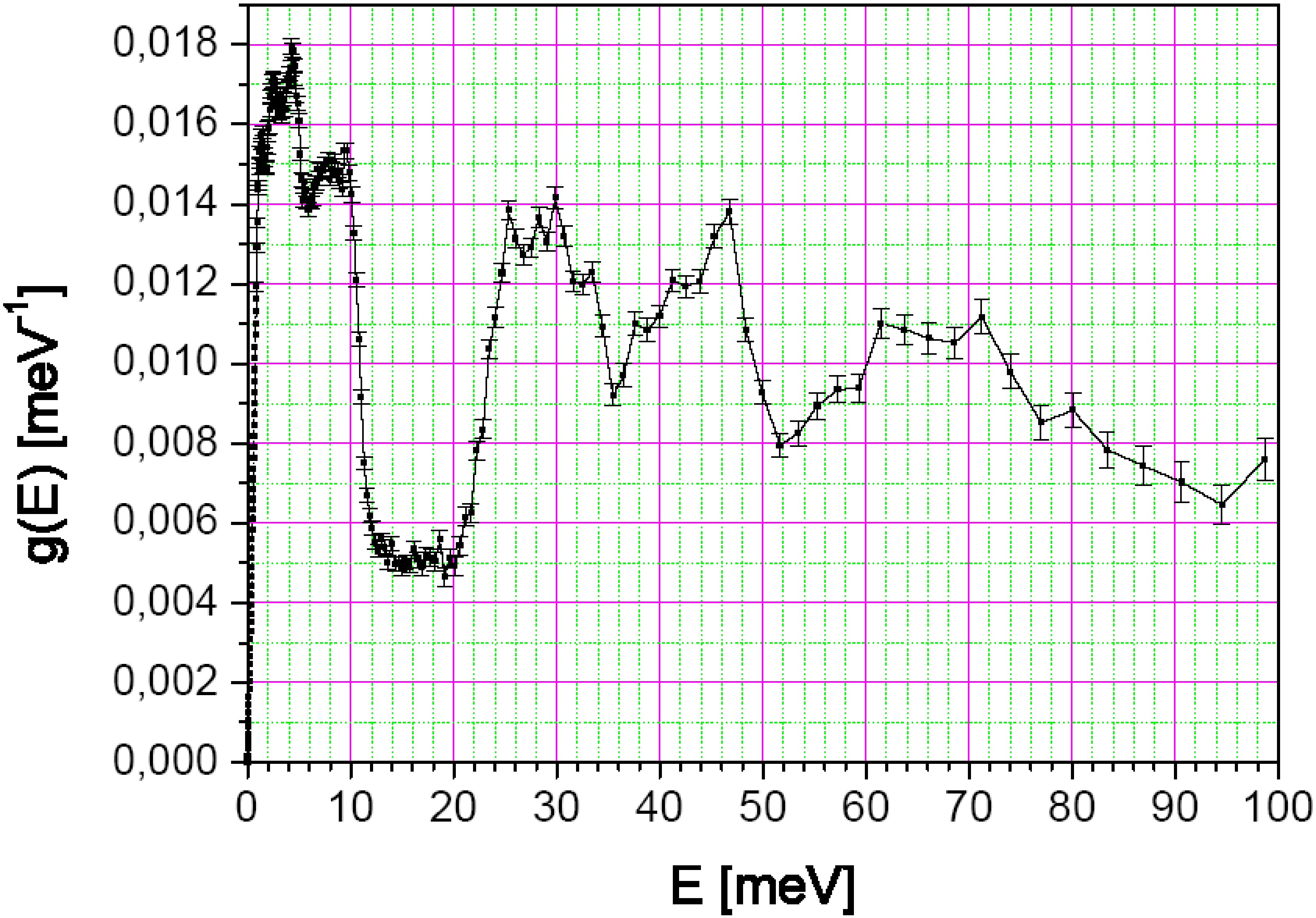
PFPE (PERM) $CF_3O(CF_2O)_{m1}(CF_2CF_2O)_n(CF_2O)_{m2}CF_3$

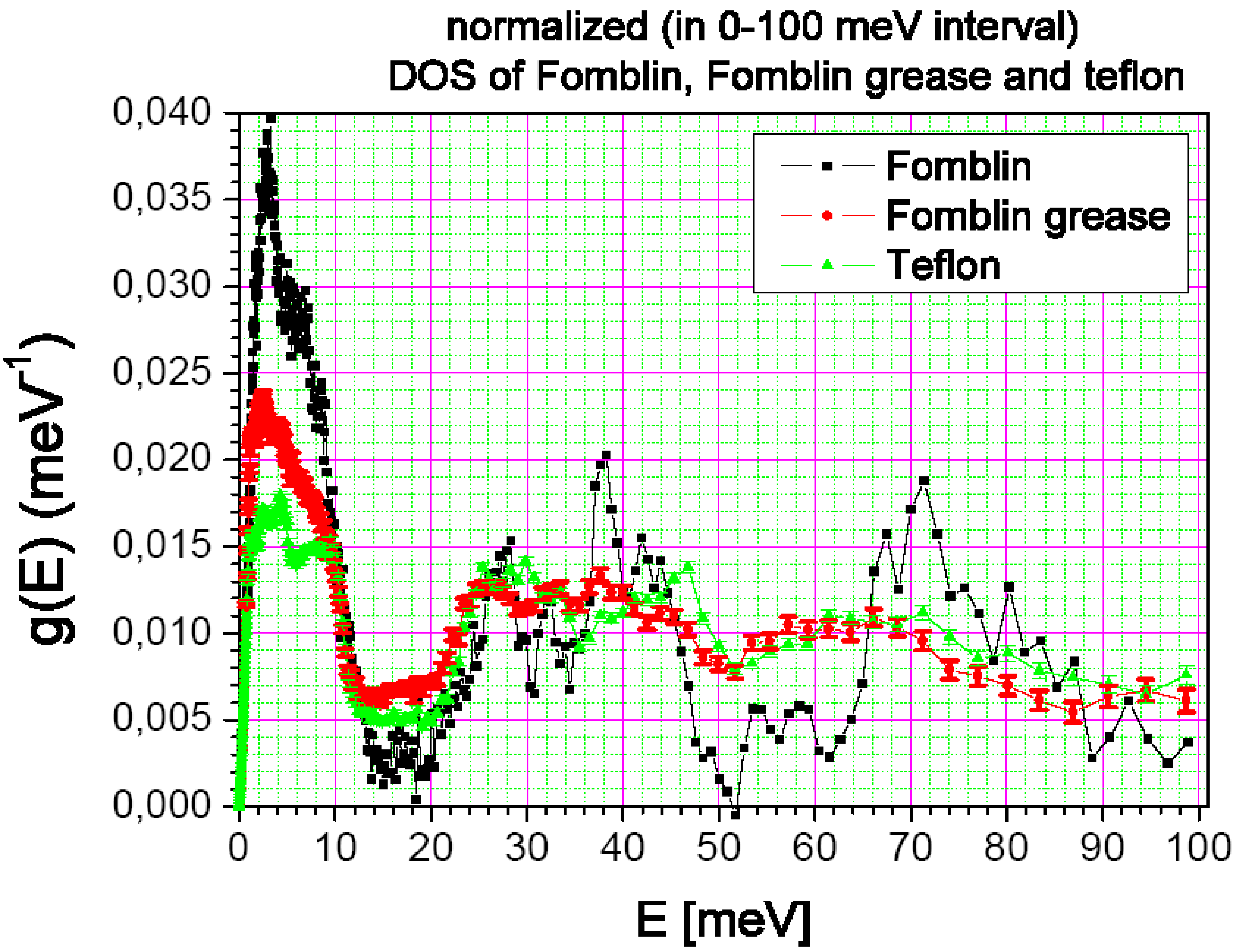


$CF_3(CF_2)_3\text{-}OCF_2\text{-}O\text{-}(CF_2)_3CF_3$ PFPF - density of states

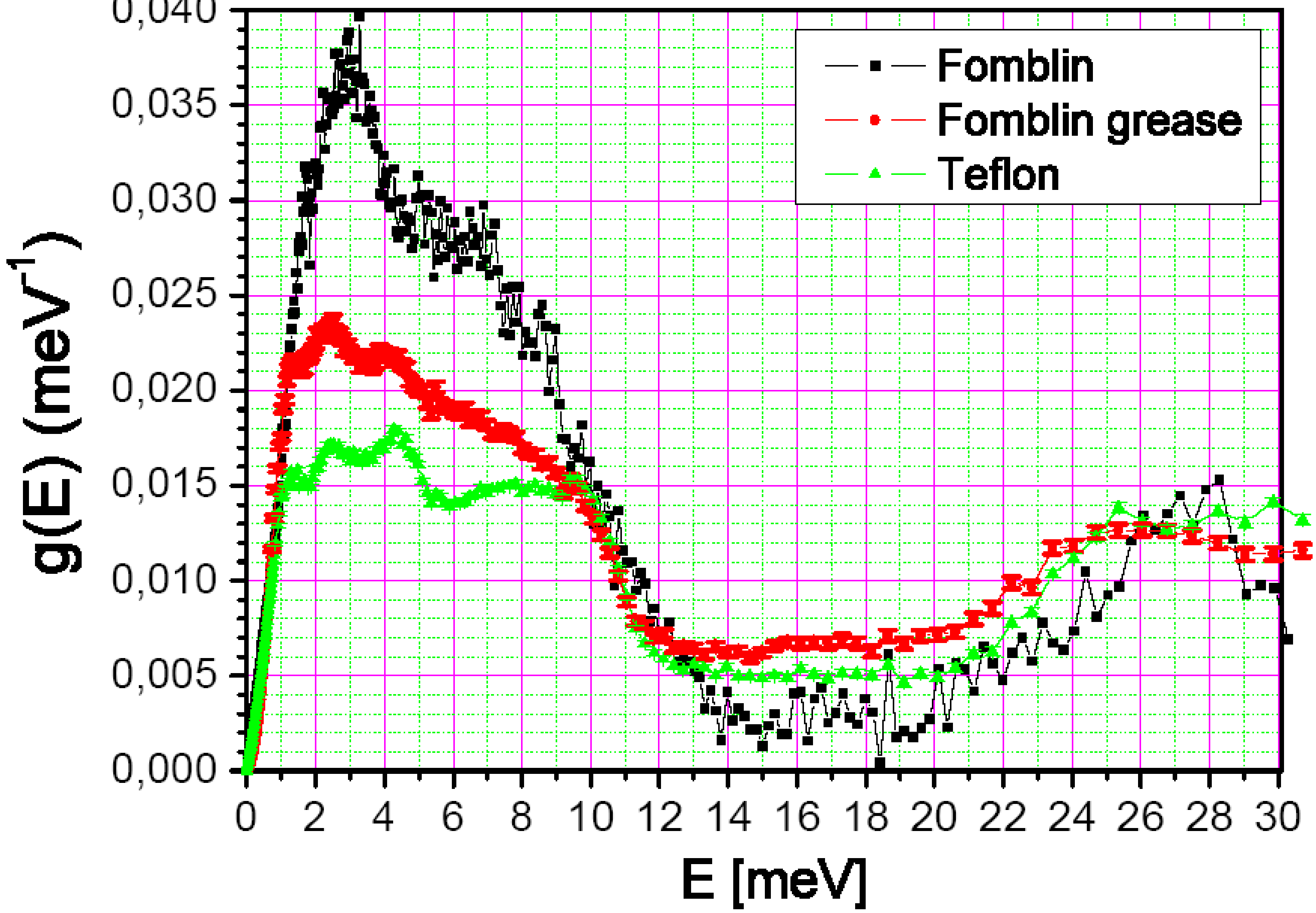


teflon $(C_2F_4)_n$




normalized (in 0-100 meV interval)
DOS of Fomblin, Fomblin grease and teflon
g(E) (meV^{-1})
0,040
0,035
0,030
0,025
0,020
0,015
0,010
0,005
0,000
0
10
20
30
40
50
60
70
80
90
100
E [meV]
Fomblin
Fomblin grease
Teflon

normalized (in 0-100 meV interval)
DOS of Fomblin, Fomblin grease and teflon



The loss probability (averaged over isotropic angular distribution) of neutrons with energy *E* in a trap with boundary energy *U* is:

$$\bar{\mu}(E) = 2\eta\left[\frac{V}{E}\arcsin\left(\sqrt{\frac{E}{V}}\right) - \sqrt{\frac{V-E}{E}}\right].$$

The loss coefficient is expressed through the complex potential *U*, describing UCN interaction with the walls

$$\eta = -\operatorname{Im} U / \operatorname{Re} U; \quad U = (\hbar^2/2m)4\pi\sum_i N_i b_i; \quad \operatorname{Im} b = -\sigma/2\lambda,$$

where m is the neutron mass, N_i is the number of nuclei in a unit volume of a wall material, b_i is the coherent scattering length on a bound nucleus of the wall, and σ is the cross-section of inelastic processes for neutrons with wavelength λ.

The UCN upscattering cross sections were calculated in the one-phonon incoherent approximation:

$$\frac{d\sigma}{d\epsilon} = \sigma_0 \frac{k_1}{k_0}(1 - e^{-\epsilon/kT})^{-1} \frac{g(\epsilon)}{\mu} e^{-\gamma\epsilon},$$

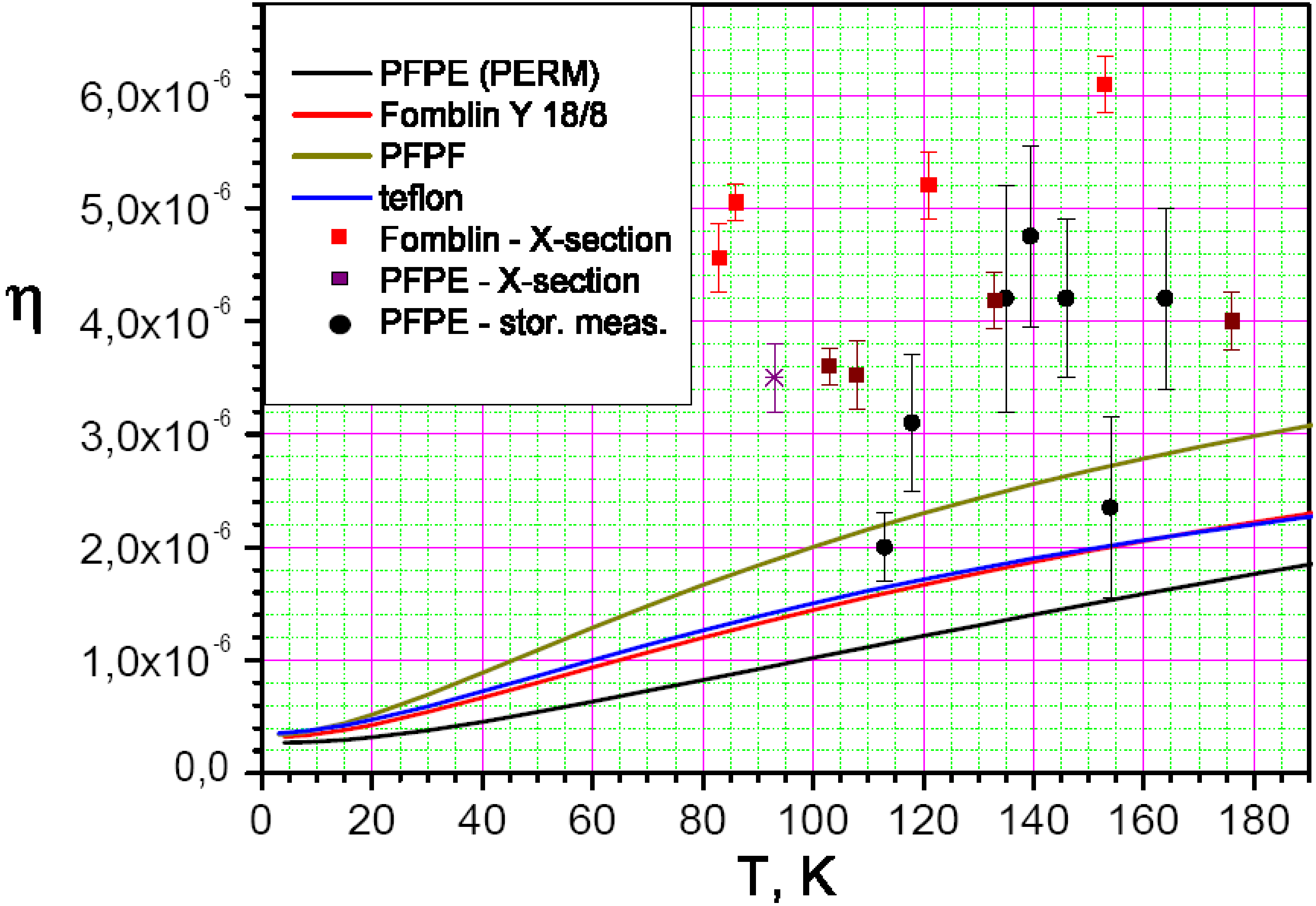
where $\sigma_0 = 4\pi|b|^2$; b is the scattering amplitude for bound nucles, k_1 and k_0 are the final and incident neutron wave vectors, ω is the energy transfer, $g(\omega)$ – the phonon density of states, μ is the relative atomic mass, γ is the Debye-Waller factor:

$$\gamma = \frac{1}{\mu} \int_0^{\epsilon_D} \frac{g(t)}{t} coth(\frac{t}{2kT}) dt.$$

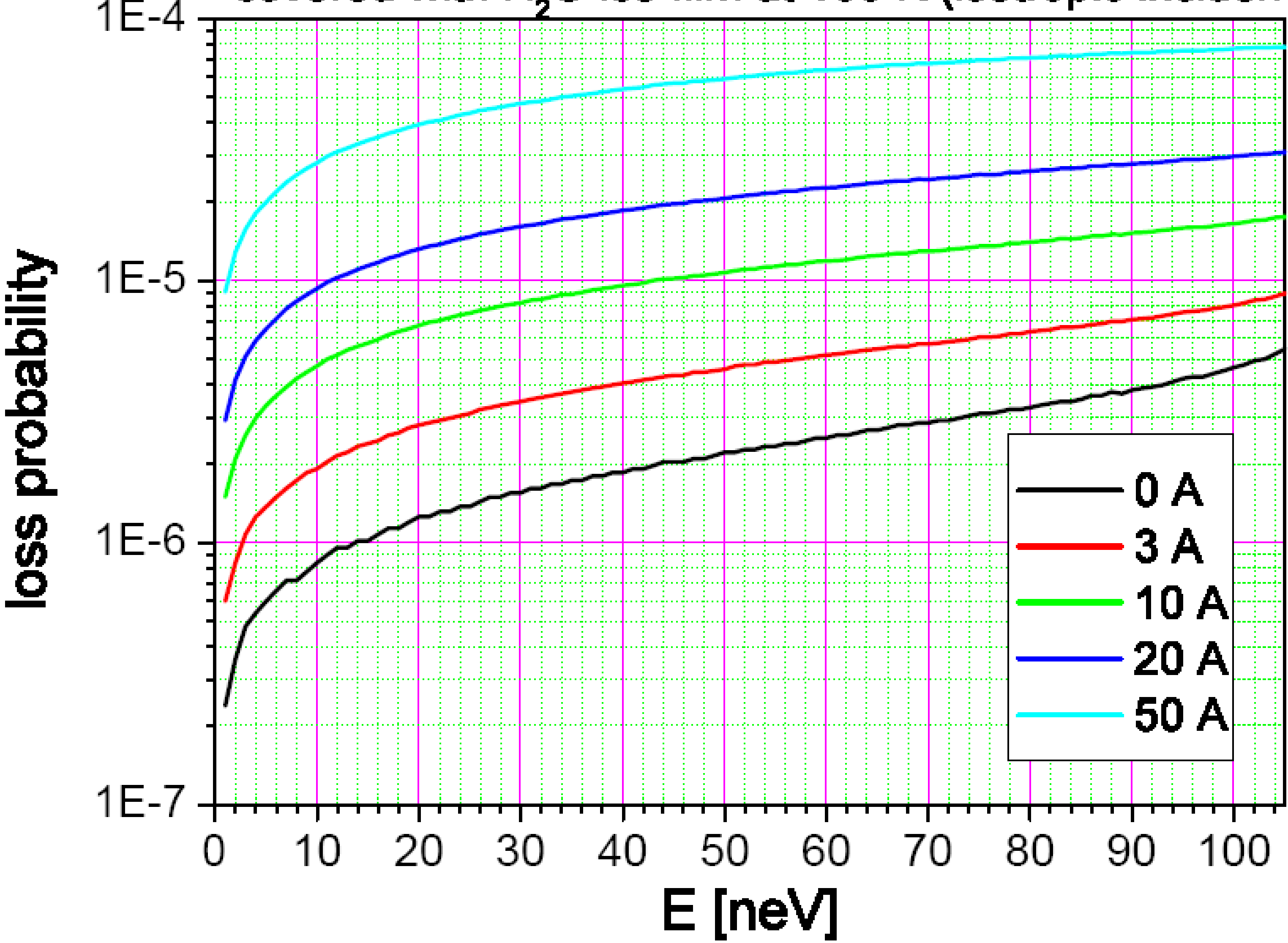
When $k_1 >> k_0$, the up-scattering cross section is:

$$\sigma_{ups} = 4\pi \int \sum \frac{b_i^2}{\mu_i} \frac{\epsilon^{1/2} e^{-\gamma\epsilon} g_i(\epsilon)}{(e^{\epsilon/kT} - 1)} d\epsilon$$

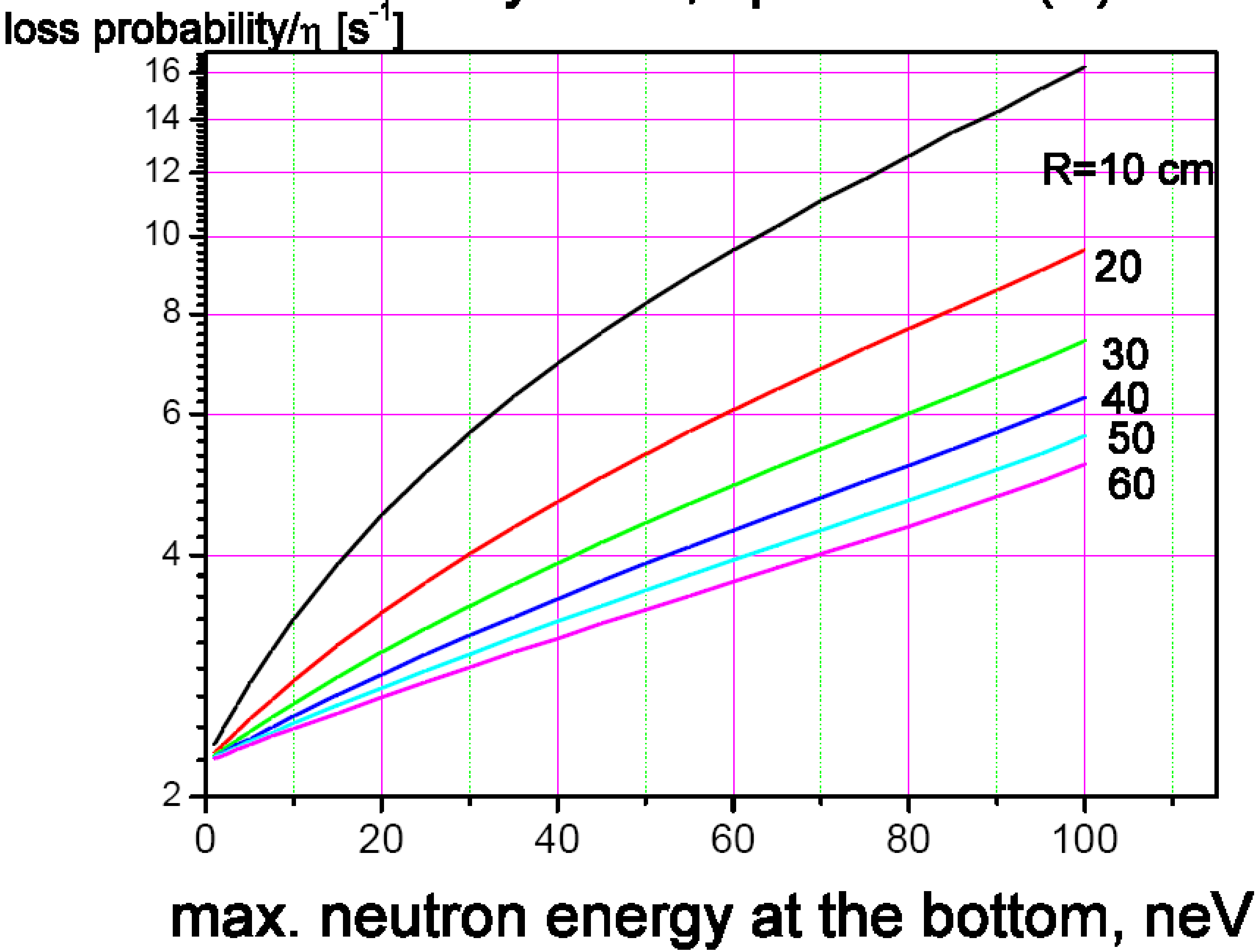
Calculated (lines) and inferred from measurements (points) UCN loss coefficient for different fluoropolymers



UCN loss probability at reflection from PFPE wall ($\eta=2*10^{-6}$) covered with H_2O ice film at 100 K (isotropic incidence)



vertical cylinder, spectrum $N(E) \sim E^{1/2}$



$$\tau_\mu = (2.1969811 \pm 0.0000022)\mu s \qquad (10^{-6})$$

$$\tau_{\pi^\pm} = (2.6033 \pm 0.0005) \times 10^{-8} s \qquad (2 \times 10^{-4})$$

$$\tau_\tau = (290.3 \pm 0.5) \times 10^{-15} s \qquad (1.7 \times 10^{-3})$$

$$\tau_n = (880.3 {\pm} 1.1) s \qquad (1.25 {\times} 10^{-3})$$