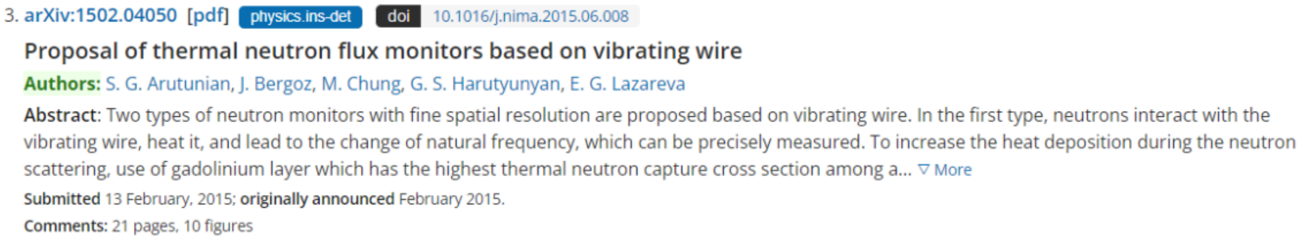
Update on STEREO: “Diffusion”

ORNL $N \rightarrow N'$ Meeting
03/23/2023
Cary Rock



3. arXiv:1502.04050 [pdf] physics.ins-det doi 10.1016/j.nima.2015.06.008

Proposal of thermal neutron flux monitors based on vibrating wire

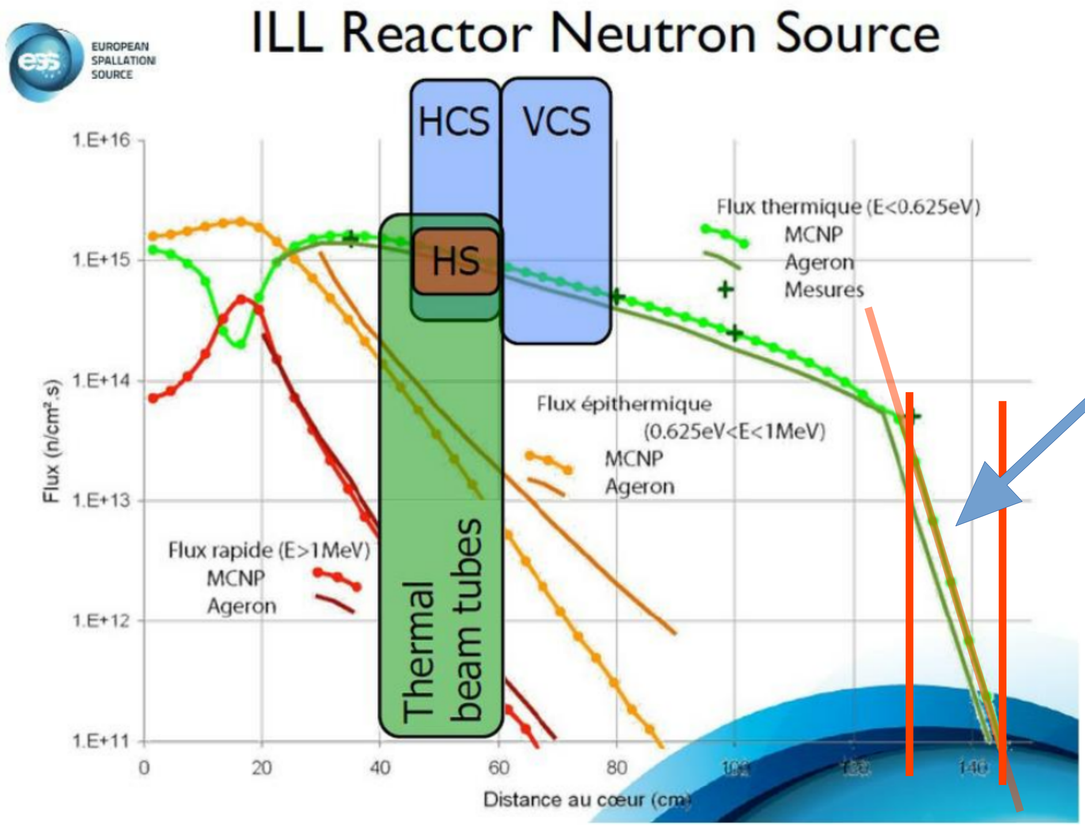
Authors: S. G. Arutunian, J. Bergoz, M. Chung, G. S. Harutyunyan, E. G. Lazareva

Abstract: Two types of neutron monitors with fine spatial resolution are proposed based on vibrating wire. In the first type, neutrons interact with the vibrating wire, heat it, and lead to the change of natural frequency, which can be precisely measured. To increase the heat deposition during the neutron scattering, use of gadolinium layer which has the highest thermal neutron capture cross section among a... ▽ More

Submitted 13 February, 2015; **originally announced** February 2015.

Comments: 21 pages, 10 figures

https://arxiv.org/abs/1502.04050



Slope = λ_{abs}

≈ 3.37 cm

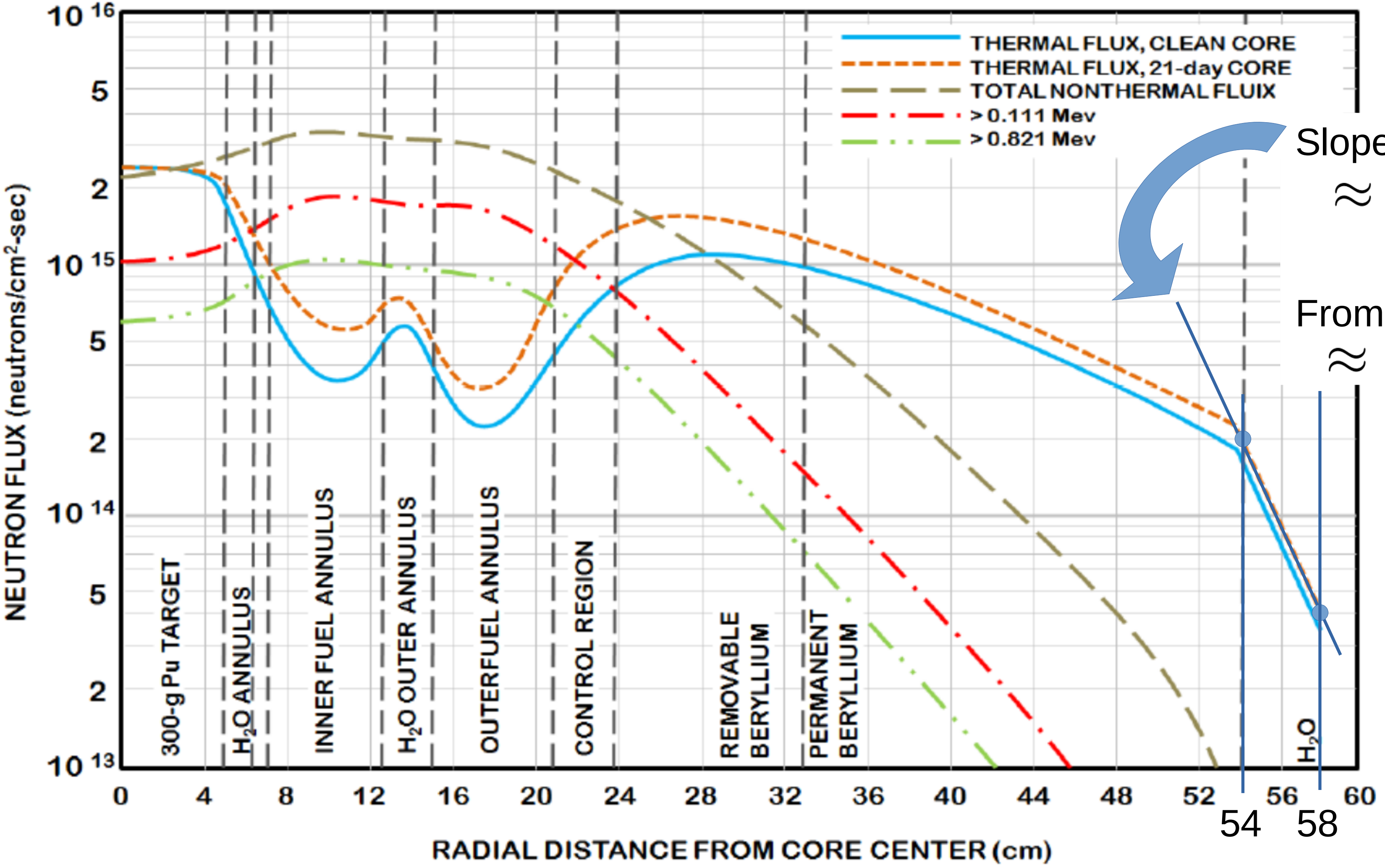
From table:

≈ 45.5 cm

l_sc = 0.27 cm – known

l_abs = 45.5 cm – known form Nuc. Eng.

HFIR – Checking λ_{abs}

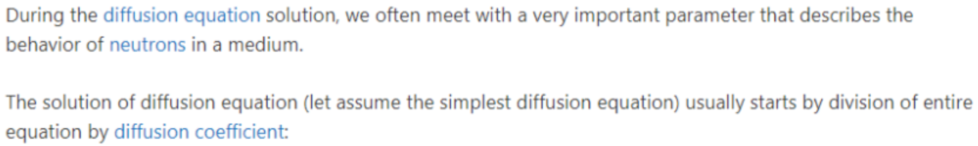


Slope = λ_{abs}
≈ 2.86 cm

From table:
≈ 45.5 cm

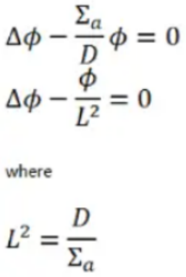
https://www.nuclear-power.com/nuclear-power/reactor-physics/neutron-diffusion-theory/diffusion-length/

The physical meaning of the ***diffusion length, L,*** *can be seen by calculating the* ***mean square distance*** *that a neutron travels in the one direction from the plane source to its absorption point.****L^2 is equal to one-sixth of the square of the average distance (in all dimensions) between the neutron's birth point (as a thermal neutron) and its absorption****.*



During the diffusion equation solution, we often meet with a very important parameter that describes the behavior of neutrons in a medium.

The solution of diffusion equation (let assume the simplest diffusion equation) usually starts by division of entire equation by diffusion coefficient:

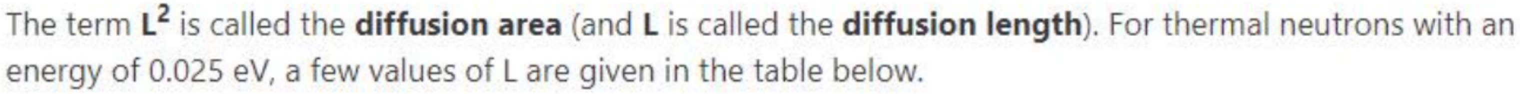


$$\Delta\phi - \frac{\Sigma_a}{D}\phi = 0$$

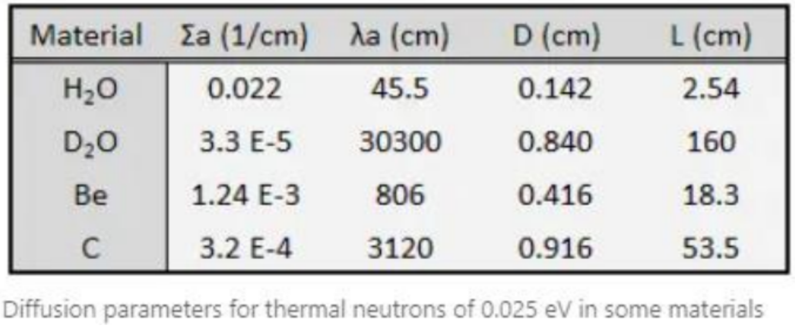
$$\Delta\phi - \frac{\phi}{L^2} = 0$$

where

$$L^2 = \frac{D}{\Sigma_a}$$



The term **L^2** is called the **diffusion area** (and **L** is called the **diffusion length**). For thermal neutrons with an energy of 0.025 eV, a few values of L are given in the table below.



Material	Σa (1/cm)	λa (cm)	D (cm)	L (cm)
H_2O	0.022	45.5	0.142	2.54
D_2O	3.3 E-5	30300	0.840	160
Be	1.24 E-3	806	0.416	18.3
C	3.2 E-4	3120	0.916	53.5

Diffusion parameters for thermal neutrons of 0.025 eV in some materials

Calculation of number of elastic collisions from diffusion length in heavy and light water

L – is diffusion length in one dimension, say in radial direction.
Average length where one absorption occurs for thermal neutrons.
ΔR – radial thickness of the reactor layer
λ_{sc} – scattering length in material
λ_{abs} – absorption length in material

Radial number of diffusion lengths : $\frac{\Delta R}{L}$. L is the radial length where flux attenuated by e^{-1} times.

At one average scattering length λ_{sc} (between two elastic scatterings) flux is attenuated by factor $e^{-\lambda_{sc}/\lambda_{abs}}$

On the radial distance L the number of scatterings $= k$. Total attenuation at radial distance L is $\left(e^{-\lambda_{sc}/\lambda_{abs}}\right)^k = e^{-1}$

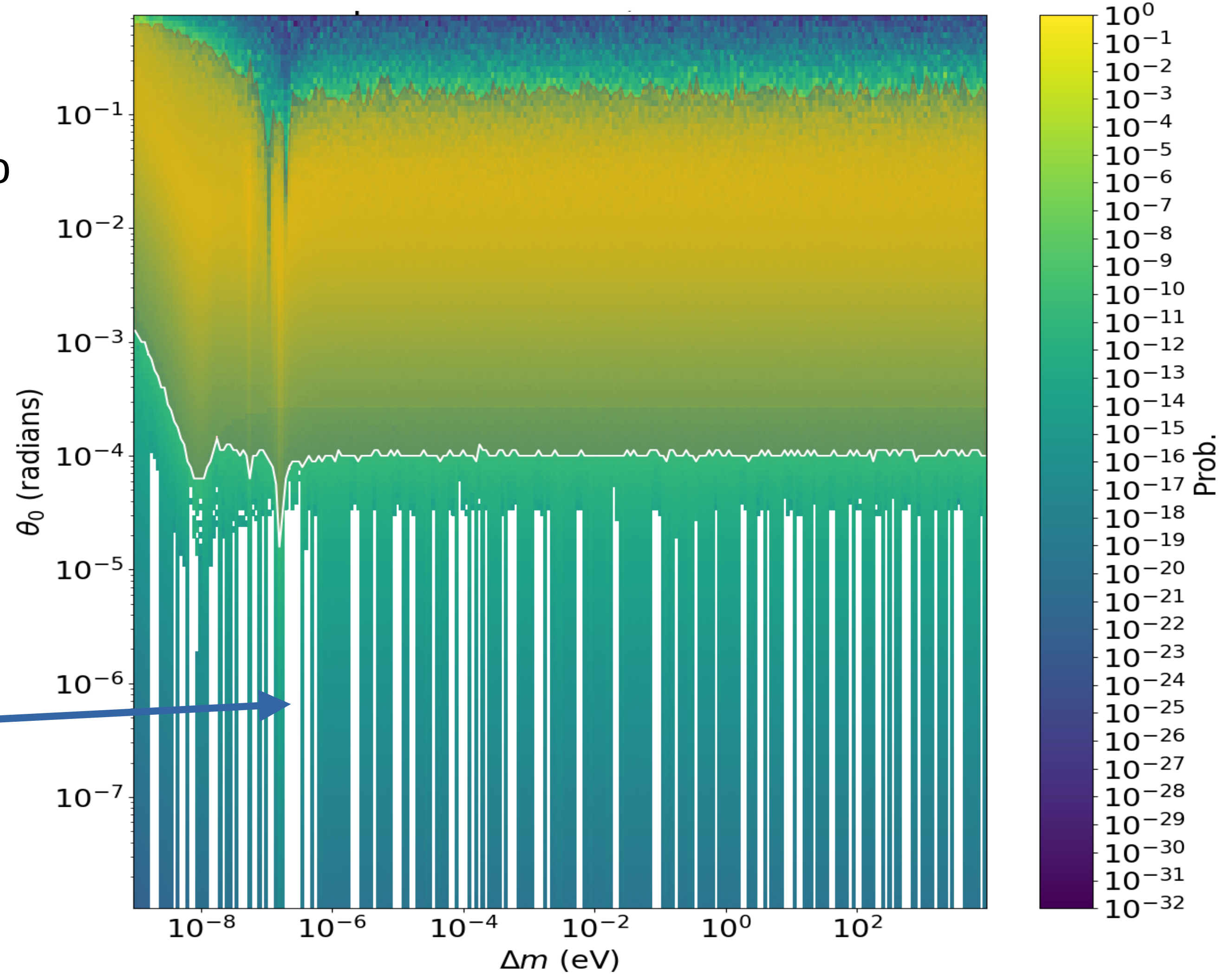
For L diffusion length $k = \lambda_{abs}/\lambda_{sc}$. For total layer thickness ΔR total number of scatterings: $\boxed{K = \frac{\lambda_{abs}}{\lambda_{sc}} \cdot \frac{\Delta R}{L}}$

	$\Delta R, cm$	L , cm	λ_{sc}, cm	λ_{abs}, cm	K
D_2O	105	160	2.2	303	90
H_2O	150	2.54	0.27	45.5	9952

← Was 123
← Was 1403

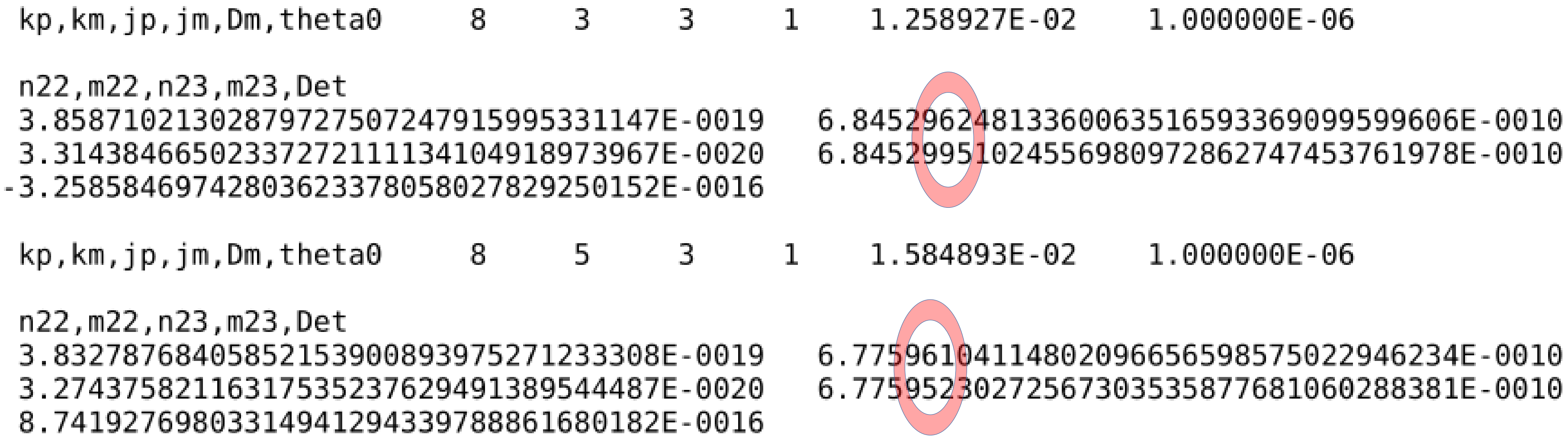
STEREO Prob. 100 velocities; 3/23/2023

Production of n' unchanged, seeking to understand this effect



Zeros in this plot are not fully understood

$$\text{Detect} = (P(n)_{22} + P(n')_{22}) - (P(n)_{23} + P(n')_{23})$$



```
 kp,km,jp,jm,Dm,theta0      8      3      3      1    1.258927E-02    1.000000E-06

 n22,m22,n23,m23,Det
 3.85871021302879727507247915995331147E-0019    6.84529624813360063516593369099599606E-0010
 3.31438466502337272111134104918973967E-0020    6.84529951024556980972862747453761978E-0010
-3.25858469742803623378058027829250152E-0016

 kp,km,jp,jm,Dm,theta0      8      5      3      1    1.584893E-02    1.000000E-06

 n22,m22,n23,m23,Det
 3.83278768405852153900893975271233308E-0019    6.77596104114802096656598575022946234E-0010
 3.27437582116317535237629491389544487E-0020    6.77595230272567303535877681060288381E-0010
 8.74192769803314941294339788861680182E-0016
```

n22, m22,
n23, m23,
Det →

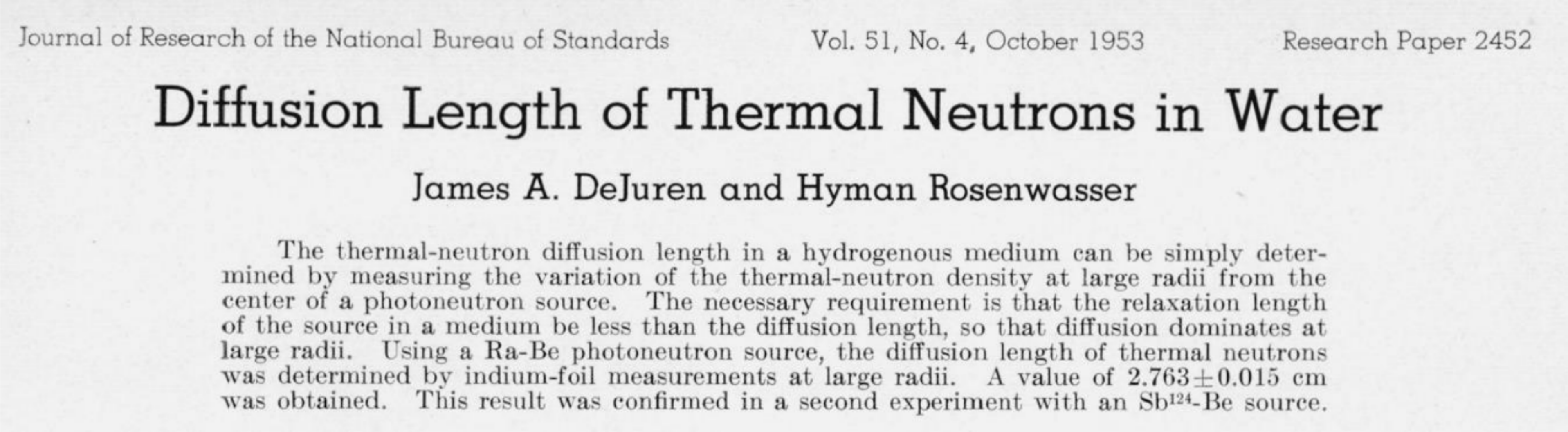
n22, m22,
n23, m23,
Det →

Difference in the 15th or 16th decimal place – insufficient accuracy in program?

Plans for the Immediate Future

- STEREO neglects n’ production in H2O. We see this as the main source of n’.
  - STEREO assumes D2O is the main source of n’ production – trying to reconcile STEREO’s stated limit with reactor’s flux.
- Compare STEREO’s n’ production from D2O with our production in D2O.
- At the level of projection, *p*, we are the same

https://nvlpubs.nist.gov/nistpubs/jres/51/jresv51n4p203_a1b.pdf

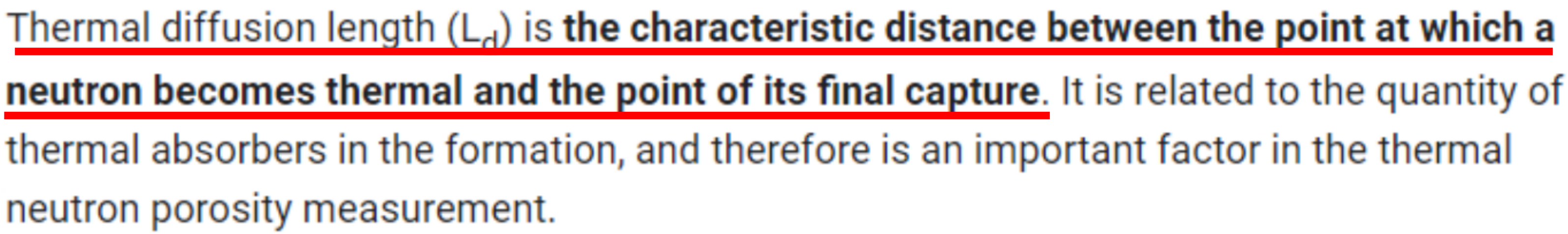


Journal of Research of the National Bureau of Standards Vol. 51, No. 4, October 1953 Research Paper 2452

Diffusion Length of Thermal Neutrons in Water

James A. DeJuren and Hyman Rosenwasser

The thermal-neutron diffusion length in a hydrogenous medium can be simply determined by measuring the variation of the thermal-neutron density at large radii from the center of a photoneutron source. The necessary requirement is that the relaxation length of the source in a medium be less than the diffusion length, so that diffusion dominates at large radii. Using a Ra-Be photoneutron source, the diffusion length of thermal neutrons was determined by indium-foil measurements at large radii. A value of 2.763±0.015 cm was obtained. This result was confirmed in a second experiment with an Sb^{124}-Be source.



Thermal diffusion length (L_d) is **the characteristic distance between the point at which a neutron becomes thermal and the point of its final capture**. It is related to the quantity of thermal absorbers in the formation, and therefore is an important factor in the thermal neutron porosity measurement.

STEREO's Probability Calculation

STEREO's final calculation depends on:
1. computing the prob. per neutron, *p*,
2. multiplying by the visible flux, $\Phi_{vis}(\vec{r})$, to give the volumic rate of projections, $S_{hid}(\vec{r})$,
3. and then integrating over the reactor volume to get $\Phi_{hid}(\vec{r})$.

$$\varepsilon = \Delta m \theta_0 \qquad \Gamma = v\Sigma_{sc}$$

$$p = \frac{2\varepsilon^2}{(\pm\Delta m + V_F)^2 + 4\varepsilon^2 + \hbar^2\Gamma^2/4}$$

$$S_{hid}(\vec{r}) = p\frac{\Sigma_S}{2}\Phi_{vis}(\vec{r})$$

$$\Phi_{hid}(\vec{r}_d) = \frac{1}{4\pi}\int_{Reactor}\frac{S_{hid}(\vec{r})}{|\vec{r}-\vec{r}_d|^2}d^3r$$

Probability Calculations

$$\mathrm{Detect} = (P(n)_{22} + P(n')_{22}) - (P(n)_{23} + P(n')_{23})$$

Negative values in detection indicate something unexpected – either the n counts are not as expected (absorption, more n’ than expected) or the n’ counts are not as expected.

The data files indicate more n’ *after* the Gd scintillator than expected, leading to negative results. Currently being investigated.

Diffusion Calculation

There is some reason to think some of this is due to a lacking method of calculating the diffusion insde the reactor.

Outline

1) STEREO’s Probability Calculation
2) Probability Calculations – Considerations
3) Diffusion Calculations