Neutrino Technology

Because of (neutron number)^2

$$\sigma = \frac{G^2}{4\pi} N^2 E^2$$

Neutral-Current Coherent Scattering Gives Large Cross Sections on Nuclei for MeV Neutrinos

For example at a reactor

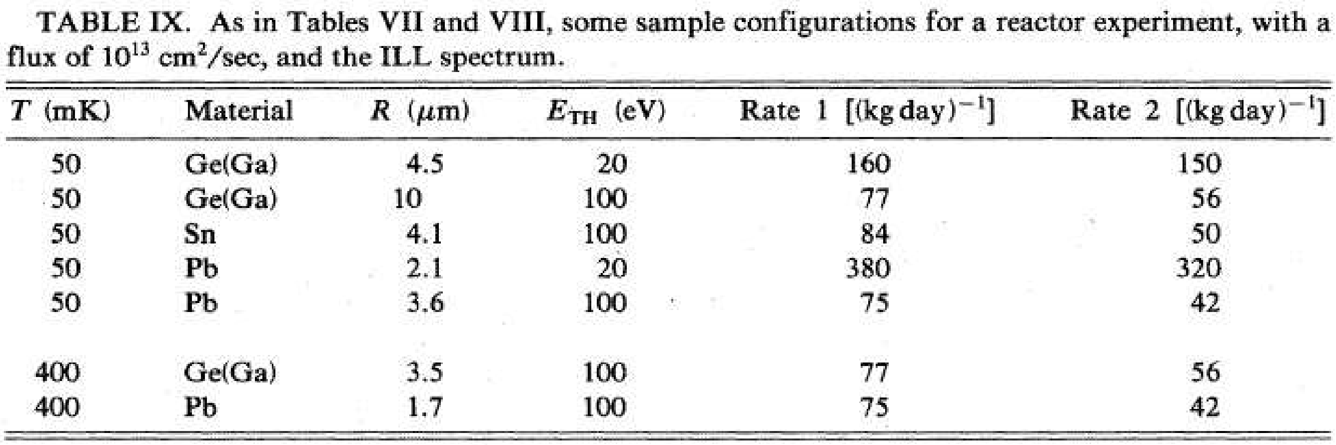

TABLE IX. As in Tables VII and VIII, some sample configurations for a reactor experiment, with a flux of 10^{13} cm^2/sec, and the ILL spectrum.

T (mK)	Material	R (μm)	E_{TH} (eV)	Rate 1 [(kg day)$^{-1}$]	Rate 2 [(kg day)$^{-1}$]
50	Ge(Ga)	4.5	20	160	150
50	Ge(Ga)	10	100	77	56
50	Sn	4.1	100	84	50
50	Pb	2.1	20	380	320
50	Pb	3.6	100	75	42
400	Ge(Ga)	3.5	100	77	56
400	Pb	1.7	100	75	42

Seem to only need kilograms!

But Must detect very small recoil of nucleus

10's eV to keV's

Hence

Cryo-Detectors

Many technological and practical difficulties

Nevertheless prospect of small, light, possibly mobile, neutrino detector suggested consideration of practical applications

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NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH, vol.201, no. 1,Oct 1982, pages 77-84; North Holland Publishing Company, Amsterdam, NL; A. K. DRUKIER: "On the possible application of superheated superconducting colloid as a synchrotron radiation detector" & Proceedings of the International Conference on X-Ray detectors for synchrotron radiation, Hamburg, DE, November 17-21, 1980

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20. Apparatus in accordance with claim 19 wherein the superconducting metal elements are in the form of grains and the superconducting bodies are in the form of grains which are at least ten times larger than said superconducting grains and are preferably made of material having a change of state temperature threshold lower than that of said superconducting elements.

21. Apparatus in accordance with any one of the preceding claims 12 to 15 and 17 to 20 wherein said means for detecting the change of state of said superconducting elements and/or bodies comprises a means for detecting the change of state of said superconducting elements and/or bodies comprises a plurality of pick-up loops disposed between said superconducting elements, and means for detecting e.m.f.'s induced in the pick-up loops as a result of said magnetic field being perturbed by a change of state of one of said superconducting elements, and wherein means are preferably provided for comparing the size of said e.m.f.'s with a range of values corresponding to the expected energies deposed by the neutrinos, and for accepting said count only when a measured e.m.f. falls within the expected range.

22. Apparatus in accordance with any one of said claims 12 to 21 wherein said means for discriminating between the change of state of just one of said elements and the change of state of a plurality of said elements, at least within a specified volume of said elements, comprises a coincidence or delayed coincidence circuit.

23. Apparatus in accordance with preceding claim 14 wherein said matrix is optically transparent and wherein said means for detecting a change of state of said superconducting elements comprises means for directing a beam of polarised light through said matrix, and means for detecting a change of polarisation in said beam of light due to a perturbation of the magnetic field associated with a change of state of said superconducting element, and wherein, optionally, means is provided for forming a holographic image of the matrix and superconducting elements.

24. Apparatus in accordance with any one of said claims 13 to 20 wherein said superconductor is selected from metals which do not have long-lived radioactive isotopes.

25. Apparatus in accordance with any one of the preceding claims 12 to 24 wherein signals representative of the change of state of the individual superconducting elements are in, or converted into, electrical form and are passed to a computer for processing.

26. Neutrino detection apparatus for carrying out the method of claim 1 and comprising a semiconductor detector, electrical means to detect signal pulses from said semiconductor device due to incident radiation, pulse height and width analysis circuits for discriminating between signals due to the recoil of a single nucleus in the semiconductor device within an energy range corresponding to the expected energies of the incident neutrinos and other signals.

27. Apparatus according to claim 26 wherein the semiconductor detector consists either of a single crystal with a volume larger than 100 cc or of a collection of crystals having a total volume larger than 100 cc, and wherein said semiconductor device is preferably based on silicon, or germanium (either intrinsic or lithium drifted) or on a compound such as Hg I, Pb I or CdTe of which at least one component has a high atomic weight A ≧ 100, said semiconductor device being preferably of high purity of at least 99.9%, the apparatus preferably further comprising passive and/or active shielding against other types of radiation.

28. The use of a neutrino detector operating in accordance with the method of one of the preceding claims 1 to 11 or a neutrino detector in accordance with one of the preceding claims 12 to 27, for monitoring a nuclear installation such as a reactor and in particular for at least one of the following purposes: for searching for major leaks from fuel elements into the moderator/coolant matrix, for monitoring a reactor following an accident and for assessing changes in the elemental/isotopic composition of fissionable material inside the fuel rods by measurement of the neutrino energy spectrum.

29. The use of a neutrino detector in accordance with claim 28 wherein the detector is placed outside the reactor confinement but preferably within 100 m of the reactor core and wherein, optionally, the mass of the detector is divided into at least three modules placed around the reactor core.

30. The use of a neutrino detector in accordance with one of the preceding claims 28 or 29 wherein the total mass of the detecting material is at least one hundred kilograms and wherein the measured flux of neutrinos is used for dynamic analysis of reactor performance.

31. The use of a neutrino detector in accordance with any one of the preceding claims 28 to 30 wherein the total mass of the detecting materials is larger than 1000 kgs and wherein the detector is either divided into several modules or is arranged for movement around the reactor core for tomographic reconstruction of the location of fission products inside the reactor core.

32. The use of a neutrino detector operating in accordance with the method of one of the preceding claims 1 to 11 or a neutrino detector in accordance with one of the preceding claims 12 to 27 for monitoring installations for the storage and/or processing of radioactive materials.

33. The use of a neutrino detector operating in accordance with the method of claims 1 to 11 or a neutrino detector in accordance with claims 12 to 27, for studying the geological structure of the earth through the neutrino signature of radioactive elements.

34. The use of a neutrino detector in accordance with claim 33 for at least one of the following purposes: for detecting raw material deposits in the earth, for detecting deposits of one or more of the naturally radioactive elements, in particular K 40, U 238, U 235 and thorium, for detecting raw material resources which are found in association with one or more radioactive elements, for detecting deposits of materials with lower than average neutrino activity, in particular oil, gas and coal deposits, and for finding additional deposits of raw materials in existing mines from the neutrino signature of these deposits; wherein the neutrino detector is arranged for movement in mine shafts and tunnels, said neutrino detector being preferably either mounted, towed or suspended for geological prospecting beneath the oceans, seas or lakes or appropriately shielded and transported by a movable vehicle for above ground prospecting.

Revendications

1. Procédé pour la détection de neutrinos comprenant les étapes consistant à: exposer un détecteur à un environnement afin de permettre à tout neutrino présent de diffuser sur les noyaux du détecteur, et à analyser les signaux fournis par le détecteur pour distinguer entre le recul d'un seul noyau et les autres interactions dans lesquelles une pluralité d'électrons et/ou de noyaux reculent, et d'accepter le signal comme compte-neutrino seulement s'il y avait recul d'un seul noyau .

2. Procédé selon la revendication 1 caractérisé en ce que les signaux d'une pluralité de volumes du détecteur sont analysés et en ce que ledit compte-neutrino n'est augmenté que s'il y a recul d'un seul noyau dans l'un desdits volumes.

3. Procédé selon l'une des revendications précedentes 1 et 2 caractérisé en ce que lesdits noyaux sont présents comme les noyaux d'une pluralité d'éléments métalliques supraconducteurs, par exemple sous forme de grains, de fils ou de couches minces, et en ce que l'étape de la détection du recul du noyau est effectuée par la détection de l'échauffement et du changement d'état y faisant suite de l'un des éléments métalliques supraconducteurs.

4. Procédé selon la revendication 3 caractérisé en ce que lesdits éléments métalliques supraconducteurs ne sont pas dans l'état surchauffé et comprenant de plus les étapes consistant á observer le temps nécessaire pour que ledit élément métallique supraconducteur revienne à l'état supraconducteur à comparer ce temps avec une plage de temps caractéristiques et d'accepter le compte-neutrino seulement quand ledit temps tombe dans ladite plage de temps.

5. Procédé selon l'une des revendications 3 ou 4 caractérisé en ce que lesdits éléments métalliques supraconducteurs sont chacun très petits dans au moins une dimension et sont distribués dans une pluralité de volumes, et en ce que au moins un corps supraconducteur relativement massif est présent dans chaque volume, le procédé de plus comprenant les étapes consistant à détecter les changements d'état desdits corps supraconducteurs relativement massifs comme mesure de l'instabilité de la température locale dans les volumes associés et à rejeter d'autres signaux provenant du volume

FIG.18

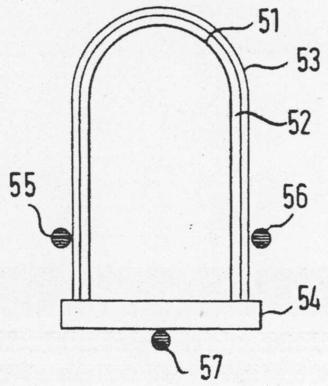


FIG.19

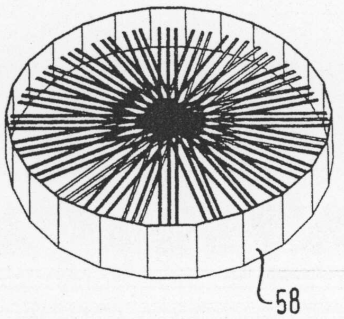
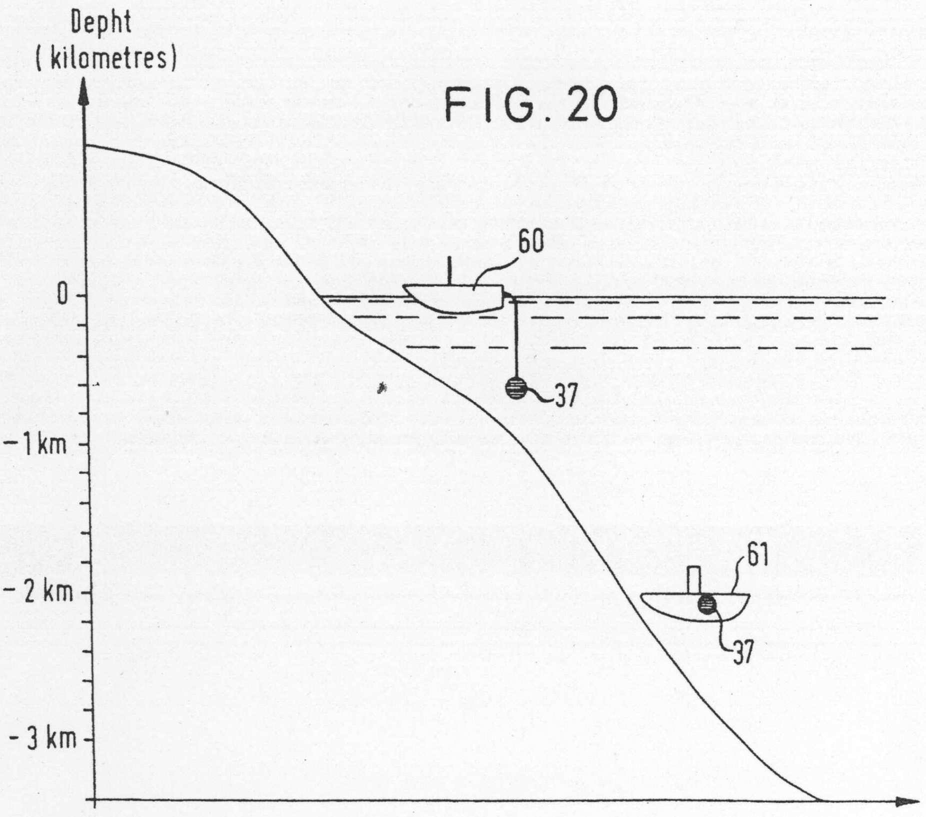


FIG. 20



Claim 34–Geological studies, with tomography and mobiblity, potentially *very* interesting.

Look for oil-bearing formations, U deposits (could have seen one later discovered in Canada),...

Main Practical Applications Seen At Present

Reactor Monitoring

- In case of accident and no access into reactor, neutrino detector can follow state of nuclear reactions

- Neutrino energy spectrum can determine composition of fissile materials and so indicate illegal use for bomb materials

Geological Studies

Search for mineral, fuel deposits

DIFFICULTIES

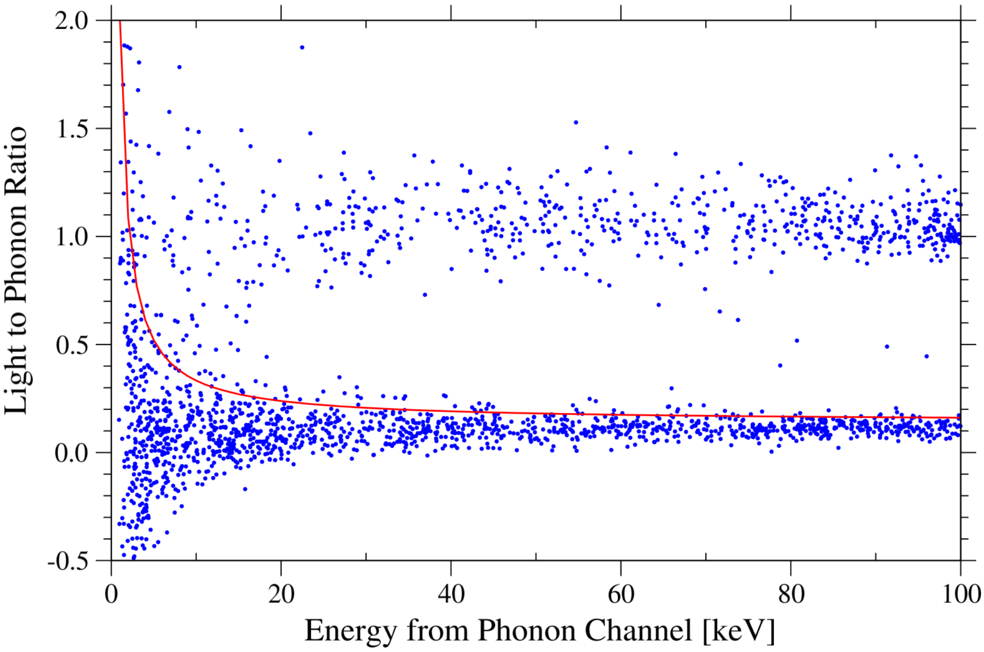
I Neutral Current Detector sees all neutrino types

II Backgrounds

- A) Experimental (not in an underground lab)
- B) Intrinsic (solar, whole earth neutrinos)

Experimental backgrounds: Dark Matter searches have made much progress with two-channel readout. Distinguish nuclear recoils (want to see) from e/γ backgrounds (want to eliminate).

CRESST uses light signal in addition to heat signal:



Clear separation into nuclear recoil and e/γ bands.

Can such techniques be extended to lower energies?

Or consider detectors not responding to e/γ background, like COUPP.

In geological application:

Instrinsic background for coherent (neutral current) detector: solar neutrinos.

Not true for detector which distinguishes neutrino and antineutrino.

Solar and Terrestrial Neutrinos

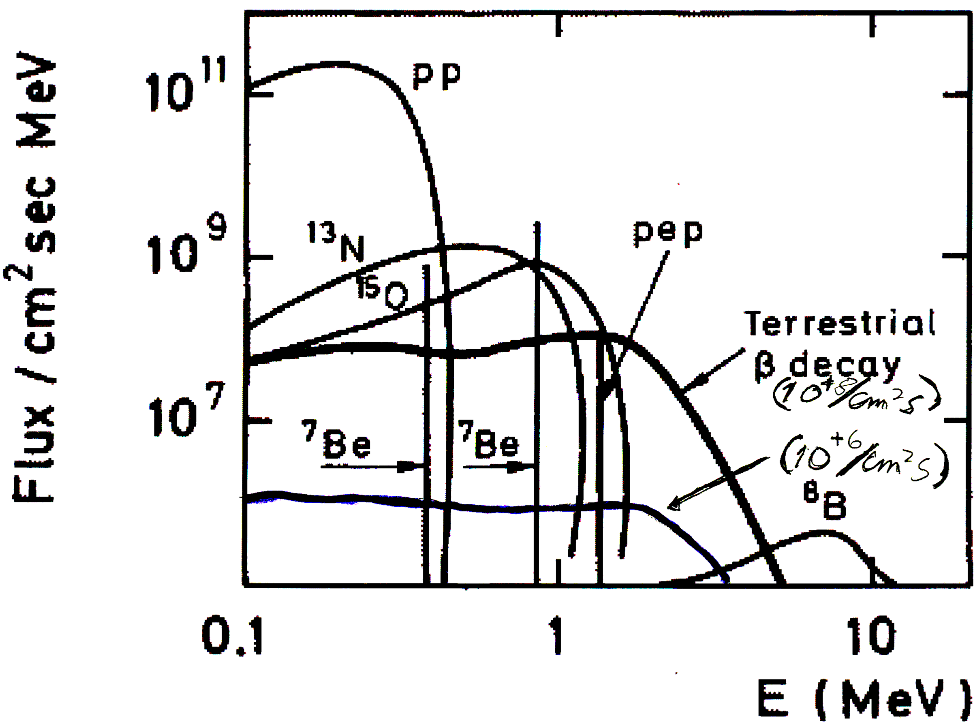


FIG. 11. Solar- and terrestrial-neutrino spectra plotted together. Line sources are in number/cm^{2}sec.

Seems to be a “window” 2-5 MeV.

Note for geology we are interested in local positional variations of neutrino flux, while solar, whole earth, reactor, backgrounds vary little.

Can adequate statistics be collected to see these variations?

100's /kg-day on first pages are now 10^{-5}/kg-day. Formidable task– but not impossible?

Present Situation

- Coherent Scattering: Developments are in progress to observe the process. Cryo- and semiconductor-methods.

- Geology: Large liquid scintillator detectors have seen geo-neutrinos from the whole earth at about the expected level of $10^6/cm^2sec$ (Kamland).

Future very large liquid scintillator detectors (LENA...) should improve signal considerably. A fundamental new tool for geophysics.

Will it be possible to see local variations?

Note the ^{40}K neutrino–important for earth – is below threshold for such (liquid scintillator, $\bar{\nu}p \rightarrow e^+n$) detectors.

- Reactor Monitoring: There is interesting progress on relatively simple, ‘inexpensive’ liquid scintillator detectors which would be fixed installations at reactors.

TASKS

- For coherent scattering, further develop techniques for seeing small nuclear recoils (superconducting grains still the most beautiful?)

- While simultaneously suppressing electron-photon backgrounds without heavy shielding

- Light, compact, accessory equipment (cryostats, gas handling....)

- For inverse-beta detectors, develop small, practical systems

- Understand neutrino signal of various geological formations

APPENDIX–Grain properties

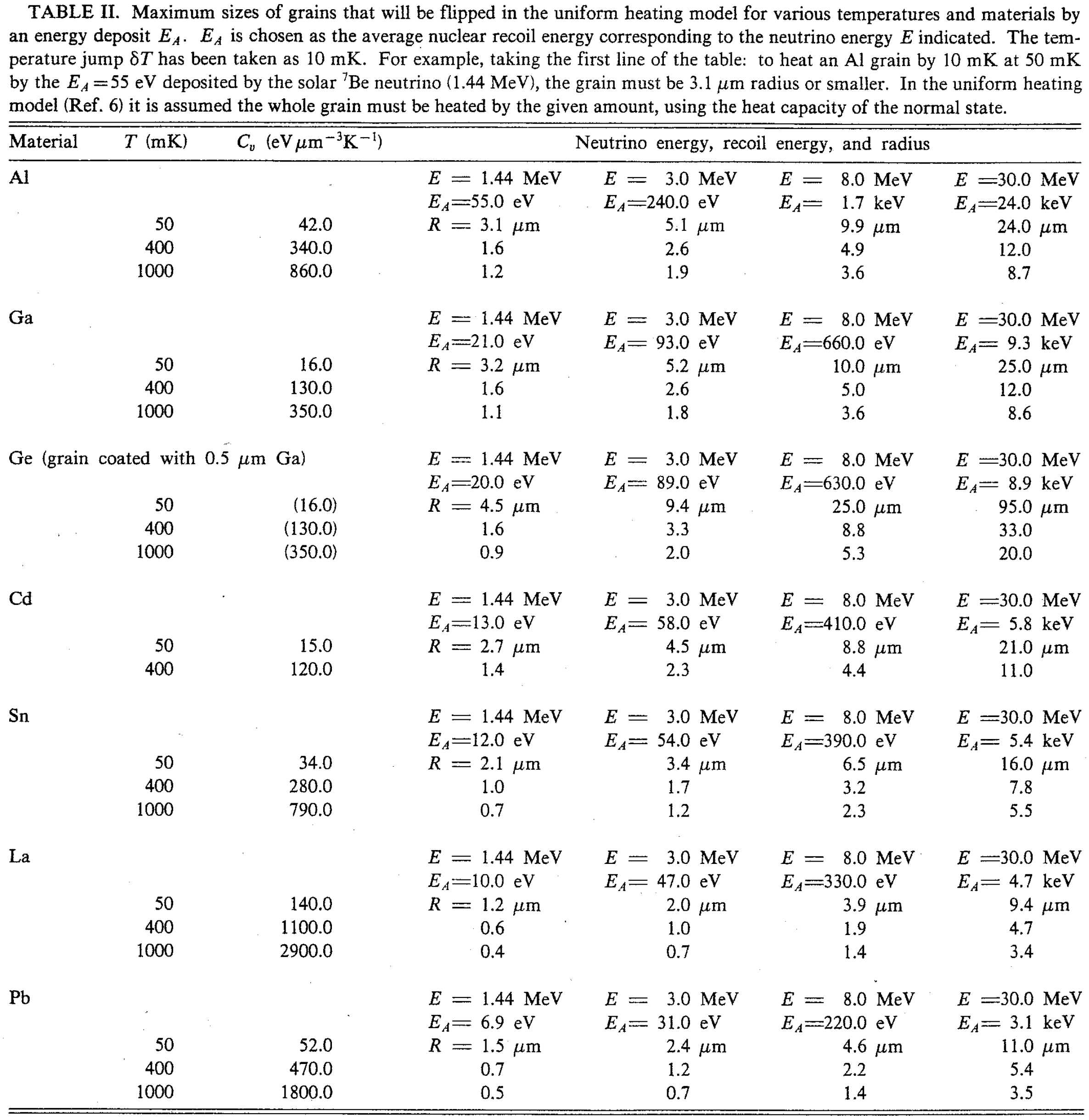


TABLE II. Maximum sizes of grains that will be flipped in the uniform heating model for various temperatures and materials by an energy deposit E_A. E_A is chosen as the average nuclear recoil energy corresponding to the neutrino energy E indicated. The temperature jump δT has been taken as 10 mK. For example, taking the first line of the table: to heat an Al grain by 10 mK at 50 mK by the $E_A = 55$ eV deposited by the solar ^{7}Be neutrino (1.44 MeV), the grain must be 3.1 μm radius or smaller. In the uniform heating model (Ref. 6) it is assumed the whole grain must be heated by the given amount, using the heat capacity of the normal state.

Material	T (mK)	C_v (eV μm^{-3}K^{-1})	Neutrino energy, recoil energy, and radius			
Al			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=55.0 eV	E_A=240.0 eV	E_A= 1.7 keV	E_A=24.0 keV
	50	42.0	R = 3.1 μm	5.1 μm	9.9 μm	24.0 μm
	400	340.0	1.6	2.6	4.9	12.0
	1000	860.0	1.2	1.9	3.6	8.7
Ga			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=21.0 eV	E_A= 93.0 eV	E_A=660.0 eV	E_A= 9.3 keV
	50	16.0	R = 3.2 μm	5.2 μm	10.0 μm	25.0 μm
	400	130.0	1.6	2.6	5.0	12.0
	1000	350.0	1.1	1.8	3.6	8.6
Ge (grain coated with 0.5 μm Ga)			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=20.0 eV	E_A= 89.0 eV	E_A=630.0 eV	E_A= 8.9 keV
	50	(16.0)	R = 4.5 μm	9.4 μm	25.0 μm	95.0 μm
	400	(130.0)	1.6	3.3	8.8	33.0
	1000	(350.0)	0.9	2.0	5.3	20.0
Cd			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=13.0 eV	E_A= 58.0 eV	E_A=410.0 eV	E_A= 5.8 keV
	50	15.0	R = 2.7 μm	4.5 μm	8.8 μm	21.0 μm
	400	120.0	1.4	2.3	4.4	11.0
Sn			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=12.0 eV	E_A= 54.0 eV	E_A=390.0 eV	E_A= 5.4 keV
	50	34.0	R = 2.1 μm	3.4 μm	6.5 μm	16.0 μm
	400	280.0	1.0	1.7	3.2	7.8
	1000	790.0	0.7	1.2	2.3	5.5
La			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A=10.0 eV	E_A= 47.0 eV	E_A=330.0 eV	E_A= 4.7 keV
	50	140.0	R = 1.2 μm	2.0 μm	3.9 μm	9.4 μm
	400	1100.0	0.6	1.0	1.9	4.7
	1000	2900.0	0.4	0.7	1.4	3.4
Pb			E = 1.44 MeV	E = 3.0 MeV	E = 8.0 MeV	E =30.0 MeV
			E_A= 6.9 eV	E_A= 31.0 eV	E_A=220.0 eV	E_A= 3.1 keV
	50	52.0	R = 1.5 μm	2.4 μm	4.6 μm	11.0 μm
	400	470.0	0.7	1.2	2.2	5.4
	1000	1800.0	0.5	0.7	1.4	3.5

REFERENCES

Many of the points on the present situation were presented at the NUTECH-09 Workshop (Triest, June 2009)http:// cdsagenda5.ictp.trieste.it/

Tables and plots on coherent scattering are from A. Drukier and L. Stodolsky, *Principles and applications of a neutral current detector for neutrino physics and astronomy*, Phys. Rev. **D 30** 2295 (1984),

The CRESST plot is Fig. 7 of G. Angloher *et al.*, *Commissioning Run of the CRESST-II Dark Matter Search* Astropartphys **31**, 270 (2009); arXiv:0809.1829 [astro-ph].