Anti-neutrino Background at Braidwood

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Abstract

In this memo I calculated the anti-neutrino reaction yield from the Braidwood reactors, and all other reactors around, in proposed near and far detectors. The non-Braidwood reactors contribute to 0.8% of anti-neutrino induced positron yield in the far detector, and have negligible contribution to signal in the near detector (0.028%). This contribution is even lower, when oscillations are taken into account: 0.6% and 0.021%, respectively. Depending on whether the fuel composition is available or not, the resulting uncertainty in the far detector signal would be up to 0.024% or 0.08%.

1 Positron Rate Calculation

The geographical locations of Braidwood reactors are listed in Table 1. The coordinates are expressed in form of a latitude (ϕ_i) and longitude (λ_i), in WGS84 compatible elliptical coordinates. The latitudes and longitudes are obtained from Terra Server [1] and crosschecked with data from International Safety Center in Argonne [2]. The altitudes (h_i) are available from topological maps [1]. Areas around Braidwood reactors have the altitudes between 178 and 182 m. It is therefore assumed that the reactors are at level $h = 180$ m. Both near and far detectors are located at 180 m underground, that is, at sea level $h = 0$ m.

The elliptical coordinates of the detectors and all reactors are converted to Cartesian coordinates (x_i, y_i, z_i) using the following relations:

$$x_i = (n_i + h_i)\cos\phi_i \cos\lambda_i \tag{1}$$

$$y_i = (n_i + h_i)\cos\phi_i \sin\lambda_i \tag{2}$$

$$y_i = [n_i(1-e^2) + h_i]\sin\phi_i, \tag{3}$$

where $n_i = a/\sqrt{1-e^2\sin^2\phi_i}$, and $e^2 = f(2-f)$. The equatorial earth radius is $a = 6378137\ m$. The eccentricity of the ellipsoid is $f = 0.0033528106648$. The linear distance between the near (far) detector and reactor i is calculated as

$$L_i = \sqrt{(x_{n(f)} - x_i)^2 + (y_{n(f)} - y_i)^2 + (z_{n(f)} - z_i)^2}. \tag{4}$$

US reactor thermal powers have been obtained from US Nuclear Regulatory Commission [3]. The coordinates of the near and far detectors are given in Table 2.

Reactor Unit	Latitude	Longitude	Licensed Thermal Power [MWt]
Braidwood 1	41.24318	-88.22885	3586.6
Braidwood 2	41.24402	-88.22885	3586.6
Dreseden 2	41.389722	-88.271111	2957
Dreseden 3			2527
La Salle County 1	41.243889	-88.670833	3489
La Salle County 2			3489

Table 1: Coordinates and licensed thermal powers of Braidwood reactors, and several other reactors being close to the far and near detectors.

Detector	Latitude	Longitude
Near	41.2436	-88.22645
Far	41.2436	-88.2108

Table 2: Coordinates of the far and near detectors [4].

Given the coordinates, one calculates baselines from Braidwood reactors to near and far detectors to be 274 and 1524 m, respectively. Assuming the detectors with liquid scintillator (LS) composition identical to KamLAND's($8.48 \cdot 10^{28}$ target protons per ton of LS), detection efficiency of 75%, an average capacity factor of 92% for the reactors, and relative fission yields from fuel components as reported by KamLAND [5], one gets

Table 3. (Standard references, for the energy release per fission [6], and the anti-neutrino reactor spectra parametrization [7], were used in the calculation.).

Detector	Reactors (contributing to to the signal)	Positron Rate $[1/year \cdot ton]$ No Oscillation Case	Positron Rate $[1/year \cdot ton]$ Oscillation Case	Average Distance $[m]$
NEAR	Braidwood (only)	25726.5	25725.2	274.0
	US + Canada	25733.6	25730.6	280.0
	US + Canada - Braidwood	7.1	5.3	31321
	Dreseden (only)	5.3	4.5	16655
	La Salle (only)	1.4	0.6	37251
FAR	Braidwood (only)	831.4	830.1	1524
	US + Canada	838.1	835.2	1710
	US + Canada - Braidwood	6.8	5.0	32282
	Dreseden (only)	5.1	4.2	16997
	La Salle (only)	1.3	0.5	38563

Table 3: Expected positron yield in the far and near detectors. The yield is calculated for anti-neutrinos coming from Braidwood reactors, and all other reactors as well. In the case of oscillation, KamLAND best-fit parameters ($\Delta m^2 = 7.9 \cdot 10^{-5} eV^2$, $\sin^2 2\theta = 0.863$) were used.

2 Discussion

The non-Braidwood reactors contribute to 0.8% of anti-neutrino induced positron yield in the far detector, and have negligible contribution to signal in the near detector (0.028%). This contribution is 0.6% and 0.021%, respectively, when the oscillations are taken into account.
To calculate, precisely, an uncertainty in the anti-neutrino yield from non-Braidwood reactors, one needs knowledge of the thermal power and fuel composition, with corresponding uncertainties. Given these numbers, the relative uncertainty in the anti-neutrino rate would not exceed 3% (Thermal power uncertainty is conservatively taken as 2%. Different nuclear fuel components exhibit up to 7% quantitative uncertainty. However, fission rates from individual fuels are constrained by the thermal power, resulting in no more than

3% uncertainty in emitted antineutrino flux.). If the fuel composition is not known (this information is usually available upon special agreements with reactor companies), the uncertainty in the anti-neutrino rate from the reactors would be 8-10% [8], assuming the thermal power is available. Therefore, depending on whether the fuel composition is available or not, the resulting uncertainty in the far detector signal would be up to 0.024% or 0.08%, respectively.
An unlikely possibility: If Braidwood is shut down for a year, and the detectors are taking data, the baseline would shift to about 32 km. In this region, the anti-neutrino survival probability is close to 74%. Each detector would detect about 330 anti-neutrino events in 1 year, more than KamLAND so far. Our experiment would, then, crosscheck the Δm^2_{12} and $\sin^2 2\theta_{12}$ values.

References

[1] http://terraserver.microsoft.com

[2] http://www.insc.anl.gov/

[3] Information Digest 2004-2005 Edition (NUREG-1350, Vol. 16), US Nuclear Regulatory Commission

[4] Jonathan Link, private communication.

[5] T. Araki *et al.* (KamLAND Collaboration) hep-ex/0406035 (2004).

[6] G. Zacek *et al.*, Phys.Rev. D 34 (1986) 2621.

[7] P. Vogel and J. Engel, Phys.Rev. D 39 (1989) 3378.

[8] Andreas Piepke, private communication and discussion of Palo Verde experiment.