Reactor Anti-Neutrino Background in KamLAND

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Abstract

In this note I examine the anti-neutrino reaction yield of all reactors world wide in KamLAND. Input data, such as reactor electrical power, operational status and geographical location have been obtained from the International Nuclear Safety Center in Argonne. Reactor thermal power was obtained from the IAEA in Vienna.
It is found that the Korean stations provide 2.2% of the reactor signal, while the rest of the non-Japanese reactors is responsible for about 0.5% of the total reactor induced yield.
I also compared the reaction yield due to the Japanese reactors calculated using Argonne's reactor locations to those provided by the Tokyo power company. I find the two estimates in agreement within 0.3%. This value might serve as an estimate of the maximum possible systematic uncertainty in our knowledge of the detector to reactor distances.
Finally the ellipsoidal heights of the reactor stations is not known, as only their geographical latitudes and longitudes have been provided. The uncertainty introduced into the calculated yield due this unkonwn variable is less than 0.4%.

1 The Flux Model

All flux calculations presented in this note were done under the no-oscillation hypothesis. A total of 439 operational reactor units at 308 independent locations have been included in this analysis. It was further assumed that all operational reactors are running at full power. The fractional contribution of reactors all over the world to the KamLAND signal should not be affected by this assumption if the average on-off time ratio is the same everywhere. The reaction yield, Y_i (in units of $kT^{-1}\ y^{-1}$), due to reactor station i, with a thermal power P_i [1] (in MW), located at a distance L_i (in km) was calculated using the following equation:

$$Y_i = \frac{3.625 \cdot 10^2\ \frac{km^2}{MW\ kT\ y} \cdot P_i}{L_i^2}. \tag{1}$$

The same reaction cross section as in the US KamLAND proposal [2] was used. It was further assumed that in all stations the contribution of the fissile isotopes ^{235}U, ^{239}Pu, ^{238}U and ^{241}Pu to the thermal power is 62%, 27%, 7% and 4%, like in the US KamLAND proposal [2].
Geographical reactor locations were obtained from the International Nuclear Safety Center, at Argonne National Laboratory [3]. The coordinates were supplied in form of a latitude, ϕ_i, and longitude λ_i, in WGS84 compatible elliptical coordinates. The elliptical heights h_i were not available. It was assumed that all reactors are at sea level or $h = 0$. Due to the cooling requirements of nuclear reactors this is probably a good assumption for most reactors. It also turns out that the results are insensitive to this variable. Even if all reactors are placed at $h = 9000\ m$, or on top of Mount Everest, the difference in the KamLAND signal amounts to no more than 0.43%. It can therefore be concluded that this variable is irrelevant for the modeling of the reactor signal in KamLAND.
The geographical location of the KamLAND detector (ϕ_d, λ_d, h_d) were taken from reference [4] and [5]. The latter reference was used to define the height h_d. It was assumed that KamLAND is situated at the same height as Super-K. The elliptical coordinates of the KamLAND detector used in this study are as follows:

$$\begin{aligned} \phi_d &= 36.42^\circ \\ \lambda_d &= 137.31^\circ \\ h_d &= 389\ m \end{aligned}$$

The elliptical coordinates of all reactors and of the KamLAND detector are converted into Cartesian coordinates ($x_i,\ y_i,\ z_i$) and ($x_d,\ y_d,\ z_d$) (in units of m) using the following transformation:

$$\begin{aligned} x &= (n+h)\cdot\cos(\phi)\cdot\cos(\lambda) \\ y &= (n+h)\cdot\cos(\phi)\cdot\sin(\lambda) \\ z &= [n\cdot(1-e^2)+h]\cdot\sin(\phi) \end{aligned}$$

here $n = a/\sqrt{1-e^2\sin^2\phi}$ and $e^2 = f(2-f)$, with $a = 6378137\ m$ representing the equatorial earth radius and $f = 3.35281066475\cdot 10^{-3}$ the eccentricity of the ellipsoid, respectively.
The linear distance, L_i (in km), between reactor i and the KamLAND detector is now given as:

$$L_i = \frac{1}{1000}\sqrt{(x_d-x_i)^2+(y_d-y_i)^2+(z_d-z_i)^2}. \quad (2)$$

2 Results

Using this input data the following reaction yields are predicted: From ta-

Origin	Yield $[\frac{1}{kT\ y}]$	Fractional yield
Japan	1095.8	0.973
Korea	24.3	0.022
Asia (Japan and Korea excl.)	1.9	$1.6\cdot 10^{-3}$
Europe	2.9	$2.5\cdot 10^{-3}$
North America	1.4	$1.2\cdot 10^{-3}$
South America	0.01	10^{-5}
Africa	0.02	$1.3\cdot 10^{-5}$
Total	1126.3	1.0

Table 1: Calculated reactor anti-neutrino reaction yield using the best available input.

ble 1 we see that only the Korean reactors contribute significantly to the reactor signal. The summed signal of all other power reactors world wide

amounts to only 0.5% of the total signal. This "background" is hence negligible.
The calculation was repeated using latitudes and longitudes for the Japanese reactors as provided by the Tokyo Power Company [6], instead of the Argonne coordinates. The corresponding total reaction yield for all Japanese reactors is $Y_{Japan} = 1092.4 \frac{1}{kT\,y}$. This amounts to a 0.3% difference.
Finally, if all reactor stations are placed at a height of 9000 m the total reaction yield is estimated to be $Y_{Tot} = 1121.5 \frac{1}{kT\,y}$. Even this drastic misplacement results only in a 0.4% variation. The systematic uncertainty introduced by the lack of elliptical heights is hence much smaller than 0.4%.
The rather long, detailed breakdown of the power, distance and signal contribution for each reactor is available (for KamLAND collaborators only!) upon request. Note: the Japanese research reactors have not been included in this estimate.

References

[1] Private communication with R.Spiegelberg-Planer of the IAEA, and http://www.iaea.org/worldatom/Programmes/Nuclear_Energy/

[2] P. Alivisatos et al., KamLAND a Liquid scintillator Anti-Neutrino Detector at the Kamioka site, Stanford-HEP-98-03 and RCNS-98-15, (1998)

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

[4] K. Nakamura, T. Kajita and A. Suzuki, in "Physics and Astrophysics of Neutrinos", Springer Verlag (1994), p249.

[5] H. Noumi et al., KEK Internal Report 96-17, (1997)

[6] All coordinates were provided by F. Suekane and will be treated confidential upon his request.