Low Background Measurement by Means of NaI(Tl) Scintillator—Improvement of Sensitivity for Cosmic Dark Matter—

Ken-Ichi Fushimi

Department of Physics, Tokushima University
2–1 Minami Josanjimacho, Tokushima-shi, Tokushima Pref. 770–8506, Japan
kfushimi@tokushima-u.ac.jp

Search for cosmic dark matter is one of the most important tasks in both astrophysics and particle physics. Various types of highly sensitive radiation detectors have been applied to searching for dark matter in the world. The NaI(Tl) scintillator is well-known radiation detector: it has been applied to the studies of dark matter and rare processes of fundamental physics. One needs to purify the detector down to a few µBq/kg to search for dark matter because of extremely small expected event rate of dark matter candidate. The author describes the recent status of low background detectors for dark matter search and the project to search for dark matter by using highly radiopure NaI(Tl) scintillator.

Key Words: NaI(Tl) scintillator, cosmic dark matter, measurement of radioactive impurity

1. Introduction

A NaI(Tl) scintillator is the most popular radiation detector for a long time. The properties in viewpoints of solid-state physics, optical physics, and radiation physics have been deeply studied. It has been applied to various fields not only in fundamental science such as nuclear and particle physics but also in applied science such as nuclear medicine and survey monitor in nuclear power plants.

In this review paper, the recent progress and future application of highly radiopure NaI(Tl) scintillator in the viewpoint of cosmic dark matter search are described. The basic property of NaI(Tl) scintillator is shortly described to help the reader’s deeper understanding.

The need for low background NaI(Tl) scintillator is described in the following sections. The dark matter (DM) search is one of the most advanced fields in low background measurement of radiation. Many radiation detectors have been applied to search for dark matter candidates directly by measuring extremely small event rate. The recent development of low background NaI(Tl) scintillator to search for dark matter is described. The low background property will be applicable to a quite wide range of subjects which are concerned with radiation measurements.

1.1 Basic property of NaI(Tl) scintillator

NaI(Tl) is a scintillating crystal in which a small concentration of thallium is doped. The pure NaI crystal emits ultraviolet scintillation photons whose wavelength is 303 nm at the maximum emission. Doped thallium makes the intermediate states between the valence band and the conduction band. The transition between the intermediate states gives an emission of visible photons whose wavelength is between 300 nm and 550 nm. The wavelength of the maximum emission, around 415 nm, is suitable for the commonly used photomultiplier tubes (PMTs).
The number of scintillation photons depends on the concentration of thallium in the crystal. Fig. 1 shows the dependence of light yield and energy resolution on the thallium concentration. Note that the light outputs have a plateau in the interval between 0.022 mol% and 0.073 mol% of thallium concentration. On the other hand, the energy resolution of high energy gamma-ray (662 keV) has its minimum around 0.07 mol% and it becomes quickly worse for denser thallium impurity. The commonly provided NaI(Tl) detector consists of thallium with the concentration between 0.05 mol% and 0.08 mol%, which have been determined empirically.

The scintillation output largely depends on the incident particle due to the difference of the linear energy transfer (LET). The scintillation output is reduced for a low energy heavy ion whose LET is much larger than electrons because the low energy heavy ion cannot hit the electrons directly. The number of scintillation photons $N_h$ by a heavy ion whose kinetic energy is $E_i$ and the one $N_e$ by an electron with the same kinetic energy is related by a simple equation as

$$f = \frac{N_h}{N_e}. \quad (1)$$

The parameter $f$ called quenching factor depends on the passing particle in the detector. The behavior of the quenching factor was investigated theoretically. The quenching factor for alpha rays in NaI(Tl) is between 0.6 and 0.7, depending on the kinetic energy of the alpha ray. The quenching factor for an extremely low energy ion by nuclear recoil has a large dependence on the kinetic energy and the factor for inorganic scintillator does not fit the theoretical calculation well. Many experimental efforts have been performed to estimate the quenching factor for NaI(Tl) scintillator because it is essential to calculate the expected response of WIMPs dark matter in NaI(Tl) scintillator. The measured values of the quenching factors of sodium and iodine ions in a NaI(Tl) scintillator are shown in Table 1.

### Advantage and disadvantage of NaI(Tl) scintillator

The characteristics of inorganic scintillators are listed in Table 2. The NaI(Tl) scintillator is attractive one in view of applying it to a normal PMT because of its wavelength, however, the decay time is too long to use fast timing application such as positron emission tomography. The NaI(Tl) has one more disadvantage of its hygroscopicity. One needs to put the crystal into a hermetic container to avoid humid-

### Table 1 Quenching factors for heavy ions passing through a NaI(Tl) scintillator.

| Ion | Recoil energy keV | $f$ | Ref. |
|-----|------------------|-----|-----|
| I   | > 10             | 0.09| 3)  |
| I   | > 10             | 0.086 ± 0.007| 4)  |
| Na  | > 4              | 0.4 | 3)  |
| Na  | > 4              | 0.275 ± 0.018| 4)  |
| $\alpha$ | 4000 ~ 6000 | 0.6 | 5)  |
ity. The container obviously limits the detection efficiency of low energy radiation.

Despite its disadvantages, the NaI(Tl) scintillator has been applied to dark matter search experiments. The requirements for DM search are quite suitable to NaI(Tl) scintillator because it needs a low background and low energy measurement. Both the longer decay time and hygroscopicity are no disadvantage to low background experiments because the event rate is sufficiently low and the experiment needs thick and firm shield against the background from surrounding materials and pure nitrogen gas is filled in the shield.

2. Dark matter search

2.1 Basic property of dark matter

The dark matter problem suggested by F. Zwicky who analyzed the kinetic mass of the galaxy cluster. The kinetic mass of the galaxy cluster was obtained by the deviation of the velocity of galaxies in the cluster. The obtained kinetic mass was more than ten times larger than the luminous mass which was obtained by the optical measurement of the galaxies. The cosmic dark matter exists also in our Galaxy. The mass density in the vicinity of the solar system is obtained as $0.3 \sim 0.5 \text{ GeV}/c^2/\text{cm}^3$.

Many candidates for cosmic dark matter have been proposed by many theoretical works. There are other promising candidates such as axion, hidden photon and so on. The search for various dark matter needs common techniques; a low background and low energy measurement of radiation. The detail of WIMPs search technique will be described below for cosmic dark matter search.

One of the most promising candidates is a sort of heavy unknown particle which interacts via gravitational and weak interactions, so-called WIMPs (Weakly Interacting Massive Particles). The mass of the WIMPs candidate is expected to be heavier than a few GeV/c^2. The WIMPs interact with a nucleus of the normal matter via the weak interaction. Many theoretical studies suggest that the cross-section of the elastic scattering between WIMPs and a proton, $\sigma_{\chi-p}$, is smaller than $10^{-43} \text{ cm}^2$.

The velocity distribution of WIMPs is in thermal equilibrium in the galactic gravity field with its most probable speed as $v_{\chi} \approx 230 \text{ km/s}$. The directional distribution of the WIMPs velocity is isotropic in the galactic rest frame. The solar system travels to the direction of the constellation Cygnus and the earth revolves around the sun with the speed of 30 km/s. The earth’s revolution plane inclines 30°, consequently, the relative velocity of the earth to the WIMPs rest frame varies with its maximum in June and minimum in December. About ±6.5% difference of relative velocity of earth results in the annually modulating signal of WIMPs.

2.2 Signal of WIMPs candidates

The WIMPs signals are given by elastic and in-

| Scintillator | Photon yield (/MeV) | Decay time (nsec) | Max. wave length (nm) | Density (g/cm$^3$) | Hygroscopic | Background |
|--------------|---------------------|------------------|----------------------|-------------------|-------------|------------|
| NaI(Tl)      | 38000               | 230              | 415                  | 3.67              | High        | U,Th,40K   |
| CsI(Na)      | 39000               | 630              | 420                  | 4.51              | High        | U,Th,137Cs,40K |
| CsI(Tl)      | 52000               | 1000             | 540                  | 4.51              | High        | U,Th,137Cs,40K |
| BGO          | 8200                | 300              | 480                  | 7.13              | No          | U,Th,40K   |
| CaF$_2$(Eu)  | 24000               | 900              | 435                  | 3.19              | No          | U, Th,40K |
| GSO(Ce)      | 10000               | 30-60            | 430                  | 6.71              | No          | U,Th,40K,160Gd |
| LSO(Ce)      | 26000               | 42               | 420                  | 7.4               | No          | U,Th,40K,176Lu |
| Liq. Xe      | 42000               | 40               | 175                  | 2.95              | –           | U,Th,40K,85Kr |
elastic scattering off a target nucleus in a radiation detector. The recoil energy of nucleus $E_R$ which is given by the elastic scattering is given by

$$E_R = \frac{4m_\chi m_N}{(m_\chi + m_N)^2} E_x (1 - \cos^2 \theta),$$

(2)

where $m_\chi$ and $m_N$ are the mass of WIMPs and target nucleus, $E_x$ is the kinetic energy of incident WIMPs and $\theta$ is scattering angle in the laboratory frame.

The expected energy spectrum of recoil energy of target nucleus is given as

$$\frac{dR}{dE_R} = \frac{R_0}{rE_0} \frac{\sqrt{\pi}}{4y} \{\text{erf}(x + y) - \text{erf}(x - y)\}|F(q)|^2,$$

(3)

where

$$r = \frac{4m_\chi m_N}{(m_\chi + m_N)^2},$$

(4)

$$x = \sqrt{\frac{E_R}{rE_0}},$$

(5)

$$y = \frac{v_\chi}{v_0},$$

(6)

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int^x \exp(-t^2)dt.$$  

(7)

$R_0$ is total scattering rate and $F(q)$ is the form factor of the scattering with the momentum transfer $q$, respectively. The typical energy spectra of recoil iodine and sodium nuclei are shown in Fig. 2.

The total scattering rate $R_0$ depends on the cross-section of WIMPs-nucleus scattering $\sigma$ [cm$^2$] and the dark matter density near the earth $\rho$ [GeV/c$^2$/cm$^3$] as

$$R_0 = \frac{2}{\sqrt{\pi}} \frac{N_A g}{A} \frac{D_r}{m_\chi} v_\chi [\text{sec}^{-1}\text{kg}^{-1}],$$

(8)

where $N_A$ [kmol$^{-1}$] is Avogadro number, $A$ [kg/kmol] is the mass number of the target nucleus, $m_\chi$ [GeV/c$^2$] is the mass of WIMPs and $v_\chi$ [cm/s] is the most probable speed of WIMPs.

As shown in equation (3), the energy spectrum modulates with the period of one year. The maximum of the mean energy occurs at the beginning of June and the minimum in the beginning of December. Note that the variation of the event rate in the low energy region is less than 4%; both a huge mass of the detector and continuous measurement are indispensable to get a significant signal of the annually modulating signal.

2.3 Required properties for dark matter detectors

The expected scattering rate is much less than $10^{-5}$ day$^{-1}$ kg$^{-1}$ because the expected cross-section of elastic scattering is less than $10^{-43}$ cm$^2$. We need, consequently, a low background detector to find extremely rare events due to the WIMPs-nucleus scattering. The indispensable properties for a dark matter detector are listed below.

2.3.1 Low background

A dark matter detector is principally a sort of radiation detector, consequently, a small number of dark matter events are hidden by a lot of background events from environmental radiation. The main sources of background are natural radioactive impurities (RIs) listed in Table 3.

We must take care of considering U-chain contamination because this chain is divided to five sub-chains by long-life isotopes, $^{234}$U (2.45×10$^5$ years), $^{230}$Th (8.0×10$^4$ years), $^{226}$Ra (1600 years), and $^{210}$Pb (22.4 years). Moreover, the radioactivity of the downstream of $^{222}$Rn may not in secular equilibrium because a long-life (3.82 days) $^{222}$Rn escapes from
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These RIs emit various energies of gamma rays, X-rays, and beta rays: all the background events are piled up resulting that the event rate is several orders of larger than DM events. The required RI concentration in a dark matter detector is optimized by compared with the Monte Carlo simulation.

### Table 3 Main sources of background against dark matter search. \(a\) is the natural abundance of isotopes.

| RI     | Parent | Progeny | Chain | \(T_{1/2}\) [y] | \(a[\%]\) |
|--------|--------|---------|-------|----------------|-----------|
| U-chain | \(^{235}\)U | \(^{206}\)Pb | Yes   | \(4.5 \times 10^9\) | 99.27     |
| Th-chain | \(^{232}\)Th | \(^{208}\)Pb | Yes   | \(1.4 \times 10^{10}\) | 100       |
| K      | \(^{40}\)K | \(^{40}\)Ca, \(^{40}\)Ar | No    | \(1.2 \times 10^9\) | 0.0117    |

### Table 4 The present and projected mass of the detectors for dark matter search. The mass of the detector is their fiducial (effective) mass.

| Group         | Detector | Present (kg) | Projected (kg) | Ref. |
|---------------|----------|--------------|----------------|------|
| DAMA/LIBRA    | NaI(Tl)  | 250          | 1000           | 17)  |
| KIMS          | NaI(Tl)  | 3.3 ~ 11.4   | 200            | 18)  |
| DM-ICE        | NaI(Tl)  | 8.47         | 106            | 19)  |
| ANAIS         | NaI(Tl)  | 12.5         | 250            | 20)  |
| PICO-LON      | NaI(Tl)  | 5.9          | 1000           | 21)  |
| Xenon         | Xe       | 1000         | 6000           | 22)  |
| LZ            | Xe       | 1000         | 7000           | 23)  |
| PICO-2L       | C\(_3\)F\(_8\) | 36.8  | 100            | 24)  |
| Super-CDMS    | Ge       | 4.6          | 45             | 25)  |

The future DM search project aims to construct a huge detector whose fiducial masses are larger than several hundred kgs. The mass of semiconductors such as Si and Ge is limited to small mass because of the production cost. Nevertheless, the sensitivity of semiconductor detectors to DM is sufficiently large because of large quenching factors (\(f=0.2\sim0.3\)) and selection power of background due to good energy resolution.

### 2.3.2 Large mass detector

The expected event rate \(R_0\) is as small as \(10^{-3}\)day\(^{-1}\) kg\(^{-1}\) when \(\sigma_{X-P}\) is smaller than \(10^{-43}\)cm\(^2\). Such a small event rate means that one must prepare a huge amount of the detector mass \(M_{det}\) and the long-term experiment \(T_{Exp}\); the product of the mass and live time must be larger than \(M_{det}T_{Exp}>10^5\)day\(^{-1}\)kg. To enlarge the mass of the detector is the most simple way to get a sufficient statistics of the WIMPs events. At least one ton of the detector mass is needed to get sufficient sensitivity to dark matter candidates.

Present dark matter detectors are aiming to construct huge mass detectors. The present status and future plan of several leading groups in dark matter search are listed in Table 4.
applied to almost all the DM search projects. The quantum efficiency of an ultra/super bialkali PMTs is as large as 30–40%.

The next method to enhance the photon collection is the design of the detector. The areas of photocathode of a PMT and an optical window of a detector should be the same to get the most effective photon collection. When all the area of the optical window cannot be covered with the photocathode, in many cases, one can get larger photon collection by putting a diffusive reflector on the optical window where the PMT cannot cover.

The number of photoelectrons for 1 keV events is more than 10 by using normal NaI(Tl) scintillator for DM searches. The trigger for data acquisition system is set above a few photoelectrons to avoid a large trigger rate by dark current noise (\(\sim 1\) kHz). The stable event rates are obtained by several event selections which remove the accidental noise event due to many electric noises in data acquisition system, resulting in the low energy threshold around 1 keV.

### 3. Development of highly radiopure NaI(Tl) crystal

#### 3.1 PICO-LON dark matter search project

Development of low background NaI(Tl) detector is described in this section. Normally provided NaI(Tl) detector contains a lot of RIs which produces obstructive events against fundamental rare processes. The groups searching for fundamental processes in particle physics have made extensive efforts to develop highly radiopure NaI(Tl) scintillators.

PICO-LON group (Pure Inorganic Crystal Observatory for LOw energy neutr(al)ino) is developing highly radiopure NaI(Tl) scintillator to search for DM. Measuring the contamination in a NaI(Tl) was difficult before constructing a detector because the intensities of the radiation from the RIs were too small to detect them by a Ge detector. The purification of a NaI(Tl) detector was performed by following these steps listed below.

1. Make a NaI(Tl) ingot by using a selected crucible.
2. Construct a detector by using selected housing, reflector, and an optical window.
3. Measure alpha rays by a pulse shape discrimination (PSD) method to determine the concentrations of U-chain and Th-chain.
4. Discuss the origin of the concentration and select the material and the method for further purification.

We used a graphite crucible to make a crystal because of good production yield of crystal without any cracks. High purity graphite does not interact with melted NaI, consequently, no impurity comes into the NaI(Tl) crystal from the crucible.

After the crucible selection, we started to purify the raw powder of NaI. The NaI powder which was provided by a chemical company contained a significant amount of U-chain and \(^{210}\)Pb. We performed the chemical process to remove the lead ions from raw powder. The procedure of chemical processing was carefully optimized by investigating the background spectrum from produced NaI(Tl) detectors.

#### 3.2 Measurement of purities in NaI(Tl) crystal

We measured alpha ray intensities due to U-chain and Th-chain to determine the purity, which is the most important work for purification. A simple PSD technique was applied to select alpha-ray events from a lot of beta/gamma-ray background. An inorganic scintillator usually has a shorter decay time when heavy particles pass through the scintillator. The decay times of the scintillation output by NaI(Tl) are 230 nsec for electrons and 190 nsec for alpha rays. Particle identification is performed by calculating the charge integration ratio by the equation
where $I_0$ and $\tau$ are the initial current and the decay constant of an input signal, respectively. Factor $D$ is an attenuation factor due to long cable delay. It is unity if the pulse shape is digitized by a flash analog-to-digital converter (ADC). A typical PSD spectrum is drawn in Fig. 3. The data shown in Fig. 3 were taken in the surface laboratory without any shield. Consequently, a lot of events of beta/gamma rays are plotted in the locus $0.6 < R < 0.7$. However, extremely rare alpha ray events were clearly distinguished from the beta/gamma events: the deviation between beta/gamma rays and alpha rays was $11\sigma$.

Recently, measurement of RIs in extremely high sensitivity has been attempted by using inductively coupled plasma mass spectrometry (ICP-MS). The detection limits of U and Th have reached to 8.4 ppq (0.034 $\mu$Bq/kg) and 10.6 ppq (0.131 $\mu$Bq/kg), respectively. Measuring $^{nat}$K is difficult because of the interference of $^{38}$Ar$^+$, $^{40}$Ar$^+$ and so on. The detection limit of $^{nat}$K is improved by using the selected reaction gas which consists of 10% NH$_3$ and 90% He. The improved detection method gives an extremely small concentration of 0.5 ppb of $^{nat}$K which corresponds to 16.4 $\mu$Bq/kg. The measurement by ICP-MS is a quick and highly sensitive method to test the materials of NaI(Tl) crystal in each process of detector construction.

The values of contamination were measured for each trial of purification. The reduction of U and Th chain impurities are clearly depicted in Fig. 4. The results of purification steps are listed in Table 5. We have successfully reduced RIs step by step.

A higher contamination caused by insufficient amount of chemical process. We already concluded

![Fig. 3 The typical PSD diagram taken by the pure NaI(Tl) scintillator (Ingot #24). The horizontal axis is ADC channel.](image)

![Fig. 4 The change of alpha ray intensity. Black: Ingot 16 made by normal crucible. Red: Ingot 20 made by high purity graphite crucible. Blue: Ingot 24 made by further purified graphite crucible](image)

| Ingot | Process        | $^{238}$U $\pm$ | $^{226}$Ra $\pm$ | $^{210}$Pb $\pm$ | Th chain $\pm$ | $^{nat}$K  |
|-------|----------------|-----------------|-----------------|-----------------|----------------|-------------|
| 16    | Nomal crucible | 520 $\pm$ 73    | 4510 $\pm$ 60   | 9600 $\pm$ 100  | 243 $\pm$ 11   | -           |
| 20    | Pure crucible  | 372 $\pm$ 23    | 81 $\pm$ 11     | 440 $\pm$ 22    | 60 $\pm$ 14    | -           |
| 23    | 20+Pb resin    | 66 $\pm$ 10     | 108 $\pm$ 18    | 58 $\pm$ 26     | 13 $\pm$ 8     | -           |
| 26    | 23+cation resin| < 0.5           | 57 $\pm$ 4      | 29 $\pm$ 7      | 1.5 $\pm$ 1.9  | 81000       |
| 37    | Less resin     | 13              | 13              | 2280 $\pm$ 20   | 4.8            | 3700        |
the origin of contamination and optimized the process to make large volume NaI(Tl) detector in the future project.

3.3 Present status of highly sensitive measurement

The test of low background measurement was performed in Kamioka underground laboratory, located in Gifu Prefecture, Japan. The experimental area for PICO-LON project is placed in KamLAND area, which is placed 1000 m below the top of Mt. Ikenoyama (2700 m water equivalent) as shown in Fig. 5.

Radioactive $^{222}\text{Rn}$ ($T_{1/2} = 3.82$ days) is the serious background in Kamioka underground laboratory because it was previously a lead mine. The concentration of $^{222}\text{Rn}$ in the air in the laboratory sometimes exceeds 1000 Bq/m$^3$. Rn-free air is introduced into the experimental room and the concentration of $^{222}\text{Rn}$ in the air is kept lower than 100 Bq/m$^3$. However, the concentration is rather high to perform sufficiently low background measurement. Pure nitrogen gas was flushed into the shield to purge $^{222}\text{Rn}$ and the background was effectively reduced by one order of magnitude.

A medium size of NaI(Tl) crystal whose dimension was 101.6 mm$\phi \times 76.2$ mm, named ingot #37, was installed into the shield. The shield consisted of 5 cm thick oxygen free high conductive copper and 20 cm thick old lead. The cosmogenic backgrounds from the shielding materials are negligible because all the materials were kept underground for more than 10 years.

The test experiment was performed in September 2016, with the live-time of 36.5 day×kg. The waveforms from PMTs were digitized by fast flash ADC whose sampling rate was 1 GHz for highest gain ($\times 120$) and 200 MHz for lower three gains ($\times 24$, $\times 2.4$ and $\times 0.24$, respectively). Precise noise reduction was performed by removing fast single-hit noises due to the dark current of the PMT. The resulting effective energy threshold was as low as 1 keV$_{ee}$.

The energy spectrum together with the background component is shown in Fig. 6. There are three prominent peaks around 3 keV$_{ee}$, 46 keV$_{ee}$, and 5500 keV$_{ee}$. The Monte Carlo simulation was performed by assuming known contamination in surrounding materials. The simulated energy spectra were fitted to the experimental result by changing the concentration of unknown RIs.

We determined by extensive analysis that all three prominent peaks were originated by the contamination in NaI(Tl) crystal. The best fit values of the concentration were listed in the bottom line of Table 5. A less amount of resins were applied to making ingot

![Fig. 5 A schematic drawing of the position of KamLAND. The experimental cite of PICO-LON is in the KamLAND area (Color online).](image)

![Fig. 6 The low background energy spectrum taken by ingot #37. See text the description of background component (Color online).](image)
#37 to lower the fabrication cost, however, the concentrations of RIs increased significantly. Especially, the concentration of $^{210}$Pb reverted almost the first status of our project. Note that the concentration of potassium was effectively improved by using proper cation exchange resin.

The background level in the low energy region around 6 keV$_{ee}$ was $3.5\text{keV}^{-1}\text{kg}^{-1}\text{day}^{-1}$, which was 1/3 of DM-ICE$^{(19)}$ and the same level of ANAIS-D1 detector.$^{20}$

4. Future prospects

KamLAND-PICO, the combined name of KamLAND and PICO-LON, aims to search for dark matter by means of a large volume NaI(Tl) scintillator array. A module of the highly radiopure NaI(Tl) scintillator whose dimension is $127.0\text{mm} \times 127.0\text{mm}$ will be developed in summer 2017.

The first aim is to settle the annual modulation signal which has been observed by DAMA/LIBRA group. The DAMA annual modulating signal has not been verified by the same target nuclei although it has been excluded by using other targets such as Si, Ge, and Xe. The existing DM search projects which apply NaI(Tl) scintillator are suffered their sensitivities from the intrinsic RIs. The PICO-LON group has developed a highly radiopure NaI(Tl) crystal and established the method to purify the crystal. The result of our investigation for annual modulation gives a big impact in either case whether the significant modulation is detected or not. We are planning to construct a large volume NaI(Tl) array whose total mass is 248 kg.

The final aim is to find the dark matter by a huge NaI(Tl) array with an effective active shield against neutrons and gamma rays. The total mass of the NaI(Tl) scintillator is 1000 kg using 170 modules of NaI(Tl) detector. The array of NaI(Tl) detectors will be installed at the center of KamLAND detector.$^{27}$ The KamLAND detector is a huge liquid scintillation detector whose diameter is 13 m.$^{34}$

Fig. 7 Plan of KanLAND-PICO project to search for dark matter (Color online).

Acknowledgments

The author thanks the editorial committee of RADIOISOTOPES for inviting to publish this
review article. The author thanks the collaborators of KamLAND-PICO collaboration, D. Chernyak, H. Ejiri, R. Hazama, S. Hirata, H. Ikeda, K. Inoue, K. Imagawa, G. Kanazaki, A. Kozlov, R. Orito, T. Shima, Y. Takemoto, Y. Teraoka, S. Umehara and S. Yoshida. This work was supported by Grant-in-Aid for Scientific Research (B) number 24340055 and Grant-in-Aid for Scientific Research on Innovative Areas number 26104008. The author thanks Kaminokami Mining and Smelting Company for supporting activities in the Kamioka mine and Horiba Ltd. for constructing NaI(Tl) detectors.

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要 目

低バックグラウンドのNaI(Tl)による計測
宇宙未知素粒子の探索に向けた高純度化

—宇宙未知素粒子の探索は、宇宙物理学および素粒子物理学の両分野に対して大きな意義を持つ研究テーマである。世界各地で探索用の高感度放射線検出器が開発されている。NaI(Tl)検出器は古くから知られた放射線検出器で、その特性とよく知られているため、宇宙暗黒物質の探索やその他の基礎物理学に関わる実験に広く応用されてきた。宇宙未知素粒子探索には、予想される計数率の低さから放射性不純物の濃度を数μBq/kgまで低減させる必要がある。本論文では、最近の超高純度放射線検出器の動向及び著者が取り組んでいるNaI(Tl)検出器による宇宙暗黒物質探索計画について解説する。