THE MINE DETECTION SYSTEM COUPLED WITH A COMPACT TANDEM ACCELERATOR


Abstract
We have been developing a mine detection system coupled with a 1MV compact tandem accelerator. This system will consist of a compact high current tandem accelerator, a target system, a detection system, a power generator system and a transportation system for application in the mine field. The tandem accelerator designed to be accelerated a proton of a 1.75MeV energy up to 10mA beam current. We developed new mine detection method for a scattered 9.17MeV gamma-ray produced from the \(14N(\gamma, \gamma)14N\) photo-resonant reaction. The incident gamma-rays are produced by 1.75MeV proton beam bombarding at a \(^{13}C\) target. New method can be separated a scattered gamma-rays from \(^{13}C\) target gamma-rays within 0.1% energy resolution by using Doppler effect due to nucleus recoil mechanism.

1 INTRODUCTION
Several methods of mine and explosive detection were suggested, for example, NQR(Nuclear magnetic resonance), metal survey meter and so on. However, while applied to anti-personal mine which dose not contains any metal components, a conventional method based on metal survey is not effective. NQR method is deeply depended on the large electric quadrupole moment comparing with other stable element under ground, and this method was known that NQR detection frequency varied as a chemical composition and temperature. Our new mine and explosive detection technique is directly detected a nucleus by using the photo-nuclear resonant reaction for the \(^{14}N\). The main goal of this work is to confirm our new detection mechanism in principle by performing a basic nuclear resonant reaction experiment.

2 NEW MINE/EXPLOSIVE DETECTION PRINCIPLE
The mine/explosive detection mechanism is in two step.
- Generation of \(\gamma\)-ray
  \[ p + ^{13}C \rightarrow ^{14}N + ^{14}N + \gamma \]
- Gamma resonance absorption and scattering
  \[ \gamma + ^{14}N \rightarrow ^{14}N + ^{14}N + \gamma \] or \(^{13}C + p\)

The photo-nuclear resonance gamma-rays are produced by nuclear reactions \(^{13}C(p, \gamma)^{14}N\), in which target is bombarded with a 1.75MeV proton beam extracted from the proton accelerator. To avoid other neighboring resonant gamma-rays, we selected a higher resonant energy of 9.17MeV. The 9.17MeV gamma rays produced are absorbed or scattered when they react with \(^{14}N\) included in the mines and explosives. We can determine existence of mines or explosives by detecting the absorption and scattering gamma-ray signals.

In the study of explosives detection, we have surveyed the various present technologies and the requirements. The explosive detector based on the gamma resonance reaction should be relatively superior to the present ones in accuracy. The gamma resonance absorption in \(^{14}N\) rich compounds was verified successfully by using a Tandem accelerator at low beam current. But for the verification of the field application, a higher beam current over 10mA is needed.

The major difficulty is that the energy of an absorbed and re-emitted gamma-ray from \(^{14}N(\gamma, \gamma)^{14}N\) reaction is almost same with that of a target gamma-ray come from \(^{13}C(p, \gamma)^{14}N\) resonant reaction. The over 30 cm thick Pb shield needed to overcome the \(^{13}C\) target gamma-ray yield, and it is big burden for the system designer as a movable machine. The gamma-rays are produced by nuclear reactions that occur when an \(^{13}C\) target is bombarded with a 1.75MeV proton beam, which is obtained from the proton accelerator. The 9.17MeV gamma-rays produced are absorbed or scattered when they react with \(^{14}N\) included in the mines and explosives. We can determine the position of mines or explosives by detecting the absorption and scattering of the gamma-rays.

3 TANDEM ACCELERATOR DESIGN SPECIFICATION
Accelerator have to satisfied following specifications.
- Particle : proton
- Beam Energy : 1.8MeV ± 0.04MeV
- Beam Current : 10mA ± 0.5mA
- Target diameter : 20mm
- Beam divergency : Less than 10mrad

*This work was supported by mid- and long-term project (Project No. 53564-00) of Ministry of Science and Technology in 2000.
4 PHYSICAL DATA FOR DETECTION ENVIROMENT

Before performing the experiment, we have done an estimation calculation for our new detection principle. The properties of a 9.17MeV gamma-ray production $^{13}$C target by 1.75MeV proton summarized as that natural abundance is 1.11%, $J^\pi$ is 1/2-, density is 2.253 g/cm$^3$, $dE/dx = 35.69$ MeV/mm, and range is 30.02µm. The range and stopping power is calculated by TRIM code. The resonance width was reported as 122eV [1], and the calculated thick target yield as $0.64 \times 10^{-8}$ [$\gamma/p$]. However, it does not consistent with each experimental data [1-5]. The 9.17MeV production yield as a unit of [$\gamma/p$] are varied with respect to several experiments, so in the simulation $0.88 \times 10^{-8}$ [$\gamma/p$] is used, which was obtained by average some previous experiments, $0.74 \times 10^{-8}$ [2], $1.1 \times 10^{-8}$ [3], $1.01 \times 10^{-8}$ [4] and $0.63 \times 10^{-8}$ [5].

The underground condition was assumed as attenuation coefficient 0.0289/cm, and explosive part of anti-personal mine dimension is that 1.5 cm or 5 cm radius and 1cm or 5cm height with a density of $^{14}$N element 0.5 g/cm$^3$.

5 DETECTION TEST EXPERIMENTS

Experiments were performed several times by using KIGAM 1.7MV Tandem and SNU-AMS 3MV Tandetron accelerators. The main experiment was performed by using SNU-AMS Tadetron accelerator. Firstly, we reviewed previous experiments by using the NaI(Tl) with anti-cosmic ray by the thick plastic detectors. We used BGO scintillator to increase detection yield than NaI(Tl) scintillator. At least 30 cm Pb shield was required to distinguish the real signal of mine from observed signals.

We also developed new detection technique to detect the scattered gamma-ray from the nitrogen target by using the energy difference between the Doppler effected gamma-ray from the $^{13}$C(p,γ)$^{14}$N reaction, and the resonant absorbed and scattered gamma-ray from the $^{14}$N(γ,γ)$^{14}$N reaction, especially, 9.17MeV resonance state gamma-ray. In this experiment, the thickness of the enriched $^{13}$C target was 121µg/cm$^2$ self-supporting foil, and we used liquid nitrogen with 20 liter as a resonant absorption target as mine/explosive emulator. We used a HP-Ge detector with 30% efficiency and less 2keV energy resolution. Fig. 4. is the observed spectrum near single escape peak region.

6 DISCUSSION

The resonant gamma-ray production yield of the thick target with 121 µg/cm$^2$ is maximized near 1.745MeV, which is agreed well with previous result [1].

We will realize that the detection system based on the BGO detectors has a sufficient lead shield system. Even though, the detection system based on the BGO scintillator has much more yield about 100 times than that on the HP-Ge detector, we want to prove our detection method and technique in principle by using Doppler effect, based on a HP-Ge detector guaranteed 2keV energy resolution at a several MeV energies. This system did not need any shield in principle, but when performing experiment 10cm Pb brick was used between $^{13}$C target and mine/explosive emulator. The major merit of this technique is that we can separated the gamma-ray from $^{13}$C and mine/explosive emulator when we choose well detection angle of mine gamma-ray. This method is
deeply related on the Doppler effect, because the gamma-ray energies come from $^{13}$C target are a function of detection angle, and the gamma-ray energy from mine emulator is almost a resonant energy. Such gamma-ray energy deviation is maximize when the detection angle is far from resonant angle.

The gamma-ray production and absorption process are the inverse mechanism, and the available angle of this mechanism is only 80.1°. The difference from Doppler effect between forward and backward detection angle is about 130 keV.

We also measured the angular distribution of the gamma-ray production by using the SNU-AMS tandetron accelerator. We used two HP-Ge detectors, in which one was used for the movable angular detector and the other was used for the normalization detector. Fortunately, the yield shows a maximum near at the detection angle 80° near resonant angle.

The scattered gamma-ray yield from $^{14}$N($\gamma$,\$\gamma\$) $^{14}$N resonant reaction is somewhat less than the expected yield calculated by using previous data. The measured scattered yield is 1.8 count/sec/10mA and the expected one is 4.2 count/sec/10mA. When we calculated the yield, some assumptions are used that thick target yield is 1x10^-8 $\gamma$ /p, Hp-Ge detector absolute efficiency is 0.1% for the 59.2 mm(dia) x 76.2mm(L) detection crystal dimension, the attenuation is 30% due to liquid nitrogen dewar case [6].

Fig. 4. The spectrum measured for the photo-nucleus resonant reaction. Spectrum at 108° is measured at a off-resonance angle and Spectrum 81° is at an on-resonance angle.

### 8 REFERENCES