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Weak Nuclear Response studies & Nuclear Isotope Detection using muon probes at the MuSIC facility at RCNP

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Abstract: MuSIC is a highly intense muon facility at RCNP, Osaka University, where negative muons of about 10^8 muons/sec can be produced. The muon yield available at MuSIC is almost the same as the world highest. By using nuclear muon capture reactions, nuclear weak/neutrino responses are studied by measuring emitted gamma-rays from residual nuclear states and nuclear radioactive isotopes. They provide important information relevant to matrix elements for neutrinoless double beta decays and for supernova neutrino processes. This gives unique opportunities to study them directly through the weak interaction. In addition, negative muons are useful to determine rare isotope concentration by measuring muonic X rays and gamma rays from nuclear radioactive isotopes. Both of the measurements can be carried out by using high-resolution Ge detectors at RCNP. We are planning to carry out the experiment at MuSIC in June. Preliminary results will be presented.

1.0 INTRODUCTION

MuSIC is a highly intense muon facilities at RCNP, Osaka University. Equipped with continuous time structure, MuSIC can produced about 10^8 negative muons /sec using a 400W proton beam [1-3]. The muon yield available in MuSIC is almost the same as the world highest. MuSIC was consists of a pion capture system using a superconducting solenoid magnet, and a part of superconducting muon transport solenoid channel have been build on 2009 and started operating since then.

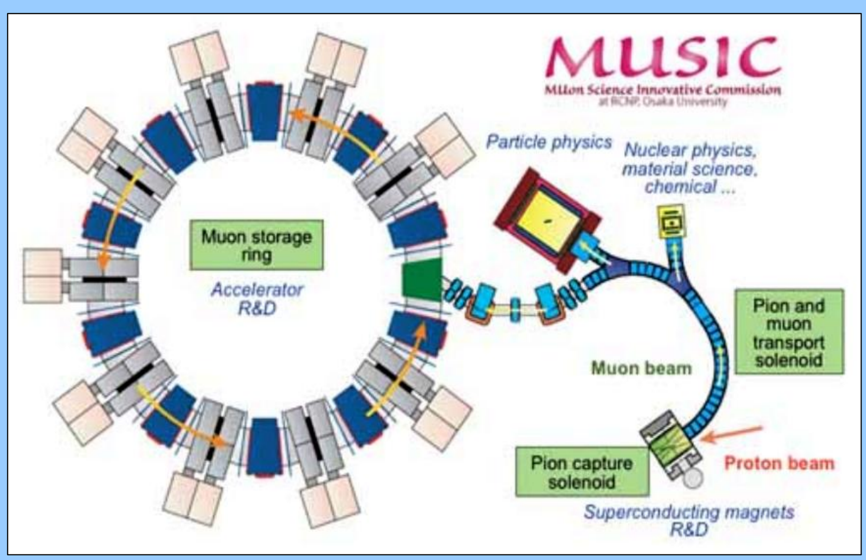

Figure 1: Schematic layout of MuSIC

Fundamental properties of neutrinos and weak interactions can be studied in atomic nuclei by measuring double beta decays (ββ), inverse beta decays induced by solar and supernova neutrinos, and astroneutrino nuclear interactions [4,5]. The nuclear weak for low-lying states are obtained from β decay rates and electron capture rates. However, they are limited to β decays from the ground state in the intermediate nucleus only[6].

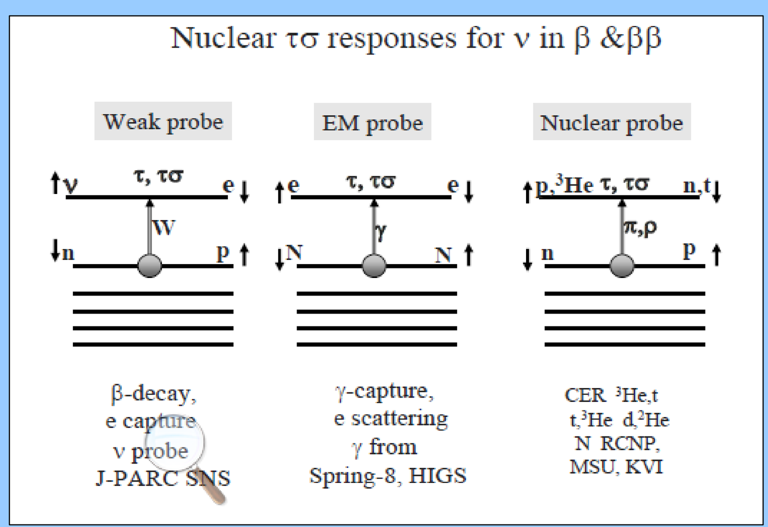

Figure 1:Nuclear spin isospin responses for neutrinos studied by weak, electromagnetic and nuclear probe interactions [4].

A non-destructive detection of nuclear isotopes by measuring γ rays following a photonuclear reaction product have been of great interests for basic and applied science. It was a powerful studies of nuclear isotopes which sensitivities is in the orders of ppm-ppb and μgr-ngr [8].

In probing the nuclear responses with muon probe from MuSIC, muon capture reactions of (μ,ν_μ) are used to get the β+ strength in the intermediate nuclei [4,8]. Excitation energies and angular momenta involved in this reaction are between the energy range of 0 < E < 50MeV and $0^{\pm}$, $1^{\pm}$ and $2^{\pm}$. Furthermore, by observing muon capture in heavy material, it will be useful in determining rare isotope concentration by measuring muonic atomic X-rays[7].

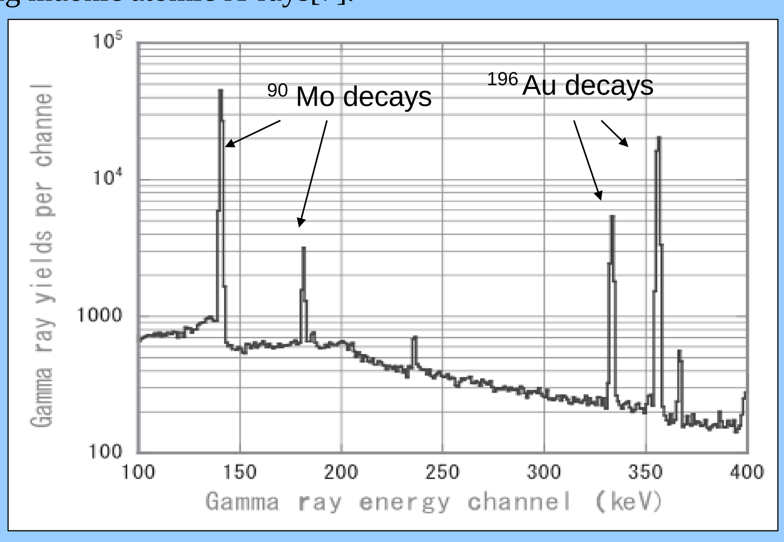

Figure 3: Energy Spectrum of γ-ray from natural Mo sample with 0.074 of Au weight [8].

4.0 EXPERIMENTAL METHOD

In order to demonstrate the feasibilities of nuclear weak response studies and nuclear isotope detection by using μ probe from MuSIC, a molybdenum target will be irradiated by a medium energy muon. There will be two setup is needed for this experiment during the June beam test.

For muonic X-ray measurement to determine the isotope separation, the online set up will be used. The online measurement (Figure 5) was taken in order to observe muonic atomic X-ray from Mo target by using ORTEC GMX45 Ge detector and determine the isotopes separation from ^{100}Mo $(\mu,\gamma)^{100}$Nb and ^{100}Mo$(\mu,\nu\gamma)^{99}$Nb decays [8-10].

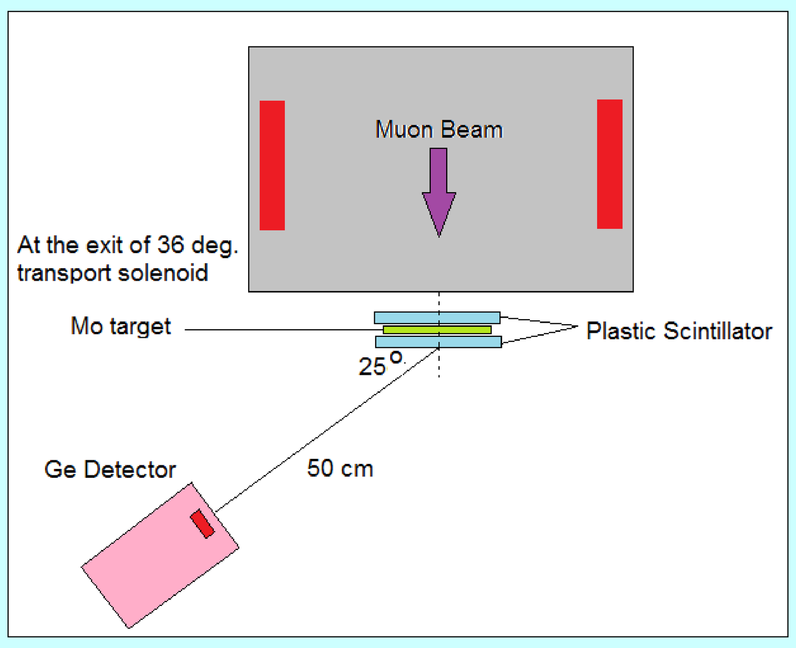

Figure 5: Online measurement setup.

2.0 MuSIC STATUS

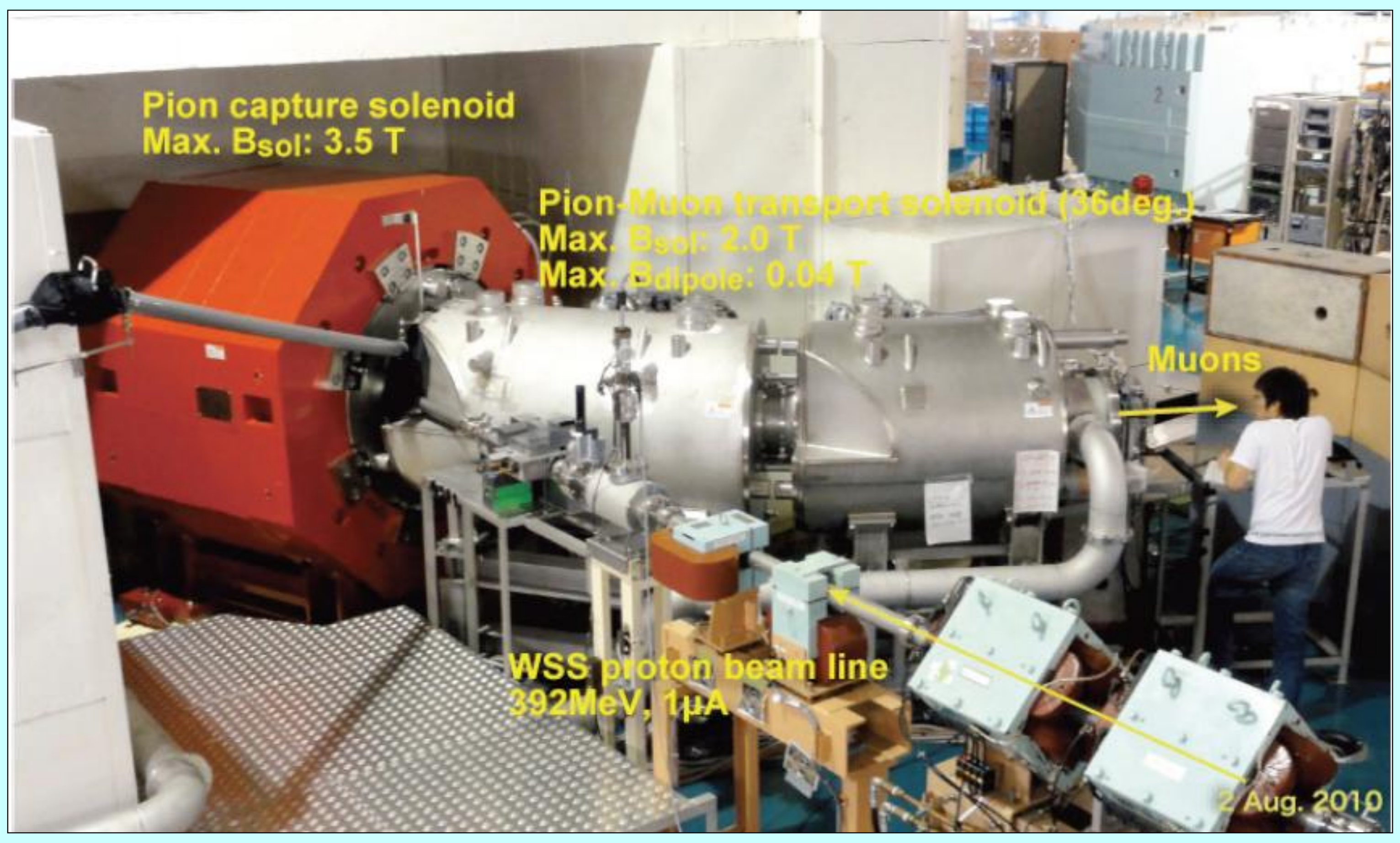

Figure 3(a): MuSIC facilities at west experimental hall RCNP

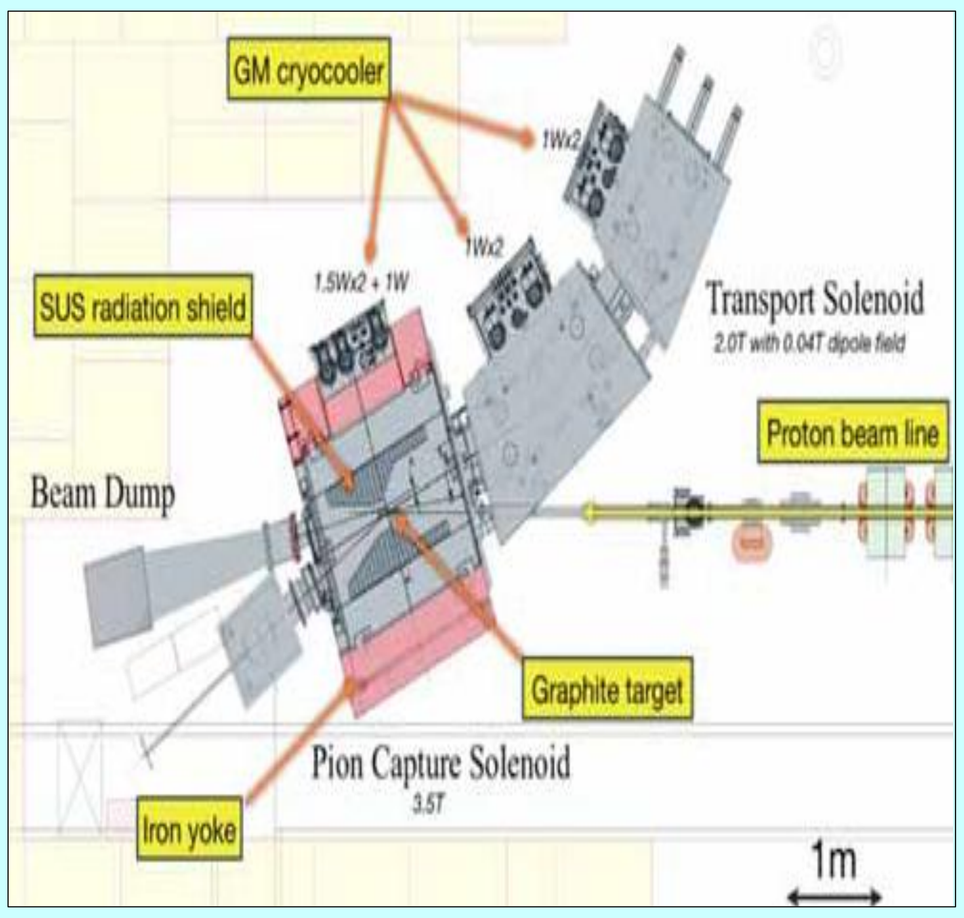

Figure 3(b):Drawing of MuSIC layout up on construction year 2011.

MuSIC facilities provide the world's highest intensity muon beam using a 400W proton beam provided by the cyclotron. The layout of the proposed system of MuSIC was consists of pion capture system and followed by a muon transport solenoid. The 180 degrees arc of solenoid can make a dipole field up to 0.04 Tesla, in addition to the solenoidal field for charge and momentum selection of the muon beam. A beam current of 4nA is available at present, for June beam test 1μA beam current will be use [1]. MuSIC was currently under construction at the experimental hall in RCNP of Osaka University since 2009. The pion capture system and muon transport solenoid up to 36 degrees was already operated. (Figure 3(a) and 3(b)).

3.0 4th BEAM TEST

Four beam tests have been performed to check the performance of muon beam intensity and the muon yield by MuSIC. Graphite target was injected by up to 10 nA proton beam to produce pions. At the end of the 36 degrees solenoid, the detector and stopping target (Mg or Cu) was put into position. In the last beam tests, muon lifetime measurement and muonic X-ray measurement with higher statistics have been analyze in order to determine number of muon yield by MuSIC [1]. Figure 4(a) illustrates the experimental setup for muon lifetime measurement and muonic X-ray measurement. The results of muon lifetime measurement and muonic X-ray measurement can be seen in figure 4(b) and 4(c).

Figure 4(a): Experimental setup for muon lifetime and muonic X-ray measurements.

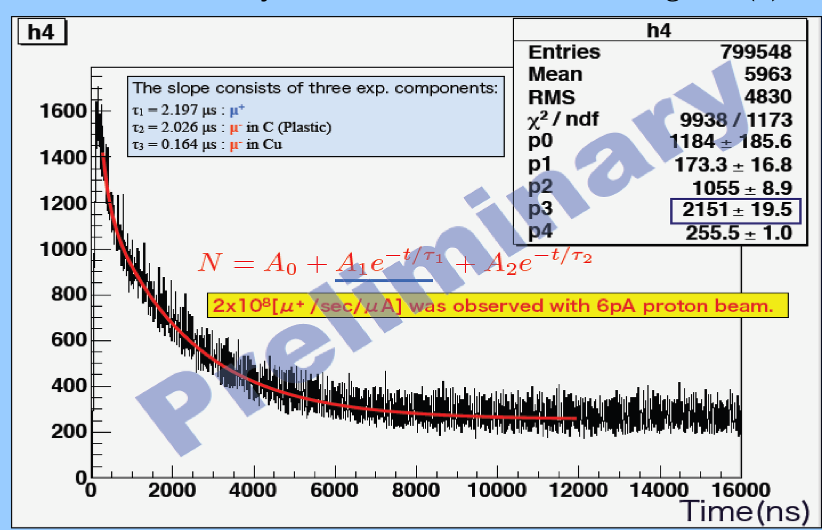

Figure 4(b): Results for muon lifetime measurements using Cu as a stopping target.

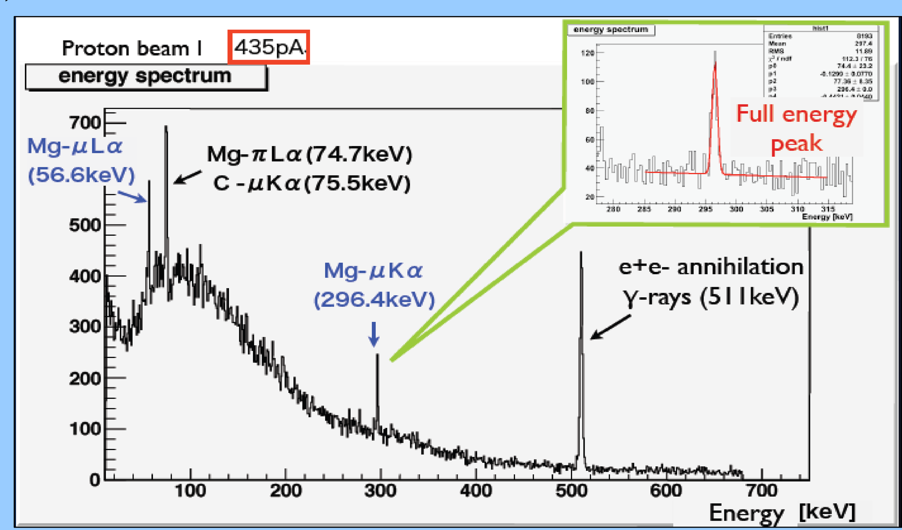

Figure 4(c): Results for muonic X-ray measurements using Mg as a stopping target.

After 5 hours irradiation time, the Mo target was taken for offline measurement. The offline measurement uses to record the gamma ray energy for the weak nuclear response studies of Mo target isotopes. Mo target was place near to a high definition Ge Detector for data taking.

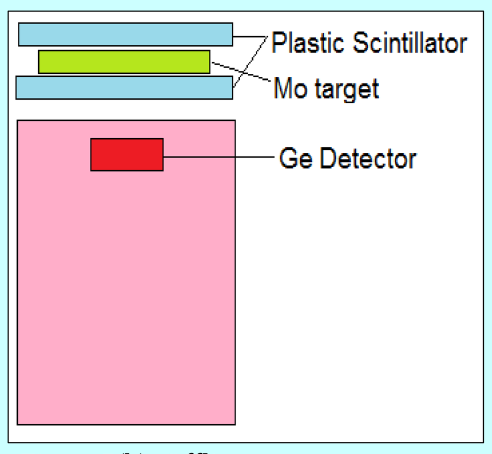

Figure 5(b): Offline measurement setup

5.0 SIMULATION

From the Geant 4 simulation on a natural Mo target with ^{100} Mo 9.6% for supernova neutrino responses with the dimension of 100 mm x 100 mm x 5 mm and density of 11 g/cm3, the were about 75% from total muon yield by MuSIC will stop on target. Figure 6 shows the simulation results of muon stopped on Mo target. The stop rate of muon when 10nA proton beam is injected on Mo target is 4X10^4 muons/sec.

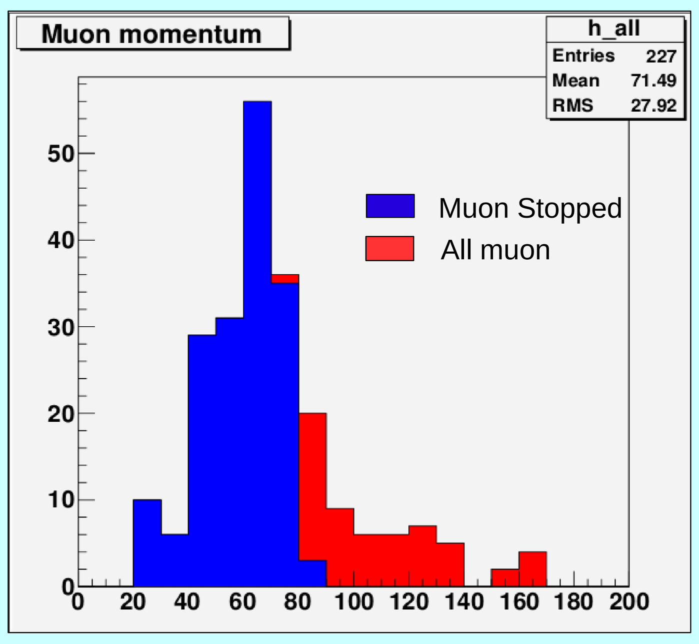

Figure 6: Number of muon stopped on Mo target.

The yield of γ and X rays at 10 nA beam current was calculated . Yield of X-ray energy from K-Mg at 259 keV, K-Mo at 3622 keV and L-Mo at 476 keV will be observed when the peak efficiency, ε(X) ~ 2x10^{-5} where ε(X) is the peak efficiency of 25mm diameter of Ge detector at 50 cm distance from the solenoid exits.

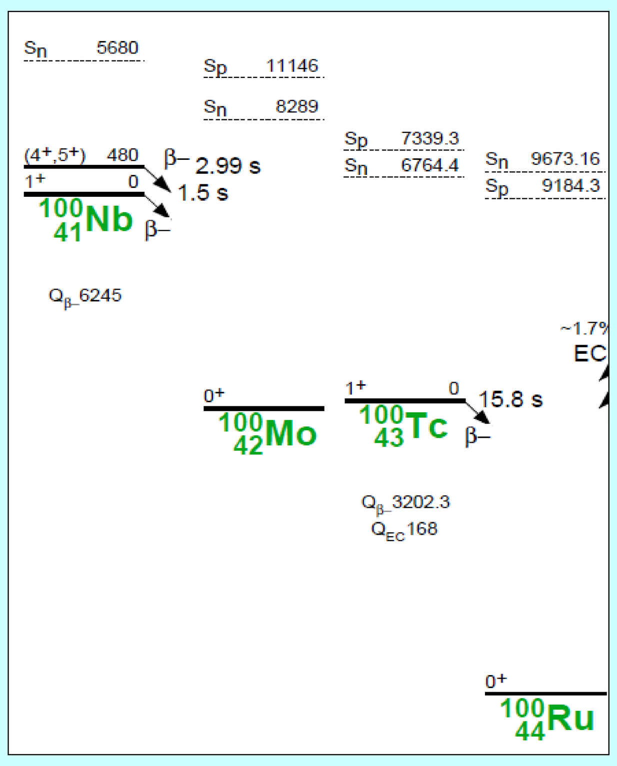

Figure 7(a): Decay of ^{100}Mo $(\mu,\gamma)^{100}$Nb with γ emission at 536 keVand 600 keV.

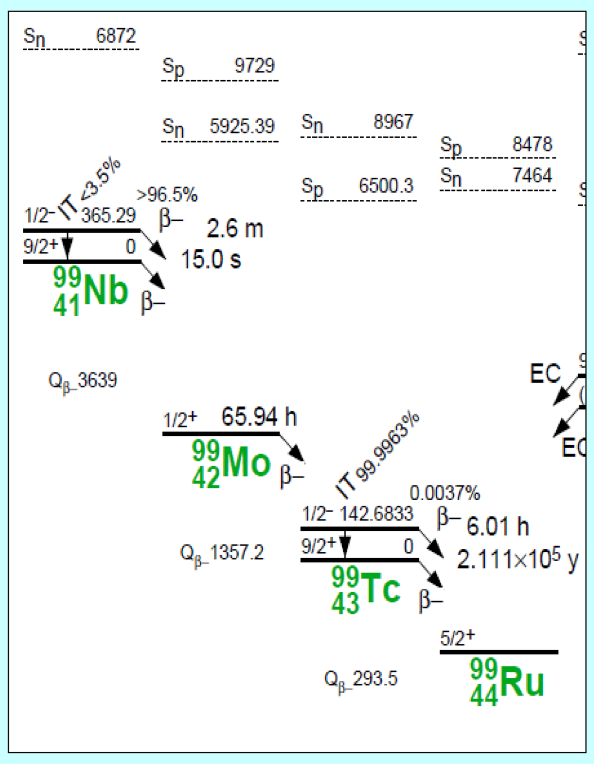

Figure 7(b): Decay of ^{100}Mo $((\mu, n\gamma)^{99}$Nb with β$^-$and γ emission at 98 keV and 138 keV.

The X-ray energy yield from 5 hour irradiation, Y(X) ~ 5.52x10^{-1}/sec or about 2.0 k/hour for each yield of gamma ray, Y(γ) from ^{100}Mo with the ratio of 0.096. In the online measurement, the decays of ^{100}Mo (μ,γ) ^{100}Nb can be observes at 1.5 second and 3 second at X-ray energy of 536 keV as shown in figure 7(a). However, in the ^{100}Mo $(\mu, \nu\gamma)$ ^{99}Nb decays at 15 second and 2.6 min with X-ray energy 98keV and 139 keV respectively (Figure 7(b)). After 5 hours of irradiation time, the total yield on Molybdenum target, Y(X) will be about 1.38x10^{-3}/sec.

For offline measurement, the 5 hours bombardment on radioisotope of ^{99}Mo/^{99}Tc the gamma ray energy at145 keV might be observed on energy spectrum. The production ratio of gamma ray for offline measurement can be calculated by irradiation time, t'/mean life of radioisotope ^{99}Mo, which is about 0.05. In offline measurement, the Mo metal is placed on top of Ge detector of 50 mm diameter with the peak efficiency, ε(γ) about 10^{-2}.The total yield of gamma ray for offline measurement, Y(γ) is 0.394 k /sec = 1.42 M / hour.

6.0 CONCLUSIONS

Medium energy μ from MuSIC are use for the study of nuclear weak response by observing the nuclear activities following (μ, νγ) reactions. The muon captures use to determine nuclear isotopes separation by the emission of atomic muonic X-ray. The gamma ray emission from offline measurement might gives unique opportunities to study them directly through weak interaction. We aim to promising future of the study of nuclear weak response by using μ probe.

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