Development of the measurement system of the ^{189}Os(n,n'γ) cross section and Re/Os chronometer

Y.Temma, M.Segawa, Y.Nagai, T.Ohta, A.Nakayoshi, S.Fujimoto, H.Ueda, T.Shima, M.Igashira[1], T.Ohsaki[1], J.Nishiyama, T.Masaki[2]

Research Center for Nuclear Physics, Osaka Univ.,
[1]Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology,
[2]Kobe University
e-mail: temma@rcnp.osaka-u.ac.jp

Abstract

The keV neutron inelastic scattering reaction off the ground state of ^{189}Os to the 36 keV excited state is important in the study of Re/Os chronometer. So far, the cross section has been measured by detecting neutrons inelastically scattered by ^{189}Os. However, it is not easy to accurately measure the cross section with the mentioned method, because both the inelastically and elastically scattered neutrons from ^{189}Os are detected simultaneously by a neutron detector. Hence, we are now developing a new measurement system to detect the γ-ray from the ^{189}Os(n,n'γ)^{189}Os reaction.

1. Introduction

The age of the universe is one of the most interesting themes in astrophysics. It is known that ^{187}Re/^{187}Os pair is one of the good chronometers to estimate the age of the universe, since it has unique features described below. First, the parent nucleus ^{187}Re is formed only by a rapid neutron capture process in stars and its half life is quite long 42.3 Gyr. Second, the chemical property of ^{187}Re and ^{187}Os is similar, so the chemical affection for ^{187}Re and ^{187}Os is cancelled in taking the abundance ratio of ^{187}Re to that of ^{187}Os. However there are a few problems in the ^{187}Re/^{187}Os chronometer. First, ^{187}Os abundance increases by the β decay of ^{187}Re, and also by a slow neutron capture (s-) process of ^{186}Os, and decreases by the s-process of ^{187}Os. Second, inside stars ^{187}Os could be significantly populated at a stellar temperature (~ 30keV), and ^{187}Os is also depleted by the excited neutron capture process. Therefore the neutron capture cross sections of ^{186,187}Os through the ground- and excited states are very important in order to precisely derive the age of the universe. Since it is not possible to measure the excited neutron capture cross section at a terrestrial laboratory, the cross section should be estimated by a theoretical calculation. For constructing the reliable theoretical model to calculate the excited neutron capture cross section of ^{187}Os, measurements of the inelastic scattering cross section off the ground state (J^{π}= 1/2$^-$) of ^{187}Os to its excited 10keV state (J^{π}= 3/2$^-$), and the neutron capture cross section of the ground state (J^{π}= 3/2$^-$) for ^{189}Os and inelastic cross section off the ground state (J^{π}= 3/2$^-$) of ^{189}Os to its excited 36keV state (J^{π}=1/2$^-$) were suggested firstly by Fowler [1]. Here, it should be noted that the nuclear structure of these two odd-A Os isotopes has the same active nucleon configurations, the same deformation, the same spin-parity for the ground state and 1st excited state in ^{187}Os are 1/2$^-$ and 3/2$^-$, while those in ^{189}Os are 3/2$^-$ and 1/2$^-$, respectively (Figure 1).

We are planning to measure the inelastic cross section off the ground state of ^{189}Os to its excited 36keV state, $\sigma_{n,n'}$(^{189}Os). So far, $\sigma_{n,n'}$(^{189}Os) was measured by detecting the neutrons inelastically scattered by ^{189}Os with scintillation counters [2]. However, it is not easy to accurately measure $\sigma_{n,n'}$(^{189}Os) by detecting neutrons, because both the inelastically and elastically scattered neutrons from ^{189}Os are detected simultaneously by neutron detectors. We also made the (n,n') reaction experiment by employing a ^{6}Li-glass detector, but the obtained signal-to-noise ratio was low 0.0084. Hence, we are now developing a new measurement system to detect the 36 keV γ-ray from the ^{189}Os(n,n'γ)^{189}Os reaction by using Si detectors. This new method is expected to have high sensitivity to detect the γ-ray, but there are a few problems. First, the self-absorption of the 36 keV γ-ray by ^{189}Os sample is large. Second, the 36 keV γ-ray competes with an internal conversion electron process. Third, it is difficult to separate the 36 keV γ-ray signal from the background γ-ray due to the ^{7}LI(p,γ)^{8}Be reaction because of the low time resolution of Si detectors. Hence the intensity of the 36 keV γ-ray due to the ^{189}Os(n,n'γ)^{189}Os reaction is estimated to be quite low, and therefore it is crucial to develop a high sensitive system to measure $\sigma_{n,n'}$(^{189}Os).

2. Experimental procedure

In order to construct the mentioned system we measured γ-ray background by placing Si detectors and Pb shield at various places. The neutrons with an averaged energy of 30 keV were produced by the ^{7}Li(p,n)^{7}Be reaction using a pulsed proton beam provided from the 3.2 MV Pelletron accelerator of the Research Laboratory for Nuclear Reactors at Tokyo Institute of Technology. The produced neutrons were emitted into a corn of about 50° with respect to the proton beam direction. Main γ-ray background was found to be the γ-ray due to the ^{7}Li(p,γ)^{8}Be reaction. We measured pulse height and time-of-flight (TOF) spectra to obtain net γ-ray yields as a function of the neutron energy by separating the γ-ray from the ^{189}Os(n,n'γ)^{189}Os reaction from the γ-ray due to the ^{7}Li(p,γ) ^{8}Be reaction. An experimental setup is shown in figure 2.

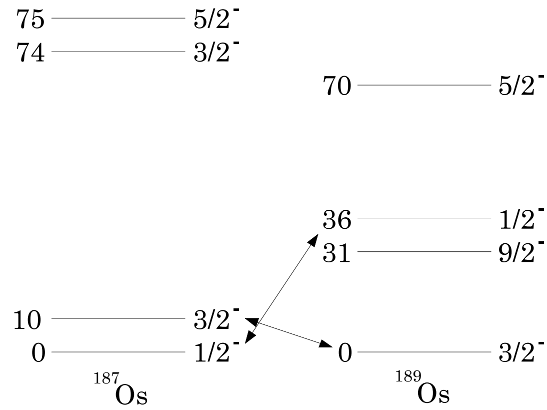

Figure 1 : level scheme of ^{187}Os and ^{189}Os

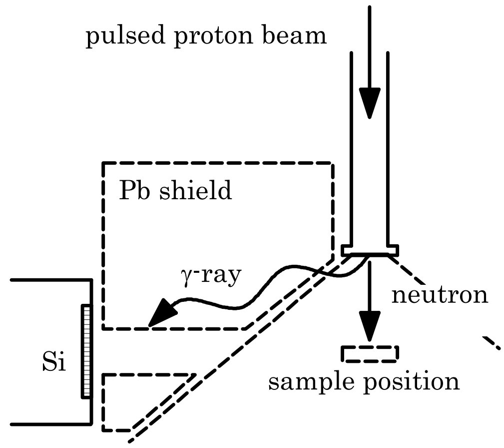

Figure 2 : the measurement geometry

3. Result

We measured the TOF spectra without putting a sample at a sample position by using Pb shield with various thicknesses. A typical TOF spectrum taken without Pb shield around the Si detector is shown in figure 3(a). By covering the Si detector with Pb shield and placing Pb shield with a thickness of 5, or 10, and/or 15 cm (picture 2) between the Li neutron production target and the Si detector, we obtained the spectrum as shown in figure 3(b). It is clearly seen that we needed to put Pb shield with a thickness of 15 cm to construct the system with a large signal-to-noise ratio.

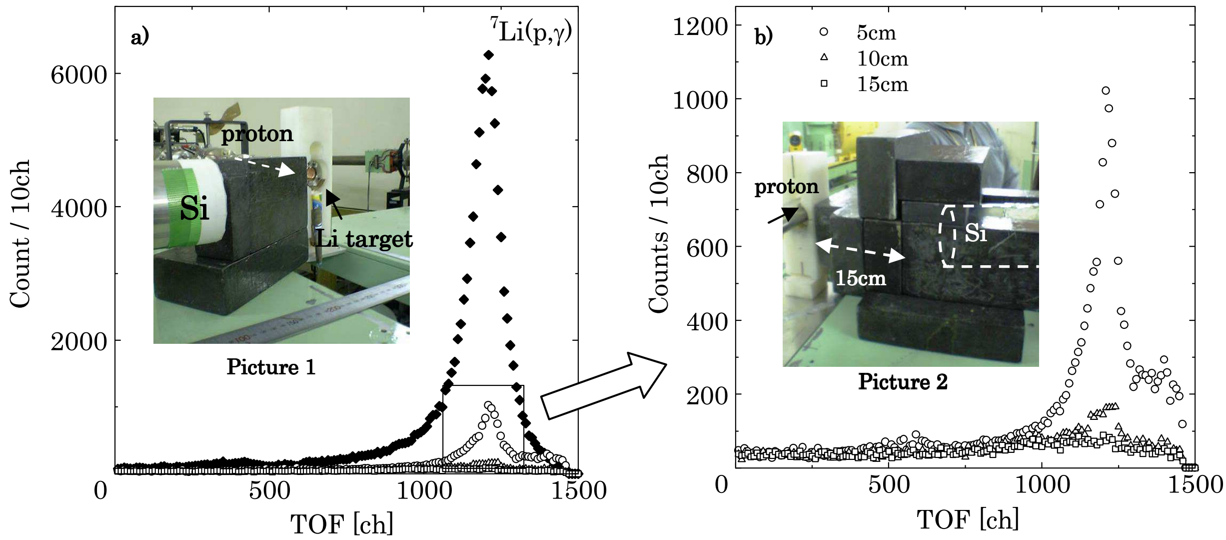

Figure 3 : TOF spectra without sample due to the ^{7}Li(p,γ)^{8}Be reaction

In order to study the performance of a system, we measured a TOF and γ-ray spectra taken by bombarding a ^{159}Tb sample. The γ-ray spectrum for the neutron energy range from 36 to 70 keV is shown in Figure 4, where the sharp peaks at around 45 and 75 keV are due to the X-rays from ^{159}Tb and Pb shield, respectively. We estimated the counting rate of the background around 36 keV region from the obtained γ-ray spectrum by taking into account the energy resolution of Si detector 1.8 keV (FWHM) at 31 keV (Figure 5) to be 84 cph. While the 36 keV γ-ray yield due to the $^{189}Os(n,n'\gamma)^{189}Os$ reaction was estimated to be about 8 cph according to a previous result. Therefore, the signal-to-noise ratio could be 0.09, 10 times larger than that for the detection of inelastic neutrons.

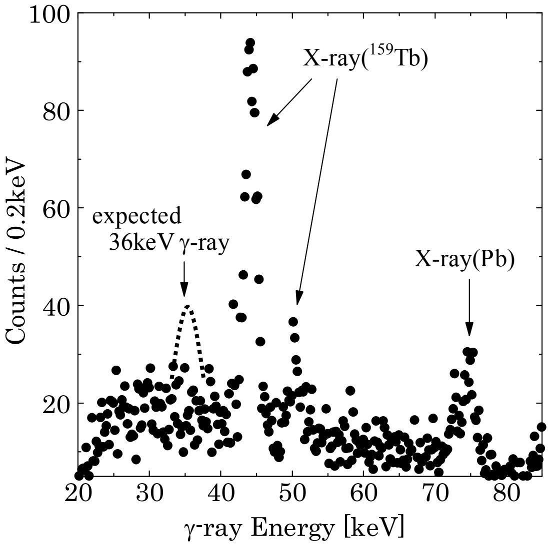

Figure 4：
γ-ray spectrum taken with ^{159}Tb sample

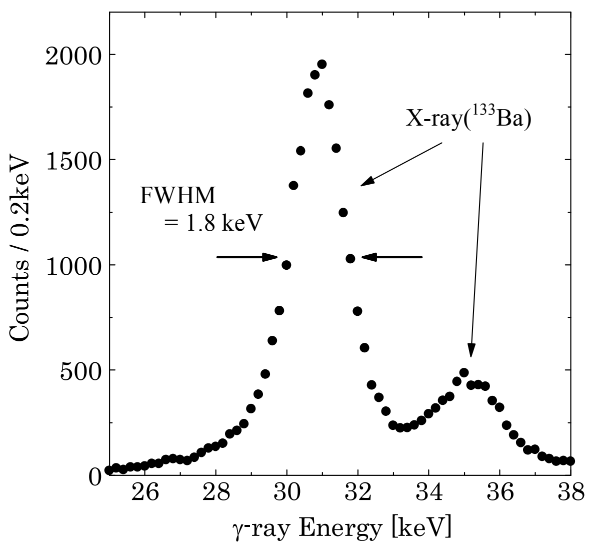

Figure 5：energy resolution of Si detector

4. Summary

We have made a test experiment to detect the γ-ray due to the inelastic scattering off the ground state of ^{189}Os to its excited 36keV state by means of a Si detector to determine its reaction cross section. We are now making a proper shield based on the present result to measure the $^{189}Os(n,n'\gamma)^{189}Os$ cross section using four Si detectors.

Reference

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[2] M. T. McEllistrem, R.R.Winters, R.L.Hershberger, Z.Cao, Phy. Rev. C**40** (1989) 591