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Nuclear temperature and PEQ effect of neutron cascade

I. H. Hashim[1], *S. S. Saroni*[1], *H. Ejiri*[2], *W. N. A. W. M. Rasdi*[1]

[1] **Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, MALAYSIA**
[2] **Research Center for Nuclear Physics, Osaka University, 10-1 Mihogaoka Ibaraki, Osaka 567-0047 JAPAN**

Objectives

1) To determine the effects of target concentration towards isotopic distribution after muon capture
2) To study the effect of nuclear temperature towards the isotope population after muon capture process.
3) To provide useful information about the muon capture strength by compare with experimental observation at J-PARC, MLF

Introduction

The neutrino response was studied by implementing the ideas of neutron decays after muon capture. There are several parameters needed to deduce the information that is useful for resolving nuclear matrix element (NME) uncertainties:

a) The ratio of PEQ and EQ neutron emissions toward isotopic distribution
b) The initial excitation energy (strength distribution) of excited nuclei
c) PEQ and EQ neutron emissions and formation of compound and pre-compound nucleus after muon capture
d) Nuclear temperature relationship with nuclear density parameter

Assumptions :

PEQ and EQ nuclei will be performed by every muon captures in the nucleus and eventually undergo isomeric transition and neutron emission

Neutron emission occurs either in EQ or PEQ phase.

The nuclear density parameter was set to be constant, a = 12 MeV with mass region of A = 100

The nuclear temperature is defined from the excitation energy of nuclei and directly proportional to excitation energy after neutron emission

A realistic neutron binding energy is used as the threshold energy of the neutron emission

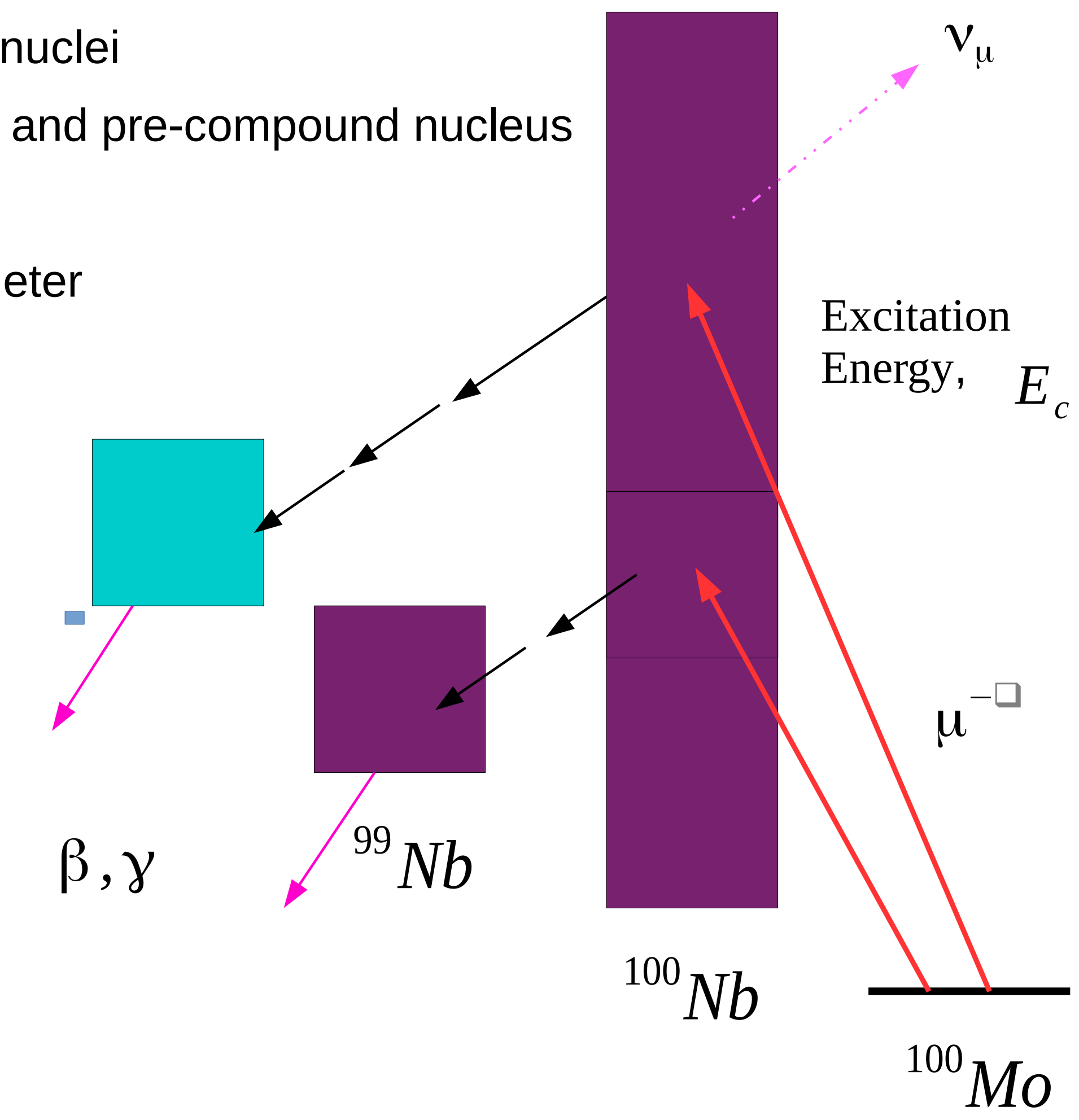

Figure 1: Layout of neutron statistical model with muon captures on target nuclei and emission of x neutrons

1.
The negative muon beam is captured by a nucleus. It was expected that **most muon are capture by nuclei with Z>10.**
The capture process will emit the muon **neutrino that carries most of its energy.**

$$\mu + {}^{A}_{Z}X \rightarrow {}^{A}_{(Z-1)}Y + \nu_\mu$$

2.
Muon capture reaction excites the nucleus into some excited level. Excited nuclei tends to **formed compound and pre-compound nucleus** by emission of **equilibrium and pre-equilibrium neutron** through **beta and delayed beta decay.**

$${}^{A}_{Z}X \rightarrow {}^{A}_{(Z+1)}Y + {}^{0}_{-1}\beta + \bar{\nu}_e$$

3.
If the excitation energy is **greater than the neutron binding energy** of the nuclei, there are probability that **more than one neutron will be emitted**.

$${}^{A}_{Z}X \rightarrow {}^{(A-1)}_{Z}Y + {}^{1}_{0}n$$

4.
Detection of delayed gamma rays from beta decay or delayed beta decay **discriminates the isotope production** after the nuclear reaction.

$${}^{A}_{Z}X' \rightarrow {}^{A}_{Z}X + \gamma$$

Results and discussion

Model 1 and 2 are proposed to reproduce the experimentally observe isotope distribution from MLF, J-PARC experiment obtained in July 2014. These model represent the excitation energy after muon capture reaction and formation of compound and pre-compound nucleus.

It is expected that the neutrino nuclear responses for muon capture reaction are in the same order with responses of neutrino-less double beta decay, Thus, both models will study from the range of 0 to 70 MeV. The primary peak response are suggested by H.Ejiri in 1972 at 9-13 MeV. The effect of secondary resonance peak at 30-33 MeV will be represents by Model 2.

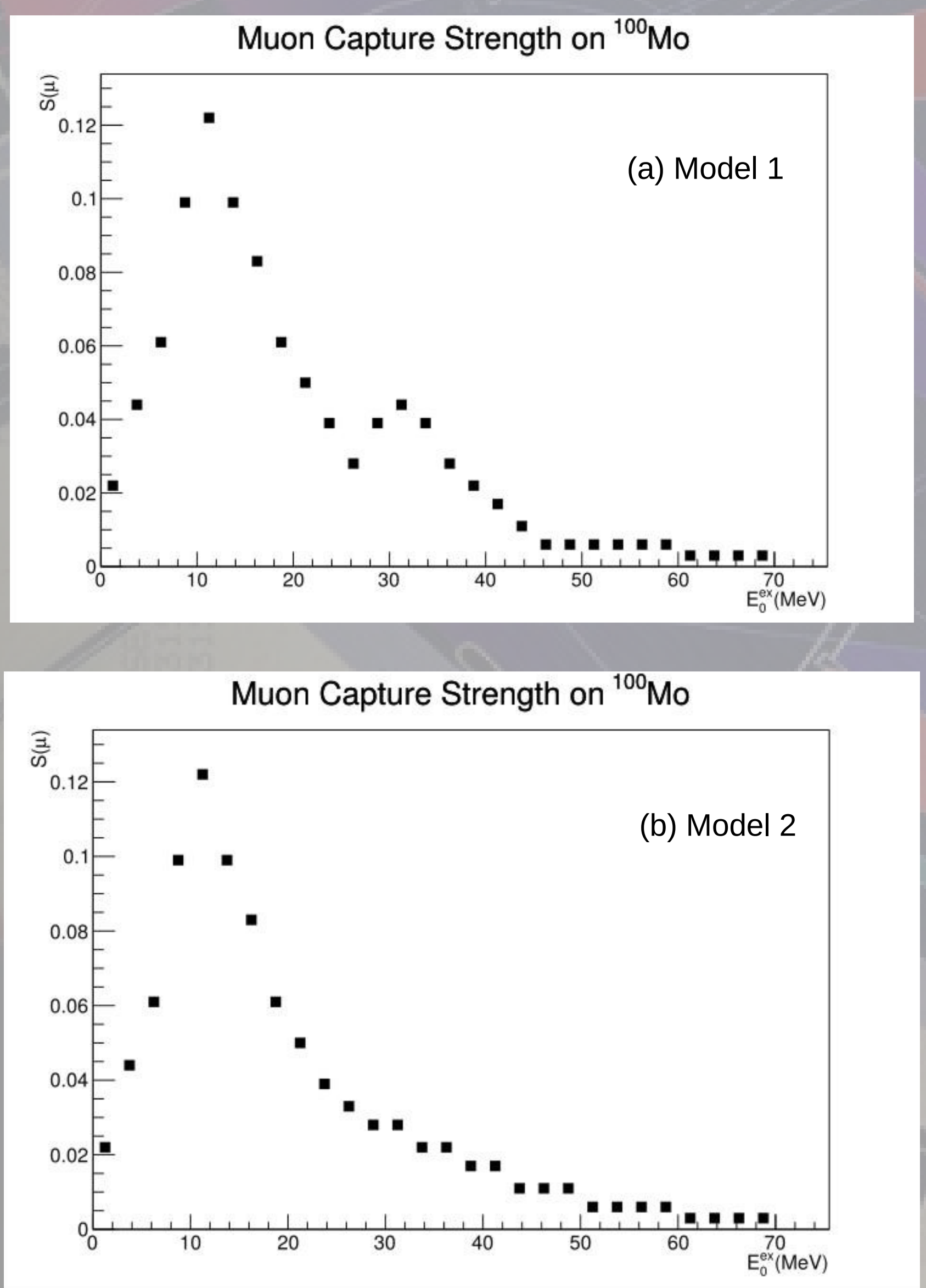

Figure 2: Initial excitation distribution (a) Model 1 (b) Model 2

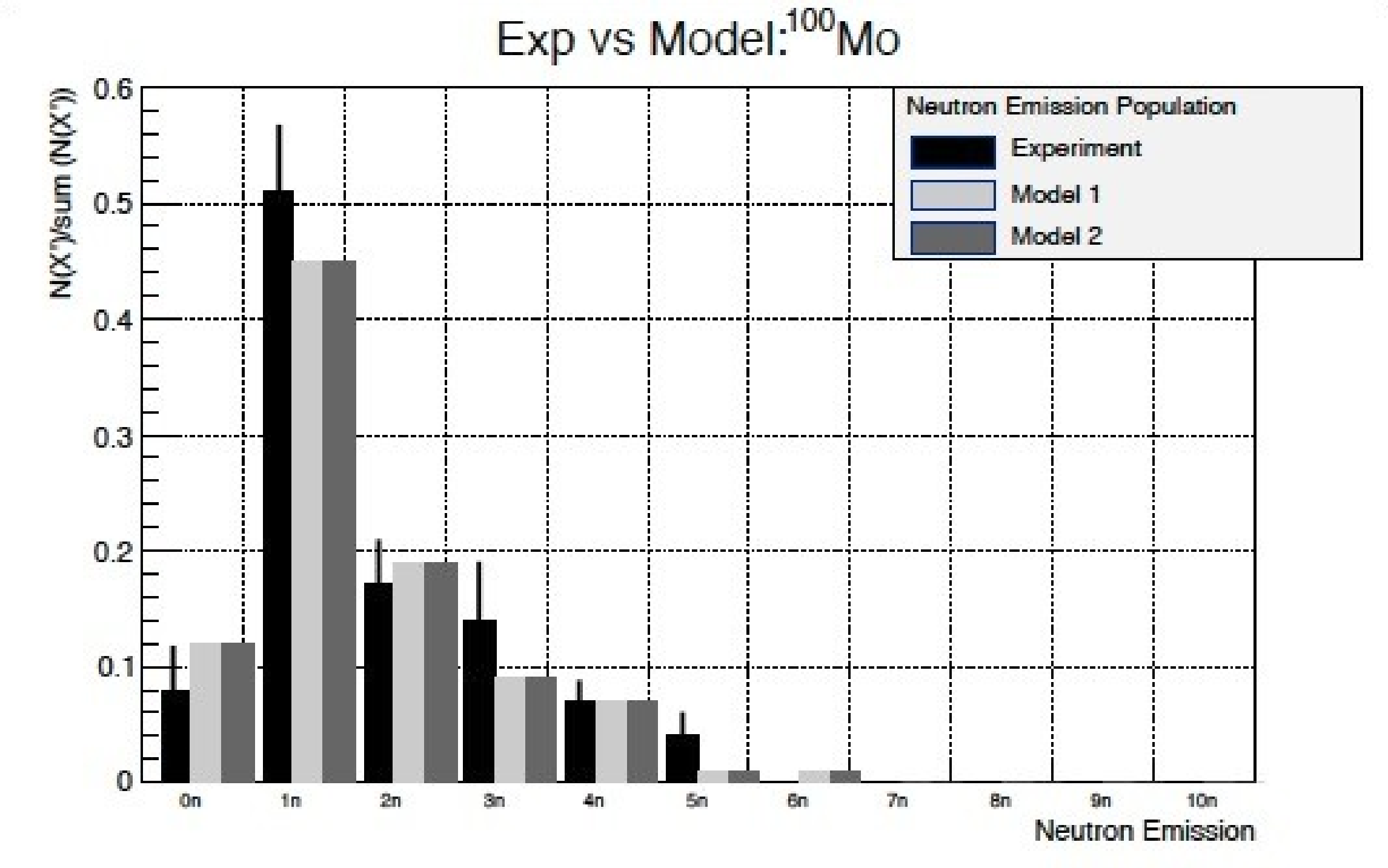

Figure 3: Neutron emission distribution for comparison of experimental observation and models.

Figure 3 shows the comparison between model 1 and 2 with the experimental data. There are slight difference are observed at 3 and more neutron emissions due to the response from secondary resonance peak. Also the neutron emissions tends to increase with the existence of the resonance peak. However, because the experimental error was large, we cannot confirmed the necessities of secondary peak in the initial excitation energy distribution.

Figure 4 and 5 illustrates the effects of nuclear temperature ratio plotted using model 1 and 2. The effective nuclear temperature ratio proposed in 1989 and 2001 for selected material with atomic mass number 16 to 158 are 1:5. However, there are some argument regarding determination of nuclear density parameter (a) which causes large uncertainty towards nuclear temperature especially on heavy nuclei. These data, shows better reproducibility when the ratio of T_{EQ} and T_{PEQ} is 1:3. While if the ratio of the nuclear temperature is larger, the neutron emission distribution is wider.

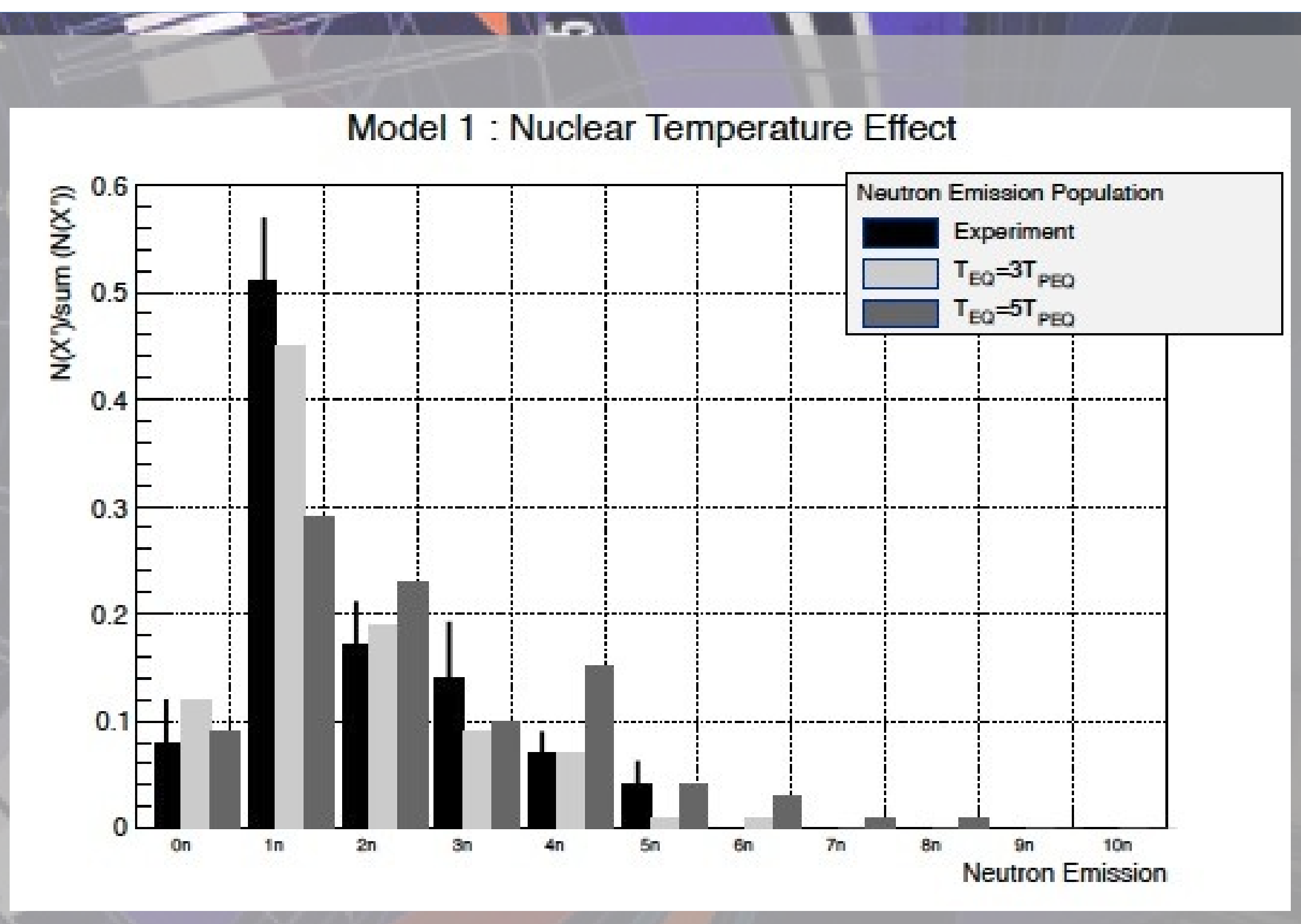

Figure 4: Nuclear temperature effect on model 1

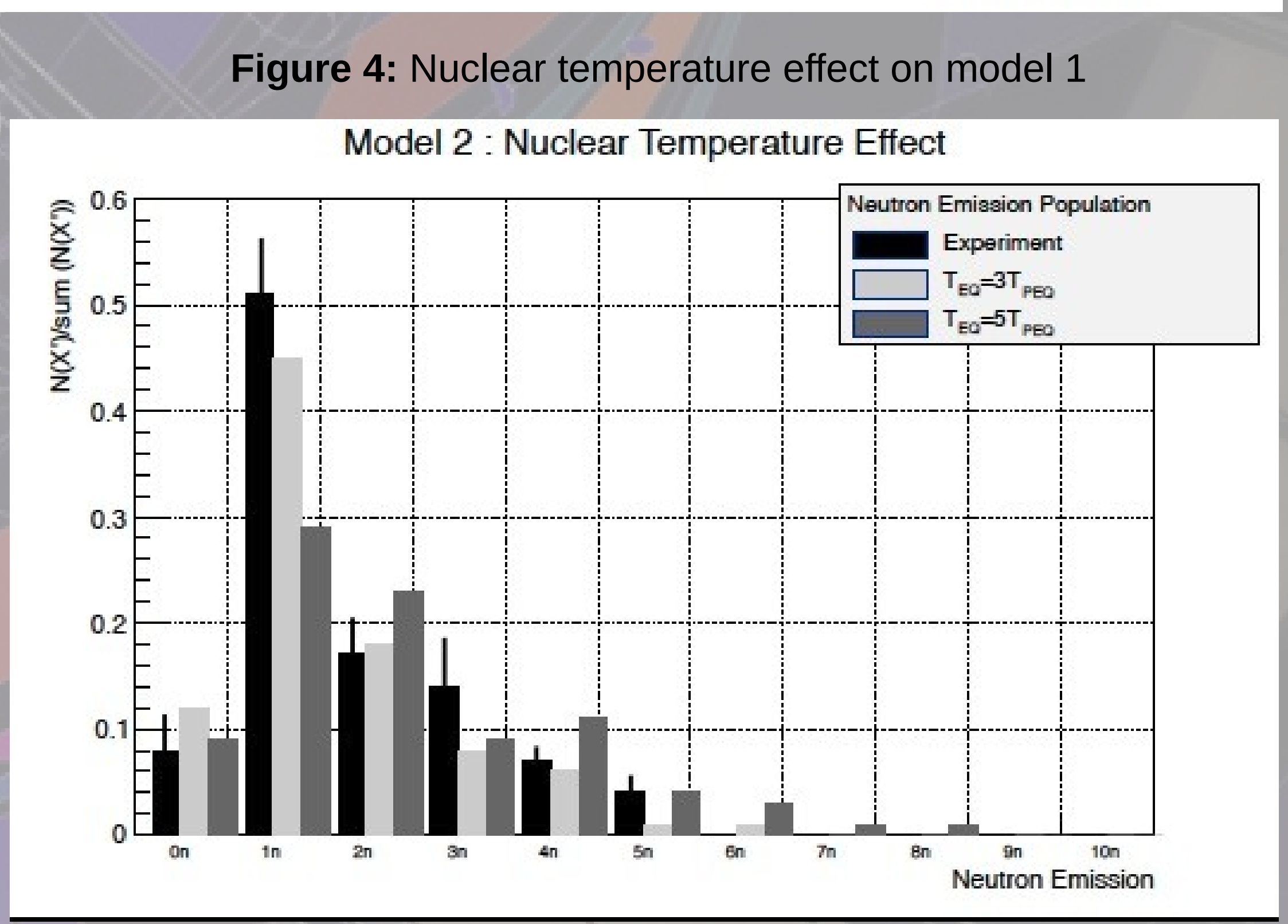

Figure 5: Nuclear temperatures effect on model 2

The purity of the target used in the model are similarly reported in 1992 which are 94.5% of ^{100}Mo and 5.5% comes from the natural abundance of Mo isotopes. The effect of isotope concentration in the target material used for the reaction was about 5%.

Concluding Remarks

The relative capture strength for ^{100}Mo are compared with model 1 and 2. The weak strength distributed in the range of 0 -70 MeV which are similar response to neutrino-less double beta decay with the maximum strength at 9 to 13 MeV. The existence of secondary resonance peak at 30-33 MeV shown by model 1 was not proven necessary since both model estimate the value in the range of experimental error. More accurate data are requires for comparison.

Muon irradiation experiment have been proposed to study the prompt gamma and X-ray of ^{100}Mo and prompt gamma and X-ray and delayed gamma rays of ^{100}Ru at MuSIC, RCNP. MuSIC facility provides highly intense continuous muon beam might help to reduce the pile-up effect in prompt gamma and X-ray measurement. The absolute life-time measurement will also be held during the beamtime.

The concentration and type of the target does not effect the data due to highest purity is saturated at atomic mass 100. However, for natural target where the concentration is distributed accordingly the effect my cause observation of more than 4 neutron emissions.

The effects of nuclear temperature is large, a calculator for calculation of nuclear density parameters might help to study these problems.

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