Verification of the Surrogate Ratio Method

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Abstract

Effects of difference in the spin and parity distributions for the surrogate and neutron-induced reactions are investigated. Without assuming specific (schematic) spin-parity distributions, it was found that the surrogate ratio method can be employed to determine neutron fission and capture cross sections if 1) weak Weisskopf-Ewing condition (defined in this paper) is satisfied, 2) there exist two surrogate reactions whose spin-parity distributions of the decaying nuclei are almost equivalent, and 3) difference of the representative spin values between the neutron-induced and surrogate reactions is no much larger than 10 $\hbar$. If these conditions are satisfied, we need not to know the spin-parity distributions populated by the surrogate method. Instead, we should just select a pair of surrogate reactions which will populate the similar spin-parity distributions, using targets having similar structure and reactions having the similar reaction mechanisms. Achievable accuracy is estimated to be around 5 and 10 $\%$ for fission and capture channels, respectively, for nuclei of the Uranium region. The surrogate absolute method, on the contrary, can be marginally applicable to determination of fission cross sections. However, there will be little hope to apply this method for capture cross section measurements unless the spin-parity distributions in the neutron-induced and surrogate reactions are fairly close to each other or the difference can be corrected theoretically. The surrogate ratio method was shown also to be a robust method in the presence of breakup reactions, again, without assuming specific breakup reaction mechanisms.

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I. INTRODUCTION

With the advance of nuclear science and technology, neutron cross sections of unstable nuclei, such as minor actinides (MAs) and long-lived fission products (LLFPs), are becoming more and more necessitated. Neutron cross sections of radioactive nuclei also play important roles in astrophysical nucleosynthesis. In spite of the importance, however, measurement of neutron cross sections are extremely difficult for these nuclei since preparation of enough amount of sample is difficult or practically impossible. At the same time, theoretical determination of the fission and capture cross sections still suffers from a large uncertainty if there exists no experimental data; an error of factor of 2, namely the uncertainty of 100 %, will be a reasonable estimate. These fundamental problems prevent us from accurate determination of neutron cross sections of unstable nuclei including MAs and LLFPs.

Recently, a new method, called surrogate method, has come to be used actively to determine neutron cross sections of unstable nuclei (see, e.g., Refs. [1 –11] and references therein). This is a method which uses (multi) nucleon transfer reactions (both stripping and pick-up) or inelastic scattering on available target nuclei and produce the same compound nuclei as those of the desired neutron-induced reactions, and measure the decay branching ratios leading to capture and/or fission channel. Identification of the produced compound nuclei and their excitation energies can be done by detection of the ejectile species and their energies.

At a first glance, it seems to be a simple and effective method to simulate the neutron-induced reactions. However, the thing is not that easy. Even if we produce the same compound nuclei at the same excitation energy as produced in the desired neutron-induced reactions, the spin-parity distributions are plausibly different between them. Since we are interested in low-energy neutron cross sections relevant to reactor applications and astrophysics, the produced compound nuclei decay statistically, and the branching ratio is strongly influenced by the spin and parity. Therefore, difference of the spin-parity distributions between the surrogate and neutron-induced reactions must be properly taken into account in converting the branching ratio determined by the surrogate method to the one for neutron-induced reactions. Up to now, however, it has not been able to deduce the spin-parity distribution in the surrogate reactions, since they are normally multi-nucleon transfer reactions, the reaction mechanisms of which are not understood well. What have been done so far is to assume that the decay branching ratio does not depend on the spin-parity and ig-
nore the difference; the so-called Weisskopf-Ewing condition, or to assume schematic (rather arbitrary) spin-parity distributions for the surrogate reaction and argue that they do not affect the decay branching ratio sensitively. Both of these approaches, however, are based on arbitrary assumptions which have not been justified theoretically nor experimentally. On the other hand, it is also true that the surrogate method has yielded a rather accurate cross sections, verified when the corresponding neutron data are available. Therefore, it is natural to expect that there is a certain condition to equate the results from the surrogate method and the neutron-induced reactions. However, the condition under which the surrogate method works is not clearly understood yet.

In this paper, we investigate the spin-parity dependence of the branching ratios of Uranium isotopes to the fission and capture channels and clarify the condition for the surrogate (ratio) method to work, and estimate the accuracy achievable by it.

II. SURROGATE “ABSOLUTE” AND “RATIO” METHODS

In the surrogate method, we measure a branching ratio to a specific decay channel, normally the fission or capture channel by populating the same kind of compound nucleus as the desired neutron-induced reactions. We denote the decay channel by a subscript \( i \) (\( i = \text{fission or capture} \)), and then the surrogate method hopefully gives a ratio of the neutron cross section \( \sigma_n^i \) to the total neutron reaction cross section \( \sigma_n^R \) of the compound system, namely,

\[
R_S^i \equiv \frac{\sigma_n^i}{\sigma_n^R}, \tag{1}
\]

The symbol \( R_S^i \) denotes the branching ratio of the nucleus decaying to channel \( i \) populated by the surrogate reaction, and is defined later by Eq. (6). By multiplying it the total reaction cross section \( \sigma_n^R \) calculated by the optical or coupled-channel model, we can determine the neutron cross section \( \sigma_n^i \). Here, a question mark is explicitly shown since it is not obvious if this equality holds or not. It is due to the reason that the spin-parity distributions populated in the surrogate (left-hand-side) and neutron-induced (right-hand-side) reactions are different, and the branching ratio is dependent on them in general. This is the very fundamental problem to be resolved for the surrogate method to yield correct neutron-induced cross sections. This method is referred to as the surrogate absolute method. On the contrary, these ratios can be measured for two nearby nuclei 1 and 2 by using the same
kind of surrogate reactions, $S_1$ and $S_2$, e.g., $(t, p)$ reactions on different targets. If we know the neutron cross section $\sigma_i^{n_2}$ for the reaction leading to the same compound nucleus as the $S_2$ reaction, we can determine the neutron cross section ($\sigma_i^{n_1}$) which leads to the same compound nucleus as $S_1$ reaction via the equality (with a question mark)

$$\frac{R_{S_1}^{S_1}}{R_{S_2}^{S_2}} = \frac{\sigma_i^{n_1}}{\sigma_i^{n_2}},$$

$$\rightarrow \sigma_i^{n_1} = \sigma_i^{n_2} \cdot \frac{R_{S_1}^{S_1}}{R_{S_2}^{S_2}} \cdot \frac{R_{S_1}^{S_1}}{R_{S_2}^{S_2}}, \quad (i = \text{fission or capture}).$$

Here, $\sigma_i^{n_j}$ denotes the neutron fission ($i=$fission) or capture ($i=$capture) reaction cross section, and $\sigma_R^{n_j}$ the total neutron reaction cross section for the reaction $n_j$ ($j = 1$ or 2). Provided that the above equations hold, we can determine the neutron cross section $\sigma_i^{n_1}$ from this formula, since we know $\sigma_i^{n_2}$, we measure the ratio $R_{S_1}^{S_1}/R_{S_2}^{S_2}$ and we can calculate the ratio of the reaction cross sections $\sigma_R^{n_1}/\sigma_R^{n_2}$ by the coupled-channel theory rather accurately\cite{12, 13}. This method is referred to as the surrogate ratio method or relative surrogate method. It is naively expected to give a result better than the surrogate absolute method, since we do not need to know in the relative method all the experimental artifacts such as the detector efficiency and geometrical factor required to deduce the ratio in the absolute method. However, all these methods require a fact that the branching ratios are equal for the surrogate and the neutron-induced reactions. This is true only when 1) the ratios are independent of the spin-parity of the decaying nuclei (Weisskopf-Ewing condition\cite{14}), or 2) the spin-parity distributions are equivalent for the surrogate and neutron reactions, or 3) the ratio is not sensitive to the difference of the spin-parity distributions between the neutron-induced and surrogate reactions. Below, we will investigate if these assumptions are justified or not, and when justified, what accuracy will be.

III. COMPUTATIONAL METHOD AND RESULTS

We use the Hauser-Feshbach theory\cite{15} to calculate the decay branching ratios of various spin-parity ($J^\pi$) states of $^{239}\text{U}$ by using CCONE code system\cite{16}. It represents a nucleus produced by $n+^{238}\text{U}$ reactions and corresponding surrogate reactions such as $^{237}\text{U}(t, p)^{239}\text{U}$. This nucleus was chosen just as an example. In the calculation, the same parameter values for discrete level structures, transmission coefficients, level density, fission barrier and
GDR as used in the evaluation of JENDL Actinoid File 2008[17] were used. Therefore, the present calculation contains realistic information of the characteristics of participating nuclei adjusted to reproduce neutron cross sections.

Figures 1 and 2 shows the branching ratios (decay probabilities) to the fission (Fig. 1) and capture (Fig. 2) channels for various $J^\pi$ states of $^{239}$U up to $J^\pi = (21/2)^\pm$ and neutron energy of 5 MeV. The upper panels in Figs. 1 and 2 show branching ratios from positive parity states, while the lower ones denote those from negative parity states. If the Weisskopf-Ewing condition is fulfilled, the various lines in these figures must coincide (at least approximately); if it is the case both of the surrogate absolute and ratio methods can be justified. However, Fig. 1 shows that the fission decay ratio varies depending on $J^\pi$ by about 15 % at 5 MeV but variation is about 50 % at 1.5 MeV. The convergence is much worse for the capture channel as shown in Fig. 2; the branching ratios scatter by a factor of about 10 at 5 MeV, and the variation is much larger at lower energies. Therefore, we have to conclude that there is only little hope to use surrogate method to determine neutron capture cross sections at these energies, since the low-energy neutron-induced reactions bring only small angular momentum to the compound system in general, while the surrogate method will bring much more. The absolute surrogate method, therefore, will never work to measure capture cross sections unless the spin-parity distribution between the neutron-induced and surrogate reactions are fairly close to each other or the difference is corrected theoretically. It will be also only marginally applicable to measure the fission cross sections.

However, the $J^\pi$ dependence of the branching ratios to the fission and capture reactions show rather systematic behaviors. Above 2.5 MeV, the fission probability shown in Fig. 1 increases monotonically as $J$ increases. Same trend is true for the capture reaction. Since it was found also to be true for other compound nuclei in this mass region, $^{236}$U and $^{237}$U (not shown here), we may expect that there is a possibility to cancel out the large $J^\pi$ dependence by taking ratios of the branching ratios for each $J^\pi$. We have done such calculations and the results are shown in Figs. 3 and 4. Figure 3 shows the ratios of fission probabilities (branching ratios) for $^{239}$U and $^{237}$U for various values of $J^\pi$. We can notice an astonishingly good convergence. The thick black line denotes the ratios of the neutron fission probabilities ($\sigma_f^d/\sigma_f^R$) for the corresponding neutron-induced reactions. All the curves converges to the ratio of the neutron fission probabilities very well. The deviation is only a level of 3 % at 5 MeV. The largest scatter lies at about 1.6 MeV, but the scatter around the neutron curve is
only a level of several % nominally, while that was about 50 % in Fig. 1. This means that we can determine the unknown fission cross sections by taking this kind of ratio if we know one of the other neutron cross section. The convergence seems to be valid also for somewhat higher value of spins. Similar convergence, although less dramatic, can be seen in Fig. 4 for capture probabilities. At 5 MeV, the ratios of the capture branching ratios for the 2 nuclei scatter only by about ±5 % around those for the neutron capture reaction. At energies from 2.5 to 4 MeV, the surrogate ratios are all larger than the neutron ratio, but the deviation is still only 10 %. The same ratios were compared for various \( J^\pi \) states produced in the neutron-induced reactions on \(^{197}\text{Au}\) and \(^{193}\text{Ir}\) in Fig. 5. We can notice that very good mutual convergence up to \( 8^+ \) and equivalence to the neutron ratio are obtained in this mass region as well. Therefore, these data can be used to determine the GDR parameters at an energy region of, e.g., 2 to 5 MeV to normalize the calculated neutron capture cross section, and these parameters can be used to calculate the capture cross sections at lower energies since the Hauser-Feshbach theory can predict the shape of the energy dependent cross section rather accurately if normalization is given correctly at certain energies. Therefore, there is a fair possibility that we can determine the neutron capture cross section with accuracy of several % by the surrogate ratio method in combination with a theoretical calculation. The convergence of the ratios of fission and capture probabilities are very important to validate the surrogate technique and can be a base of the validity of surrogate ratio method.

IV. FORMAL VERIFICATION OF THE SURROGATE RATIO METHOD

In the previous section, we have seen that the ratios of fission and capture probabilities at various values of \( J^\pi \) between 2 nuclei have a dramatic convergence to the ratios of the neutron reactions. This can be utilized to verify the surrogate ratio method as follows. Let 2 surrogate reactions used for the ratio method be denoted as \( S_1 \) and \( S_2 \), and corresponding neutron reactions as \( n_1 \) and \( n_2 \). The reactions \( S_j \) and \( n_j \) (\( j=1,2 \)) are chosen to lead to the same compound nucleus. Let us assume that we know the neutron cross section \( \sigma_n^{12} \) for the \( n_2 \) reaction. The branching ratio of the surrogate reaction for channel \( i \) (\( i = \text{fission or capture} \)) may be written as \( B_{ij}^{S_j}(U, J^\pi) \), where \( U \) denotes the equivalent neutron energy (\( U \) can be the excitation energy as well). Then, the identity of the branching ratios shown in
Figs. 3 and 4 can be expressed as

$$\frac{B_{S_1}^i(U, J^\pi)}{B_{S_2}^i(U, J^\pi)} = \frac{R_{n_1}^i(U)}{R_{n_2}^i(U)}$$

(4)
to the accuracy mentioned above, where

$$R_{n_j}^i \equiv \frac{\sigma_{n_j}^i}{\sigma_{R_i}^i}.$$  

(5)

Relation of the $B_x^i$ and $R_x^i$ ($x = S_j$ or $n_j$) are expressed as follows:

$$R_{x_j}^i(U) \equiv \sum_{J^\pi} \frac{\sigma_{x_j}^i(U, J^\pi) \cdot B_{x_j}^i(U, J^\pi)}{\sum_{J^\pi} \sigma_{x_j}^i(U, J^\pi)},$$

(6)

where $\sigma_{x_j}^i(U, J^\pi)$ denotes the formation cross section of $J^\pi$ states in reaction $x_j$ including the factor of $(2J + 1)$. Equation (4) can be rewritten as

$$B_{S_1}^i(U, J^\pi) = B_{S_2}^i(U, J^\pi) \cdot \frac{R_{n_1}^i(U)}{R_{n_2}^i(U)}.$$  

(7)

Then, the decay probability for reaction $i$ in surrogate $S_1$ measurement, $R_{i}^{S_1}$, can be written as

$$R_{i}^{S_1}(U) = \frac{\sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi) \cdot B_{S_1}^i(U, J^\pi)}{\sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi)} = \frac{\sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi) \cdot B_{S_1}^i(U, J^\pi) \cdot R_{n_1}^i(U)}{\sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi) \cdot R_{n_2}^i(U)} = \frac{R_{n_1}^i(U) \cdot \sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi) \cdot B_{S_1}^i(U, J^\pi)}{\sum_{J^\pi} \sigma_{S_1}^i(U, J^\pi) \cdot R_{n_2}^i(U)}.$$  

(8)

Since the 2 surrogate reactions $S_1$ and $S_2$ are assumed to be carried out for a pair of nuclei having similar mass and structure, the distribution of the formation cross section $\sigma_{S_1}^i(U, J^\pi)$ will be fairly close to that of $\sigma_{S_2}^i(U, J^\pi)$ if the nuclear structure and reaction mechanisms are similar to each other. We can write this similarity as $\sigma_{S_1}^i(U, J^\pi) = \alpha \sigma_{S_2}^i(U, J^\pi)$, where the symbol $\alpha$ denotes a constant such as the kinematical factor. If the dependence of $\alpha$ on $J^\pi$ is ignorable, Eq. (8) reads

$$R_{i}^{S_1}(U) = \frac{\sum_{J^\pi} \alpha \sigma_{S_2}^i(U, J^\pi) \cdot B_{i}^{S_2}(U, J^\pi)}{\sum_{J^\pi} \alpha \sigma_{S_2}^i(U, J^\pi)} = \frac{R_{n_1}^i(U)}{R_{n_2}^i(U)} \cdot R_{i}^{S_2}(U)$$  

by definition. This equation is equivalent to Eq. (2). Since we know $R_{n_2}^i(U)$, and we measure $R_{i}^{S_1}/R_{i}^{S_2}$ in surrogate ratio method, we can obtain $R_{n_1}^i$ to the accuracy mentioned above. This gives an explanation of the reason why the surrogate ratio method works.
The essential point in the verification is the equality given in Eq. (4) and equality of the $J^\pi$ spectra of the 2 surrogate reactions. The latter implies that the $J^\pi$ distributions in the surrogate reactions can be different from those of the neutron-induced reactions. What is important is that 2 surrogate reactions should yield equivalent $J^\pi$ distributions. It can be easily achieved in experiments by selecting targets having similar structure and using the same reaction for both the surrogate reactions. However, the difference of the representative spin between the neutron-induced and surrogate reactions should not be much larger than about 10 $\hbar$. We define the equality given in Eq. (4) as “weak Weisskopf-Ewing condition”. This condition is different from the standard Weisskopf-Ewing condition, which is written as

$$B_{i}^{S_1}(U, J^\pi) = B_{i}^{S_2}(U) = R_{i}^{S_3}(U). \quad (10)$$

If this standard condition is satisfied, we can determine the branching ratios by the surrogate absolute method. Unfortunately, it is not the case for the reactions investigated in this paper, especially it is a poor assumption for the capture reaction as shown in Fig. 2.

The surrogate ratio method has another advantage over the absolute method. Since the surrogate method uses multi-nucleon transfer reactions very often, there is a possibility, when the corresponding neutron energy increases, that the nucleons expected to be transferred to bound states of the target is actually transferred to an unbound state, eventually leading to the breakup (or preequilibrium) reactions such as $^{238}\text{U}(t, np)^{239}\text{U}$ instead of expected reaction $^{238}\text{U}(t, p)^{240}\text{U}$. This effect can be also canceled out by the surrogate ratio method as follows.

Let us denote the bound states as “Q”, and unbound ones as “P”. Since we measure the ejectile (e.g., p), the production cross section of it contains transitions to both the Q- and P-states of the residual nuclei. On the contrary, the true decay occurs only via the Q-states. Therefore, the decay probabilities measured in the surrogate method in the presence of breakup reaction, $R_{i}^{S_1}(P + Q)$, can be written as

$$R_{i}^{S_1}(P + Q) = \frac{\sum_{j} \hat{Q}\sigma^{S_1}(U, J^\pi) \cdot B_{i}^{S_1}(U, J^\pi)}{\sum_{j} (\hat{P} + \hat{Q})\sigma^{S_1}(U, J^\pi)} \leq R_{i}^{S_1}(U) = \frac{\sum_{j} \hat{Q}\sigma^{S_1}(U, J^\pi) \cdot B_{i}^{S_1}(U, J^\pi)}{\sum_{j} \hat{Q}\sigma^{S_1}(U, J^\pi)}, \quad (11)$$

where the $\hat{Q}$ and $\hat{P}$ denote fractions of transitions to the Q- and P-states, respectively, and $\hat{P} + \hat{Q} = 1$. The same is true for the $S_2$ reaction Therefore, the ratio of the measured surrogate
reaction ratios reads

\[
\frac{R_{i}^{S_{1}}(P+Q)}{R_{i}^{S_{2}}(P+Q)} = \frac{\sum_{J=\pi} \tilde{Q}\sigma^{S_{1}}(U,J^\pi) \cdot B_{i}^{S_{1}}(U,J^\pi)}{\sum_{J=\pi} \tilde{Q}\sigma^{S_{2}}(U,J^\pi) \cdot B_{i}^{S_{2}}(U,J^\pi)}
\]

\[
= \frac{R_{i}^{n_{1}}(U)}{R_{i}^{n_{2}}(U)} \cdot \frac{\sum_{J=\pi} \tilde{Q}\sigma^{S_{2}}(U,J^\pi) \cdot B_{i}^{S_{2}}(U,J^\pi)}{\sum_{J=\pi} \tilde{Q}\sigma^{S_{2}}(U,J^\pi) \cdot B_{i}^{S_{2}}(U,J^\pi)}
\]

\[
= \frac{R_{i}^{n_{1}}(U)}{R_{i}^{n_{2}}(U)} \cdot \frac{\sum_{J=\pi} \tilde{Q}\sigma^{S_{2}}(U,J^\pi) \cdot B_{i}^{S_{2}}(U,J^\pi)}{\sum_{J=\pi} \tilde{Q}\sigma^{S_{2}}(U,J^\pi) \cdot B_{i}^{S_{2}}(U,J^\pi)}
\]

(12)

where the weak Weisskopf-Ewing condition (Eq. (7)) and proportionality of \(\sigma^{S_{1}}(U,J^\pi)\) and \(\sigma^{S_{2}}(U,J^\pi)\) were employed. Therefore, the surrogate ratio method has a capability to work even when breakup (or preequilibrium) reaction occurs.

Even though the derivation here is qualitative, it was enough to assume that the ratios of \(\tilde{P}\) and \(\tilde{Q}\) to be the same for the 2 surrogate reactions used in the ratio method. This can be satisfied if the breakup mechanisms are the same, which is a reasonable assumption. Again, it must be noted that we do not need to understand the breakup reaction mechanism itself, which is a formidable task, but just require them to be the same for the 2 reactions employed in the ratio method. It can be easily verified experimentally by observing the spectra of emitted particles. This may explain the reason why the ratio method worked to measure the \(^{236}\text{U}(n,f)\) cross section for energies above several MeV as reported by Lyles et al.\[8\] where the 2nd and 3rd chance fission occur, which corresponds to the condition that the breakup reaction can occur in the surrogate method.

V. CONCLUDING REMARKS

We have investigated the condition that the surrogate reaction should work. It was found that the surrogate absolute method will give a marginal result for fission cross sections but it seems to be hopeless to apply it for the capture cross section measurements. On the contrary, it was shown that, without assuming any specific (schematic) spin parity distributions, the surrogate ratio method has a high potential to determine neutron fission and capture cross sections. The achievable accuracy would be around 3~5 % for the fission and 10 % for the capture cross sections under the condition investigated in this work (up to difference of spin values of between neutron-induced and surrogate reactions of around 10 \(\hbar\)) for nuclei in Uranium region at around 2.5 to 5 MeV. The success is brought by the weak Weisskopf-Ewing
condition, namely, $J^\pi$ by $J^\pi$ convergence of the branching ratios and their coincidence to the neutron reaction ratio, defined in this work. Furthermore, it is important to select a pair of nuclei, one of which is the reference nucleus, having similar properties so that the excitation spectra of various $J^\pi$ states can be considered almost equivalent. These conditions are the basis for the surrogate ratio method to work. Furthermore, it was shown to be rather robust even breakup reaction occurs. This was shown again without assuming any breakup reaction mechanisms. Altogether, the surrogate ratio method was proved to be a useful method to determine neutron cross sections for which the direct measurements using neutrons are not possible. Generally speaking, however, application of the surrogate method must be done with a caution. It will be very sensitive to the spin and parity of the decaying nucleus at low energies since transitions to discrete levels, which differ nucleus to nucleus, occupy a dominant part of the decay branch there. This is the reason why the weak Weisskopf-Ewing condition tends to be violated at lower energies.

It must be also noted that we use a standard Hauser-Feshbach calculation using models and parameters adjusted to reproduce neutron cross sections, but the results may have some dependence on them. Such a dependence, however, is expected also to be small in the surrogate ratio method, since many factors in models and parameters can cancel out in the ratio quantities.

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FIG. 1: (Color online) Decay probabilities (branching ratios) to the fission channel from various $J^\pi$ states of $^{239}$U. (a) : positive parity states, (b): negative parity states
Capture probability for U-238+n positive parity states

Capture probability for U-238+n negative parity states

FIG. 2: (Color online) Decay probabilities (branching ratios) to the capture channel from various $J^\pi$ states of $^{239}$U. (a): positive parity states, (b): negative parity states
FIG. 3: (Color online) Ratios of decay probabilities (branching ratios) to the fission channel from various $J^\pi$ states of $^{239}$U and $^{237}$U. (a): positive parity states, (b): negative parity states.
FIG. 4: (Color online) Ratios of decay probabilities (branching ratios) to the capture channel from various $J^\pi$ states of $^{239}$U and $^{237}$U. (a): positive parity states, (b): negative parity states.
FIG. 5: (Color online) Ratios of decay probabilities (branching ratios) to the capture channel from various $J^+$ states of $^{198}$Au and $^{194}$Ir as a function of corresponding neutron energy in the case they are produced by neutron-induced reactions. Similar results were obtained for negative parity states.