DIRECT AND PREEQUILIBRIUM EFFECTS IN THE FISSION-PRODUCT MASS RANGE

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DIRECT AND PREEQUILIBRIUM EFFECTS IN
THE FISSION-PRODUCT MASS RANGE

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Abstract
Until recently inelastic scattering did not gain the proper attention in fission-product cross section evaluations. In many existing evaluations global spherical optical models have been used, neglecting direct and preequilibrium effects. There are also few experimental data relevant to inelastic scattering in fission products. This paper is focussed on the anomalously high inelastic scattering cross sections observed in even-mass nuclei near mass A = 100 at low energies. Both more data and more refined theoretical analyses are required. A number of suggestions for relevant coupled-channel calculations is made.

Keywords
- fission-products
- burn-up
- inelastic neutron scattering
- coupled channels model
- Hauser-Feshbach theory
- preequilibrium effects
- width fluctuation correction
- Pd
- evaluated nuclear data
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1 Introduction

Nuclear data evaluations for fission products are primarily made in order to make an accurate estimate of absorption possible. Therefore generally the subject of inelastic scattering is more or less neglected. However, inelastic scattering processes may yield an important contribution to the reactivity effect of fission products in fast reactors. In view of the present tendency to increase the burn-up of fuel and/or to compensate the reactivity swing by adding burnable poison or minor actinides like $^{237}$Np an accurate assessment of the total reactivity worth of fission products in fast reactors is required.

In the evaluations usually the results of nuclear model calculations are used for the description of the inelastic scattering cross section in the low-energy range ($E_n \leq 5$ MeV), because of the lack of experimental data in that energy range. Generally the spherical optical model (SOM) is used for these calculations. Furthermore in many existing evaluations pre-equilibrium effects, mainly important at higher energies, are neglected. The assumption that the nucleus can be considered to be spherical only holds for nuclei for which the value of the static or dynamical deformation parameters $\beta_2$ and $\beta_3$ (generally only the lowest multipole orders $L = 2, 3$ are important) is small.

In the fission-product mass range this assumption is not true, however. Especially in this mass range high values of $\beta_2$ occur [1], due to the fact that good vibrators and rotors can be found in this range. Thus, the SOM will be inadequate for the description of inelastic scattering cross sections for nuclides in the fission-product mass range.

Therefore it must be concluded that in order to calculate inelastic scattering cross sections for nuclides in the fission-product mass range in a reliable way direct and pre-equilibrium effects should be accounted for explicitly.

2 Problems in inelastic scattering of fission-products

As mentioned above, experimental data on inelastic neutron scattering from fission products are rather scarce. Two main sources may be distinguished, i.e. integral and differential scattering data.

A main source of integral data is the STEK experiment. In an analysis of these data it appears that there are systematic differences between evaluated and measured reactivity effects in the reactor cores for weak absorbers [2,3]. These differences may be due to several reasons [4], but it is most likely that an underestimate of the inelastic scattering cross sections of even mass (even $Z$ and even $A$) fission products in the JEF-1 evaluation, which was used in the analysis, is the main reason.

Differential scattering data are given in a few references (see e.g. [5-8]). Although there is some doubt on the quality of the experimental data, the available evidence clearly suggests that the inelastic cross section of even-mass fission products (often with high values of $\beta_2$) is severely underestimated when a
global SOM is used, see e.g. fig. 1. This problem was already noticed some years ago by Gruppelaar [4] and by Smith et al. [9], but since then only little progress has been made.

3 Possible reasons for underprediction of the inelastic scattering cross section

In the review article [4] possible reasons were given for the underprediction of the inelastic scattering cross section of fission products. These reasons are summarized below.

1. Missing levels:
   If the level scheme of the nucleus is incomplete, the inelastic scattering cross section will be underestimated. Evaluations based upon old level schemes could therefore be systematically too low. The effect of different level schemes has been studied, e.g. by Kikuchi et al. [10].

2. Width fluctuation factor:
   In all recent evaluations the width-fluctuation correction has been applied. This correction may be quite large and may reduce the "pure" Hauser-Feshbach cross sections by 50% at low incident energies. A number
of approaches exists in order to calculate the correction. They were summarized in [11]. Probably differences in methods of calculating the width-fluctuation factor do not cause differences larger than approximately 10% in the inelastic scattering cross section.

3. Optical model:
In the energy region starting at about 2 MeV the total inelastic scattering cross section becomes quite close to the compound-formation cross section. Therefore it is directly dependent on the optical model parameters. From the work of Kikuchi et al. [10] it appears that differences of 20 to 30% are no exception. Quite often global optical model potentials have been used, thus systematic effects may occur. Besides, in nearly all evaluations SOM’s have been used, whereas large deformation effects are observed for many nuclides.

4. Neglect of direct-collective excitations:
Up to 1985 no evaluations for fission-products existed in which direct-collective excitations had been taken into account. The contribution of these excitations to the inelastic scattering cross section were assumed to be small compared to the compound-nucleus contribution. There is experimental evidence, however, (see e.g. [5,8,12–15]) that this contribution may be substantial (also at low energies) not only for the statically deformed rotational nuclei, but also for the dynamically deformed vibrational nuclei. Especially the cross section of the first 2$^+$ state in even-even nuclei is strongly enhanced by a direct collective component. Enhancement factors of 1.5 or more are no exception. There is, however, some doubt about the quality of some low-energy inelastic scattering measurements.

5. Neglect of preequilibrium effects:
Up to 1985 no evaluations for fission-products existed in which preequilibrium effects had been taken into account. These effects play a role above approximately 5 MeV incident energy. The total inelastic scattering cross section below the $(n,2n)$ threshold is not very sensitive to preequilibrium effects. Mainly the energy distribution of the scattered neutrons is affected (the spectrum gets "harder"). Due to the $(n,2n)$ reaction the total inelastic scattering cross section becomes much larger above the $(n,2n)$ threshold.

6. Neglect of $(n,2n)$, $(n,3n)$, $(n,pn)$ cross sections:
For fission-product nuclides the thresholds for the above-mentioned reactions are quite high in energy. It is therefore not necessary to evaluate cross sections for these reactions with great accuracy. The complete neglect of these reactions (especially the $(n,2n)$ reaction) is a too crude approximation, however.
In the review article mentioned above [4] it was concluded, that mainly items 3 and 4 are relevant for fission reactors. This conclusion still holds for most current evaluations (ENDF/B-VI, JEF-1.2, JENDL-2) with the exception of JENDL-3. In the latter evaluation [16] all six points mentioned above were considered, particularly direct effects were included applying the Distorted Wave Born Approximation (DWBA).

4 Progress

4.1 Analysis of ANL-data using a SOM

Already in 1984 Smith et al. [9] presented the results of an optical model analysis of low-energy (1.5 MeV < \( E_n \) < 4.0 MeV) neutron scattering from elemental Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, In, Sn and Sb. The elastic angular distribution and the total cross section were fitted in the framework of a spherical optical model, resulting in a rather accurate "regional" optical model for \( Z = 39 \) − 51.

The resulting SOM indicates that the imaginary potential \( W_D \) has a cosine-like mass-dependence:

\[
W_D = 11.70 - 25.0(N - Z)/A - 1.8 \cos(2\pi(A - 90)/29) \text{ MeV.} \tag{1}
\]

Besides, \( W_D \) has an anomalously high value for most nuclei, especially for nuclei in the Pd-region.

With these potential parameters a very good fit of the elastic angular distribution \( \sigma_{el}(\theta, E) \) and the total cross section \( \sigma_{tot}(E) \) is obtained over a large mass range and for the energy range \( E_n < 5.0 \text{ MeV} \).

Using the potential parameters of [9], a relatively high inelastic cross section results (compared to almost all existing evaluations), but especially in the low-energy range \( E_n < 2 \text{ MeV} \) the value of the inelastic cross section may still be too low if compared to the existing and possibly unreliable measurements [5,13,14].

The authors analysed the effect of using a SOM instead of a deformed optical model (in which the effects of strongly excited levels on the potential are explicitly taken into account) for \(^{92}\text{Zr}\) and \(^{106}\text{Pd}\). They concluded that part of the cosine-like modulation of the imaginary potential \( W_D \) is to be ascribed to the simplified procedure they followed (using a SOM instead of a CC model), but the modulation would still be needed in order to describe the data.

4.2 Analysis of ANL-data using a CC model

At ECN Petten work has been done in order to describe low-energy neutron scattering data (\( E_n < 4.0 \text{ MeV} \) from \(^{92}\text{Mo}, ^{102}\text{Ru}\) and \(^{106}\text{Pd}\) in the framework of a coupled channels model (CC) [17]. For this reason use was made of the computer code HETEROCLITE [18], in which a one-phonon vibrational model was adopted. Couplings with the first 2\(^+\) (quadrupole phonon) and 3\(^-\) (octupole phonon) states were taken into account exactly.
A coupled-channels potential was used, in which the values of $\beta_2$ and $\beta_3$ were taken from $(p,p')$ studies [17]. Starting from the SOM of Smith et al. [9] $V$ and $W_D$ were fitted to the values of $\sigma_{el}(E)$ and $\sigma_{tot}(E)$. The $E$-dependence of $V$ and $W_D$ used by Smith et al. was also used in [17].

The results from [17] are that the data for $\sigma_{el}(E)$ and $\sigma_{tot}(E)$ can also be described using a smaller value of $W_D$ without the anomalous cosine-like modulation: the following equation for $W_D$ was adopted:

$$ W_D = 6.93 - 25(N - Z)/A \text{ MeV}. \quad (2) $$

Besides, using this CC model a rather high value of the inelastic cross section is obtained.

Some problems arise from this analysis, however. They are summarized below.

- The angular distribution for elastic cross section is not in very good agreement with the experimental data. A much better agreement is obtained using the SOM of Smith et al. [9].

- The calculated value of $\sigma_{21^+}(E)$ is rather high, and may even become too high at high energies.

- A first-order vibrational model was used, taking into account only the couplings with the $2_1^+$ and $3_1^-$ states. Maybe this coupling scheme should be extended.

- In the compound-nucleus model that was used in [17] transmission coefficients $T$ were used, which were taken from the SOM calculation [9], retaining the compound formation cross section from the CC model. Actually, these transmission coefficients should also be taken from a CC calculation.

### 4.3 New ANL measurements for $^{nat}Pd$

In 1989 new, high-quality experimental data have become available for low-energy elastic and inelastic neutron scattering from elemental Pd [19]. In this work the elastic angular distribution was measured at $E_n = 5.9, 7.1$ and $8.0$ MeV. Besides, at one scattering angle ($\theta_{\text{lab}} = 80^\circ$) the cross section of the excited levels with $260$ keV $< E_{\text{exc}} < 560$ keV was measured. Under the assumption that the $2_1^+$ states of all even-mass Pd isotopes are excited equally, the cross section of the $2_1^+$ states was thus determined. It appears, that the value of the direct $2_1^+$ cross section is approximately 150 mb in the energy range $6$ MeV $< E_n < 8$ MeV, so that the analysis presented in section 4.2 is clearly not correct (it predicts a much larger direct cross section).

In [19] also the results are presented of a CC analysis. Calculations were performed with the computer code ANLE CIS [20]. A compound-nucleus model was used including width-fluctuation corrections. Calculations were performed...
in the first-order vibrational model using a one-phonon coupling scheme as well as a two-phonon coupling scheme in which the two-phonon triplet was included. The two-phonon coupling scheme was used for the final calculations. Potential parameters $V$, $a_V$, $W_D$ and $a_W$ were fitted to $\sigma_{el}(\theta, E)$ using ANLECIS.

The results from the analysis presented in [19] are that a good fit of $\sigma_{el}(\theta, E)$ and $\sigma_{tot}(E)$ can be obtained using $E$-dependent values of $V$, $a_V$, $W_D$ and $a_W$.

Some problems still remain, however.

- The calculated inelastic cross section is still low compared to experimental data at $E_n < 2.5$ MeV of [19] and much lower than the older measurements (see fig. 2).

- The transmission coefficients used in the analysis of [19] were calculated using a SOM, which is inconsistent with the CC calculations in this reference.

4.4 Reanalysis of ANL Pd data by ECN Petten (this work)

As mentioned above, the main source of reliable low-energy neutron scattering data on $^{104}$Pd is the work of Smith et al. [19,21]. Scattering data from $E_n = 1.4$ to 3.85 MeV are given in ref. [21], in ref. [19] data measured at $E_n = 5.9$, 7.1 and 8.0 MeV are presented.
In the present work a reanalysis is performed of the scattering data given in refs. [19,21]. For the even isotopes the data were analysed in a first-order vibrational model, using a coupling scheme in which the 1-phonon (2\(^+_1\)) state is included as well as the 2-phonon triplet. For all calculations the coupled-channels code ECIS88 was used [22,23]. Using this code it is possible to perform calculations in a coupled-channels formalism and to take into account CN contributions to elastic and inelastic scattering cross sections using the model developed by Moldauer [24–26].

A crucial assumption in the work of Smith et al. is that in the analysis transmission coefficients based on a spherical optical model (SOM) may be used instead of the consistent transmission coefficients based on a first-order vibrational coupled-channels model. This assumption was made because of the fact that the code used in their analysis, ANLECIS [20], is not capable of calculating the required compound cross sections. In fig. 3 for the elastic angular distribution of \(^{105}\)Pd the results are presented of two calculations: one in which a CC model was used, using generalized transmission coefficients and one in which an equivalent SOM was used. It is clear from this figure that the difference between both calculations is small indeed.

The situation for the 2\(^+_1\) state in \(^{105}\)Pd is completely different, however. At \(E_n = 1.5\) MeV the 2\(^+_1\) state is mainly excited by means of CN processes, so that
Figure 4: Comparison of angular distributions of the $2^+_1$ state in $^{106}$Pd at $E_n = 1.5$ MeV as calculated using a coupled channels (CC) and a SOM (SOM) model. Also the compound contribution (CN) is given for these two cases.

A correct calculation of the CN contribution to the cross section for this state is crucial. From fig. 4 it is clear that using SOM transmission coefficients (indicated by the label SOM (CN) in fig. 4) instead of consistent CC transmission coefficients (indicated by the label CC (CN) in fig. 4) will lead to a severe overestimation of the CN contribution. At $E_n = 1.5$ MeV the angle-integrated cross section in the former calculation amounts to 886 mb, whereas it amounts to 738 mb in the latter case (see table 1). It is noted that the absolute difference (see fig. 4) between the compound contributions using a CC model or a SOM in the case of the elastic angular distribution is about the same as in the case of the $2^+_1$ angular distribution. The main difference between both cases is the fact that the direct contribution is much smaller for the $2^+_1$ state than it is for elastic scattering, so that the relative difference strongly increases.

A second assumption in the work of Smith et al. is that $^{nat}$Pd is adequately represented by $^{106}$Pd. Although this might be the case for the calculation of the elastic angular distribution (see fig. 5, in which the elastic angular distributions are given for $^{106}$Pd, $^{104}$Pd and $^{110}$Pd), the validity of this assumption is quite questionable for the calculation of the excitation of the $2^+_1$ state (more precisely: levels in $^{nat}$Pd with $260$ keV < $E_{exc}$ < $560$ keV (see ref. [19]), as can be seen from table 1. A comparison of cross sections calculated for the different isotopes with the optical potential data given in ref. [19] is also given in table 1. The "elemental"
Figure 5: Comparison of angular distributions for the elastic cross section of $^{106}$Pd, $^{108}$Pd and $^{110}$Pd at $E_n = 1.5$ MeV as calculated using a coupled channels (CC) model.

Pd cross section as given in this table was calculated using the contributions of the different isotopes. Comparing these data with the measured data given in refs. [21] and [19] it is clear that using a first-order vibrational coupled channels model and the theory of Moldauer for the CN contribution to the cross sections, it is not possible to describe the anomalously high cross section for the excitation of the $^2I^+_2$ state when the potential data of ref. [19] are used.

If $V$ and $W_P$ are fitted to the elastic and $2^+_1$ angular distributions for $^{106}$Pd, assuming that these distributions are equal to the ones for $^{nat}$Pd, it appears to be impossible to get simultaneously a good description of both angular distributions.

<table>
<thead>
<tr>
<th>$\sigma$ (mb)</th>
<th>$^{104}$Pd</th>
<th>$^{105}$Pd</th>
<th>$^{106}$Pd</th>
<th>$^{108}$Pd</th>
<th>$^{110}$Pd</th>
<th>$^{nat}$Pd</th>
<th>exp</th>
</tr>
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<tbody>
<tr>
<td>$\sigma_{tot}$</td>
<td>5611</td>
<td>6175</td>
<td>5744</td>
<td>5818</td>
<td>5903</td>
<td>5803</td>
<td>5825</td>
</tr>
<tr>
<td>$\sigma_{elas}$</td>
<td>4181</td>
<td>4114</td>
<td>4129</td>
<td>4057</td>
<td>3947</td>
<td>4049</td>
<td>4251</td>
</tr>
<tr>
<td>$\sigma_{2^+_1}$</td>
<td>788</td>
<td>647</td>
<td>693</td>
<td>641</td>
<td>547</td>
<td>656</td>
<td>$\approx 1100$</td>
</tr>
<tr>
<td>$\sigma_{n,\gamma}$</td>
<td>66</td>
<td>79</td>
<td>82</td>
<td>67</td>
<td>29</td>
<td>69</td>
<td>-</td>
</tr>
<tr>
<td>$\sigma_{reac}$</td>
<td>1420</td>
<td>2060</td>
<td>1615</td>
<td>1761</td>
<td>1956</td>
<td>1756</td>
<td>1574</td>
</tr>
</tbody>
</table>
For all reasonable values of $V$ and $W_D$ the cross section for the $2^+_1$ state remains too low.

Another possibility is the use of a different coupling scheme: if only the coupling to the 1-phonon state is taken into account, it is possible to increase the $2^+_1$ cross section. When $V$ and $W_D$ are fitted, it appears to be possible to get a fair description of the elastic angular distribution and of the $2^+_1$ angular distribution at low values of $E_n$ ($E_n < 2.0$ MeV). At higher values of $E_n$ the direct part of the cross section is far too high, however. Thus, this option, already tried before (see section 4.2), seems not realistic.

A last possibility is to assume that the Moldauer theory for calculating the CN contribution to the cross section is not valid in this case. If the width fluctuation factor is taken to be equal to 1 for all transitions, the cross section for the $2^+_1$ state increases. However, it is still not possible to describe the high cross section data as given in ref. [19]. Furthermore, it is questionable whether this approach can physically be justified.

The question remains if there are other ways in order to re-distribute the compound contribution over the elastic and inelastic levels.

5 Problems with the width fluctuation correction

From section 4 it seems that the underprediction of the inelastic scattering cross section of fission product nuclei may at least be partly due to problems with the width fluctuation correction.

There are several methods to calculate the width fluctuation factor [11], the best ones are described by Moldauer [26] and by Hofmann et al. [27]. The parametrisations used in these references are based upon Monte Carlo simulations. These parametrisations are quite practical in nuclear model calculations and their validity has been checked, e.g. by comparison with the exact "triple integral method" [28] and by performing a computational benchmark [29]. However, most of the existing nuclear model codes do not take into account the modifications required in case of the presence of direct reactions. These modifications could enhance or reduce the width fluctuation correction. To our knowledge these have only been coded in ECIS8S [23], using Moldauers' theory. ECIS88 has been applied in the present work, but since the direct effects are still relatively small near threshold, no large effect is observed.

Even the best expressions used for the width fluctuation corrections are based upon a statistical model and therefore there is an inherently associated uncertainty, due to fluctuations in the width distributions. This gives some (small) flexibility to explain the discrepancy between experimental and calculated inelastic scattering cross sections at low energies. In addition, non-statistical effects other than the direct-collective excitation could be important in the mass range near $A = 100$. In this mass range the p-wave strength function is quite
large and there might be a predominant channel in inelastic scattering, like

$$0^+ \stackrel{i=1}{\rightarrow} 3/2^- \stackrel{i=1}{\rightarrow} 2^+_1,$$

(3)

If this channel is governed by a doorway state mechanism or preequilibrium channel, the present theory fails. This is a speculation and it might also be that a more simple explanation is valid. In any case it has to be checked that the optical model used in the calculations is consistent with the experimental s- and p-wave strength functions, in particular for the de-excitation from the compound state, where the emission energy is quite low. In that case the energy-dependence of the optical model at very low energies should be studied, e.g. in terms of the dispersion relation.

6 Conclusions

In the present paper some remarks have been made on the evaluation of inelastic scattering cross-sections in the fission-product mass range. It was argued that more emphasis is needed in nuclear model calculations on an accurate description of direct and preequilibrium effects. In particular the situation at low incident energies was considered. This paper was focussed on problems in the mass range near \(A = 100\), where large discrepancies between measured and calculated inelastic scattering data were observed. Although the quality of the inelastic scattering measurements is not very high in general, it is clear that the inelastic scattering cross sections at low energies are underpredicted in most evaluations. A notable exception is the recent JENDL-3 evaluation [16], where the inelastic scattering has received much more attention, by using a non-global SOM with a DWBA correction for direct-collective effects.

From the present work the following conclusions and recommendations follow:

- It is recommended to include preequilibrium effects in the evaluation codes. This may not be very important for fission reactors; the main effect is a change in the spectra at high incoming neutron energies.

- It is recommended to include direct-collective effects in the evaluation codes and in the nuclear data evaluations.

- The best method seems to be to use the most sophisticated calculational methods, like coded in ECIS88 [23] and to
  
  - use a one- or two-phonon vibrational model for the vibrational nuclei and a full-order rotational model for rotational nuclei
  - use a coupled channels (CC) model
  - use generalized transmission coefficients for compound contributions, i.e. transmission coefficients calculated in a CC model

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- use an expression for the width fluctuation factor $W_a$ which is corrected for the presence of direct reactions (as in ECIS88)
- include the value of $S_1$ in the fit of the potential data at very low energy.

- More theoretical analysis is urgently needed:
  - why is the inelastic scattering cross section enhanced?
  - is a regional coupled channels model useful?

- It is quite clear from this paper that more experimental data of high quality are essential for the progress in this field.
References

1. S. Raman, C. H. Malarkey, W. T. Milner, C. W. Nestor and P. H. Stelson, "Transition probability, B(E2)↑, from the ground to the first-excited 2↑ state of even-even nuclei", At. Data Nucl. Data Tables 36 (1987) 1


14. L. I. Govor, A. M. Demidov and M. M. Komkov, "Cross sections for the excitation of levels in the \( (n,n'\gamma) \) reaction in spherical even-even nuclei with \( 28 < A < 152 \)". Sov. J. Nucl. Phys. 29 (1979) 731


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