Study of impact factors on the decay heat calculation of neutron sufficient even-even nuclei of Te, Xe, Ba, Ce, Nd and Sm isotopes

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Abstract. The impact factors on the decay heat calculation are studied for the neutron sufficient even-even nuclei of Te, Xe, Ba, Ce, Nd and Sm isotopes, including: nuclear deformation, nuclear structure complexity and level density. By comparing the calculated results of QRPA method and gross theory with the experimental results, it is found that for the case of even-even nuclei considered in this paper: gross theory presents better results for the situation of daughter nuclei with complex level scheme, showing its statistical method nature; QRPA method presents better results for near spherical nuclei. Both methods are not affected by the level density.

1 Introduction

Beta decay heat is an important factor for the nuclear reactors' design and safety analysis, and massive experimental and theoretical efforts have been devoted for its accurate prediction [1–9]. For theoretical calculation, kinds of nuclear models based on various approximations or in a limited configuration space are developed for this topic, including the macroscopic gross theory (GT) [4–7], and two different microscopic approaches i.e., shell model [8] and the quasiparticle random phase approximation (QRPA) approach [9–20, 22]. The gross theory is the most successful and frequently used model for this topic, but it is proved to be less successful when consider the energy of the electron and photon in the β decay separately and in the case of some neutron deficient nuclei. The self-consistent QRPA approach has become a current trend in nuclear structure study and successfully described some nuclear properties like the beta-decay half-lives. Hence it is tempting to apply this method to calculate this factor. In this paper, the comparison has been presented, for the decay heat of neutron sufficient even-even nuclei of Te, Xe, Ba, Ce, Nd, Sm and Gd isotopes, among the experiment data, the calculation results of the self-consistent QRPA approaches based on covariant density functional theory (CDFT) and the gross theory. It would be worthy to discuss the factors impacting the theoretical calculation, like the nuclear deformation, level density and level scheme complexity, to help improve the ability and reliability of the theoretical prediction.

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2 Systematic study and the comparison of calculated results

From Figure 1 (a), we roughly sorted the even-even Te, Xe, Ba, Ce, Nd and Sm isotopes into different kinds as below: 1. Nuclei near the magic number and having near spherical shape, whose 2^+ and 4^+ exciting states are dominated by single particle excitation with exciting energy ratio below 2.0 or by vibration excitation with exciting energy ratio of about 2.0; 2. Nuclei with deformed shape whose 2^+ and 4^+ states dominated by the rotational excitation with exciting energy ratio near 3.3. Two other impact factors are shown in Fig. 1 (b) and (c), which are the approximate level density got by dividing the number of energy levels by the energy of the highest excited energy level and the level scheme complexity presented by the number of the daughter nuclei. The level density and level number are also presented in Table 1. Hence, we also sorted the even-even nuclei with high and low level density and simple and complex of daughter nuclei structure. The comparison between gross and QRPA calculations and experiment results are shown in Fig.1 (d) and (e), and Table 1. It could be seen that: For gross calculation, the results of ^{138}Xe, ^{140}Xe, ^{144}Ba, ^{154}Nd and ^{158}Sm are better and ^{142}Ba, ^{146}Ce and ^{148}Ce are of some deviation; For QRPA calculation, the results of ^{134}Te, ^{136}Te, ^{138}Xe, ^{140}Xe, ^{142}Ba, ^{144}Ba and ^{148}Ce are better and ^{140}Ba, ^{146}Ba, ^{148}Ba, ^{146}Ce, ^{152}Nd and ^{154}Nd are of some deviation.

3 Discussion

Considering QRPA calculation, it could be seen clearly that for each isotope chain, the calculated deviation would increase with the neutron number, which also means the increase of the deformation. For gross calculation, the better results got for ^{138}Xe, ^{140}Xe, ^{144}Ba, ^{154}Nd and ^{158}Sm nu-

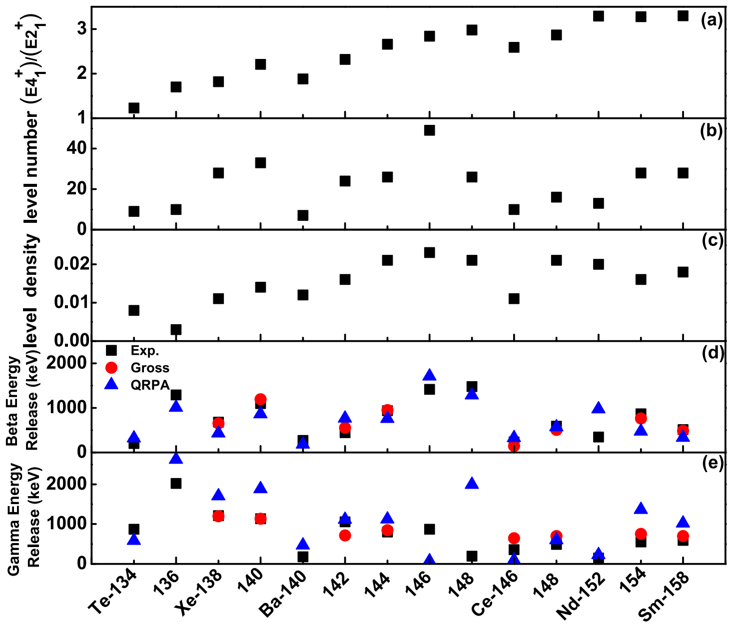

Figure 1. (a) The ratio of the exciting energies between first 4^{+} state and the first 2^{+} state of the parent nuclei; (b) The number of levels observed in the β decay; (c) The level density below the highest level in the β decay; (d) Comparison between experimental [22–33] and calculated E_{β} by the Gross [21, 22] and QRPA; (e) Comparison between experimental [22–33] and calculated E_{γ} by the Gross [21, 22] and QRPA

Table 1. The ratios of E^{1}_{4+} and E^{1}_{2+}, level numbers for daughter nuclei, level density and deviation between calculations and experiment.

Nuclide	$R_{(E_{4+}/E_{2+})}$	Number of levels	Level density	Gross $\lvert\frac{E_{theory}-E_{exp}}{E_{exp}}\rvert_{\beta}$	Gross $\lvert\frac{E_{theory}-E_{exp}}{E_{exp}}\rvert_{\gamma}$	QRPA $\lvert\frac{E_{theory}-E_{exp}}{E_{exp}}\rvert_{\beta}$	QRPA $\lvert\frac{E_{theory}-E_{exp}}{E_{exp}}\rvert_{\gamma}$
^{134}Te	1.23	9	0.008			56.08%	33.05%
^{136}Te	1.7	10	0.003			22.14%	29.75%
^{138}Xe	1.82	28	0.011	4.75%	11.65%	36.98%	40.42%
^{140}Xe	2.21	33	0.014	8.90%	0.22%	21.79%	66.18%
^{140}Ba	1.88	7	0.012			33.38%	156.36%
^{142}Ba	2.32	24	0.016	25.80%	35.30%	72.18%	4.78%
^{144}Ba	2.66	26	0.021	2.10%	5.80%	19.03%	40.42%
^{146}Ba	2.84	49	0.023			20.73%	91.76%
^{148}Ba	2.98	26	0.021			13.43%	910.83%
^{146}Ce	2.59	10	0.011	38.91%	78.38%	38.49%	75.08%
^{148}Ce	2.87	16	0.021	13.07%	42.86%	3.34%	22.88%
^{152}Nd	3.29	13	0.02			182.91%	53.96%
^{154}Nd	3.28	28	0.016	12%	38.10%	45.41%	148.77%
^{158}Sm	3.3	28	0.018	5.80%	18.40%	34.72%	72.67%

clide having a more complex level structure in the daughter nuclei with more than 24 level numbers at least, reflection its statistics model nature obviously. Moreover, no relationship was found between the level density and gross theory as well as QRPA results, indicating both gross and QRPA calculations will not be impacted by the level intensity.

4 Conclusion

The decay heat calculation was performed using QRPA and the results were compared with the Gross theory calculation and experiments values for the neutron sufficient even-even nuclei of Te, Xe, Ba, Ce, Nd and Sm isotopes. The influence of the impact factors on the calculation, like the nuclear deformation, complexity of the nuclear structure and level density, was studied. At least for the cases of even-even nuclei in this paper, the QRPA calculations shows more calculation deviation for the large deformed nuclei and the gross statistic model is more accurate for the cases with complex structure daughter nuclei. The level density shows no effect on both methods.

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