Identification of Highly Deformed Even-Even Nuclides in the Neutron- and Proton-Rich Regions of the Nuclear Chart from the $B(E2) \uparrow$ and $E2$ Predictions in the Generalized Differential Equation Model

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Abstract

We identify here possible occurrence of large deformations in the neutron- and proton-rich regions of the nuclear chart from extensive predictions of the values of the reduced quadrupole transition probability $B(E2) \uparrow$ for the transition from the ground state to the first $2^+$ state and the corresponding excitation energy $E2$ of even-even nuclei in the recently developed Generalized Differential Equation model exclusively meant for these physical quantities. This is made possible from our analysis of the predicted values of these two physical quantities and the corresponding deformation parameters derived from them such as the quadrupole deformation $\beta_2$, the ratio of $\beta_2$ to the Weisskopf single-particle $\beta_{2(sp)}$ and the intrinsic electric quadrupole moment $Q_0$, calculated for a large number of both known as well as hitherto unknown even-even isotopes of Oxygen to Fermium ($Z=8$ to 100). Our critical analysis of the resulting data convincingly support possible existence of large collectivity for the nuclides $^{30,32}Ne$, $^{34}Mg$, $^{60,62,64}Ti$, $^{42,62,64}Cr$, $^{50,68}Fe$, $^{52,72}Ni$, $^{72,70,96}Kr$, $^{74,76}Sr$, $^{78,80,106,108}Zr$, $^{82,84,110,112}Mo$, $^{140}Te$, $^{144}Xe$, $^{148}Ba$, $^{122}Ce$, $^{128,156}Nd$, $^{130,132,158,160}Sm$, and $^{138,162,164,166}Gd$, whose values of $\beta_2$ are found to exceed 0.3 and even 0.4 in some cases. Our findings of large deformations in the exotic neutron-rich regions support the existence of another "Island of Inversion" in the heavy-mass region possibly caused by breaking of the N=70 sub-shell closure.

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1 Introduction

Studies of the nuclear structure for nuclei lying away from the $\beta$-stable valley of the nuclear chart has been a challenging situation of late, due to new phenomena being observed such as the shell-quenching\cite{1,2} of the so-called magic shell gaps, and the onset of exotic deformations leading to the existence of the so-called "Island of Inversion"\cite{3,4,5}. Improved experimental technology and increased accuracy of the necessary tools have provided the desired boost making feasible for such discoveries. More or less, such issues are associated with the onset of increased collectivity\cite{6,7} leading to possible occurrence of large deformations of those nuclei lying in the exotic regions of the nuclear chart. In this connection values of the physical quantities such as the reduced electric quadrupole transition probability $B(E2)$ for the transition from the ground state to the first $2^+$ state and the corresponding excitation energy $E2$ of even-even nuclei play very decisive role\cite{8} in identifying such occurrences of increased collectivity. Particularly the resulting quadrupole deformation parameters $\beta_2$ and the ratio of $\beta_2$ to the Weisskopf single-particle $\beta_{2(sp)}$ derived from them significantly help in this regard. Over the years host of such experimental data for these two physical quantities have led Raman et al.\cite{9} to undertake the well-known Oak-Ridge Nuclear Data Project\cite{10} to make a comprehensive analysis of all such data leading to compilation of the desired adopted data table in the year 1987\cite{10} and 2001 \cite{9}. More recently Pritychenko et al.\cite{11} have continued the same Oak-Ridge program in compiling the newly emerging data for even-even nuclei near $N \sim Z \sim 28$.

Thus the study of these two physical quantities $B(E2) \uparrow$ and $E2$ has been under constant investigation both by experimentalists and theorists. Several theoretical study of these quantities have been the epitome of various models and authors [see for instance Raman et al.’s\cite{8} comprehensive analysis]. Global systematics particularly by Grodzins\cite{12}, Bohr and Mottelson\cite{13} and Wang et al.\cite{14} were quite useful in the past. However for local systematics of these quantities, models in terms of difference equations developed by Ross and Bhaduri\cite{15} and by Patnaik et al.\cite{16} were found to be successful to some extent. In this regard our recently developed differential equation model\cite{17,18} for the physical quantity $B(E2) \uparrow$ has been found to be quite successful. In fact we could later on succeed in extending \cite{19} the same model to include its complementary physical quantity, namely the excitation energy $E2$. According to this model which we may term it as the Generalized Differential Equation (GDE) model, the value of both these quantities for a given even-even nucleus is expressed in terms of their derivatives with respect to the corresponding neutron and proton numbers $N, Z$. The same differential equation in the model has been further exploited to generate two recursion relations, which are mainly responsible for the success\cite{17,18,19} of the model not only for fitting the known data, but also for predicting the unknown
when compared with the recently compiled experimental data of Pritychenko et al. [11] in the $N \sim Z \sim 28$ region. In passing, we may note that we[17, 19] could visualize such a differential equation for these quantities on the basis of their close similarity in reflecting the shell-structure with the so-called local energy of the Infinite Nuclear Matter (INM) Model[20, 21, 22, 23] of atomic nuclei developed over the years primarily based on the generalized[24] Hugenholtz-van Hove theorem[25] of many-body theory. It may be of interest to note that the form of the differential equation in the GDE model as well as for the local energy in the INM model are exactly similar to that of the generalized[24] HVH theorem of many-body theory. We may further stress here that any relation in the form of a differential equation for any physical quantity is intrinsically sound enough to possess the desirable feature of good predictive ability. In fact this was found to be true behind the success[23] of the INM model as a mass formula and also with the presently considered GDE model[17, 18, 19].

Here in the present work, we are particularly interested to focus possible occurrence of increased collectivity leading to identification of exotic deformations for the nuclides lying mostly in the neutron- and proton-rich (n-rich and p-rich) regions of the nuclear chart. This is achieved from our analysis of the widely predicted data made in our model for the two physical quantities $B(E2) \uparrow$ and $E2$, and from the deformation parameters calculated from them. Accordingly we used our model first, in predicting their values for most of the even-even isotopes lying in the nuclear chart from $Z=8$ to 100 (O to Fm) confined to the known data-set region of Raman et al. [9], and then to the adjacent isotopes for which such values are not yet experimentally available. Then in the second step, we utilized these predicted values in calculating the relevant deformation parameters, namely the quadrupole deformation $\beta_2$, the ratio of $\beta_2$ to the Weisskopf single-particle $\beta_{2(sp)}$, and the intrinsic electric quadrupole moment $Q_0$ following the usual model-dependent formalism, in which nuclei are treated as having uniform charge distributions. These calculations provide us the necessary tools to analyze our data in a better way in identifying possible occurrence of increased collectivity and the resulting exotic deformations.

In the following section 2, we first of all discuss our model in brief for sake of continuity and fruitful analysis of the resulting data. Section 3 deals with the usual details of calculation. Subsequently we present our results and discuss them in section 4. Finally we highlight our main findings in the concluding section 5.

2 The Generalized Differential Equation Model for $B(E2) \uparrow$ and $E2$

General features along with the details of the model has been well described elsewhere first[17] for $B(E2) \uparrow$ and secondly[19] for $E2$. Since our main interest here is to analyze the model predictions for identifying exotic
deformations, we simply highlight its basic equations and features. The principal equation of the model valid for both \( B(E_2) \uparrow \) and the corresponding excitation energy \( E_2 \) is given by

\[
\frac{C(N, Z)}{A} = \frac{1}{2} \left[ (1 + \beta) \left( \frac{\partial C}{\partial N} \right)_Z + (1 - \beta) \left( \frac{\partial C}{\partial Z} \right)_N \right],
\]

where \( N, Z \) and \( A \) refer to the neutron, proton and mass numbers of the given nucleus. \( \beta \) is the usual asymmetry parameter \( (N-Z)/A \) of the nucleus. The variable \( C \) represents both the physical quantities \( B(E_2) \uparrow \) and \( E_2 \). As we can see, the relation (1) connects both \( B(E_2) \uparrow \) and \( E_2 \) of a given nucleus to their partial derivatives with respect to the neutron and proton numbers \( N \) and \( Z \). We may state here for sake of a comprehensive understanding, that the very basis behind its proposition goes to a similar equation being satisfied by the local energy component of the ground-state energy of a nucleus, specifically simulating its shell and deformation behavior in the infinite nuclear matter (INM) model [20, 21, 22, 23] of atomic nuclei primarily built on the basis of the generalized [24] HVH theorem [25] of many-body theory. Even though its proposition for these two physical quantities \( B(E_2) \uparrow \) and \( E_2 \) has been made on close similarity with the local energy term of the INM model, it can be treated as a semi-empirical equation as it has been found [17, 19] to be satisfied by them by virtue of their slow variation with neutron and proton numbers \( N \) and \( Z \) locally. Hence the differential Eq. (1) for these two physical quantities may be better termed as localized semi-empirical equation like the difference equations of Ross and Bhaduri [15] and Pattnayak et al. [16]. We further like to highlight the interesting fact that the form of the differential equation (1) for these two physical quantities, for the local energy \( \eta \) of the INM model and the generalized HVH theorem concerning energy per nucleon of the asymmetric nuclear matter are all exactly similar in nature. Of course the genesis of the local energy relation in the INM model owes its origin to the generalized HVH theorem, whereas formulation of the differential equation for the two physical quantities \( B(E_2) \uparrow \) and \( E_2 \) simulating the local energy \( \eta \) obviously got the same form. At the same time however we should note that while the HVH theorem is an exact theorem of the many-body theory, the differential equation (1) for all the physical quantities concerning the finite nucleus can be termed as model-dependent.

Then using the usual forward and backward definitions pair-wise for both the derivatives given by

\[
\left( \frac{\partial C}{\partial N} \right)_Z \simeq \frac{1}{2} \left[ C[N + 2, Z] - C[N, Z] \right],
\]

\[
\left( \frac{\partial C}{\partial Z} \right)_N \simeq \frac{1}{2} \left[ C[N, Z + 2] - C[N, Z] \right],
\]

and

\[
\left( \frac{\partial C}{\partial N} \right)_Z \simeq \frac{1}{2} \left[ C[N, Z] - C[N - 2, Z] \right],
\]

\[
\left( \frac{\partial C}{\partial Z} \right)_N \simeq \frac{1}{2} \left[ C[N, Z] - C[N, Z - 2] \right],
\]

(2)
the following two recursion relations in C would result

\[ C[N,Z] = \frac{N}{A-2} C[N-2,Z] + \frac{Z}{A-2} C[N,Z-2], \]  
\[ C[N,Z] = \frac{N}{A+2} C[N+2,Z] + \frac{Z}{A+2} C[N,Z+2]. \]  

These recursion relations connecting values of both \( B(E2) \uparrow \) and \( E2 \) of the neighboring even-even nuclei from lower to higher mass and vice-verse, are primarily responsible in reaching out from known to the unknown terrain of the nuclear landscape, and thereby facilitate their predictions throughout. One may further note that the choice of either forward or backward definitions for both the two derivatives occurring in the Eq. (1) facilitate derivation of the close-knit first order recursion relations (4 and 5), each connecting three immediate neighboring even-even nuclei with neutron, proton and mass numbers differing at best by two units in the nucleon space as shown in Fig. 1(a), a fact which is of our primary concern. In contrast, mixed definitions, i.e, one forward and the backward for the derivatives would lead to second order relations connecting nuclei having mass numbers differing up to four units as can be seen in Fig. 1(b) and hence are ignored.

It is essential to stress here that these recursion relations not only connect isotopes of the same element but also different neighboring elements having proton numbers \( Z, Z-2 \) and \( Z+2 \). Therefore these recursion relations should not be interpreted as interpolation and extrapolation formulas. Moreover one should also note that since these relations connect isotopes of the neighboring elements, they facilitate prediction of the hitherto unknown data for the desired isotopes of a given element using the existing data of the relevant isotopes of the neighboring elements, even if its own data for the neighboring isotopes are either not available or scantily available. Even these interconnections connecting the isotopes of the neighboring elements provide possible means of bridging sharply changing isotopic variations of these two physical quantities across the isotopes of a given element.

In actual practice, we use the known available data in the neighborhood of a given nucleus in the two recursion relations (4) and (5) separately to generate its all possible values for \( B(E2) \uparrow \) and \( E2 \). Since each of these relations can be rearranged in three different ways by shifting the three terms occurring in them from left to right and vice-verse, in principle one can generate up to six alternate values at best for a given nucleus. This is however subject to availability of the corresponding data. Again each of them being equally probable, the predicted value is then obtained by the arithmetic mean of all those generated values so obtained. We would like to comment here that this method of taking the arithmetic mean of the equally-probable generated values for a given isotope in a way, achieves some sort of uniqueness in the model predictions and at the same time automatically takes care of all possible local connections in a given locality. That is why this scheme has been found to be successful\[17, 18, 19\] in our limited predictions made earlier for both the physical quantities \( B(E2) \uparrow \) and \( E2 \). Thus, our actual
calculation procedure uses the available experimental data in predicting values of these two physical quantities both for the known as well as for the hitherto unknown even-even nuclides. The predictions made in the first generation thus obtained for the unknown, are again used along with the known data in the second step to generate the next generation predictions and so on. This procedure is continued to reach out more and more neighboring regions of the nuclear chart. However we must mention here, that although this scheme in principle can be continued as widely as we please in the nuclear chart, in practice, it is terminated to avoid accumulation of errors. Nevertheless, we find that three to four generations are sufficient enough to reach out a large number of isotopes on either side of the normal $\beta$-stable valley for our present study.

3 Calculation of the Deformation Parameters from the $B(E2) \uparrow$ and $E2$

Model Predictions

Following the procedure laid down in the previous section, we have carried out the prediction scheme in the model using the combined data set of both Raman et al. [9] and Pritychenko et al. [11] near $N \sim Z \sim 28$ as the input experimental data. Accordingly the total number of $B(E2) \uparrow$ input data comprises altogether 330 even-even nuclides spread over the entire nuclear landscape ranging from O to Fm ($Z=8$ to 100), while the same for $E2$ is 557. Since our main interest in the present study is to identify possible occurrence of exotic regions of deformation in the n- and p-rich regions adjacent to the already known data valley, we have confined our calculations up to three to four generations of our prediction scheme. As a result, our present calculations have yielded hitherto unknown $B(E2) \uparrow$ data of 278 adjacent isotopes and $E2$ values of 175 isotopes apart from for those of the known data set.

In the next step, we used these predicted data for calculating the standard deformation parameters such as the quadrupole deformation $\beta_2$ and the ratio of $\beta_2$ to the Weisskopf single-particle $\beta_{2(sp)}$, termed here as $\beta_r$ for simplicity. We would like to stress here that the value of the quadrupole deformation $\beta_2$ more or less reflects the nature of collectivity of a given nucleus. Its zero value would mean no deformation at all while its finite value would otherwise indicate increasing deformations or collectivity of a given nucleus. In general, its value up to 0.1 more or less reflects spherical nuclei while that of in the range 0.1-0.2 usually correspond to normal deformations. On the contrary its value in the range 0.3-0.5 has been shown[27, 28, 29, 30, 31] to reflect strong deformations in nuclei while its value of $\approx 0.55-0.65$ has been considered[32, 33] to indicate super deformation. Therefore any such value beyond 0.3 for a given nucleus may be considered as to reflect large deformation. Apart from $\beta_2$, we
would also consider a supplementary quantity namely $\beta_r$ as referred above. We may point out here that the ratio $\beta_r$ has been considered more significant in reflecting possible occurrence of the collective effects in nuclei.

The expressions for these quantities can be obtained in a model-dependent formalism, in which nuclei are treated as to have uniform charge distributions out to distance $R(\theta, \phi)$ and zero charge beyond. The defining equation for the quadrupole deformation parameter $\beta_2$ is as usual given by

$$R(\theta, \phi) = R_0[1 + \beta_2 Y_{20}^*(\theta)],$$

(6)

where $R_0$ corresponds to the radius of a constant density undistorted nucleus and $Y_{20}^*$ is the usual axially-symmetric spherical harmonics. Then the well-known relation that has been widely used in the literature for computing the deformation parameter $\beta_2$ from the model-independent physical quantity $B(E2) \uparrow$ simply follows as [see for instance Roy & Nigam]

$$\beta_2 = (4\pi/[3Zr_0^2A^{2/3}])[B(E2) \uparrow/e^2]^{1/2}.$$  

(7)

Here $r_0$ is the usual nuclear radius parameter, the value of which is usually taken for compilation of such data as 1.2 fm and $B(E2) \uparrow$ is in units of $e^2b^2$. We would like to make a note here that the above expression for $\beta_2$ [notations may vary] has been widely used invariably by most of the groups see for instance Raman et al for extracting its value from the experimental $B(E2) \uparrow$ data.

For calculating the Weisskopf single-particle $\beta_{2(sp)}$ value, its expression can be derived by substituting the corresponding Weisskopf single-particle $B(E2) \uparrow$ value given by

$$B(E2) \uparrow_{sp} = 2.97 \times 10^{-5}A^{4/3}(e^2b^2)$$

(8)

in Eq. (7). Then the expression for $\beta_{2(sp)}$ simply follows as

$$\beta_{2(sp)} = (4\pi/[3Zr_0^2]) \times \sqrt{0.297},$$

(9)

which numerically can be simplified as $1.59/Z$ as has been done by Raman et al. Thus one can calculate the ratio $\beta_r$ using Eqs. (7 and 9).

Apart from these two quantities, we also calculate another useful physical quantity, namely, the intrinsic electric quadrupole moment $Q_0$ in units of $b$ given by

$$Q_0 = \left[\frac{16\pi B(E2) \uparrow}{5 \frac{e^2}{e^2}}\right]^{1/2}.$$  

(10)
Thus we see that using these Eqs. (7, 9 and 10), all the relevant deformation parameters can be calculated from $B(E2) \uparrow$.

Before ending this section it is worth mentioning the fact that $\beta_{2(sp)}$ as can be seen from Eq. (9) remains a fractional constant for all the isotopes of a given element, and hence simply acts as a constant dividing factor for the quantity $\beta_r$ for all those isotopes. Thus the numerical values of the deformation parameter $\beta_r$ effectively gets enhanced for all those isotopes having large deformations by virtue of their larger $\beta_2$ values compared to those lying in the normal $\beta$-stable valley for a given element. As a result there cannot exist a definite value for this quantity to decide whether a particular isotope has a larger or a smaller deformation. Therefore the nature of deformation for a given isotope can only be ascertained by comparing its $\beta_r$ value with those of its already known neighboring isotopes.

### 4 Results and Discussion

#### 4.1 Identification of Exotic Deformed Nuclides

As per the details laid down above, we have first carried out the predictions of $E2$ and $B(E2) \uparrow$ data for the desired isotopes lying both in the known and the hitherto unknown regions of the nuclear chart. Then using these predicted data we subsequently calculated the deformation parameters $\beta_2$ and $\beta_r$ by using the formulas (7, 9). Our calculations have yielded $B(E2) \uparrow$ values of altogether 608 nuclides which include the input data of 330. Similarly our $E2$ predictions have yielded 732 nuclides that include input data of 557. Since our main interest being the identification of the possible exotic deformations in the hitherto unknown data regions, we present here in Table 1 only such data that are confined to those regions. We also present in the same table the calculated values of the deformation parameters $\beta_2$, $\beta_r$ and $Q_0$.

In general, one can easily identify possible occurrence of the increasing collectivity and the consequent exotic deformations specially from the relatively larger values of $\beta_2$ and $\beta_r$ from Table 1. As stated earlier any value of $\beta_2$ larger than 0.3 more or less reflects higher deformation and increasing collectivity of the given nucleus. Such observations can be further supplemented by the increasing values of $\beta_r$. However, for sake of conveying better visual display of such occurrences as scrutinized from the tabulated values, we graphically present values of these two deformation parameters for the isotope series as isolines only for those elements in the Figs. 2-7. Accordingly the graphs displayed in these figures correspond to such elements having proton number $Z=10, 22, 24, 26, 28, 36, 38, 40, 42, 52, 54, 56, 58, 60, 62, 64, 66$ and $Z=92$. We would like to again stress here that our choice of
these elements purely follows from our primary interest of identifying any possibility of exotic deformation in the exotic n- and p-rich regions of the nuclear chart. Consequently our close scrutiny of Table 1 shows increasing trends in the values of the deformation parameters for either in the n-rich or p-rich or both for the isotopes of the stated elements except however for Z=66. For instance the \( \beta_2 \) value increases from 0.075 to 0.513 with increasing neutron number from N=32 to 38, while \( \beta_r \) values increase from 1.043 to 7.116 for the element Z=22. We have intentionally chosen to include the isoline for Z=66 just to highlight how such cases need not be considered due to the uninteresting nature of variation of the deformation parameters in the exotic n- and p-rich regions. For sake of comparative analysis and continuity in the graphical presentations, we have also included in these graphs our predictions in the known-data regions along with the adopted experimental values\[^9,11\] to help us to compare the relative values of both \( \beta_2 \) and \( \beta_r \) in our endeavor for identification of possible exotic deformations. Inclusion of the adopted experimental values in these graphs on the other hand would testify the goodness of the model predictions. In fact one can easily identify hitherto unknown-data isotopes from these graphs having large values of \( \beta_2 \) (\( \geq 0.3 \)) and relatively larger values of \( \beta_r \) both in the n- and p-rich regions. Such relatively large values of these parameters obviously signify possible occurrence of exotic deformations for those isotopes.

Now coming to analyzing the individual cases, we find [see Figs. 2 (a) and Table 1] the values of the deformation parameter \( \beta_2 \) as 0.59 and 0.63 respectively at N=20 and 22 for Ne (Z=10). Despite N=20 being a magic number and N=22 is close to it, both these two n-rich isotopes are found to have such large values of \( \beta_2 \). On the other hand the \( \beta_r \) values of these isotopes are respectively 3.73 and 3.99, which are definitely larger than those of its own known neighbors as can be seen from Fig. 5 (a). Thus such increase is a clear indication of the possible occurrence of higher deformations in both \(^{30}\)Ne and \(^{32}\)Ne. Fortunately this finding of ours is well-supported by the recent experimental observation of enhanced collectivity for \(^{30}\)Ne and the resulting disappearance of N=20 shell-closure by Yanagisawa et al.\[^6\]. The authors of this experiment have attributed such occurrence of strong collectivity by breaking of the N=20 shell-closure by the intruder states from the pf-shell and hence are in favor of its inclusion in the ”Island of Inversion” \[^35,36\]. Even the neighboring nuclide \(^{34}\)Mg has been also found to be highly deformed as its \( \beta_2 \) value is 0.50 [see Table 1] in agreement with the experimental finding by Iwasaki et al. \[^37\]. Incidentally this nuclide has also the same neutron number N=22 as that of \(^{32}\)Ne.

Our close scrutiny [see Fig. 4 (a)] also lead us to find possible occurrence of large collectivity for \(^{60}\)Ti as its \( \beta_2 \) value is 0.51, which is almost close to that of super deformation. Its \( \beta_r \) value has been found to be 7.11 which is again much larger compared to its neighboring known isotopes [see Fig. 7 (a)]. Accordingly this n-rich isotope of Ti is most likely be heavily deformed despite its neutron number 38 is very close to the semi-magic number 40 and
its proton number is also very close to the magic number 20, thereby clearly supporting the possible manifestation for the occurrence of another "Island of Inversion" caused by the intruder states from gd-shell\[30\].

Similarly such occurrences are also seen in case of $^{42,62,64}Cr$, $^{50,68}Fe$ and $^{52,72}Ni$ [see Figs. 2(b-d), 5(b-d) for $\beta_2$ and $\beta_r$ respectively]. The $\beta_2$ values for all these nuclei lie in the range 0.29-0.41 signifying large collectivity. We also see that the $\beta_r$ values for all these nuclei lying in the range 4.96-6.13 are well above the corresponding values of their neighboring known isotopes. Incidentally these predictions of ours are again well-supported by the recent experimental observation of increased quadrupole collectivity in $^{64}Cr$ and $^{68}Fe$ in a Coulomb-excitation experiment by Crawford et al. [7]. It is further interesting to find more support from another experimental observation of strong deformation by Sorlin et al [30] for the isotopes $^{60,62}Cr$. In all these n-rich isotopes including $^{60}Ti$ as stated above, the N=40 sub-shell closure most possibly gets broken due to the intruder orbitals $g_{9/2}$ and $d_{5/2}$ leading to strong collectivity in agreement with the conclusions arrived at by Sorlin et al. [30].

Concerning isotopes of Kr, Sr and Zr (Z=36, 38 and 40), we find the exotic isotopes $^{70,72,96}Kr$, $^{74,76}Sr$ and $^{78,80,106,108}Zr$ to have values of $\beta_2$ lying in the range 0.40-0.49 [see Figs. 2(e-f), 4(b)], while those of $\beta_r$ lie in the range 10.3-11.6 [see Figs. 5(e-f), 7(b)]. Obviously such values of $\beta_2$ for these isotopes are quite large enough to signify high deformations in them. It is quite satisfying to note here that our present finding of large deformation with a $\beta_2$ value of 0.4 for $^{80}Zr$ in fact has been well-corroborated by Lister et al. [28] long back experimentally. One can also see that the n-rich isotope $^{102}Sr$ [see Figs. 4(b) and 7(b)] can also be treated as highly deformed as its $\beta_2$ and $\beta_r$ values are almost close to the above ranges. For the neighboring element Mo, we also find relatively larger values of $\beta_2$ lying in the range 0.39-0.46 [see Fig. 3(a)] for the isotopes $^{82,84,110,112}Mo$. Whereas their $\beta_r$ values lying in the range 10.3-12.2 are quite large enough compared to their known neighbors qualifying them to have large deformations [see Fig. 6(a)]. Prediction of such strong collectivity for the exotic isotopes $^{108}Zr$ and $^{112}Mo$ may be again connected to the possible existence of another "Island of Inversion" by breaking of the N=70 sub-shell closure by the intruder states from hfp- shell. Thus the existence of two "Islands of Inversion" already detected experimentally with the breaking of shell-closures at N=20 and N=40, and our present prediction of another one at N=70 sub-shell closure appears to be a general feature of nuclear dynamics in the exotic n-rich regions of the nuclear chart.

Similarly for the isotopes of Te, Xe and Ba (Z=52, 54 and 56), we see relatively higher than normal deformations for the nuclides $^{140}Te$, $^{144}Xe$ and $^{148}Ba$ as their $\beta_2$ values range from 0.25 to 0.33 [see Fig. 3(b-d)]. The same feature is well reflected with the wide-ranging values of $\beta_r$ from 7.5 to 11.7 [see Fig. 6(b-d)]. We would like to further add here that our calculation also shows the p-rich isotope $^{122}Ba$ to be well-deformed [see Fig. 3(d) and
6(d)] in agreement with the experimental findings by Morikawa et al.[26]. Concerning the isotopes of Ce, Nd, Sm and Gd (Z=58, 60, 62 and 64), we find the values of $\beta_2$ to lie in the range 0.36-0.46 [see Figs. 3(e-f), 4(c-d)], thereby indicating possible occurrence of exotic deformations for the isotopes $^{122}Ce$, $^{128,156}Nd$, $^{130,132,158,160}Sm$ and $^{138,162,164,166}Gd$. These findings are once again well supported by the values of $\beta_r$ lying in the range 14.2-17.5 [see Figs. 6(e-f), 7(c-d)]. As usual these values are larger than the corresponding values of their respective known neighboring isotopes.

As mentioned earlier, we have also shown $\beta_2$ and $\beta_r$ isolines for Z=66 in the Figs. 4 (e) and 7 (e) just to highlight the border cases that we have ignored. We see that both the deformation parameters almost remain unchanged with increase of neutrons and even show decreasing trends. This is perhaps a clear indication of no substantive change in nuclear structure. Hence such variation in the deformation parameters for the isolines of other elements that we have not included in our present study may not be of much interest.

Finally coming to the case of Uranium (Z=92) in the very heavy-mass region as shown in the Figs. 4 (f) and 7 (f), we find slight increasing trends in the values of the deformation parameters with the increasing neutron number from N=146 to 154. We see that $\beta_2$ value increases monotonically from 0.29 to 0.30 and those of $\beta_r$ from 16.73 to 18.62. Therefore we are of the view that the tendency for higher deformation possibly exists, but without having any dramatic change in the nuclear structure.

Thus, in general the regions in the nuclear chart corresponding to the said isotopes discussed above as well as some in the immediate neighborhood could be possible regions of large scale exotic deformations, as the values of the quadrupole deformation parameter $\beta_2$ are closer to and even greater than 0.3. As usual the values of $\beta_r$ are relatively larger than their respective known neighboring isotopes. Expectedly such behavior is well supported by the values of the other physical quantity namely the intrinsic electric quadrupole moment $Q_0$, which we have plotted for all the isotope series against the neutron number N in Figs. 8-10. The increasing value of $Q_0$ for those isotopes as seen from these figures clearly corroborate our findings.

Even more importantly, all these findings of exotic deformation listed above have been well borne out with our predicted values of the other physical quantity, namely, the excitation energy $E2$ as can be seen from Table 1. Graphical presentations as shown in Figs. 11-13 also bear out the same features more convincingly. We should remember that unlike the deformation parameters derived from the values of $B(E2) \uparrow$, values of $E2$ are determined completely independent of the former. Hence the nature of the isotopic behavior of $E2$ is expected not only independent but at the same time opposite to that of the $B(E2) \uparrow$. This is exactly the case as it should be with $E2$, as we see from the complementary nature of the graphs displayed in the Figs. 11-13 in contrast to
those of the deformation parameters $\beta_2$ and $\beta_r$. We find that the $E2$ values of the concerned isotopes claimed to have large deformations are almost increasingly small as they lie on the peripheral portions of the graphs, in contrast to the opposite behavior in case of $B(E2) \uparrow$ and the deformation parameters derived from it such as $\beta_2$, $\beta_r$ and $Q_0$. Numerically our predicted $E2$ values for almost all the isotopes of Ne, Ti, Cr, Fe, Ni and Kr in the low- and medium-mass regions claimed to have large deformations lie in the range 0.35-1.4 MeV. Even experimental $E2$ values of some of these isotopes also lie in the range 0.7-1.1 MeV [see for instance Fig. 11 for the isotopes $^{50}Fe$, $^{72}Kr$ and $^{72}Ni$]. Whereas both predicted and experimental $E2$ values of the claimed isotopes having high deformations in the heavy-mass region almost lie in the range 0.07-0.5 MeV. Thus our predicted $E2$ values convincingly support possible existence of exotic high deformations perceived from the predicted $B(E2) \uparrow$ values and the deformation parameters calculated from it.

Before ending this section, we just want to highlight here regarding the nature of agreement of our model predictions with the adopted $B(E2)$ and $E2$ data, which of course has been well-demonstrated while developing\cite{17, 19} the model. Here the goodness of agreement is once again borne out from the close agreement of the derived quantities $\beta_2$, $\beta_r$ and $Q_0$, and $E2$ itself as seen from the Figs. 2-13. It is rather remarkable to see the nature of good agreement of the sharply changing isotopic variations of our model predictions with those of experiment in almost all the cases as seen from the Figs. 2-13, vindicating our assertion made earlier about the recursion relations \cite{4} and \cite{5} that they should not be treated as interpolation or extrapolation formulas. The data of the isotopes of the neighboring elements play decisive role in this regard as the recursion relations connect nuclei having proton numbers $Z$, $Z-2$ and $Z+2$. Thus such remarkable agreement with the experimental data \cite{9, 11} throughout and particularly the nature of sharply changing isotopic variations in most cases bear clear testimony of the goodness of the GDE model.

4.2 Comparison with the Latest Experimental Data

Having identified possible regions of exotic deformation with our predicted data, it would be of interest to compare our predicted values of $E2$ and $B(E2) \uparrow$ against any new experimental data if available, which we have not included in our prediction scheme. This would be highly desirable as they would provide the test of reliability of our predictions and establish our model for good. In this connection, we happened to come across a recent arxive article by Pritychenko et al. \cite{38} of their latest data compilation for some of the neighboring nuclides adjacent to the already known data set. Obviously this new adopted data set at least would give us a good opportunity to test our model predictions for some if not for all. From our close scrutiny of our predicted data given in Table
1 and those of the latest experimental data [38], we find that hitherto unknown data of 77 nuclides in case of $B(E2)$ and 65 nuclides in case of $E2$ are available for this comparative analysis. With this view we followed Raman et al.'s [9] prescription of comparing in terms of the order of agreement of our predicted data with these new experimental data. Accordingly we have presented the ratio of the predicted values with those of the newly adopted data for $E2$ and $B(E2)$ respectively in Figs. 14 and 15. One can easily see that 60 out of 65 data points for $E2$ (see Fig. 14) lie within the box indicating the percentage of agreement as 92%. Such an agreement can be termed excellent as per the yardstick stipulated by Raman et al [9].

Similarly in case of $B(E2)$ predictions, we see that 62 data points out of 77 lie within the box (see Fig. 15) with the resulting percentage of agreement as 81%. Compared to $E2$ the degree of agreement for $B(E2)$ is somewhat less. However on close scrutiny we find, that most of the 14 cases that lie outside the box (see Fig. 15) have relatively larger experimental uncertainty [38] to the tune of 40 to 109%. Just to cite few examples, the adopted $B(E2)$ value of $^{148}Gd$ is $0.2279 \pm 0.1144$ ($^{+0.0548}_{-0.0548}$), while the same for $^{124}Cd$ is $0.35\pm 0.19$ and that of $^{74}Ni$ is $0.0642\pm 0.0442$. All these values quoted here are in the usual units of $e^2b^2$. Thus such large experimental uncertainty would obviously affect the actual experimental value. Secondly for some of these 14 cases, the adopted $B(E2)$ values are themselves negligibly small, and accordingly any good agreement in such cases may not be feasible to achieve. Just to cite few such examples for which the adopted $B(E2)$ values being very small are $0.0096\pm 0.0030$, $0.00373\pm 0.0038$ and $0.060\pm 0.020$ in case of $^{24}Si$, $^{50}Ca$, and $^{56}Ti$ respectively. In view of these two aspects we can very well say, that the quality of agreement of our model predictions for $B(E2)$ with the newly adopted data is rather excellent. Thus, more or less we see that our predictions made in our GDE model both for $E2$ and $B(E2)$ very well stand the test of reliability and thereby support once again the goodness of the GDE model.

5 Concluding Remarks

In conclusion, we would like to say that our main concern in the present work is to identify possible occurrence of large deformations for some of the even-even nuclides lying in the n- and p-rich regions of the nuclear chart from our extensive predictions for the reduced quadrupole transition probability $B(E2)$ and the complementary excitation energy $E2$. We have made these predictions using our recently developed Generalized Differential Equation model for these two physical quantities. These predictions include the hitherto unknown data for the nuclides lying adjacent to the already known data-regions of Raman et al. [9] for most of the even-even isotopes.
of Oxygen to Fermium (Z=8 to 100). For sake of facilitating our desired task, we have also included in our calculation values of the model-dependent deformation parameters such as $\beta_2$, the ratio of $\beta_2$ to the Weisskopf single-particle $\beta_{2\text{(sp)}}$ and and the intrinsic electric quadrupole moment $Q_0$ using the predicted values of $B(E2) \uparrow$ and $E_2$. In this regard, our critical analysis of the resulting data convincingly support possible existence of large collectivity and the consequent exotic deformations for the nuclides $^{30,32}Ne$, $^{34}Mg$, $^{60,62,64}Cr$, $^{50,68,52,72}Fe$, $^{52,72}Ni$, $^{72,70,96}Kr$, $^{74,76}Sr$, $^{78,80,106,108}Zr$, $^{82,84,110,112}Mo$, $^{140}Te$, $^{144}Xe$, $^{122}Ce$, $^{128,156}Nd$, $^{130,132,158,160}Sm$ and $^{138,162,164,166}Gd$. The quadrupole deformation parameter $\beta_2$ for all these nuclei mostly exceeds 0.3 and even lies in the range 0.45-0.55 for some of them like $^{30,32}Ne$, $^{34}Mg$, $^{60}Ti$, $^{62}Cr$, $^{72,70,96}Kr$, $^{74,76}Sr$, $^{106,108}Zr$ and $^{82}Mo$. Such large collectivity is well supported by the corresponding relatively smaller values of the supplementary physical quantity, namely, the excitation energy $E_2$. The $E_2$ values mostly lie in the range 0.35-1.4 MeV for these nuclei in the low- and medium-mass region, while the same in heavy-mass region lie in the range 0.07-0.5 MeV. Even some of the available experimental data in this regard do lie in the range 0.7-1.1 MeV.

Our prediction of strong deformation in case of $^{30,32}Ne$ and $^{34}Mg$ in fact are in close agreement with the experimental observation by Yanagisawa et al.\[6\] and Iwasaki et al. \[37\] respectively leading to the existence of the “Island of Inversion” caused by breaking of the N=20 shell-closure by the intruder states from the pf-shell\[35,36\]. Similar predictions in case of $^{60}Ti$, $^{62,64}Cr$, $^{68}Fe$ also agree with the experimental findings\[7,30\] again leading to the existence of another ”Island of Inversion” caused by the breaking of the N=40 sub-shell closure by the intruder states from the gd-shell. Thus such agreement with the experimental findings in the medium-low and medium mass nuclei in the exotic n-rich regions have made us to conjecture the existence of another ”island of Inversion” in the heavy-mass region possibly caused by breaking of the N=70 sub-shell closure by the intruder states from the hfp-shell as we find strong deformation for the nuclides $^{108}Zr$ and $^{112}Mo$. Thus it appears that the existence of such ”Islands of Inversion” in the exotic n-rich regions of the nuclear chart may be a general feature of nuclear dynamics waiting for to be explored by future experiments. In fact analysis\[23\] of two two-neutron separation energy systematics derived from mass predictions in the INM model of atomic nuclei supports the existence of such islands in the heavy-mass n-rich region of the nuclear chart apart from the ones in the lower- and medium-mass regions.

Apart from serving the primary purpose of the present work in predicting exotic deformations in the exotic regions of the nuclear chart as highlighted above, we also observe rather good agreement of our predictions with the adopted experimental data. Even our model could reproduce the sharply changing isotopic variations of the two physical quantities $B(E2) \uparrow$ and $E_2$ in agreement with those of experiment, vindicating our assertion that the
recursion relations [4, 5] derived in the model should not be treated as interpolation or extrapolation formulas. In this regard the interconnecting relations connecting the neighboring elements having proton number Z, Z-2 and Z+2 facilitate achieving this. This supplements our earlier observation of good agreement with experiment while developing [17, 19] the model.

Even to our satisfaction, we could further succeed in establishing the goodness of the model in comparing some of our predictions with the latest experimental data [38] which we have not included in our prediction process. In this respect it is quite remarkable to find, that the quality of agreement of our predictions for both these two physical quantities $B(E2) \uparrow$ and $E2$ is rather excellent.

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Figure 1: Schematic diagram showing how the recursion relations connect the neighboring even-even nuclei. (a) corresponds to the first order relations connecting nuclei shown here as the vertices of the two triangles 1 and 2, while (b) shows those of the second order relations (see text for details).
Figure 2: Values of the calculated quadrupole deformation parameter $\beta_2$ (see text) for the isotope series $Z=10, 24, 26, 28, 36$ and $40$ plotted here as isolines against neutron number $N$. Thick lines connecting open circles represent our predicted values while solid squares with vertical lines marked as [Adpt.] correspond to those of the adopted values[9, 11]. The vertical lines as usual represent the uncertainty in the adopted values.
Figure 3: Same as Fig. 2 but for $Z=42$, 52, 54, 56, 60 and 62.
Figure 4: Same as Fig. 2 but for Z=22, 38, 58, 64, 66 and 92.
Figure 5: Similar to Fig. 2 but for the values of the deformation parameter $\beta_r$ (see text) for the series $Z=10, 24, 26, 28, 36$ and $40$. 
Figure 6: Similar to Fig. 3 but for the values of the deformation parameter $\beta_r$ for $Z=42, 52, 54, 56, 60$ and 62.
Figure 7: Similar to Fig. 4 but for the values of the deformation parameter $\beta_r$ for $Z=22, 38, 58, 64, 66$ and $92$. 
Figure 8: Similar to Figs. 2 but for the values of the Intrinsic Electric Quadrupole Moment $Q_0$ for the series $Z=10, 24, 26, 28, 36$ and $40$. 
Figure 9: Similar to Figs. 3 but for the values of the Intrinsic Electric Quadrupole Moment $Q_0$ for the series $Z=42, 52, 54, 56, 60$ and 62.
Figure 10: Similar to Figs. 4 but for the values of the Intrinsic Electric Quadrupole Moment $Q_0$ for the series $Z=22, 38, 58, 64, 66$ and 92.
Figure 11: Similar to Fig. 2 but for the values of the excitation energy E₂ (see text) for the series Z=10, 24, 26, 28, 36 and 40. However adopted data are shown without uncertainties as these values are very small.
Figure 12: Similar to Fig. 11 but for the values of the excitation energy $E_2$ (see text) for the series $Z=42, 52, 54, 56, 60$ and 62.
Figure 13: Similar to Figs. [11] and [12] but for the values of the excitation energy $E_2$ (see text) for the series $Z=22$, $38$, $58$, $64$, $66$ and $92$. 
Figure 14: Comparison between the model predictions for the excitation energy $E_2$ with the latest adopted experimental data [38] (see text) plotted here in the form of their ratio versus those of the adopted experimental data. The data points lying inside the box indicate the degree of agreement within a factor of two.
Figure 15: Same as Fig. 13 but for $B(E2) \uparrow$ compared with the latest adopted experimental data\cite{38} (see text). The data points lying inside the box indicate the degree of agreement within a factor of two.
### Table 1. Predicted E2 & B(E2)\(\uparrow\) Values and the Corresponding Calculated Deformation Parameters (See Text)

| \(Z\) | \(A\) | \(N\) | \(E2\) | \(B(E2)\) | \(\beta_2\) | \(\beta_2/\beta_{2(sp)}\) | \(Q_0\) | \(Z\) | \(A\) | \(N\) | \(E2\) | \(B(E2)\) | \(\beta_2\) | \(\beta_2/\beta_{2(sp)}\) | \(Q_0\) |
|-------|------|------|-------|----------|----------|----------------|-------|-------|------|------|-------|----------|----------|----------------|-------|
|   8 (O) | 12   |  4   |  5.505 |  0.010 |  0.701   |  3.536 |  0.320 |      | 14   |  6   |  4.529 |  0.006 |  0.497   |  2.507 |  0.252 |      |
|       | 24   |  16  |  3.005 |  0.014 |  0.513   |  2.591 |  0.372 |      | 26   |  18  |  1.360 |  0.038 |  0.591   |  3.729 |  0.622 |      |
|       | 30   |  20  |  1.360 |  0.038 |  0.591   |  3.729 |  0.622 |      | 32   |  22  |  0.948 |  0.048 |  0.632   |  3.988 |  0.695 |      |
|       | 34   |  22  |  0.678 |  0.047 |  0.501   |  3.790 |  0.687 |      | 36   |  24  |  0.361 |  0.016 |  0.284   |  2.149 |  0.405 |      |
|       | 38   |  26  |  0.396 |  0.030 |  0.371   |  2.807 |  0.548 |      |      |      |      |      |      |      |
|   10 (Ne) | 18   |  6   |  1.910 |  0.027 |  0.579   |  4.382 |  0.520 |      | 20   |  8   |  1.500 |  0.030 |  0.569   |  4.306 |  0.548 |      |
|       | 24   |  10  |  1.673 |  0.029 |  0.428   |  3.781 |  0.544 |      | 36   |  18  |  1.679 |  0.027 |  0.272   |  2.406 |  0.518 |      |
|       | 26   |  12  |  2.228 |  0.035 |  0.371   |  3.744 |  0.597 |      |      |      |      |      |      |      |
|   12 (Mg) | 24   |  10  |  1.673 |  0.029 |  0.428   |  3.781 |  0.544 |      | 36   |  18  |  1.679 |  0.027 |  0.272   |  2.406 |  0.518 |      |
|       | 28   |  12  |  2.228 |  0.035 |  0.371   |  3.744 |  0.597 |      |      |      |      |      |      |      |
|       | 46   |  30  |  1.275 |  0.040 |  0.282   |  2.848 |  0.632 |      |      |      |      |      |      |
|       | 48   |  32  |  1.234 |  0.049 |  0.304   |  3.072 |  0.701 |      |      |      |      |      |      |
|   14 (Si) | 32   |  14  |  2.071 |  0.026 |  0.261   |  2.958 |  0.515 |      | 36   |  16  |  2.326 |  0.011 |  0.138   |  1.741 |  0.328 |      |
|       | 38   |  26  |  0.396 |  0.030 |  0.371   |  2.807 |  0.548 |      |      |      |      |      |      |      |
|       | 40   |  26  |  1.022 |  0.029 |  0.303   |  2.672 |  0.540 |      |      |      |      |      |      |      |
|       | 42   |  26  |  1.022 |  0.029 |  0.303   |  2.672 |  0.540 |      |      |      |      |      |      |      |
|       | 44   |  30  |  1.679 |  0.027 |  0.272   |  2.406 |  0.518 |      |      |      |      |      |      |      |
|   16 (S) | 40   |  26  |  1.022 |  0.029 |  0.303   |  2.672 |  0.540 |      |      |      |      |      |      |
|       | 44   |  30  |  1.679 |  0.027 |  0.272   |  2.406 |  0.518 |      |      |      |      |      |      |      |
|   18 (Ar) | 30   |  12  |  2.057 |  0.029 |  0.283   |  3.208 |  0.535 |      | 38   |  32  |  1.510 |  0.028 |  0.203   |  2.304 |  0.526 |      |
|       | 50   |  32  |  2.712 |  0.037 |  0.228   |  2.590 |  0.607 |      |      |      |      |      |      |      |
|   20 (Ca) | 50   |  30  |  1.075 |  0.037 |  0.206   |  2.594 |  0.608 |      | 52   |  32  |  1.079 |  0.032 |  0.186   |  2.341 |  0.564 |      |
|       | 54   |  34  |  2.108 |  0.366 |  0.616   |  7.766 |  1.917 |      |      |      |      |      |      |      |
|       | 56   |  34  |  1.182 |  0.145 |  0.344   |  4.770 |  1.207 |      |      |      |      |      |      |      |
|       | 58   |  36  |  0.843 |  0.155 |  0.347   |  4.817 |  1.247 |      |      |      |      |      |      |      |
|       | 60   |  38  |  0.552 |  0.353 |  0.513   |  7.116 |  1.885 |      |      |      |      |      |      |      |
|       | 62   |  40  |  0.491 |  0.066 |  0.216   |  3.000 |  0.812 |      |      |      |      |      |      |      |
|       | 64   |  40  |  0.349 |  0.202 |  0.341   |  5.158 |  1.426 |      |      |      |      |      |      |      |
|       | 66   |  42  |  0.366 |      |      |      |      |      |      |      |      |      |      |      |
|       | 68   |  42  |  0.413 |  0.203 |  0.302   |  4.956 |  1.427 |      |      |      |      |      |      |      |
|       | 70   |  44  |  0.421 |      |      |      |      |      |      |      |      |      |      |      |
|       | 72   |  46  |  0.833 |      |      |      |      |      |      |      |      |      |      |      |
|       | 74   |  48  |  0.866 |      |      |      |      |      |      |      |      |      |      |      |
| A  | N  | E2  | B(E2)↑ | β2  | β₂/β₂(sp) | Q₀   | A  | N  | E2  | B(E2)↑ | β2  | β₂/β₂(sp) | Q₀   |
|----|----|-----|--------|-----|-----------|------|----|----|-----|--------|-----|-----------|------|
| Z = 28 (Ni) |    |     |        |     |           |      | Z = 36 (Kr) |    |     |        |     |           |      |
| 50 | 22 | 1.217 |       |     |           |      | 70 | 34 | 0.624 |       |     | 0.913 | 0.455 | 10.323 | 3.030 |
| 52 | 24 | 1.308 | 0.148 | 0.287 | 5.070 | 1.221 | 72 | 36 | 0.567 |       |     | 0.991 | 0.465 | 10.552 | 3.156 |
| 70 | 42 | 1.397 | 0.096 | 0.190 | 3.351 | 0.983 | 88 | 52 | 1.138 |       |     | 0.142 | 0.154 | 3.496 | 1.195 |
| 72 | 44 | 1.020 | 0.225 | 0.285 | 5.027 | 1.503 | 90 | 54 | 0.762 |       |     | 0.109 | 0.133 | 3.022 | 1.049 |
| 74 | 46 | 0.942 | 0.173 | 0.245 | 4.326 | 1.318 | 92 | 56 | 0.734 |       |     | 0.118 | 0.136 | 3.089 | 1.088 |
| 78 | 50 | 1.924 |       |     |           |      | 94 | 58 | 0.746 |       |     | 0.414 | 0.251 | 5.708 | 2.039 |
| Z = 30 (Zn) |    |     |        |     |           |      | 96 | 60 | 0.595 |       |     | 1.609 | 0.489 | 11.103 | 4.022 |
| 54 | 24 | 1.329 | 0.096 | 0.210 | 3.971 | 0.980 | 98 | 62 | 0.099 |       |     |       |      |       |      |
| 56 | 26 | 0.277 | 0.080 | 0.187 | 3.544 | 0.896 | 100| 64 | 0.113 |       |     |       |      |       |      |
| 58 | 28 | 2.070 | 0.026 | 0.105 | 1.994 | 0.516 |   |    |      |       |     |       |      |       |      |
| Z = 38 (Sr) |    |     |        |     |           |      | 74 | 36 | 0.527 |       |     | 1.236 | 0.483 | 11.573 | 3.525 |
| 60 | 30 | 1.275 | 0.095 | 0.195 | 3.690 | 0.977 | 76 | 38 | 0.321 |       |     | 1.086 | 0.445 | 10.660 | 3.305 |
| 76 | 46 | 0.745 | 0.163 | 0.218 | 4.125 | 1.279 | 102| 64 | 0.118 |       |     | 1.319 | 0.403 | 9.652  | 3.641 |
| 78 | 48 | 0.800 | 0.080 | 0.150 | 2.834 | 0.894 | 104| 66 | 0.121 |       |     |       |      |       |      |
| 80 | 50 | 1.573 | 0.078 | 0.146 | 2.764 | 0.887 |   |    |      |       |     |       |      |       |      |
| 82 | 52 | 1.638 | 0.085 | 0.150 | 2.838 | 0.925 | 76 | 36 | 0.538 |       |     |       |      |       |      |
| Z = 32 (Ge) |    |     |        |     |           |      | 78 | 38 | 0.272 | 1.051 | 0.408 | 10.304 | 3.251 |
| 62 | 30 | 0.956 | 0.048 | 0.127 | 2.572 | 0.696 | 80 | 40 | 0.294 | 1.042 | 0.400 | 10.089 | 3.237 |
| 64 | 32 | 0.923 | 0.075 | 0.155 | 3.137 | 0.867 | 98 | 58 | 1.088 | 0.463 | 0.233 | 5.873  | 2.157 |
| 78 | 46 | 0.585 | 0.179 | 0.211 | 4.256 | 1.343 | 104| 64 | 0.136 | 1.561 | 0.411 | 10.367 | 3.961 |
| 80 | 48 | 0.828 | 0.071 | 0.131 | 2.635 | 0.845 | 106| 66 | 0.171 | 1.980 | 0.457 | 11.526 | 4.461 |
| 82 | 50 | 1.414 | 0.072 | 0.129 | 2.605 | 0.850 | 108| 68 | 0.175 | 1.961 | 0.449 | 11.332 | 4.441 |
| 84 | 52 | 1.334 | 0.097 | 0.148 | 2.980 | 0.987 |   |    |      |       |     |       |      |       |      |
| Z = 34 (Se) |    |     |        |     |           |      | 82 | 40 | 0.323 | 1.575 | 0.460 | 12.200 | 3.979 |
| 64 | 30 | 0.856 | 0.263 | 0.274 | 5.878 | 1.625 | 84 | 42 | 0.427 | 1.451 | 0.435 | 11.524 | 3.819 |
| 66 | 32 | 0.802 | 0.289 | 0.282 | 6.043 | 1.705 | 86 | 44 | 0.550 | 0.759 | 0.310 | 8.206  | 2.762 |
| 68 | 34 | 0.889 | 0.321 | 0.291 | 6.236 | 1.795 | 88 | 46 | 0.688 | 0.066 | 0.090 | 2.386  | 0.816 |
| 84 | 50 | 1.234 | 0.171 | 0.184 | 3.950 | 1.309 | 90 | 48 | 0.942 | 0.318 | 0.194 | 5.149  | 1.787 |
| 86 | 52 | 1.182 | 0.187 | 0.190 | 4.070 | 1.370 | 110| 68 | 0.194 | 1.650 | 0.388 | 10.268 | 4.073 |
| 88 | 54 | 0.625 | 0.054 | 0.101 | 2.161 | 0.739 | 112| 70 | 0.173 | 1.769 | 0.396 | 10.503 | 4.217 |
| 90 | 56 | 0.823 | 0.124 | 0.150 | 3.219 | 1.117 |   |    |      |       |     |       |      |       |      |
| 92 | 58 | 0.461 |       |     |           |      | 86 | 42 | 0.490 |       |     |       |      |       |      |
Table 1. Predicted E2 & B(E2)\(\uparrow\) Values and the Corresponding Calculated Deformation Parameters (See Text)

| A  | N  | E2  | B(E2) \(\uparrow\) | \(\beta_2\) | \(\beta_2/\beta_{2(sp)}\) | \(Q_0\) | A  | N  | E2  | B(E2) \(\uparrow\) | \(\beta_2\) | \(\beta_2/\beta_{2(sp)}\) | \(Q_0\) |
|-----|----|-----|-------------------|--------------|--------------------------|--------|-----|----|-----|-------------------|--------------|--------------------------|--------|
| Z = 44 (Ru) |     |     |                   |              |                          |        | Z = 50 (Sn) |     |     |     |                  |              |                          |        |
|   | 92 | 48  | 0.906 0.380 0.200 | 5.547 1.953  | 126 76 1.046 0.117 0.079 | 2.496 1.084 | 94 | 50  | 1.390 0.141 0.120 | 3.333 1.191 | 128 78 1.101 0.152 0.089 | 2.814 1.235 |
|   | 114 | 70  | 0.260 1.337 0.325 | 9.024 3.666 | 130 80 1.276 0.032 0.040 | 1.277 0.566 | 116 | 72  | 0.421 1.058 0.286 | 7.935 3.261 | 136 86 0.485 |        |
|   | 118 | 74  | 0.535 |                |             |                          |        |      |     |       |                  |              |                          |        |
| Z = 46 (Pd) |     |     |                   |              |                          |        |      |     |       |                  |              |                          |        |
| Z = 52 (Te) |     |     |                   |              |                          |        |      |     |       |                  |              |                          |        |
| Z = 48 (Cd) |     |     |                   |              |                          |        | Z = 54 (Xe) |     |     |     |                  |              |                          |        |
|   | 96 | 48  | 0.770 0.169 0.116 | 3.501 1.303 | 112 58 0.434 0.669 0.190 | 6.458 2.593 | 100 | 52  | 1.055 0.352 0.165 | 4.990 1.882 | 138 84 0.798 0.529 0.147 | 4.997 2.306 |
|   | 102 | 54  | 0.820 0.352 0.165 | 4.990 1.882 | 138 84 0.798 0.529 0.147 | 4.997 2.306 | 124 | 76  | 0.719 0.864 0.227 | 6.860 2.948 | 142 88 0.313 0.830 0.180 | 6.142 2.889 |
|   | 126 | 78  | 0.731 0.779 0.213 | 6.445 2.799 | 144 90 0.246 1.797 0.263 | 8.953 4.250 | 128 | 80  | 0.804 |             |            |                          |        |
|   | 130 | 82  | 0.720 |                |             |                          |        |      |     |       |                  |              |                          |        |
| Z = 50 (Sn) |     |     |                   |              |                          |        |      |     |       |                  |              |                          |        |
|   | 100 | 50  | 1.862 |                |             |                          |        |      |     |       |                  |              |                          |        |
|   | 104 | 54  | 1.252 0.365 0.159 | 5.011 1.915 | 118 62 0.257 1.037 0.220 | 7.766 3.228 | 106 | 56  | 1.071 0.427 0.170 | 5.354 2.072 | 120 64 0.239 2.351 0.327 | 11.565 4.862 |
|   | 108 | 58  | 1.108 0.403 0.163 | 5.136 2.013 | 148 92 0.199 3.160 0.330 | 11.658 5.636 | 110 | 60  | 1.115 0.243 0.125 | 3.939 1.563 | 150 94 0.113 2.524 0.292 | 10.326 5.037 |
Table 1. Predicted E2 & B(E2)↑ Values and the Corresponding Calculated Deformation Parameters (See Text)

| A  | N  | E2  | B(E2)↑ | β2  | β2/β2(sp) | Q0  | A  | N  | E2  | B(E2)↑ | β2  | β2/β2(sp) | Q0  |
|----|----|-----|--------|-----|-----------|-----|----|----|-----|--------|-----|-----------|-----|
| Z = 58 (Ce)  |    |     |        |     |           |     | Z = 64 (Gd)  |    |     |
| 120 | 62 | 0.213 | 3.032  | 0.359 | 13.132 | 5.521 140 | 76  | 0.331 | 3.074 | 0.296 | 11.931 | 5.559 |
| 122 | 64 | 0.132 | 4.370  | 0.426 | 15.594 | 6.628 142 | 78  | 0.506 | 0.241 | 0.082 | 3.313 | 1.558 |
| 142 | 84 | 0.954 | 0.394  | 0.116 | 4.234  | 1.991 144 | 80  | 1.125 | 0.250 | 0.083 | 3.341 | 1.586 |
| 144 | 86 | 0.415 | 0.863  | 0.170 | 6.205  | 2.945 146 | 82  | 1.618 | 0.101 | 0.052 | 2.107 | 1.010 |
| 152 | 94 | 0.090 | 2.804  | 0.295 | 10.789 | 5.310 148 | 84  | 1.228 | 0.920 | 0.156 | 6.292 | 3.042 |
| 154 | 96 | 0.074 | 2.011  | 0.248 | 9.056  | 4.496 150 | 86  | 0.583 | 0.997 | 0.161 | 6.490 | 3.166 |
| Z = 60 (Nd)  |    |     |        |     |           |     | Z = 66 (Dy)  |    |     |
| 124 | 64 | 0.099 | 5.634  | 0.463 | 17.516 | 7.526 164 | 100 | 0.075 | 5.479 | 0.355 | 14.335 | 7.421 |
| 126 | 66 | 0.107 | 4.988  | 0.431 | 16.306 | 7.082 166 | 102 | 0.073 | 5.728 | 0.360 | 14.539 | 7.588 |
| 128 | 68 | 0.127 | 4.392  | 0.400 | 15.141 | 6.645 168 | 104 | 0.065 |     |     |       |     |
| 136 | 76 | 0.381 | 1.008  | 0.184 | 6.965  | 3.183Z = 66 (Dy) |    |
| 138 | 78 | 0.544 | 1.322  | 0.209 | 7.901  | 3.646 140 | 74  | 0.200 |     |     |       |     |
| 142 | 80 | 0.991 | 0.455  | 0.121 | 4.590  | 2.138 150 | 84  | 1.074 | 0.241 | 0.077 | 3.193 | 1.558 |
| 154 | 94 | 0.070 | 4.187  | 0.345 | 13.069 | 6.488 166 | 100 | 0.073 | 5.560 | 0.344 | 14.325 | 7.476 |
| 156 | 96 | 0.067 | 5.011  | 0.374 | 14.174 | 7.098 168 | 102 | 0.075 | 5.694 | 0.345 | 14.381 | 7.566 |
| 158 | 98 | 0.065 | 170    | 0.072 | 5.542  | 0.338  | 14.076 | 7.464 |     |     |       |     |
| Z = 62 (Sm)  |    |     |        |     |           |     | Z = 68 (Er)  |    |     |
| 128 | 66 | 0.108 |        |     |         |     |     |     |     |     |       |     |
| 130 | 68 | 0.107 | 5.087  | 0.412 | 16.127 | 7.151 146 | 78  | 0.431 |     |     |       |     |
| 132 | 70 | 0.119 | 4.811  | 0.397 | 15.525 | 6.955 152 | 84  | 1.029 | 0.564 | 0.113 | 4.839 | 2.382 |
| 140 | 78 | 0.521 | 0.862  | 0.162 | 6.319  | 2.944 154 | 86  | 0.581 | 0.512 | 0.106 | 4.568 | 2.268 |
| 146 | 84 | 1.008 | 0.390  | 0.106 | 4.132  | 1.980 172 | 104 | 0.076 | 5.705 | 0.330 | 14.170 | 7.573 |
| 156 | 94 | 0.075 | 4.844  | 0.356 | 13.936 | 6.978 174 | 106 | 0.084 | 4.179 | 0.281 | 12.036 | 6.482 |
| 158 | 96 | 0.072 | 5.431  | 0.374 | 14.631 | 7.389 176 | 108 | 0.085 | 3.987 | 0.272 | 11.667 | 6.331 |
| Z = 70 (Yb)  |    |     |        |     |           |     |     |     |     |     |       |     |
| 160 | 98 | 0.067 | 5.745  | 0.382 | 14.923 | 7.600 150 | 80  | 1.454 |     |     |       |     |
| 162 | 100 | 0.072 | 5.594  | 0.373 | 14.604 | 7.499 150 | 80  | 1.454 |     |     |       |     |
| Z = 64 (Gd)  |    |     |        |     |           |     |     |     |     |     |       |     |
| 154 | 84 | 0.865 | 3.184  | 0.258 | 11.396 | 5.657  |    |
| 156 | 86 | 0.524 | 2.010  | 0.203 | 8.978  | 4.496  |    |
| 132 | 68 | 0.116 | 178    | 0.084 | 5.016  | 0.294  | 12.987 | 7.101 |
| 134 | 70 | 0.099 | 180    | 0.091 | 4.176  | 0.266  | 11.763 | 6.480 |
| 135 | 72 | 0.123 | 182    | 0.119 | 1.219  | 0.143  | 6.307  | 3.500 |
| 138 | 74 | 0.229 | 4.394  | 0.357 | 14.403 | 6.646  |    |
Table 1. Predicted E2 & B(E2)↑ Values and the Corresponding Calculated Deformation Parameters (See Text)

| A  | N  | E2   | B(E2)↑ | β2  | β2/β2(sp) | Q0  | A  | N  | E2   | B(E2)↑ | β2  | β2/β2(sp) | Q0  |
|----|----|------|--------|-----|----------|-----|----|----|------|--------|-----|----------|-----|
| Z = 72 (Hf) | Z = 78 (Pt) |
| 152 | 80 | 1.460 |        |     |           |     | 176 | 98 | 0.287 | 2.580 | 0.191 | 9.385 | 5.093 |
| 158 | 86 | 0.633 | 1.120  | 0.146 | 6.645 | 3.356 178 | 100 | 0.182 | 5.098 | 0.266 | 13.093 | 7.159 |
| 160 | 88 | 0.402 | 0.601  | 0.106 | 4.827 | 2.458 180 | 102 | 0.187 | 4.810 | 0.257 | 12.623 | 6.954 |
| 182 | 110 | 0.108 | 4.062  | 0.254 | 11.515 | 6.390 182 | 104 | 0.183 | 3.583 | 0.220 | 10.816 | 6.002 |
| 184 | 112 | 0.113 | 2.982  | 0.216 | 9.794 | 5.475 200 | 122 | 0.489 | 0.737 | 0.094 | 4.607 | 2.723 |
| 186 | 114 | 0.135 | 2.537  | 0.197 | 8.970 | 5.050 202 | 124 | 0.459 | 0.130 | 0.039 | 1.919 | 1.141 |
| 188 | 116 | 0.297 |        |     |           |     | 204 | 126 | 2.037 | 0.457 | 0.073 | 3.581 | 2.144 |
| Z = 74 (W ) | Z = 80 (Hg) |
| 156 | 82 | 2.301 |        |     |           |     | 170 | 90 | 0.681 |     |     |     |     |
| 158 | 84 | 1.327 |        |     |           |     | 172 | 92 | 0.583 |     |     |     |     |
| 160 | 86 | 0.542 |        |     |           |     | 174 | 94 | 0.664 |     |     |     |     |
| 164 | 90 | 0.339 | 0.400  | 0.083 | 3.873 | 2.005 180 | 100 | 0.418 | 2.729 | 0.188 | 9.508 | 5.238 |
| 166 | 92 | 0.256 | 1.714  | 0.170 | 7.953 | 4.151 182 | 102 | 0.338 | 3.684 | 0.217 | 10.967 | 6.086 |
| 176 | 102 | 0.110 | 4.433  | 0.264 | 12.301 | 6.676 188 | 108 | 0.414 | 2.793 | 0.185 | 9.345 | 5.299 |
| 178 | 104 | 0.105 | 4.591  | 0.266 | 12.425 | 6.794 190 | 110 | 0.464 | 4.085 | 0.222 | 11.221 | 6.408 |
| 188 | 114 | 0.176 | 3.089  | 0.211 | 9.827 | 5.573 | Z = 80 (Hg) |     |     |     |     |     |     |
| 190 | 116 | 0.173 | 1.663  | 0.153 | 7.160 | 4.089 192 | 112 | 0.498 | 1.623 | 0.139 | 7.023 | 4.039 |
| 192 | 118 | 0.220 | 1.206  | 0.130 | 6.055 | 3.482 194 | 114 | 0.506 | 1.521 | 0.134 | 6.753 | 3.910 |
| 194 | 120 | 0.421 |        |     |           |     | 206 | 126 | 0.638 | 0.622 | 0.082 | 4.150 | 2.501 |
| Z = 76 (Os) |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 162 | 86 | 0.620 |        |     |           |     | 208 | 128 | 0.788 | 0.418 | 0.067 | 3.381 | 2.051 |
| 168 | 92 | 0.356 | 1.393  | 0.148 | 7.114 | 3.742 212 | 132 | 0.866 |     |     |     |     |
| 170 | 94 | 0.290 | 3.025  | 0.217 | 10.399 | 5.514 | Z = 82 (Pb) |     |     |     |     |     |     |
| 176 | 100 | 0.113 | 5.438  | 0.284 | 13.624 | 7.394 178 | 96 | 0.695 |     |     |     |     |
| 178 | 102 | 0.128 | 4.071  | 0.244 | 11.700 | 6.397 180 | 98 | 0.984 |     |     |     |     |
| 194 | 118 | 0.279 | 1.686  | 0.148 | 7.110 | 4.117 186 | 104 | 0.614 | 2.933 | 0.186 | 9.645 | 5.430 |
| 196 | 120 | 0.305 | 0.599  | 0.088 | 4.207 | 2.453 188 | 106 | 0.665 | 2.293 | 0.164 | 8.467 | 4.801 |
| 198 | 122 | 0.397 | 0.243  | 0.056 | 2.663 | 1.563 190 | 108 | 0.693 | 1.120 | 0.114 | 5.876 | 3.356 |
| Z = 78 (Pt) |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 192 | 110 | 0.772 |        |     |           |     | 192 | 110 | 0.772 | 3.963 | 0.212 | 10.976 | 6.312 |
| 166 | 88 | 0.699 |        |     |           |     | 194 | 112 | 0.881 | 1.805 | 0.142 | 7.357 | 4.260 |
| 172 | 94 | 0.434 | 1.382  | 0.142 | 6.975 | 3.727 196 | 114 | 0.947 | 1.829 | 0.142 | 7.355 | 4.288 |
| 174 | 96 | 0.359 | 1.229  | 0.133 | 6.527 | 3.515 198 | 116 | 0.947 | 1.411 | 0.124 | 6.415 | 3.766 |
Table 1. Predicted E2 & B(E2)↑ Values and the Corresponding Calculated Deformation Parameters (See Text)

|      | A   | N   | E2  | B(E2)↑ | β2  | β2/β2(sp) | Q0  |      | A   | N   | E2  | B(E2)↑ | β2  | β2/β2(sp) | Q0  |
|------|-----|-----|-----|--------|-----|-----------|-----|-----|-----|-----|-----|--------|-----|-----------|-----|-----|-----|
| Z = 82 (Pb) |     |     |     |        |     |           |     | Z = 88 (Ra) |     |     |     |        |     |           |     |     |     |
| 200  | 118 | 0.919 | 1.217 | 0.114 | 5.918 | 3.498236 | 148 | 0.037 | 9.642 | 0.269 | 14.920 | 9.845  |
| 202  | 120 | 0.833 | 0.618 | 0.081 | 4.190 | 2.492     |     | Z = 90 (Th) |     |     |     |        |     |           |     |     |     |
| 212  | 130 | 0.671 | 0.064 | 0.025 | 1.302 | 0.800208 | 118 | 0.423 | 210  | 120 | 0.419  |
| 210  | 134 | 0.732 |     |       |     |           |     | Z = 84 (Po) |     |     |     |        |     |           |     |     |     |
| 184  | 100 | 1.138 |     |       |     |           |     | 124   | 1.065 |     |     |        |     |           |     |     |     |
| 186  | 102 | 0.767 |     |       |     |           |     | Z = 92 (U) |     |     |     |        |     |           |     |     |     |
| 188  | 104 | 0.601 |     |       |     |           |     | 128 | 0.886 | 0.551 | 0.066 | 3.759 | 2.353  |
| 190  | 106 | 0.677 |     |       |     |           |     | Z = 86 (Rn) |     |     |     |        |     |           |     |     |     |
| 196  | 112 | 0.557 | 2.112 | 0.149 | 7.904 | 4.608236 | 146 | 0.048 | 9.222 | 0.257 | 14.591 | 9.629  |
| 198  | 114 | 0.636 | 2.184 | 0.151 | 7.983 | 4.686238 | 148 | 0.044 | 10.482 | 0.272 | 15.469 | 10.265 |
| 200  | 116 | 0.716 | 1.719 | 0.133 | 7.035 | 4.158     |     | 2.651 |
| 202  | 118 | 0.741 | 2.108 | 0.146 | 7.739 | 4.604218 | 126 | 2.615 |
| 204  | 120 | 0.744 | 0.810 | 0.090 | 4.766 | 2.854220 | 128 | 1.155 |
| 206  | 122 | 0.763 | 0.258 | 0.050 | 2.673 | 1.611222 | 130 | 0.656 |
| 208  | 124 | 0.775 | 0.196 | 0.044 | 2.315 | 1.404224 | 132 | 0.190 | 4.238 | 0.176 | 10.242 | 6.527  |
| 212  | 128 | 0.820 | 0.033 | 0.018 | 0.932 | 0.572226 | 134 | 0.094 | 7.502 | 0.233 | 13.548 | 8.686  |
| 220  | 136 | 0.392 |     |       |     |           |     | 228 | 0.073 | 9.002 | 0.254 | 14.752 | 9.513  |
| Z = 86 (Rn) |     |     |     |        |     |           |     | 240 | 0.046 | 12.691 | 0.292 | 16.927 | 11.295 |
| 194  | 108 | 0.196 |     |       |     |           |     | 242 | 0.047 | 13.836 | 0.303 | 17.576 | 11.794 |
| 196  | 110 | 0.187 |     |       |     |           |     | 244 | 0.040 | 14.057 | 0.304 | 17.619 | 11.888 |
| 224  | 138 | 0.147 | 4.116 | 0.186 | 10.093 | 6.433246 | 154 | 0.040 | 15.872 | 0.321 | 18.620 | 12.632 |
| 226  | 140 | 0.056 | 5.361 | 0.211 | 11.451 | 7.341     |     | Z = 94 (Pu) |     |     |     |        |     |           |     |     |     |
| 228  | 142 | 0.046 |     |       |     |           |     | 228 | 0.114 |     |     |        |     |           |     |     |     |
| Z = 88 (Ra) |     |     |     |        |     |           |     | 230 | 0.071 | 8.664 | 0.243 | 14.388 | 9.333  |
| 200  | 112 | 0.225 |     |       |     |           |     | 232 | 0.059 | 9.461 | 0.252 | 14.948 | 9.753  |
| 202  | 114 | 0.349 |     |       |     |           |     | 234 | 0.050 | 9.213 | 0.247 | 14.667 | 9.624  |
| 204  | 116 | 0.439 |     |       |     |           |     | 236 | 0.042 | 11.257 | 0.272 | 16.121 | 10.638 |
| 220  | 132 | 0.279 | 5.062 | 0.204 | 11.329 | 7.134246 | 152 | 0.046 | 13.915 | 0.294 | 17.434 | 11.827 |
| 230  | 142 | 0.057 | 7.909 | 0.248 | 13.746 | 8.917248 | 154 | 0.043 | 15.366 | 0.307 | 18.222 | 12.429 |
| 232  | 144 | 0.056 | 6.472 | 0.223 | 12.364 | 8.066     |     | Z = 96 (Cm) |     |     |     |        |     |           |     |     |     |
| 234  | 146 | 0.053 | 7.747 | 0.242 | 13.449 | 8.825236 | 140 | 0.028 | 12.032 | 0.275 | 16.667 | 10.998 |
Table 1. Predicted E2 & B(E2)↑ Values and the Corresponding Calculated Deformation Parameters (See Text)

\[
\begin{array}{cccccccccccccc}
\hline
A & N & E2 & B(E2)↑ & \beta_2 & \beta_2/\beta_2^{(sp)} & Q_0 & A & N & E2 & B(E2)↑ & \beta_2 & \beta_2/\beta_2^{(sp)} & Q_0 \\
\hline
Z = 96 (Cm) & & & & & & & & & & & & & \\
238 & 142 & 0.040 & 15.228 & 0.308 & 18.645 & 12.373 & 238 & 140 & 0.023 & 12.734 & 0.276 & 17.050 & 11.314 \\
242 & 146 & 0.041 & 13.970 & 0.292 & 17.661 & 11.851 & 240 & 142 & 0.031 & 16.918 & 0.316 & 19.543 & 13.041 \\
250 & 154 & 0.047 & 16.004 & 0.305 & 18.498 & 12.684 & 242 & 144 & 0.035 & 15.093 & 0.297 & 18.357 & 12.318 \\
252 & 156 & 0.042 & 15.778 & 0.302 & 18.269 & 12.595 & 244 & 146 & 0.042 & 13.743 & 0.282 & 17.421 & 11.754 \\
252 & 156 & 0.042 & 15.778 & 0.302 & 18.269 & 12.595 & 246 & 148 & 0.042 & 14.559 & 0.288 & 17.834 & 12.098 \\

Z = 98 (Cf) & & & & & & & & & & & & & \\
236 & 138 & 0.020 & 7.351 & 0.211 & 13.028 & 8.597 & 238 & 140 & 0.023 & 12.734 & 0.276 & 17.050 & 11.314 \\
240 & 142 & 0.031 & 16.918 & 0.316 & 19.543 & 13.041 & 242 & 144 & 0.035 & 15.093 & 0.297 & 18.357 & 12.318 \\
244 & 146 & 0.042 & 13.743 & 0.282 & 17.421 & 11.754 & 246 & 148 & 0.042 & 14.559 & 0.288 & 17.834 & 12.098 \\
248 & 150 & 0.043 & 15.807 & 0.299 & 18.482 & 12.606 \\
254 & 156 & 0.049 & & & & & & & & & & & \\

Z = 100 (Fm) & & & & & & & & & & & & & \\
246 & 146 & 0.041 & 12.806 & 0.265 & 16.725 & 11.347 & 248 & 148 & 0.045 & 12.973 & 0.265 & 16.743 & 11.420 \\
250 & 150 & 0.044 & 15.834 & 0.292 & 18.399 & 12.617 & 252 & 152 & 0.042 & 15.241 & 0.285 & 17.955 & 12.378 \\
\hline
\end{array}
\]