C. SPECTROSCOPY OF THE TRANS-LEAD NUCLEI

The stability of the heaviest nuclei continues to provide one of the most basic challenges in understanding nuclear structure, both theoretically and experimentally. New results from Berkeley, Dubna and GSI on the very heaviest elements attract attention and draw us towards understanding their underlying structure. We have continued our long-standing program of transuranic research through radiochemistry and decay studies, and further developed our program for Coulomb excitation and transfer reactions on radioactive actinide targets. We have enhanced our program of “inbeam” spectroscopy using Gammasphere and the FMA, studying the heaviest odd-A nuclei and measuring fission barriers. We have started research, development and testing to explore the production of the very heaviest elements at Argonne.

c.1. Entry Distributions of ^{220}Th - The Measurement of Fission Barriers at High Angular Momentum

(A. Heinz, I. Ahmad, M. P. Carpenter, C. N. Davids, J. P. Greene, W. F. Henning, R. V. F. Janssens, T. L. Khoo, F. G. Kondev, T. Lauritsen, C. J. Lister, D. Seweryniak, S. Siem**, A. A. Sonzogni, J. Uusitalo,|| I. Wiedenhöver, P. Reiter,* P. Bhattacharyya,† J. A. Cizewski,‡ G. D. Jones,§ and R. Julin¶)

The fission barrier height is a fundamental property of nuclei. The height and the width of the fission barrier determine the stability of the heaviest known nuclei against spontaneous fission. The fission barrier is strongly influenced by nuclear shell effects and reflects the interplay of microscopic and macroscopic nuclear properties. However, the task of gaining experimental access to the height of the fission barrier is difficult and as a consequence the height of the fission barrier is known only for a very limited number of fissile isotopes, mainly in the vicinity of stable or long-lived isotopes. As production rates of heavy unstable nuclei via fusion-evaporation are strongly influenced by the fission barrier height, this is a crucial parameter in calculations predicting theses rates.

One promising method - the measurement of the entry-distribution - was used to estimate the fission barrier height of ^{254}No[1]and recently also for a number of isotopes near and beyond the proton-drip[2]. The entry distribution is the excitation energy as function of the nuclear spin of a compound nucleus after particle evaporation. To measure this distribution it is necessary to measure the sum energy of all gammas emitted by the compound nucleus after particle evaporation as well as the gamma multiplicity.

Here, we report on an experiment performed with Gammasphere at the FMA. We measured the entry-distribution of ^{220}Th, using a ^{48}Ca beam at 206 MeV and 219.5 MeV impinging on a 810 μg/cm^2 thick ^{176}Yb target. Gammasphere was used as an efficient calorimeter, using the total sum energy measured by the germanium and BGO detectors. The granularity of Gammasphere allows the measurement of the multiplicity of a selected event. The FMA selected the interesting evaporation residue channel and provided a complete suppression of all other channels, especially fission. A source measurement provided the response function of Gammasphere in terms of sum energy and multiplicity. The entry distribution was extracted by unfolding the measured sum-energy versus multiplicity distribution, using the measured response function[3].

The conversion from multiplicity to spin was done using the following expression:

$$I = \Delta I \bullet (m - m_{stat}) + \Delta I_{stat} \bullet m_{stat}.$$

Here, m is the measured multiplicity, m_{stat} is the multiplicity of statistical gamma rays, ΔI_{stat} is the average angular momentum carried by statistical gamma rays and ΔI is the average angular momentum carried by non-statistical gamma rays. We used the values ΔI_{stat} = 0.5 h, ΔI = 1.75 h (as suggested from the level scheme[4]) and m_{stat} = 4.

The preliminary entry distribution of ^{220}Th is shown in Fig. I-21. The upper spectrum was measured at a beam energy of 206 MeV, which corresponds to a maximum excitation energy of E^*_{max} = 14.9 MeV after the ^{224}Th compound nucleus has lost four neutrons. The lower spectrum shows the data taken at a beam energy of 219.5 MeV. The corresponding maximum excitation energy is E^*_{max} = 25.1 MeV. The larger fluctuations at the higher beam energy are due to lower statistics, corresponding to a lower production cross section at this energy. Both distributions show a tilt with respect to the yrast line, similar to observations made in ^{254}No.[1] The reason for this observation is not yet understood. Also, the maximum spin ^{220}Th seems to be about 20 h for both beam energies, which suggests that compound nuclei with higher angular momenta decay exclusively by fission. Both distributions cross the line indicating the saddle point energy (see figure caption) is higher than previously assumed.[6] Even though the compound nucleus has sufficient energy to emit 6-7 neutrons, the selection of ^{220}Th picks a specific channel with emission of only 4 neutrons. Consequently, the excess energy has to be removed by the kinetic energy of the neutrons and by gamma rays (giving a large sum energy). This accounts for the extension of the entry distribution beyond the neutron-separation line in Fig. I-21. Further analysis and model calculations are in progress.

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1P. Reiter *et al*., Phys. Rev. Lett. **82**, 509 (1999); P. Reiter *et al*., Phys. Rev. Lett. **84**, 3542 (2000).

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6P. Möller *et al*., At. Data Nucl. Data Tables **59**, 185 (1995).

7A. Grewe *et al*., Nucl. Phys. **A614**, 400 (1997).

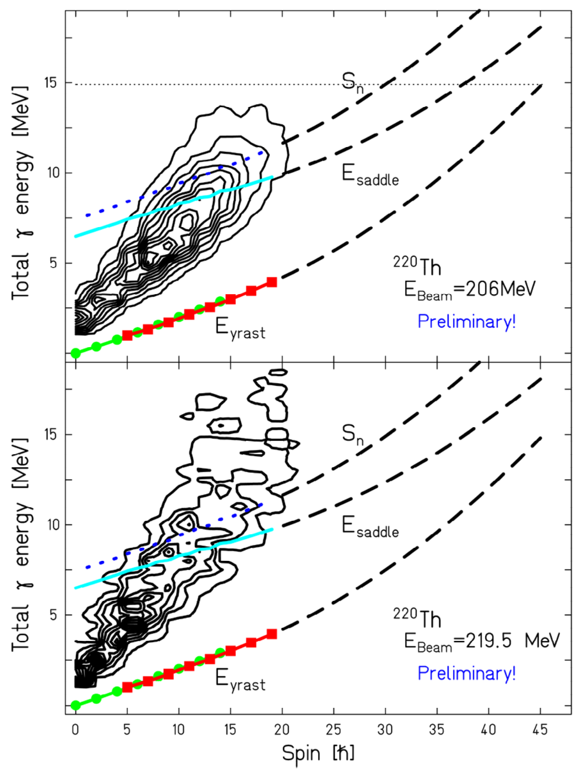

Fig. I-21. Preliminary entry distributions of ^{220}Th at beam energies of 206 MeV and 219.5 MeV. In the figure, the yrast line, the neutron-separation energy S_n and the saddle-point energy E_{saddle} are shown. The saddle point energy is defined as $E_{saddle}(I) = E_{yrast}(I) + B_f(I)$, with $B_f(I)$ being the fission barrier at a given angular momentum I. $B_f(I)$ is calculated as the sum of a liquid drop component[4] and the ground-state shell effect.[5]. The dashed lines are extrapolations. The yrast line data have been taken from reference 4. The neutron separation energy shown is calculated according to $S_n(I) = S_n(I = 0) + E_{yrast}(I)$. $S_n(I = 0)$ is taken from reference 5. The maximum available excitation energy E_{max} = 14.9 MeV is indicated by a dotted line in the upper spectrum. The corresponding line for the lower spectrum is at E_{max} = 25.1 MeVand not shown here. The highest contour lines correspond to 3500 counts and 520 counts for E_{beam} = 206,200 MeV, respectively. The 10 contour lines given in each spectrum correspond to a successive decrease of 10% of the maximum value.

c.2. Study of ^{232}Th and Neighboring Nuclei with "Unsafe" Coulomb Excitation

(R. V. F. Janssens, K. Abu Saleem,* I. Ahmad, J. Caggiano, M. P. Carpenter, J. P. Greene, A. Heinz, F. G. Kondev, T. L. Khoo, T. Lauritsen, C. J. Lister, D. Seweryniak, I. Wiedenhöver, G. Hackman,† P. Chowdhury,‡ D. Cline,§ A. Macchiavelli,¶ C. Y. Wu,§ and T. Nakatsukasa||)

The analysis of the data taken over a year ago at ATLAS with Gammasphere for the ^{209}Bi + ^{232}Th reaction at 1400 MeV continues. Specifically, the work is now focusing on the interpretation of the level schemes of ^{232}Th and the neighboring nuclei ^{230,231,233}Th and ^{231}Ac and ^{233}Pa reported last year. This interpretation is performed using two approaches. First, Cranked Shell Model (CSM) calculations were used in an attempt to obtain the alignment associated with a number of quasiparticle excitations. Figure I-22 compares the experimental total angular moment Ix as a function of frequency with the calculations for the ^{232}Th yrast band. The calculations illustrate the role of both $i_{13/2}$ protons and $j_{15/2}$ neutrons in the alignment. In addition, the numerous vibrational bands that were found in ^{232}Th are being interpreted within the framework of cranked RPA calculations. The latter attempt to reproduce all the observables, including the ratios of reduced transition probabilities which are interpreted using the generalized intensity relationships of Shimizu and Nakatsukasa[1].

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[1]Y. R. Shimizu and T. Nakatsukasa, Nucl. Phys. **A611**, 22 (1996).

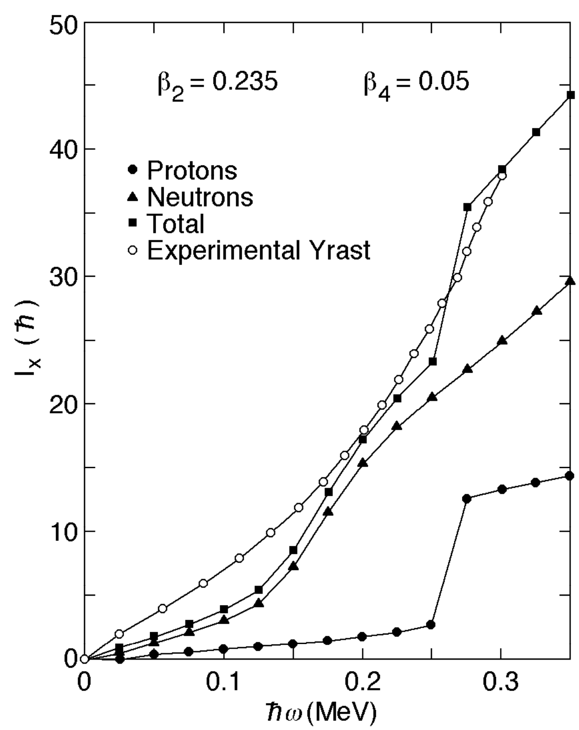

Fig. I-22. .Aligned angular momentum for the yrast band in ^{232}Th as a function of rotational frequency. The data are compared with CSM calculations showing the individual contributions of pairs of $i_{13/2}$ protons and $j_{15/2}$ neutrons.

c.3. Level Structures of the Pu Isotopes Studies by Coulomb Excitation

(R. V. F. Janssens, K. Abu Saleem,* I. Ahmad, M. Alcorta, H. Amro, J. Caggiano, M. P. Carpenter, J. P. Greene, A. Heinz, T. L. Khoo, F. G. Kondev, T. Lauritsen, C. J. Lister, D. T. Nisius, P. Reiter, D. Seweryniak, S. Siem, A. Sonzogni, J. Uusitalo, I. Wiedenhöver, G. Hackman,† P. K. Bhattacharyya,‡ P. Chowdhury,§ J. Cizewski,¶ D. Cline,|| A. O. Macchiavelli,** E. H. Seabury,§ and C. Y. Wu||)

We have been continuing on the study of plutonium nuclei with the so-called "unsafe Coulomb excitation" technique. In the experiments, targets of ^{240}Pu and ^{244}Pu were bombarded with a ^{208}Pb beam at energies 15% above the Coulomb barrier. Similar energies were used with a ^{207}Pb beam on ^{239}Pu and ^{242}Pu targets. The data include Coulomb excitation of the target isotope as well as one and two neutron transfer channels.

In the past years, the focus of our studies was on the behavior at high spins in the yrast band and the negative parity bands. Evidence was found for a possible transition with spin from an octupole vibration to an octupole rotation[1].

During this last year, our efforts concentrated on the completion of the construction of the level schemes for the various isotopes. Figure I-23 shows as an example of the complete scheme obtained for ^{242}Pu. Schemes with similar complexities are now also available for the other even-even Pu isotopes with A = 238-244. In addition, an extensive level scheme exists also for ^{239}Pu and more limited ones for ^{241,243}Pu.

A paper summarizing all these results is in preparation.

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[1] I. Wiedenhöver *et al*., Phys. Rev. Lett. **83**, 2143 (1999).

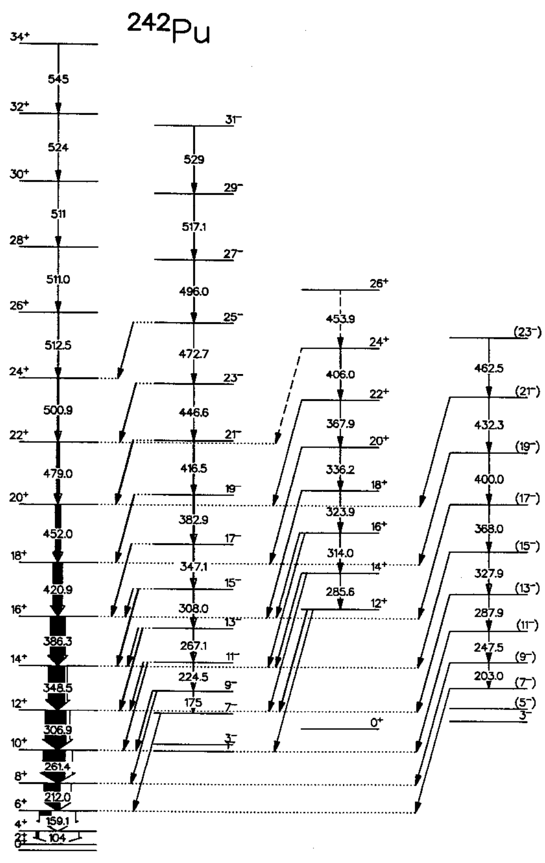

Fig. I-23. The level scheme of ^{242}Pu as obtained in the ^{207}Pb + ^{242}Pu reaction at 1400 MeV.

c.4. Proton Transfer Reactions on ^{237}Np, ^{241}Am and ^{248}Cm

(K. Abu Saleem,* R. V. F. Janssens, I. Ahmad, D. L. Bowers, J. Caggiano, M. P. Carpenter, J. P. Greene, A. Heinz, T. L. Khoo, F. G. Kondev, T. Lauritsen, C. J. Lister, D. Seweryniak, I. Wiedenhöver, G. Hackman,† P. Chowdhury,‡ D. Cline,§ M. Devlin,¶ N. Fotiades,¶ A. O. Macchiavelli,|| E. H. Seabury,¶ and C. Wu§)

Following the successful study of proton transfer reactions with ^{209}Bi beams on ^{232}Th at energies ~ 20% above the Coulomb barrier, the resolving power of Gammasphere was used to study similar reactions on ^{237}Np, ^{241}Am and ^{248}Cm. The main goals of the measurements can be summarized as follows:

1. Study the behavior with spin and frequency of the proton excitations in ^{237}Np and ^{241}Am in relation to the alignment in the Pu and Cm even-even isotopes (possible blocking of proton alignment).

2. Study the octupole excitations in ^{237}Np and ^{241}Am to see whether they follow the pattern found for the same excitation in ^{239}Pu (i.e. a transition from octupole vibration to octupole rotation) or whether they exhibit a particle alignment instead (as in the heavier Pu isotopes).

3. Study the yrast and the lowest octupole bands in ^{242}Cm to determine whether the band sequences mirror those of the isotone ^{240}Pu indicating similar octupole strength or whether they are similar to the patterns seen in the heavier Pu isotopes and in the isotone ^{238}U (upbending or backbending in both the yrast and octupole bands).

4. Delineate for the first time excitations to high spin in ^{249}Bk and ^{250}Cf as well as in all other transfer channels populated in the reaction.

The 6-day experiment was performed with a 1450 MeV ^{209}Bi beam. For each target a large statistical data set was collected. The data are still under analysis. In ^{241}Am, 4 band structures were isolated. These can be regrouped into two sets of signature partner bands associated with the [523]5/2 and [642]5/2 configurations, respectively. The first signature partner pair exhibits a sudden gain in alignment at a frequency of ~0.25 MeV which mirrors a similar upbend in the even-even ^{242}Pu nucleus. In contrast, the other signature partner pair does not exhibit a similar rise, confirming that the backbending seen in the heavy even-even Pu isotopes can be ascribed to the alignment of a pair of $i_{13/2}$ protons. The yrast band of ^{242}Cm was also found in the data and was delineated up to spin 26. The moment of inertia of this band exhibits a similar evolution with rotational frequency as that seen in the isotone ^{240}Pu, i.e. no backbending is seen. Figure I-24 shows this behavior and contrasts it with the observations in the lighter isotone ^{238}U. It is speculated that this absence of a backbending can be ascribed to the same effect (the presence of strong octupole correlations) in both nuclei.

A first phase of the analysis of the ^{237}Np revealed the presence of four bands in this nucleus as well. Differences in the alignment patterns are observed in this case as well. These are relevant for the understanding of the U and Th nuclei.

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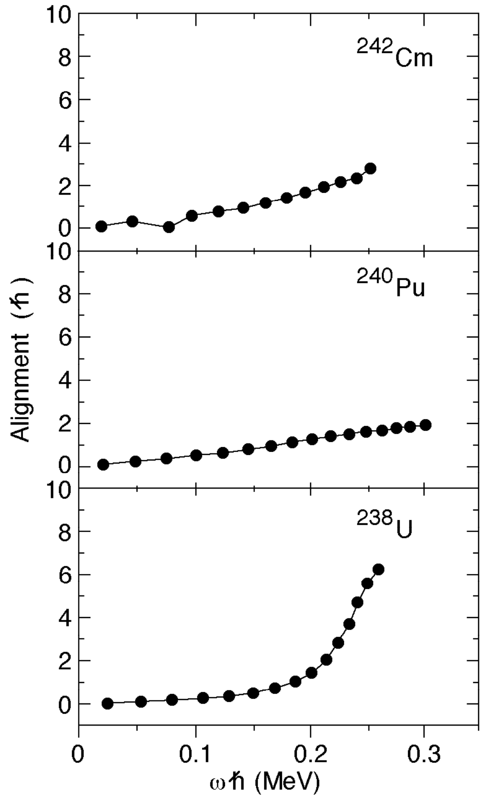

Fig. I-24. Comparison of the measured alignments as a function of rotational frequency in the isotones ^{238}U, ^{240}Pu and ^{242}Cm.

c.5. Level Structure of ^{249}Bk from α Decay of ^{253}Es (I. Ahmad, R. R. Chasman, J. P. Greene, and E. F. Moore)

The level structure of ^{249}Bk was studied by measuring γ-ray spectra of two ^{253}Es ($t_{1/2}$ = 20.5 d) samples with ~25 mCi strength. One source was obtained in January 1999 from the high flux isotope reactor (HFIR) at Oak Ridge National Laboratory and its spectra were measured with a 25% Ge spectrometer and a low energy photon spectrometer (LEPS). After measurement of several spectra, the sample was purified which retained only Es and other +3 elements in the sample. Gamma ray peaks which persisted in the purified sample and decayed with 20-d half-life were assigned to ^{253}Es decay. In these measurements main interference came from the high-energy γ rays of ^{250}Bk ($t_{1/2}$ = 3.2 h), the daughter product of ^{254}Es ($t_{1/2}$ = 276 d). A new sample was obtained from HFIR in January of this year which had less ^{254}Es and hence better sensitivity for γ rays between 500 and 1000 keV. The γ-ray spectra were measured with a LEPS spectrometer and a 25% Ge detector. In addition, an α-γ coincidence measurement was also performed. A γ-ray spectrum measured with the Ge spectrometer in the 500 to 1000 keV range is displayed in Fig. I-25. The present measurements confirm previous single-particle assignments deduced from reaction spectroscopy and from the β decay of ^{249}Cm. In addition, we identified several other bands including the β vibration built on the favored 7/2$^+$[633] band. Data analysis is still in progress and the results of this study will be published in Phys. Rev. C.

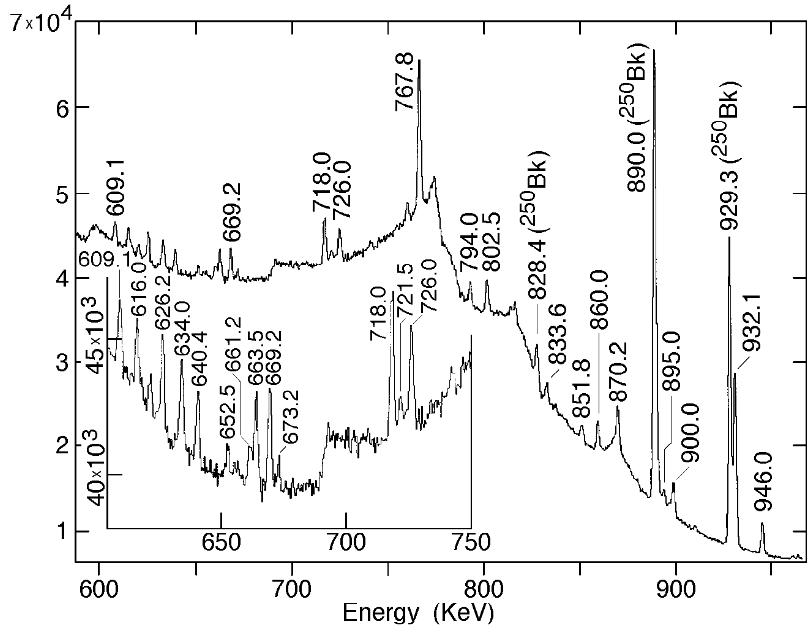

Fig. I-25. Gamma-ray spectrum of a ~25 mCi ^{253}Es sample measured with a 25% Ge spectrometer.

c.6. Energy Levels in ^{251}Cf Populated in the α Decay of ^{255}Fm (I. Ahmad, M. P. Carpenter, R. R. Chasman, J. P. Greene, R. V. F. Janssens, T. L. Khoo, F. G. Kondev, T. Lauritsen, C. J. Lister, P. Reiter, D. Seweryniak, A. Sonzogni, J. Uusitalo, I. Wiedenhöver, and P. Bhattacharyya*)

One of the important goals of nuclear research is the search for superheavy elements and the understanding of their structure and stability. The half-lives of these nuclei are largely determined by the single-particle orbitals near the Fermi surface. One way to identify these orbitals is to study the level structure of the superheavy nuclei. However, the production of only a few atoms precludes such measurements. Another approach to exploring these orbitals is the study of the excited states in the daughter nuclei populated by the heaviest nuclides available in large quantities. The nuclide with the largest number of neutrons produced in milliCurie quantity is ^{255}Fm which decays by alpha particle emission to ^{251}Cf with a half-life of 20.1 h. The level structure of ^{251}Cf has been extensively studied up to ~600 keV excitation by a variety of high resolution techniques. It is, therefore, possible to study the levels above 600 keV by using large amount of ^{255}Fm activity and highly efficient spectrometers.

The level structure of ^{251}Cf was studied by measuring the γ ray spectra of ^{255}Fm samples in singles and in coincidences. Several samples of ~2 mCi ^{255}Fm were obtained from the high-flux isotope reactor (HFIR) at the Oak Ridge National Laboratory. Gamma singles spectra were measured with a 25% Ge spectrometer and a 2 cm^2 × 7-mm low-energy photon spectrometer (LEPS). Gamma rays were assigned to ^{255}Fm decay on the basis of their half-lives and the fact that these γ rays were present in more than one sample with the same relative intensities. One sample was used to measure γ- γ coincidence spectra with Gammasphere. The superb sensitivity of the Gammasphere allowed us to observe γ rays with intensities as low as 1.0×10^{-8} photons per ^{255}Fm α decay in coincidence with other γ rays. The present study confirmed the previous assignments including the 1/2-[750] band at 632.0 keV. In addition, the $9/2^{+}$[604] orbital was identified at 974.0 keV. The $K^{\pi} = 0^{+}$ β vibration and $K^{\pi} = 2^{-}$ octupole vibration coupled to the favored band $7/2^{+}$[613] were also identified. Part of the level scheme deduced from the present study is shown in Fig. I-26. The results of this study were published.[1]

*Purdue University
[1] Phys. Rev. C **62**, 064302 (2000).

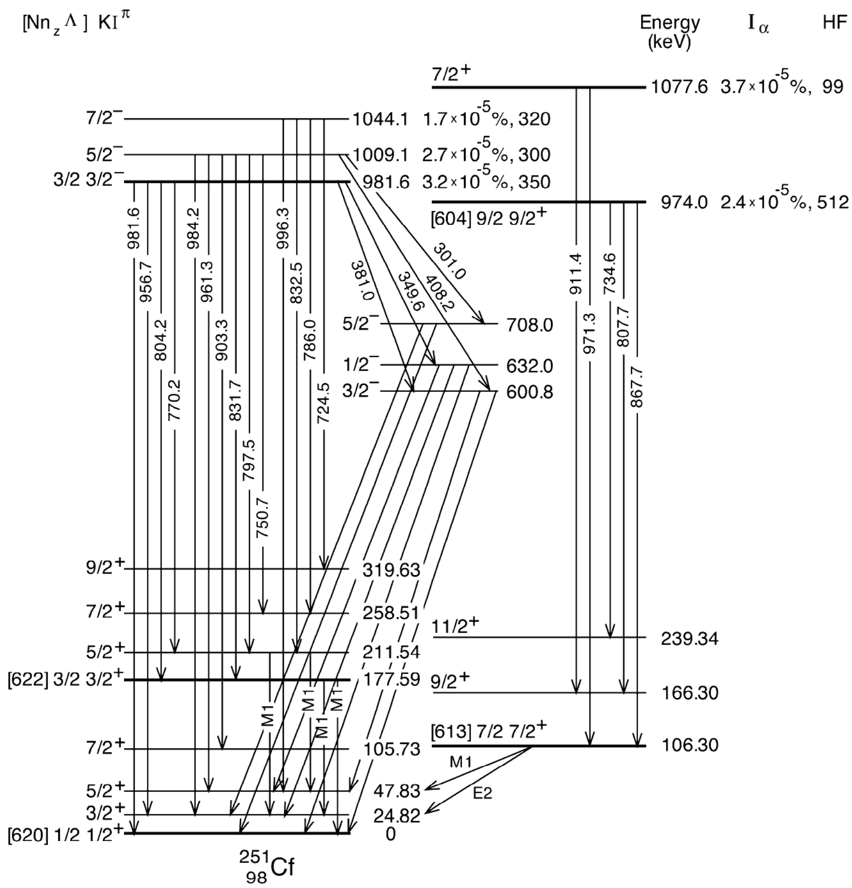

Fig. I-26. A partial level scheme of ^{251}Cf showing the excited bands above 500 keV. The bands at 974.0, 981.6, and 1077.6 keV were identified for the first time. The 981.6 and 1077.6 keV bands are interpreted as the 7/2+[613] state coupled to the 2- octupole and 0+ pair vibrations, respectively. The hindrance factors were calculated with the spin-independent theory of Preston.

c.7. Nuclear Structure and Fission Studies with ^{252}Cf (I. Ahmad, J. P. Greene, R. V. F. Janssens, C. J. Beyer,* J. K. Hwang,* A. V. Ramayya,* J. H. Hamilton,* J. O. Rasmussen,† Y. X. Luo,† S. C. Wu,† T. N. Ginter,† C. Folden,† P. Fallon,† P. Zieliuski,† S. J. Asztalos,† K. E. Gregorich,† A. O. Macchiavelli,† and M. Stoyer‡)

An experiment was performed with the Gammasphere using a ^{252}Cf source with 70 uCi activity to determine the structure of neutron-rich nuclei with small yields. Gammasphere for this experiment consisted of 102 Compton-suppressed Ge detectors. To enhance the sensitivity of the measurement, a very large number of events (10^{11}) were collected over a five-week period during August and November 2000. Care was taken that the spectra contained low-energy gamma rays. With this large data set we hope to deduce structure of odd-mass and odd-odd nuclei. A coincidence cube was generated from the data set and detailed analysis is in progress.

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c.8. Spectroscopy of the Transfermium Nucleus ^{252}No (T. L. Khoo, C. J. Lister, R.-D. Herzberg,* P. A. Butler,* N. Amzal,* A. J. C. Chewter,* N. Hammond,* G. D. Jones,* R. D. Page,* C. Scholey,* O. Stezowski,* M. Leino,† R. Julin,† J. F. C. Cocks,† O. Dorvaux,† P. T. Greenlees,† K. Helariutta,† P. M. Jones,† S. Juutinen,† H. Kankaanpaa,† H. Kettunen,† P. Kuusiniemi,† M. Muikku,† P. Nieminen,† P. Rahkila,† W. H. Trzaska,† F. Heβberger,‡ J. Gerl,‡ Ch. Schlegel,‡ H. J. Wollersheim,‡ W. Korten,§ F. Becker,§ Y. Le Coz,§ K. Hauschild,§ M. Houry,§ R. Lucas,§ Ch. Theisen,§ P. Reiter,¶ and K. Eskola||)

An experiment on ^{252}No was conducted with JUROSPHERE II and RITU at Jyväskylä, with R. Herzberg as spokesperson. The behavior at high-spin of the moment of inertia of the ground state band and the comparison with that of ^{252}No will reveal indirect information on the single-particle orbitals near the Fermi level, especially on the high-j ones which align and increase the moment of inertia. In particular, the influence of the $j_{15/2}$ orbitals is expected to lead to a larger increase in the moment of inertia in ^{252}No than in ^{254}No. Hence, the moments of inertia of shell-stabilized nuclei provide a new testing ground for theories, particularly for self-consistent mean-field theories, where the interactions are fitted to the properties of lighter nuclei.

From the experiment, the ground state band of ^{252}No was identified up to spin 20. The moment of inertia of ^{252}No starts out lower than that of ^{254}No at low frequency, but becomes larger at $\hbar\omega \sim 0.14$ MeV, as it increases more rapidly. These results support the expectations based on the cranked shell model, using single-particle levels given by a Wood-Saxon potential with the measured deformation. However, the moments of inertia at high spin were not calculated with cranked Wood-Saxon models. In contrast, there are several mean-field calculations of the moments of inertia of ^{252,254}No as a function of rotational frequency. However, they are not able reproduce the data. A paper reporting the measurements is submitted for publication.

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c.9. Structure, Fission Barrier and Limits of Stability of ^{253}No (T. L. Khoo, I. Ahmad, M. P. Carpenter, C. N. Davids, A. Heinz, W. F. Henning, R. V. F. Janssens, F. Kondev, T. Lauritsen, C. J. Lister, D. Seweryniak, S. Siem, A. A. Sonzogni, I. Wiedenhöver, J. A. Cizewski,* N. Amzal,† P. A. Butler,† A. J. Chewter,† P. T. Greenlees,† K. Helariuta,§ R. D. Herzberg,† G. Jones,† R. Julin,§ H. Kankaanp\"a\"a,§ H. Kettunen,§ W. Korten,¶ P. Kuusiniemi,§ M. Leino,§ P. Reiter,|| J. Uusitalo,§ and K. Vetter‡)

For the heaviest nuclei, including the superheavy nuclei, a large shell-correction energy provides additional binding, thereby creating a fission barrier where none (or a small one) would have existed for a liquid drop alone. Knowledge of the single-particle energies of the heaviest nuclei is important for calculating the shell-correction energy and for interpreting the α decay of the superheavy elements. The most direct information on the single-particle energies comes from an odd nucleus, ^{253}No in this case. The entry distribution gives information on the fission barrier. It is interesting to determine the mass dependence of the fission barrier around N = 152 for two reasons. First, the barrier was found to vary rapidly near N = 152 for lighter nuclei. Second, barriers of a sequence of isotopes provide a good test of theory.

For these reasons, we performed an experiment to study the levels of ^{253}No, with the use of the ^{207}Pb(^{48}Ca,2n) reaction. In a first experiment with the gas-filled separator RITU at Jyväskylä, the production cross section of ^{253}No was measured as ~0.5 μb (by comparing with the known cross section for the ^{208}Pb(^{48}Ca,2n)^{254}No reaction). This showed that a γ-ray experiment was feasible.

In a subsequent experiment at Argonne, the γ rays were detected with Gammasphere, in coincidence with the

FMA. Compared to the γ-ray spectrum for ^{254}No, that for ^{253}No (Fig. I-27b) is dominated by the K X-rays and the transitions connecting excited states are much weaker relative to the x-rays. The explanation for the difference lies in a huge conversion electron branch for ΔI = 1 intraband transitions in the odd nucleus. Even with a small M1 branching ratio, there is an overwhelmingly large conversion electron yield. The gamma flux is further fragmented over several close-lying bands and between the two signature partners of each band. (In contrast, in an even-even nucleus, much of the flux funnels into the yrast band.) Clearly, heavy odd nuclei, such as ^{253}No, represent the limits of in-beam γ spectroscopy.

A fortunate aspect in ^{253}No is that only one band is expected to have sufficiently small M1 branching ratios to permit detection. In all the other bands, which are expected to be low-lying on the basis of data in neighboring isotones,[1] the branching ratio is very small due to overwhelming competition from M1 conversion electrons. The calculated spectrum for a strong-coupled band, built on the 7/2+[624] orbital, is shown in Fig. I-27a. In the experimental spectrum of ^{253}No (Fig. I-27b), it is possible to discern a sequence of transitions with energies, which are very close to those expected for the 7/2+[624] band. As the gamma yield is less depleted in this particular band, it should have a correspondingly larger γ-ray sum multiplicity than the other bands. Indeed, by demanding that 4 or more Gammasphere modules fire, a spectrum (Fig. I-27c) is obtained, which emphasizes the candidate transitions and suppresses the others. Further evidence for assigning these transitions to a band is given by coincidence gates set on the transitions. With the low statistics, only 0-2 coincidences are seen in each gate – as expected from our model calculations. The sum spectrum from all the gates is shown in Fig. I-27e, which shows counts primarily at the expected energies. The total number of photopeak-photopeak coincidences is 18, which is close to the 20 predicted by the model. Furthermore, coincidences are observed mostly among the transitions within each signature family – as expected.

The level scheme deduced for the 7/2+[624] band is shown in Fig. I-28, which is supported by the coincidences. Since no transitions between the two signature partners were detected (in accord with the model), the relative energies between them is not given by experiment, but is based on the model calculation. The lowest levels of the band are also given by the calculation since increasing M1 competition reduces the E2 γ branch at the lowest spins. However, the E1 interband decays to the yrast band, which is expected[1] to be built on the 9/2-[734] configuration, is suggested by the enhanced strength at 355 keV in the spectra of Fig. I-27(b,c). (There is also a rotational transition at 355 keV.) This suggestion is supported by the multiplet at 353-355 keV for the interband decays given by the model calculation (see Figs. I-27a and I-28).

The moment of inertia $J^{(1)}$ of ^{253}No is ~13% larger than that of ^{254}No. A plot of $J^{(1)}$ as a function of transition energy shows that $J^{(1)}$ is almost constant at the lowest energies (up to 335 keV) and then monotonically increases thereafter. These are characteristic features of the moment of inertia of an odd nucleus. The smooth behavior of $J^{(1)}$ also provides support for the assignment of the transitions to the band.

We also measured the two-dimension entry distribution as a function of spin vs. sum energy. The entry distributions for ^{253,254}No are compared in Fig. I-29. They show that the fission barriers are similar in both nuclei and larger than 5 MeV at high angular momentum. The sharp tilt angle of the entry distribution with respect to the yrast line is seen in both entry distributions, which is attributed to a low-energy component, close to the yrast line at low spins. The low level density in this region rules out an explanation in terms of statistical neutron evaporation, suggesting a contribution from high-energy neutrons, possibly associated with pre-equilibrium emission. The observation of this feature also in ^{220}Th may suggest that this is a common phenomenon in the production of highly fissile evaporation residues.

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[1] I. Ahmad *et al*., Phys. Rev. C **14**, 218 (1976).

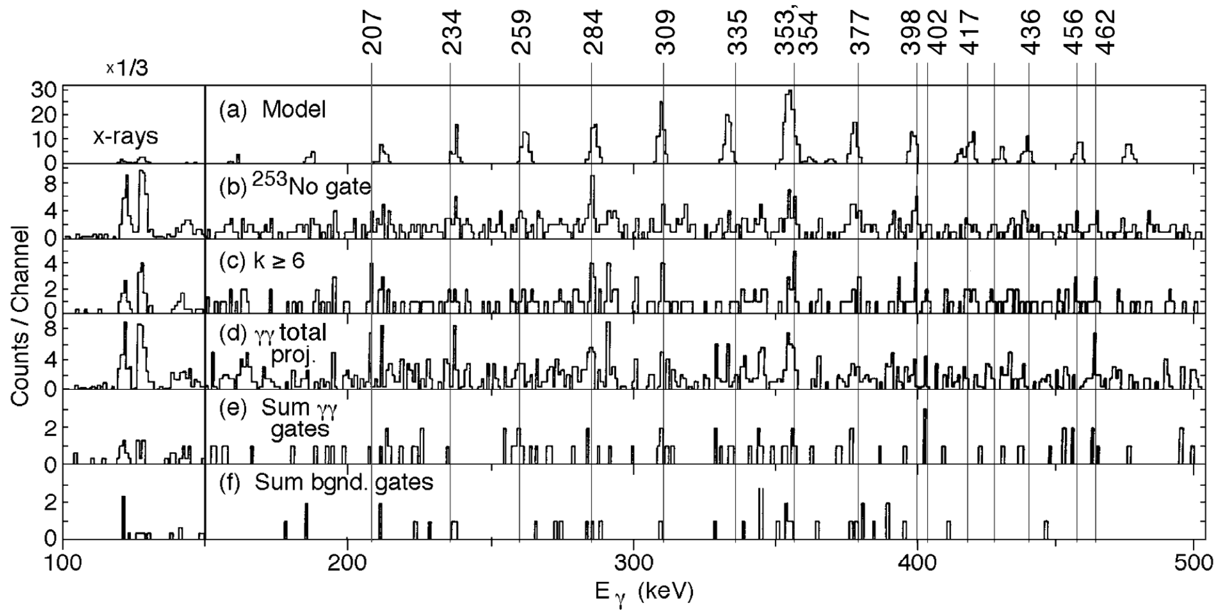

Fig. I-27. Gamma spectra of ^{253}No obtained under different conditions. (a) Calculated spectrum of the 7/2+[624] band. (b-e) Experimental γ spectra: (b)coincident with ^{253}No residues detected in the FM; (c) obtained with a requirement that 6 or more Gammasphere detectors fired; (d) total γ projection; (e) sum of all coincidence gates on all transitions in the 7/2+[624] band; (f) sum of all background gates, which are shifted 3 keV with respect to the gates in (e).

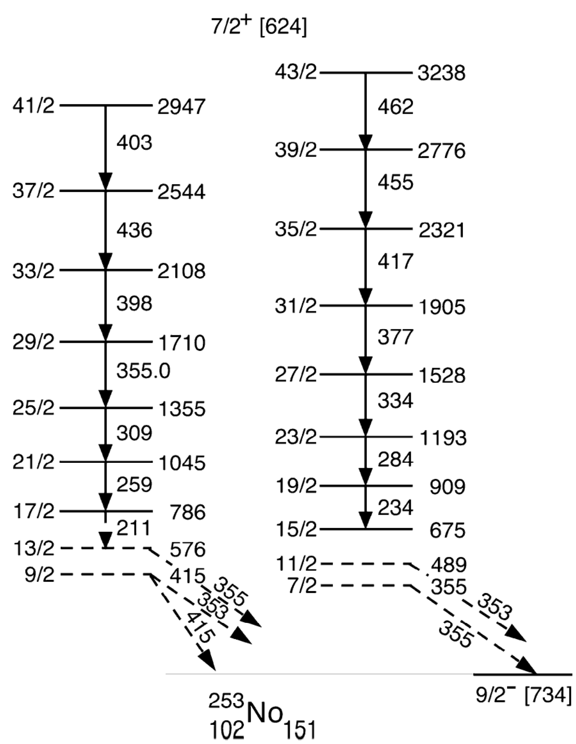

Fig. I-28. Level scheme of the 7/2+[624] band in ^{253}No, showing decay of the two signature partners. It is assumed that the signature splitting is zero.

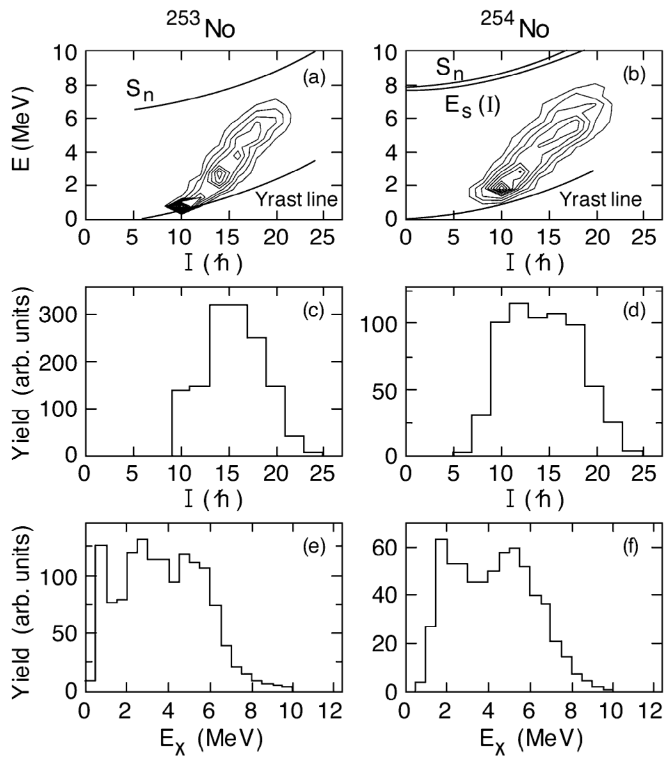

Fig. I-29. (a, b) Entry distributions in spin/excitation energy of ^{253,254}No. (c,d) Projection of (a, b) on the spin axis. (e, f) Projection of (a, b) on the energy axis.

c.10. Relativistic Mean-Field Calculations of the Structure of Very Heavy Nuclei

(T. L. Khoo, I. Ahmad, A. Afanasjev,* and S. Frauendorf*)

The properties of the heaviest nuclei provide a test bed for the predictive powers of self-consistent mean theories, which are based on interactions fitted to the properties of lighter nuclei. If these theories are able to accurately predict the properties of the heaviest superheavy nuclei, then they could provide a guide in searching for the nuclei with Z ≥ 114.

A program was started on relativistic mean-field calculations to test their predictive powers of the properties of the heaviest nuclei for which spectroscopic data exist. The goal is to calculate (i) the moments of inertia and their dependence on spin, (ii) the location of deformed shell gaps, e.g. the well-known N = 152 gap, and (iii) the quasiparticle energies. Initial results indicate that the moment of inertia of ^{254}No and the spin dependence can be reproduced. However, if particle-number projection based on the Lipkin-Nogami method is performed then there is a ~10% reduction of the moment of inertia. In contrast, the theory is able to reproduce moments of inertia of lighter nuclei from A ~ 70-200, including those of superdeformed bands. The preliminary indication is that the Gogny pairing force, which is used in these calculations, is too strong for the heaviest nuclei – as used in this framework.

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