CERN LIBRARIES, GENEVA

CM-P00064028

THE ESSENTIAL DECAY OF PANDEMONIUM: β -DELAYED NEUTRONS

J.C. Hardy^{*)}, B. Jonson^{**)} and P.G. Hansen^{***)}

CERN, Geneva, Switzerland

ABSTRACT

The β -delayed neutron decay of a fictional nuclide, Pandemonium, is created numerically using a statistical model and Monte Carlo techniques. The neutron spectra generated are compared with experimental results for the decays of ^{85}As , ^{87}Br , ^{135}Sb , and ^{137}I . Contrary to previously held beliefs, we find the experimental data to be consistent in all important aspects with a statistical interpretation. It is shown that peak-stripping analyses of the more complex experimental neutron spectra cannot yield reliable decay schemes. In particular, schemes obtained previously for the decays of ^{85}As and ^{135}Sb , together with discussions of structure supposedly observed in their β -decay strength functions, must be regarded as unjustified.

Geneva - 4 November 1977

(Submitted to Nuclear Physics A)

-
- *) On leave from: AECL, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada.
 - **) On leave from: Department of Physics, Chalmers University of Technology, Göteborg, Sweden.
 - ***) On leave from: Institute of Physics, University of Aarhus, Aarhus, Denmark.

1. INTRODUCTION

If a β -radioactive nuclide has relatively low decay energy, it cannot feed many daughter states, and the energy spectrum of γ -rays emitted following its β -decay will be characterized by a few well-resolved peaks. For nuclides with higher decay energy, the number and density of daughter states becomes rapidly higher too. Peaks in the γ -ray spectrum become less clearly defined. Already at 3 MeV in a medium-mass nucleus, the density of daughter states is high enough to distort¹⁾ the simple peak-analysis approach to a Ge(Li) detector spectrum of β -delayed γ -rays.

Beta-delayed neutron precursors, of necessity, have a rather high Q_β -value, and the neutrons themselves are emitted from states with at least a few MeV of excitation. In addition, a typical neutron spectrometer has an instrumental resolution (FWHM) that is nearly an order of magnitude worse than that of a Ge(Li) detector. Is it really appropriate, then, to analyse neutron spectra using essentially the same concepts as those developed for interpreting low-energy γ -rays?

Most recent reports of delayed-neutron spectra have remarked on the "prominent line structure" observed [see, for example, Shalev and Rudstam²⁾, and Kratz et al.³⁾]. The fact that peaks are indeed clearly visible has been taken as evidence for the "selective β -population" of individual states in the emitter^{3,4)}, the decay of each giving rise to a neutron peak. With the origin of the peaks thus decided, their measured energies and intensities have been used in some cases to construct plausible decay schemes^{3,5)}.

Since decay schemes obtained in this manner are being used to study the effects of nuclear structure on β -decay systematics^{4,6-8)}, it is of some importance to examine the precepts upon which they are based. We shall do that here by creating, as it were, a fictional nucleus, Pandemonium, whose decay we simulate numerically using Monte Carlo techniques. The only conditions that we impose upon the process are those broad statistical principles known to circumscribe nuclear excitation and decay⁹⁻¹¹⁾. In particular we do *not* artificially introduce any effects due to local nuclear structure. The delayed neutron spectrum generated for this

fictional nucleus will be seen to have the advantage that on the one hand it resembles experimental data, yet on the other corresponds to the precisely known decay of an "unstructured" nucleus. With *a priori* knowledge of what the spectrum actually represents, it is possible to test the validity of assumptions normally made in analysing those spectra for which only nature is responsible. The statistical principles that we shall adopt here have previously been used successfully to reproduce the over-all shape of β -delayed proton¹⁰⁻¹²⁾ and neutron¹³⁾ spectra. Furthermore, the peaks observed in such spectra have previously been interpreted as fluctuations^{11,14)} in the nuclear statistics (not, of course, to be confused with counting statistics). What is novel to the present approach is the creation of a complete statistical decay scheme; the neutron spectrum then grows naturally out of the sum of individual transitions. This, for the first time, permits a microscopic analysis of what is, without doubt, a completely unstructured spectrum.

We have already reported γ -emission from the decay of Pandemonium¹⁾.

2. PANDEMONIUM CREATED

An outline of our approach to the computation appears schematically in fig. 1. Initially, the mass, atomic number, spin, and decay energy for Pandemonium (A_Z) must be selected in order to approximate the actual conditions of a decay to be illustrated. Once that is done, the first step in creating a decay scheme for Pandemonium is to produce, in its daughter [the neutron emitter, $^A_{(Z+1)}$], excited states whose spins permit feeding by allowed β -decay. We required the density of these states to conform with the spin- and energy-dependent formulas of Gilbert and Cameron¹⁵⁾ but the individual level energies were determined randomly, with the spacing between them, D_i , scattered in accordance with the Wigner law¹¹⁾ (see fig. 1).

Next, transition probabilities need to be generated for Gamow-Teller β -decay to these states. Experimental studies on the gross features of high-energy β -decay between neutron-rich nuclei (see, for example, refs. 10, 13, 16) have indicated that the process is best described by a strength function varying more or less

proportionately with the density of daughter states. This is equivalent to stating that the reduced transition probabilities for individual β -branches are, on the average, constant and independent of excitation energy. In accordance with these observations, we generated transition probabilities to each state in the daughter by random selection from an energy-independent Porter-Thomas distribution of numbers (see fig. 1). The statistical rate function, computed from a simple parametrization¹⁷⁾, was then incorporated and branching ratios established.

Having dealt with the population of states in the daughter it is necessary to make them decay. We assume that they do so either by γ -ray or neutron emission, and further, we assume for simplicity that the neutrons can feed only three states in the residual nucleus $^{(A-1)}_{(Z+1)}$. Partial widths for each neutron decay channel were taken to have an average value given by

$$\langle \Gamma_{n_i} \rangle = \sum_L T_L / 2\pi\rho(E_x) , \quad (1)$$

where T_L is the transmission coefficient for neutrons of angular momentum L , and $\rho(E_x)$ is the level density at excitation energy E_x . The quantity T_L should preferably be calculated with a realistic nuclear potential, but for rapid computation nearly the same effect is achieved by replacing T_L with $k_L P_L$, where P_L is the penetrability for a simple centrifugal barrier and k_L is an *ad hoc* factor obtained by comparison with optical model calculations¹⁸⁾ of T_L . Over the region of excitation contributing to β -delayed neutron emission, k_L is effectively constant for a given nucleus. Individual neutron widths were then obtained from a random Porter-Thomas distribution about a mean value calculated from equation (1).

Unlike the neutron widths, each total γ width Γ_γ is made up of partial widths to many final states, and consequently Γ_γ is not expected to fluctuate from level to level⁹⁾. In our Pandemonium decay scheme we simply derived individual Γ_γ values from the general formulas of Cameron¹⁹⁾. These had the effect of removing strength from the neutron spectrum, but we did not probe the distribution of partial γ widths nor attempt to produce a γ -ray spectrum.

The neutron spectrum can now be obtained from a sum of all the separate transitions so far created. Each state in the emitter gives rise to three neutron groups: the intensity I of, for example, the n_1 group from one state is

$$I(E_{n_1}) = J_\beta \Gamma_{n_1} / (\Gamma_\gamma + \Gamma_{n_1} + \Gamma_{n_2} + \Gamma_{n_3}), \quad (2)$$

where E_{n_1} is the energy of the emitted neutrons, and J_β is the β -decay branching ratio for populating the state in the first place. Having enumerated the energy and intensity of each neutron transition in this way, we converted the result into a neutron spectrum by folding in a Gaussian function whose resolution could be chosen to match specific experimental conditions. A scaling factor was also introduced so that the number of counts per channel could be matched to experiment, and finally the effect of Poisson counting statistics was superimposed.

3. COMPARISON WITH EXPERIMENT

We have chosen four delayed-neutron precursors for comparison with the simulated decay of Pandemonium: ^{85}As , ^{87}Br , ^{135}Sb , and ^{137}I . All four have well-known strongly structured spectra while coming from two rather different mass regions. Also, the energy window for neutron emission (i.e. the difference between the β -decay energy of the precursor, and the neutron separation energy of its daughter: $(Q_\beta - B_n)$) is large for ^{85}As and ^{135}Sb , and small for the other two. The four precursors are thus representative of a larger body of existing experimental data.

Input information for the Pandemonium computation is listed in table 1. Since none of the precursor spins has actually been measured, we simply adopted those J^π -values, deduced from spin systematics, that were used previously in spectral analyses^{3, 5-7}). Beta-decay and neutron separation energies that are not known were taken from mass predictions²⁰⁻²²). Known excited states in the residual nuclei were included (up to a maximum of two) if their energy permits feeding by neutron decay.

Ultimately, however, it is not the detailed accuracy of this information that matters since, by its very nature, the Pandemonium computation is restricted to qualitative -- or at the very best only semi-quantitative -- comparisons with real data. What we wish to ask is: Are the experimental data consistent or not with a purely statistical origin? And if they are, how would that affect their interpretation in terms of a decay scheme?

Simulated Pandemonium spectra are compared with experiment for ^{87}Br , ^{137}I , and ^{135}Sb in figures 2-4 respectively; the results for ^{85}As were superficially quite similar to those for ^{135}Sb and so are not illustrated. For all cases, the experimental resolution was reported³⁾ to range from 12 keV (FWHM) for thermal neutrons, up to 19 keV for neutrons at 1 MeV. Nevertheless, the simulated spectra shown in the figures were computed assuming a constant 15 keV Gaussian resolution, since spectra actually generated with a graded FWHM showed few perceptible differences. More important in visual comparison is the observation that peaks in the experimental spectra show evidence of "tails", a deviation from simple Gaussian response not attempted in our simulation.

Qualitatively, there is a striking similarity between the Pandemonium spectra and those observed in nature. Although the actual location of prominent peaks from Pandemonium is of no significance, the magnitude and frequency of the peaks, as well as the general structure of each spectrum, match closely with experiment. With this similarity in mind we now discuss the spectra in terms of salient features familiar to readers of previous work in the field.

i) Prominent peak structure

All spectra, both of the natural and simulated variety, are marked by the appearance of many pronounced peaks. In fact, if one were to consider the spectra as being made up of "peaks" and "continuum" -- an approach that has been taken^{3,6,7)} -- the proportion of neutron intensity contained in "peaks" is probably greater for the Pandemonium data than it is for the real experimental results. Far from indicating a selective β -population, though, such a structure is obviously characteristic of (random) Porter-Thomas statistics^{1,10,11)}, which is *not* to say

that large differences among the β -transition probabilities are unlikely. On the contrary, large fluctuations necessarily do occur. It is just that they need not be explained by introducing a special selectivity due to local nuclear structure.

ii) Lack of high-energy neutrons

Both ^{87}Br and ^{137}I , with energy windows ($Q_\beta - B_n$) of less than 2 MeV, emit neutrons up to nearly the maximum possible energy; the equivalent Pandemonium simulations have the same property. It has been noted^{3,5,7,8)}, however, that the experimental neutron spectra for ^{85}As and ^{135}Sb apparently contain very few counts above 2 MeV even though their energy windows probably extend above 4 MeV. This lack of high-energy neutrons has been interpreted as indicating an anomalously weak population by neutron decay of the residual nucleus' ground state, an effect attributed to the structure of the nuclear states involved. It can be seen from fig. 4 that this explanation need not be invoked for ^{135}Sb ; the "structureless" Pandemonium exhibits the same lack of neutron intensity at high energies. Quantitatively, the proportion of counts above 2.2 MeV is 4%, compared with $\lesssim 5\%$ observed experimentally⁷⁾.

The situation for ^{85}As is not so clear. Experimentally, less than 3% of the neutron intensity is observed above 1.6 MeV⁷⁾ while our simulation, using the input data of table 1, produced as much as 20% of the intensity above 1.6 MeV, although all but 8% of it remains below 2.2 MeV. This discrepancy is of moot significance, since it depends quite strongly upon several factors, not the least important of them being the assumed value of ($Q_\beta - B_n$). By reducing the energy window by 1 MeV, an amount within the uncertainties of mass prediction²⁰⁾, less than 10% of the neutrons appear above 1.6 MeV and only 1.5% above 2.2 MeV.

iii) Considerable feeding of residual excited states

Experiments have been reported for several delayed-neutron activities^{23,24)}, in which γ -rays were observed corresponding to the decay of states in the residual nuclei; evidently these states are populated first by neutron emission. The proportion of emission to excited states seemed sufficiently large that it was

believed inconsistent with "energetics and angular momentum considerations" alone²³⁾ and hence indicative of structural selectivity. The validity of these arguments can now be tested by our statistical model calculations.

The excited state populations, as they appear in the Pandemonium simulations, are given in table 2 for ^{85}As (calculation 1) and ^{135}Sb . The quoted standard deviations indicate the range of values produced by (nuclear) statistical fluctuations present in any individual Pandemonium decay scheme. For comparison, the experimental populations with (counting, etc.) statistical uncertainties are shown in the same table. Evidently the decay of ^{135}Sb requires no extra-statistical explanation, although it should be noted that in our simulation the strength to "higher" states lies in populating the 4^+ state at 1.6 MeV, while surprisingly it is the 6^+ state nearby that apparently is most strongly fed in reality.

Once again, the comparison with ^{85}As is somewhat less satisfactory. The statistical simulations certainly produce considerable excited-state feeding, but not enough for the 2^+ state at 2.1 MeV. It is hard to view this too seriously, however, since a relative enhancement of the calculated $L = 1$ neutron transmission coefficients (by making $k_1 \gg k_3, k_5$ -- see Section 2) leads to much better agreement, as seen from "calculation 2" in table 2. Since this change is probably within the uncertainties of the optical model parameters, it need hardly be viewed as the result of special structure local to ^{85}As .

iv) Energy-dependence of the spectrum variance

In rejecting a purely statistical interpretation of the delayed-neutron spectra for ^{85}As and ^{135}Sb , both Franz et al.⁵⁾ and Kratz et al.⁷⁾ extracted normalized variances describing fluctuations in the spectra. The dependence of the variance on neutron energy was shown to disagree with the author's estimate of statistical model predictions. Since the apparent disagreement was most severe for ^{135}Sb (see ref. 7), we have examined that case in detail, reanalysing the original neutron data²⁵⁾ and then, with the same technique, analysing the spectrum of Pandemonium.

The previous analyses^{5,7)} of delayed-neutron spectra claimed to follow techniques used in two earlier delayed-proton studies^{26,27)} which, although different from one another, were both based on general principles outlined by Hansen²⁸⁾. In essence, the experimental variance was derived by comparing the measured spectrum with one smoothed with a Gaussian function. More recently^{11,29)} a significantly improved technique has been introduced. To alleviate distorting the gross structure of the spectrum by the smoothing function itself, a Gaussian-plus-derivative function is employed²⁹⁾. Then the autocorrelation function is evaluated for a spectrum derived from the quotients of primary and smoothed data¹¹⁾. Finally, an analysis of this function yields the variance and, independently, the contribution from counting statistics as well as a measure of the instrumental resolution. Such a procedure was used for the spectra in fig. 4 and the results are plotted in fig. 5; without doubt the experimental results are completely consistent with a statistical interpretation.

4. SPECTRUM ANALYSIS -- PEAKS OR PANDEMONIUM

The comparisons described in the preceding section lead inevitably to the conclusion that, with possibly some slight reservations concerning ^{85}As , the delayed-neutron data we have examined are indeed consistent with a purely statistical interpretation. This should not be thought of as an assertion that nuclear structure is absent; of course it is not. The experimental data simply do not show any incontrovertible evidence for structural effects beyond those resulting from the precepts used to create Pandemonium.

In the absence of any proof to the contrary, it must then be assumed that the experimental spectra behave in all respects according to the well-determined statistical principles exemplified by Pandemonium. Under such circumstances, can they still be analysed as being composed of peaks, each corresponding to an individual neutron transition, from which a decay scheme can be constructed? In attempting to answer this question we shall deal with the least ambiguous cases first.

As previously described, the decays of ^{85}As and ^{135}Sb are characterized by large energy windows, and the availability of a number of excited states in the residual nuclei. Their spectra must then include many possible transitions: for example, the first 1 MeV of the ^{85}As neutron spectrum has, in principle, 500 contributing transitions, while for ^{135}Sb the number is over 1000. Even though not all transitions will contribute significantly, it is obvious that with an experimental resolution of ~ 15 keV, any peak-stripping analysis must be fruitless. Just to emphasize that point, the three largest peaks from the Pandemonium spectrum of fig. 4 (^{135}Sb) are microscopically subdivided in terms of their component parts in fig. 6. There is no way that the same task could be performed on experimental data. Not only are many transitions involved, but these lead to the population of excited residual states as well as the ground state; thus the neutrons originate from different regions of excitation in the emitting nucleus, and one is left unable to identify even "clusters" of strength in the precursor's β -decay.

The decays of ^{87}Br and ^{137}I , with a smaller energy window, proceed entirely to the residual nucleus' ground state. (One excited state is energetically available in ^{136}Xe , but our calculations indicate it to be fed only about 0.1% of the time.) Even so, the first 1 MeV of each spectrum contains ~ 200 transitions. However, with sufficient faith in computerized peak-analysis techniques and an accurate knowledge of your detector response, it might be possible to identify individually the important transitions, at least for the first few hundred keV. More reliably, the experimental neutron spectrum can be converted into a more or less accurate picture of the precursor's β -decay strength function by considering it not as a measure of intensity per transition but rather of intensity per unit energy. In that sense, a good general picture of the corresponding decay scheme can be obtained, providing that γ -decay in the emitter does not play too large a role.

5. CONCLUSIONS

By creating a fictional nucleus and studying its decay, we provide for ourselves a situation that nature cannot match. Since the existence of Pandemonium

is confined to the functioning of a computer program, we can know with complete certainty all its relevant properties. Thus it is possible to perform the microscopic autopsy illustrated in fig. 6, something which could not properly be attempted with experimental data alone. Conversely, it does no good to explain the neutron spectrum from Pandemonium by postulating the existence of non-statistical bumps and structure in its strength functions -- as has been done for real experimental data -- because we can state unequivocally that there are none: we did not put them there.

The fact that the Pandemonium results are essentially indistinguishable from the experimental data to which we have compared them, does not guarantee that ^{85}As , ^{87}Br , ^{135}Sb , and ^{137}I all have the same featureless properties as Pandemonium. However, it does mean that, if nuclear properties are to be extracted from such real data, their extraction must proceed along lines that would yield an accurate picture of Pandemonium from its "observed" data. Consequently, we must conclude that decay schemes constructed for ^{85}As (refs. 7, 8) and ^{135}Sb (refs. 3, 8, 23) by means of spectral peak analyses must be regarded as completely unjustified. Naturally any discussion of β -decay strength functions that are based on these decay schemes (refs. 4, 8) must also be disregarded.

The difficulties with ^{87}Br and ^{137}I should be less acute. In Section 4 we concluded that a partial β -decay strength function could be extracted reliably if the neutron energy window precluded population of residual excited states. The part of the strength function that was deduced in ref. 6 from the ^{87}Br neutron spectrum should therefore accurately represent that of the β -decay of that nucleus. Unfortunately, the part that depends upon γ -ray spectroscopy cannot -- for reasons we have presented in an earlier paper¹⁾ -- be relied upon to the same extent.

It is, of course, disappointing that the effects of nuclear structure cannot be identified more immediately. To the extent to which delayed-neutron precursors resemble Pandemonium, their interest to nuclear physicists is reduced. However, it is only by such tests as we have performed here that potentially interesting features can be identified. In that spirit we can conclude by drawing attention

to the minor discrepancies in the statistical interpretation of the ^{85}As decay, as noted in Section 3. These may point out the most fruitful direction for future experimental work.

One of us (J.C.H.) expresses his thanks for the hospitality and stimulating atmosphere afforded him by the ISOLDE group during a one-year stay at CERN.

REFERENCES

- 1) J.C. Hardy, L.C. Carraz, B. Jonson and P.G. Hansen, Phys. Lett. (to be published).
- 2) S. Shalev and G. Rudstam, Phys. Rev. Lett. 28 (1972) 687.
- 3) K.-L. Kratz, W. Rudolph, H. Ohm, H. Franz, C. Ristori, M. Zendel, G. Hermann, F.M. Nuh, D.R. Slaughter, A.A. Shihab-Eldin and S.G. Prussin, Proc. 3rd Internat. Conf. on Nuclei far from Stability, Cargèse, 1976 (CERN 76-13, 1976), p. 304.
- 4) H.V. Klapdor, Phys. Lett. 65B (1976) 35.
- 5) H. Franz, K.-L. Kratz, W. Rudolph, G. Hermann, F.M. Nuh, S.G. Prussin and A.A. Shihab-Eldin, Phys. Rev. Lett. 33 (1974) 859.
- 6) F.M. Nuh, D.R. Slaughter, S.G. Prussin, H. Ohm, W. Rudolph and K.-L. Kratz, Nucl. Phys., to be published.
- 7) K.-L. Kratz, W. Rudolph, H. Ohm, H. Franz, M. Zendel, G. Hermann, F.W. Nuh, D.R. Slaughter, W. Halverson, S.G. Prussin, A.A. Shihab-Eldin and H.V. Klapdor, to be published.
- 8) A.A. Shihab-Eldin, W. Halverson, F.M. Nuh, S.G. Prussin, W. Rudolf, H. Ohm and K.-L. Kratz, Phys. Lett. 69B (1977) 143.
- 9) J.E. Lynn, The theory of neutron resonance reactions (Clarendon Press, Oxford, 1968).
- 10) P.G. Hansen, Advances in Nucl. Phys. 7 (1973) 159.
- 11) B. Jonson, E. Hagberg, P.G. Hansen, P. Hornshøj and P. Tidemand-Petersson, Proc. 3rd Internat. Conf. on Nuclei far from Stability, Cargèse, 1976 (CERN 76-13, 1976), p. 277.
- 12) J.A. Macdonald, J.C. Hardy, H. Schmeing, T. Faestermann, H.R. Andrews, J.S. Geiger, R.L. Graham and K.P. Jackson, Nucl. Phys. A288 (1977) 1.
- 13) A.C. Pappas and T. Sverdrup, Nucl. Phys. A188 (1972) 48.
- 14) P. Hoff, thesis, University of Oslo (1976), unpublished.

- 15) A. Gilbert and A.G.W. Cameron, *Canad. J. Phys.* 43 (1965) 1446;
J.W. Truran, A.G.W. Cameron and E. Hilf, *Proc. Internat. Conf. on the Properties of Nuclei far from the Region of Beta-Stability*, Leysin, 1970 (CERN 70-30, 1970), p. 275.
- 16) K. Aleklett, G. Nyman and G. Rudstam, *Nucl. Phys.* A246 (1975) 425.
- 17) D.H. Wilkinson and B.E.F. Macefield, *Nucl. Phys.* A232 (1974) 58.
- 18) G.S. Mani, M.A. Melkanoff and I. Iori, *Centre d'Etudes Nucléaires de Saclay*, report CEA 2380 (1963), unpublished.
- 19) A.G.W. Cameron, *Canad. J. Phys.* 35 (1957) 666.
- 20) S. Maripuu, ed., 1975 mass predictions, *Atomic and Nucl. Data Tables* 17 (1976) 411.
- 21) A.H. Wapstra and K. Bos, The 1977 atomic mass evaluation, *Atomic and Nucl. Data Tables* 19 (1977) No. 3.
- 22) R.L. Bunting and J.J. Kraushaar, *Nucl. Data Sheets* 13 (1974) 191.
- 23) K.-L. Kratz, W. Rudolph, H. Ohm, H. Franz, G. Hermann, C. Ristori, J. Crancon, M. Asghar, G.I. Crawford, F.M. Nuh and S.G. Prussin, *Phys. Lett.* 65B (1976) 231.
- 24) J.-V. Kratz, H. Franz, N. Kaffrell and G. Hermann, *Nucl. Phys.* A250 (1975) 13.
- 25) K.-L. Kratz, private communication.
- 26) V.A. Karnaukhov, D.D. Bogdanov and L.A. Petrov, *Nucl. Phys.* A206 (1973) 583.
- 27) B. Jonson, thesis, Chalmers University of Technology, Göteborg, Sweden, 1972.
- 28) P.G. Hansen, *in Nuclear Structure* (ed. V.G. Soloviev), *Proc. Internat. School on Nuclear Structure*, Alushta (USSR), 1972 (JINR-D-6465, 1972), p. 365.
- 29) T. Elmroth, E. Hagberg, P.G. Hansen, J.C. Hardy, B. Jonson, H.L. Ravn and P. Tidemand-Petersson, to be published.

Table 1

Input information used in the Pandemonium computations
simulating the decays of four different delayed-neutron precursors

Precursor	^{85}As	^{87}Br	^{135}Sb	^{137}I
J^π	$3/2^-$	$3/2^-$	$7/2^+$	$7/2^+$
Decay energy: Q_β (MeV)	9.00 ^{a)}	6.60 ^{a)}	8.10 ^{a)}	5.50 ^{b)}
Neutron separation energy for daughter: B_n (MeV)	4.30 ^{a)}	5.52 ^{b)}	4.00 ^{a)}	3.86 ^{b)}
Residual states after neutron emission: Ex(MeV); J^π	0.0; 0^+ 1.5; 2^+ 2.1; 2^+ } ^{c)}	0.0; 0^+	0.0; 0^+ 1.3; 2^+ 1.6; 4^+ } ^{d,e)}	0.0; 0^+ 1.3; 2^+ ^{f)}

a) See Ref. 20

d) See Ref. 3

b) See Ref. 21

e) See Ref. 7

c) See Ref. 5

f) See Ref. 22

Table 2

Comparison between statistical model calculations
and experimental results for the neutron feeding
of states in the residual nuclei ^{84}Se and ^{134}Te

Precursor	Data	Population of residual states		
		g.s.	1st excited (2^+)	Higher
^{85}As	experiment ^{a,b)}	35 ± 7	31 ± 6	34 ± 4
	calculation 1	73 ± 3	21 ± 2	6 ± 1
	calculation 2	45 ± 9	43 ± 7	12 ± 2
^{135}Sb	experiment ^{a)}	47 ± 12	26 ± 10	28 ± 7
	calculation	56 ± 3	19 ± 2	25 ± 2

a) See Ref. 23

b) See Ref. 24

Figure captions

- Fig. 1 : The decay scheme of Pandemonium, illustrating schematically the various aspects of our computation. The probability functions are shown in the insets for Porter-Thomas and Wigner distributions with average values $\langle x \rangle = 1$.
- Fig. 2 : Comparison between (a) experiment^{3,6)} and (b) Pandemonium simulation for the delayed neutron spectrum from the decay of ^{87}Br .
- Fig. 3 : Comparison between (a) experiment³⁾ and (b) Pandemonium simulation for the delayed neutron spectrum from the decay of ^{137}I .
- Fig. 4 : Comparison between (a) experiment^{3,7)} and (b) Pandemonium simulation for the delayed neutron spectrum from the decay of ^{135}Sb .
- Fig. 5 : Derived variance as a function of neutron energy for the spectra in fig. 4. The large circles joined by heavy dashed lines correspond to the experimental ^{135}Sb data, while the squares and solid line are for Pandemonium. The small circles joined by the light dashed line are from an analysis of the same ^{135}Sb data from ref. 7; apart from the deficiencies of the analysis technique used there (see text), the small size of the energy bins also increased the uncertainty from counting statistics and "edge" effects. Considering these limitations, it agrees as well as might be expected with the present analysis.
- Fig. 6 : Microscopic subdivision of the three largest peaks in the Pandemonium spectrum of fig. 4 showing the most significant contributing transitions. Including all contributions, the three peaks are composed of 44, 78, and 174 components, respectively, in order of increasing energy.

Fig. 1

Fig. 2

67165

Fig. 3

Fig. 4

Fig. 5

Fig. 6