Average resonance capture study of ^{124}Te

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An average resonance capture study of ^{124}Te was carried out by bombarding samples of ^{123}Te with 2- and 24-keV neutron beams. The complete set of 0^+, 1^+, 2^+ states disclosed by the experiment is consistent with the data of Robinson, Hamilton, and Snelling, demonstrating that there are no undetected states of these spins (especially 0^+ states) below about 2500 keV. In particular, proposed 0^+ levels at 1156 and 1290 keV are ruled out. This impacts various attempted interpretations in terms of intruder states, U(5), and O(6) symmetries.

The structure of the even Te isotopes below $N=82$ has recently been of considerable interest [1–5] with various competing interpretations. Some of these invoke intruder [4] states formed by four-particle–two-hole ($4p$-$2h$) proton excitations across the $Z=50$ closed shell gap. The need for intruders is disputed in Ref. [5]. Other papers claim evidence for U(5) (Ref. [3]) or O(6) (Refs. [1, 2]) symmetries, sometimes also in conjunction with intruder levels [4]. *A priori,* of course, O(6) would seem unlikely given the presence of only two valence protons: this is reinforced by $E(4_1^+)/E(2_1^+)$ ratios near 2.0 which suggests a vibrator spectrum. Nevertheless, the issue is still actively discussed. Finally, exposing still further the complexity in this region, Cizewski has shown [6] that the yrast states present evidence of both two-particle and collective character.

A key issue of any interpretation is, of course, the number of low-lying states of each spin. The spins of some levels are still in dispute. Particularly important is the number and excitation energies of 0^+ levels which often play the role of "bandheads" (in the generalized sense of quasiband) for entire families of excitations. Some interpretations may rely implicitly on the presumed existence of as yet undetected states or on disputed levels. Therefore, to critically test these various models for ^{124}Te it is essential to have in hand an *assured complete set* of low-lying low-spin states. Although many experiments have been performed on ^{124}Te, none is of the nonselective type that guarantees completeness. Indeed, particularly for the crucial 0^+ levels, the experimental evidence is contradictory: For example, some authors [7] report a 0^+ at 1156 keV and others claim [8] one at 1290 keV but neither has been confirmed [1,2]. Clearly, a definitive experiment is crucial to further interpretations.

It is the purpose of this work to carry out average resonance capture (ARC) studies of ^{124}Te to obtain a complete set of $0^+, 1^+, 2^+$ states (the ^{123}Te target ground state is $\frac{1}{2}^+$). This will form a basis, in combination with more detailed spectroscopic information on each level [e.g., (d,p) cross sections, decay patterns, and so on] for any future structural conclusions.

The most thorough study of ^{124}Te to date is that of Robinson, Hamilton, and Snelling [1,2]. The level scheme shown on the left in Fig. 1 is basically taken from their work, along with some information from Ref. [3]. This scheme immediately raises some of the structural issues alluded to above. For example, although the $E(4_1^+)/E(2_1^+)$ ratio is close to 2.0, suggesting a vibrator-like character, there is no close-lying 0^+ level to complete the expected two-phonon triplet. The question becomes crucial then whether the somewhat isolated 0^+ state at 1656 keV is an intruder state or the missing 0^+ level of a rather anharmonic triplet, or whether there is (are) undetected 0^+ levels lying nearer 1200 keV (e.g., 1156 or 1290 keV). The issue is complicated by the regional systematics which shows close-lying $0^+,2^+,4^+$ triplets at $\sim 2E(2_1^+)$ for $^{114\text{-}122}$Te, but with a steadily increasing 0^+ energy and only the $2^+,4^+$ doublet from ^{124}Te onward. Is the triplet just an accidental consequence of intruder 0^+ states passing nearby a $2^+,4^+$ doublet, or is it a harmonic two-phonon triplet with a change in structure at ^{124}Te? We will not attempt to resolve these nuclear structure issues here but aim only to provide the requisite ARC data to offer a complete set of low-lying low-spin states.

The ARC technique [9,10] exploits neutron capture with a nonmonoenergetic neutron beam to obtain an automatic averaging of the compound nuclear capture and decay process by simultaneously populating many capture states so that all low-lying states of a given spin are populated by primary transitions whose intensities fall in a narrow band and have a well-known dependence on excitation energy. When the number of capture states within the neutron energy window is large enough so that averaging is good, ARC gives an *a priori* assurance of the disclosure of complete sets of states. The power of the

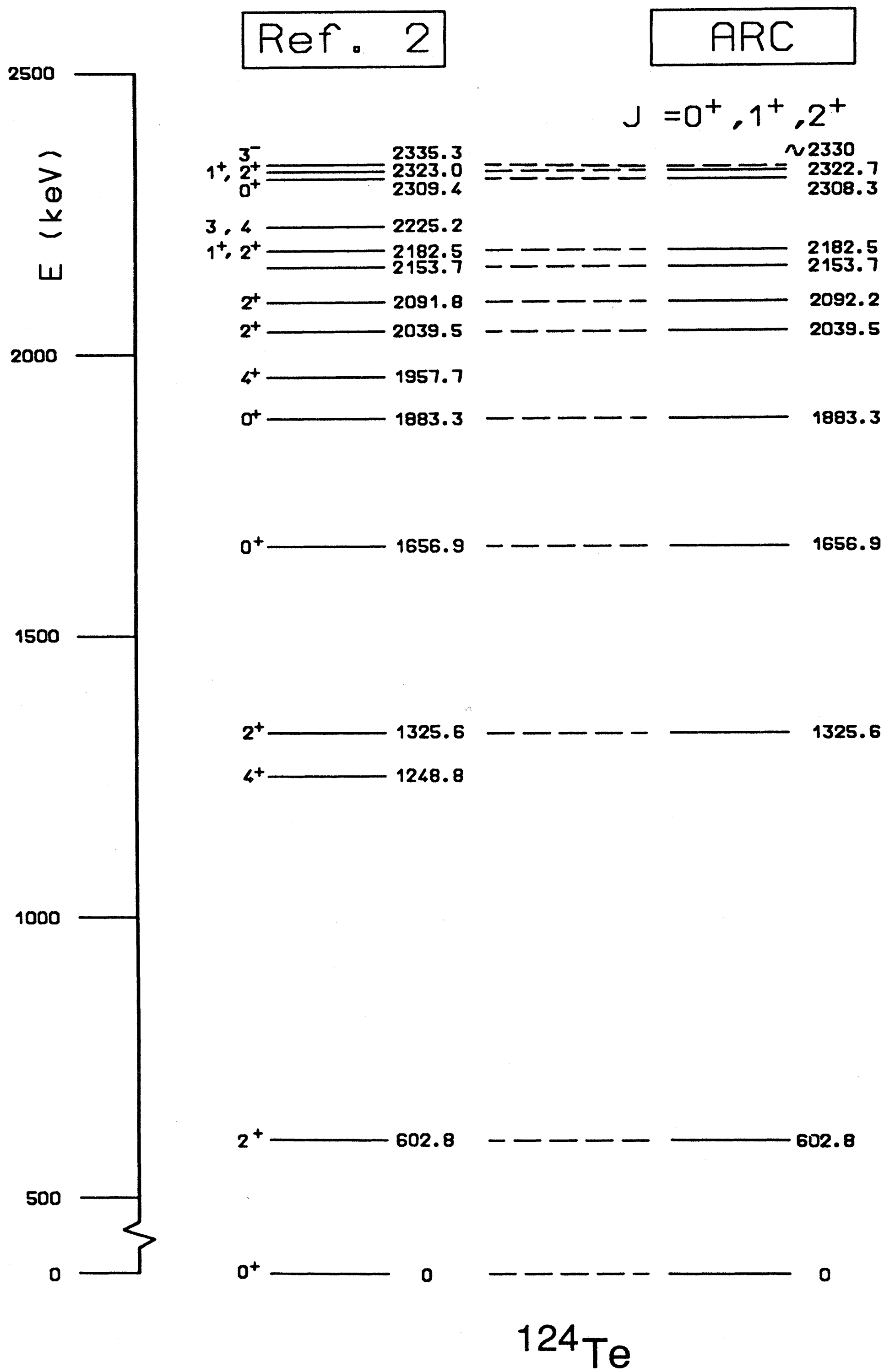

FIG. 1. Levels with $J \leq 4$ up to 2400 keV in ^{124}Te. The levels on the left are primarily from the first article of Ref. [2], those on the right are the full set of $0^+, 1^+, 2^+$ levels seen in ARC. (The ~2330-keV level is only tentatively seen in ARC at 24 keV.)

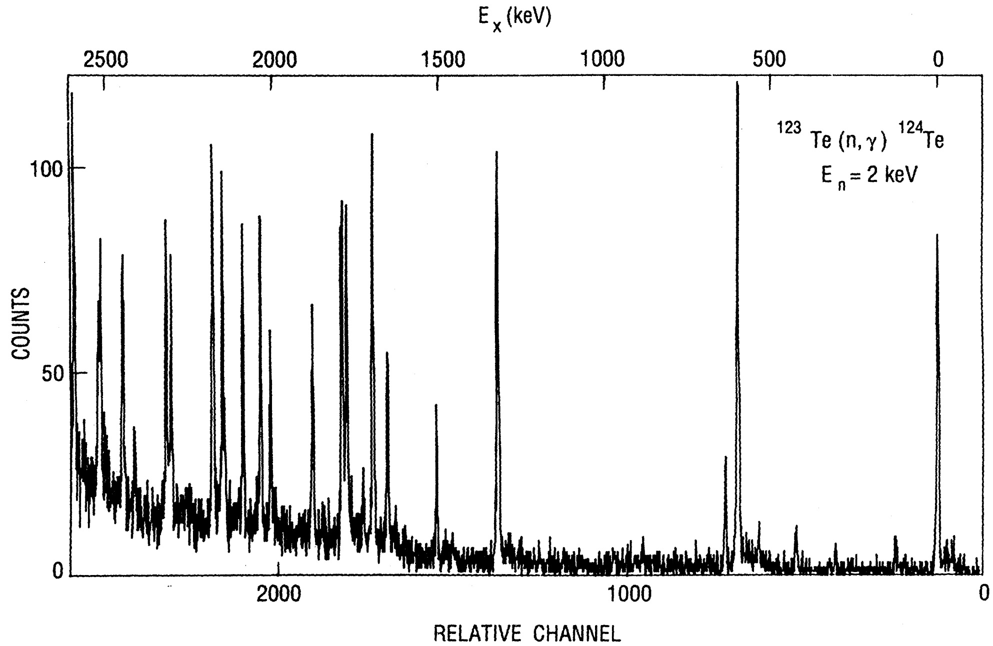

FIG. 2. ARC spectrum for ^{124}Te at $E_x = 2$ keV.

method and the advantages of completeness (some rather subtle) have been discussed in Ref. [10]. In Te, with $Z=52$, the level density of 0^+ and 1^+ capture states at $E_x = S(n) + E_n$ is not as large as in nuclei further from shell closures, but it is sufficient to provide the desired completeness, up to about 2500 keV.

The experiments were carried out with filtered neutron beams, with about 1 keV FWHM energy spread, centered at 2 and 24 keV, provided by the Tailored Beam Facility at the Brookhaven High Flux Beam Reactor (HFBR). The target consisted of 6.96 g of Te oxide enriched to 85.4% in ^{123}Te. The ARC facility has been described elsewhere [9] and numerous papers (see, e.g., Refs. [11,12]) have explained and thoroughly illustrated the technique. Therefore, no repetition of such discussions is necessary here. We shall simply present the data and results.

Figure 2 shows an example of the $E_n = 2$ keV ARC spectra. Most of the peaks are from ^{124}Te although some of the strong ones near $E_\gamma = 7700$ keV are Fe and Al contaminants. Other smaller peaks are also contaminants. All these spurious peaks are well known from contaminant libraries compiled in previous ARC studies (see, e.g., Refs. [11, 12]). Table I summarizes the results of the 2- and 24-keV ARC data. The energies were calibrated in a separate experiment with a thermal neutron beam on a target of NaCl, using the energies from Ref. [9]. The intensities given are the reduced intensities I_R, defined as $I_R = I_\gamma / E_\gamma^5$: it is the fluctuations in I_R that show the degree of averaging. It is apparent that the averaging is fairly good. Intensity variations of 2 orders of magnitude, typical of thermal capture, are here reduced to fluctuations of about a factor of 1.5 about the mean. Since the sensitivity limit ranges from about $I_R \sim 0.1$ to 0.6 from $E_x = 0$ to 2500 keV and since the 2- and 24-keV data provide independent confirmations of levels, it is apparent that all 0^+, 1^+, and 2^+ levels below about 2500 keV have been disclosed by these ARC studies.

The results are compared with the level scheme of Robinson, Hamilton, and Snelling [1,2] in Fig. 1, from which it is evident that there is a one-to-one correspondence of $0^+, 1^+, 2^+$ levels below 2500 keV. The level at 2330 keV, tentatively observed only in 24 keV, is possibly the 2335-keV negative parity level of Robinson [2]. The level at 2153 keV, with no J^π assignment in Refs. [1,2], can now be assigned $J^\pi = 0^+, 1^+, 2^+$. The 4^+ levels [1,2] at 1248 and 1957 keV are, of course, not expected to be seen in ARC nor is the 3,4 level at 2225 keV.

Thus, the ARC data are fully consistent with Ref. [2]. Further, the completeness of the ARC data now guarantees that there are no missing $0^+, 1^+, 2^+$ levels below ~ 2500 keV and, therefore, demonstrates that the levels found by Robinson [2] are indeed a complete set and, in particular, that there is *no missing* 0^+ *level* anywhere near the doublet at 1300 keV, or, indeed, below 2500 keV. Any future interpretation of the level structure must thus involve only the 0^+ levels seen in Fig. 1.

These results severely limit the various model interpretations. For example, a vibrator, or U(5) interpretation with one-phonon energy of ~ 600 keV requires two 0^+ states (two- and three-phonon levels) below ~ 2 MeV, even allowing considerable anharmonicity. In fact, there *are* exactly two 0^+ states below 2150 keV. Thus, a vibrator or U(5) *plus* intruder 0^+ state interpretation, which

TABLE I. ARC results for ^{124}Te.

2 keV			24 keV			
E_x (keV)[a]	$E_\gamma(\Delta E_\gamma)$ (keV)	$I_R(\Delta I_R)$[b]	E_x (keV)[a]	$E_\gamma(\Delta E_\gamma)$ (keV)	$I_R(\Delta_R)$[b]	$I_R(24)/I_R(2)$
0	9425.8(2)	0.80(4)		c		
602.8	8823.1(2)	1.59(7)	602.8	8845.1(4)	0.50(3)	0.31(3)
1325.6	8100.2(2)	1.93(9)	1325.6	8122.2(2)	0.56(2)	0.29(2)
1656.9	7768.9(3)	0.99(7)	1656.9	7790.9(3)	0.40(3)	0.43(5)
1883.3	7542.5(3)	1.25(10)	1882.9	7565.0(3)	0.32(2)	0.26(3)
2039.5	7386.3(2)	1.74(11)	2039.5	7408.3(2)	0.67(4)	0.39(4)
2092.2	7333.6(2)	1.86(12)	2091.7	7356.1(3)	0.43(3)	0.23(3)
2153.7	7272.1(2)	2.04(13)	2153.0	7294.8(4)	0.37(3)	0.18(2)
2182.5	7243.3(2)	2.51(14)	2182.5	7265.3(2)	0.74(3)	0.29(2)
2308.3	7117.6(3)	1.75(14)	2307.6	7140.2(4)	0.26(3)	0.15(3)
2322.7	7103.1(3)	2.25(16)	2322.3	7125.5(3)	0.37(3)	0.16(2)
	Obscured		2329.9[d]	7117.9[d]	0.10(4)	—
2454.1	6971.8(3)	1.96(14)	2454.1	6993.8(4)	0.59(5)	0.25(3)
	Obscured		2500.1	6947.7(8)	0.42(6)	—
2520.5	6905.3(3)	1.82(14)	2521.6	6926.2(5)	0.76(7)	0.42(5)
2527.4	6898.4(4)	1.27(17)	2530.5	6917.3(3)	1.18(7)	0.93(14)
2599.7	6826.1(3)	3.21(34)	2600.1	6847.8(6)	0.78(9)	0.24(4)

[a]Energy uncertainties are identical to those for E_γ.
[b]I_R is defined as I_γ/E_γ^5.
[c]Peak above top channel in analyzer.
[d]Poorly defined structure. Energy only approximate.

requires three 0^+ states, seems ruled out or else implies a quite high intruder energy. Further interpretation requires a consideration of all the spectroscopic data and is both beyond the scope of this Brief Report and is the proper purview of an anticipated article [13] on the spectroscopy of the Te isotopic chain.

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