New neutron-rich microsecond isomers observed among fission products of ^{238}U at 80 MeV/nucleon

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Eight new isomeric states in neutron-rich nuclides have been discovered in fission fragments produced by the reaction of an 80 MeV/nucleon ^{238}U beam with a ^{9}Be target and separated in-flight using the A1900 fragment separator. The experiment was conducted at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. Gamma rays were detected in a high-purity germanium detector located at the focal plane within a time window of 20 μs following ion implantation. In some cases the isomers were observed to decay into previously reported states, allowing us to assign the initial decay from the isomeric state. Among the outcomes, the results suggest that many studies on the nuclear structure of medium-mass neutron-rich nuclei are feasible at projectile fragmentation facilities using induced fission.

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I. INTRODUCTION

A number of experiments in recent years have shown that fission of a high-energy ^{238}U beam produces neutron-rich secondary beams of fission fragments, and in some cases new isotopes [1–4]. These studies rely on inverse kinematics so that the high-energy fragments can be separated using physical techniques within one microsecond of production and each individual ion identified by atomic and mass number. This rapid separation allows the most exotic nuclei to be studied with minimal decay losses, opening up possibilities for studies in nuclear structure, beta decay, magnetic moments, etc. The study of excited states far from stability provides constraints on nuclear models that are used to predict the properties of nuclei near the driplines, and the observation of isomeric states, in particular, helps to complement both decay and in-beam spectroscopic experiments.

Initial experiments to observe isomers in-flight used fragmentation of a heavy ion beam to populate the isomeric states (see, for example, [5–7]). The advantage of fission, in contrast, is the high yield of neutron-rich products, although the abundance of a single nuclide can be low, frequently less than 1% of all reaction products. Previous work on isomers produced in fission has focused on induced fission of actinides using (n, f) reactions (see, for example, [8–12]), or spontaneous fission of ^{248}Cm (see, for example, [8,13,14]) or ^{252}Cf (see, for example, [15–19]). Reviews are available in Refs. [20,21]. Additionally, fission of a relativistic 750-MeV/nucleon ^{238}U beam has been used to discover new isomers [22,23]. In this article we report on the observation of several new short-lived isomeric states that were populated by the interaction of an 80 MeV/nucleon ^{238}U beam with a ^{9}Be target and which, to the best of our knowledge, have not been reported previously.

II. EXPERIMENT

A beam of $^{238}U^{30+}$ was accelerated by the K500 cyclotron at the National Superconducting Cyclotron Laboratory (NSCL) to an energy of 7.68 MeV/nucleon, stripped to the 69+ charge state, and further accelerated to an energy of 80.0 MeV/nucleon in the K1200 cyclotron [24]. This beam, with an average intensity of 0.088 pnA, struck a ^{9}Be target with a thickness of either 9 or 94 mg/cm^2. Recoiling nuclear reaction products entered the A1900 fragment separator [25] and were spatially separated from the primary beam based on magnetic rigidity ($B\rho$). For the nuclides discussed in this work, the first half of the A1900 was set for $B\rho \approx$ 3.5 T m for the 9 mg/cm^2 target and $B\rho = 3.7$ T m for the 94 mg/cm^2 target. The momentum acceptance $\Delta p/p$ of the A1900 was varied from 0.1% to 5.6% depending on the overall rate of fission fragments in the focal plane. In some cases the primary beam was attenuated to keep the rate of events in the focal plane less than 1000 s^{-1}; this ensured that there was no degradation of mass and atomic number identification and avoided overwhelming the data acquisition system, minimizing dead time. In those runs

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with $\Delta p/p > 0.2\%$, a flat position-sensitive plastic scintillator (with reduced chemical formula C_9H_{10}, density 1.032 g/cm^3, thickness 254 μm, horizontal width 300 mm, and horizontal position FWHM ≈3.8 mm) was inserted at the dispersive plane of the A1900 so that the momentum of each particle could be reconstructed on a particle-by-particle basis. The magnetic rigidity of the second half of the separator was set for those particles that did not change charge state in the scintillator.

Products were detected at the A1900 focal plane, which contained (in order): a parallel plate avalanche counter (PPAC) with a thickness equivalent to 2 mg/cm^2 of Al, a 500 μm Si ΔE detector, four 1000 μm Si detectors, another PPAC, and a 10 cm plastic scintillator. Most particles stopped in the third or fourth Si detector. The area of the Si detectors was 50 mm × 50 mm, and they were calibrated internally using identified nuclides with the known magnetic rigidities, with corrections for pulse-height defect. The TOF was measured relative to the phase of the cyclotron and was corrected for an observed "walk" in the constant-fraction discriminators used for the experiment. Absolute measurements of TOF, $B\rho$, and total kinetic energy allowed the determination of atomic number Z, mass number A, and charge state Q on an event-by-event basis.

A single high-purity germanium (HPGe) detector with a relative efficiency of 120% was aligned perpendicular to the center of the Si stack but outside the vacuum chamber using an Al detector "can." This detector recorded gamma decays of isomers decaying within ≈20 μs of passing through the ΔE detector, which served as the trigger. Daily energy calibrations were made during the experiment using a ^{152}Eu source whose activity was certified by the U.S. National Institute of Standards and Technology. An absolute efficiency calibration was obtained by constructing a "model" detector stack of Al sheets cut to the same size and shape as the Si detectors, and mounted in the same geometry. The ^{152}Eu source was affixed to the center of the model stack, which was mounted at the A1900 focal plane. The absolute efficiency curve was fit using Eq. 1 in [26] multiplied by a scaling factor and was improved at low energy using the decays of the known isomers ^{66}Cu^m and ^{99}Mo^m. This was especially important since low-energy photons were significantly attenuated by the Si detectors and the Al detector can. The curve is shown in Fig. 1; the fit parameters are given in the figure caption. For the 1408 keV line of ^{152}Eu, the FWHM was 3.0 keV and the absolute efficiency was 1.0%. Centroid energies of gamma rays discussed below had errors of 0.7 keV or less. The energy threshold of the detector's constant-fraction discriminator was ≈45 keV. The fragments were stopped in the Si stack before the gamma rays were emitted so it was not necessary to correct for Doppler shifts.

The time difference between the implantation/trigger event and the HPGe event was recorded in order to measure the half-lives of the isomeric states. As a check of our half-life measurements, we compared our data with the previously reported half-lives for several known isomers and the results are shown in Fig. 2. These data show that our setup was not suitable for measuring half-lives less than 500 ns. This is likely due to the slow drift velocity of electrons in Ge

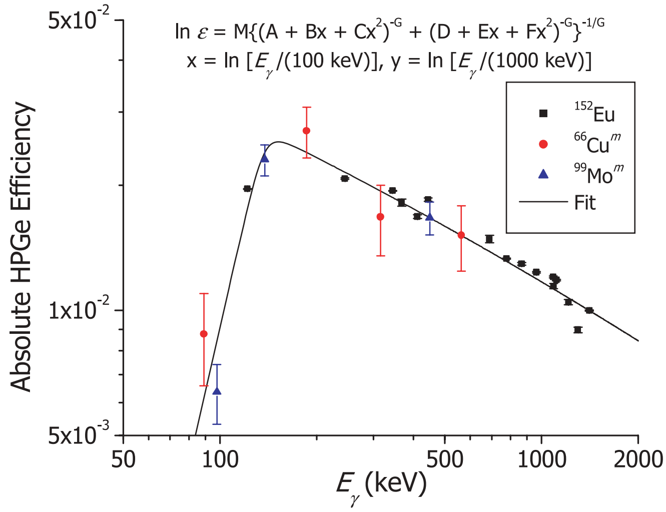

FIG. 1. (Color online) Absolute efficiency curve of the HPGe detector. Data that were used for the fit were from the decay of a ^{152}Eu source (squares), ^{66}Cu^m (circles), and ^{99}Mo^m (triangles). ε is the efficiency, and the fitted parameters were $A = 2.379$, $B = 3.399$, $C = 0$, $D = 2.632$, $E = -0.4586$, $F = -0.01902$, $G = 20$, and $M = 8.432 \times 10^{-4}$.

(<0.01 cm/ns at liquid nitrogen temperature [27]), which leads to long pulse risetimes from the large Ge detector volume and poor timing information. Our electronics were optimized for particle identification using Si detectors rather than compensating for this effect, so to be conservative, upper limits will be reported when the measured half-life falls below 500 ns.

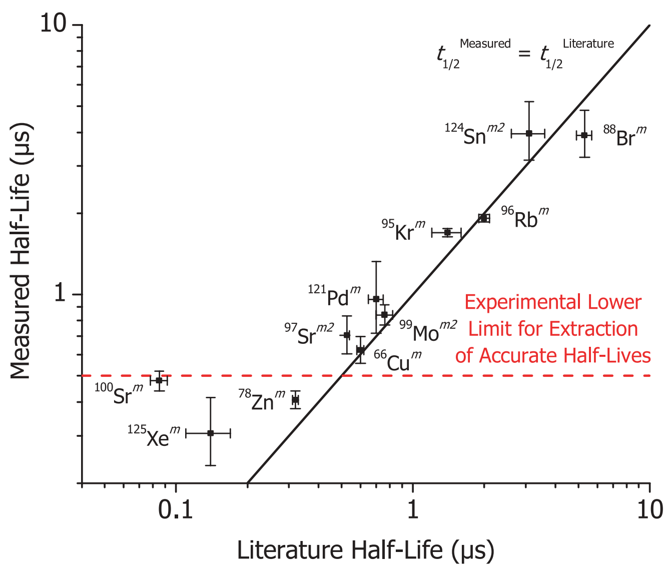

FIG. 2. (Color online) Measured half-life as a function of reported half-life for some known microsecond isomers. The solid line indicates what would be expected given perfect agreement. Our experimental setup was not suitable for measuring half-lives less than 500 ns; this cutoff is indicated by the dashed line. See the main text for a discussion.

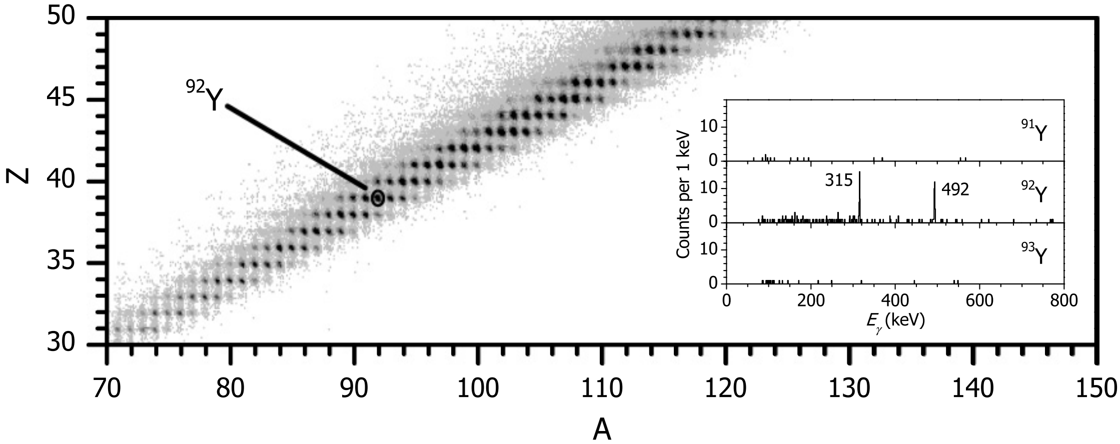

FIG. 3. Typical particle identification plot showing Z as a function of A. The inset shows the gamma spectra observed when gating on ^{92}Y and the neighboring nuclides ^{91,93}Y. Note that the ^{92}Y gamma spectrum shows two clear peaks that are absent from the ^{91,93}Y spectra. These data were obtained using a 9 mg/cm^2 ^{9}Be target, $B\rho = 3.468$ T m, $\Delta p/p = 0.1\%$, with the scintillator retracted.

We applied gates to single groups on a plot of Z as a function of A and examined the coincident gamma-ray spectra; this procedure allowed us to combine all fragment charge states together to reduce statistical uncertainty. In total, hundreds of nuclides were checked for coincident gamma spectra. A typical particle identification plot is shown in Fig. 3 along with the corresponding gamma spectrum for ^{92}Y and two neighboring nuclides. Note that the two ^{92}Y peaks do not appear in the spectra of the neighbors. We performed similar checks using known isomers (^{78}Zn^m [28], ^{97}Sr^{m1} [29], ^{100}Sr^m [30], etc.) and also confirmed that the relative transition intensities were in agreement with previous reports.

III. RESULTS AND DISCUSSION

We identified eight previously unreported isomers and an additional isomer whose decay scheme has not been published (^{78}Ga); the corresponding gamma spectra are shown in Fig. 4. In many cases, the fragment made up approximately 0.1% or less of the total beam (defined as the ratio of the counts of a single fragment to the total number of fragments), demonstrating the power of our technique. Gamma peaks were fit using the GF3 program in the RADWARE software package [31]. Time spectra were extracted for individual peaks, allowing the half-life to be determined using the maximum-likelihood

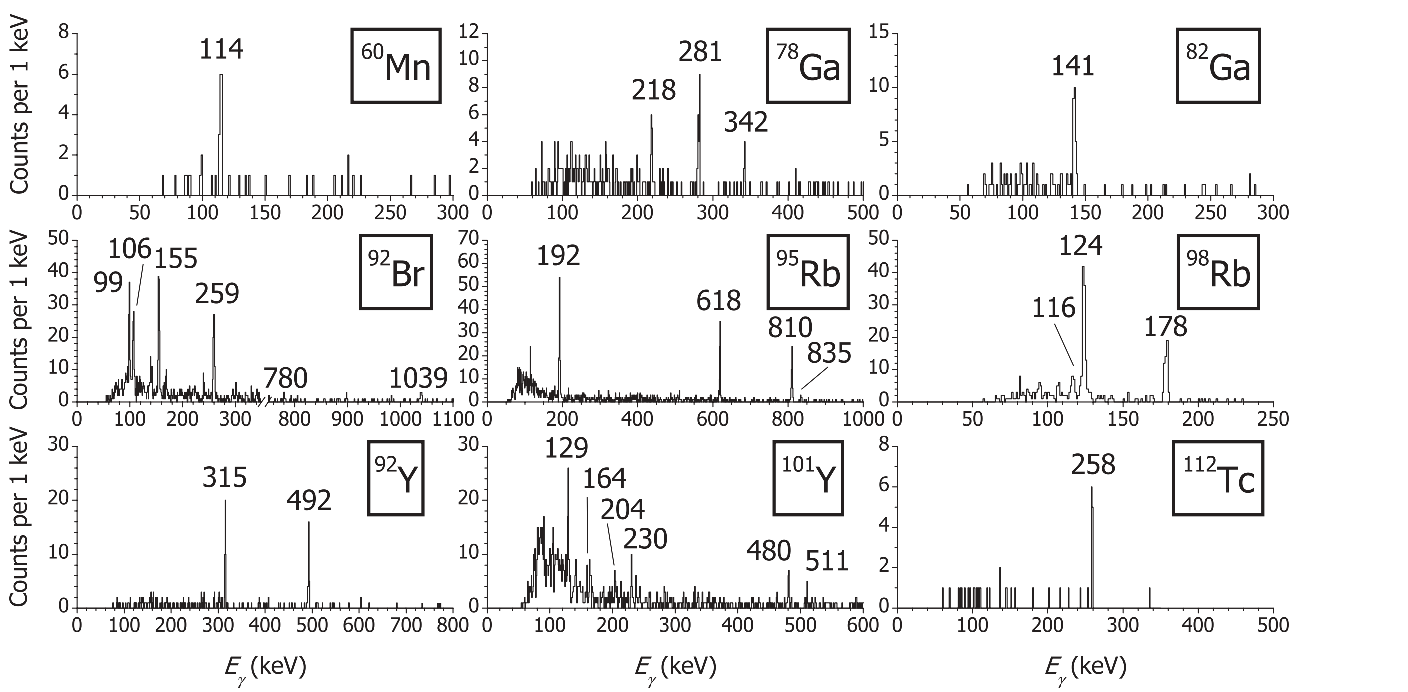

FIG. 4. Gamma-ray spectra observed within ≈20 μs of implantation of the given nuclide. Only the most intense transitions are labeled for clarity in the ^{92}Br spectrum; see Table I for a complete list. Note the break in the abscissa of the ^{92}Br spectrum, and the annihilation peak in the ^{101}Y spectrum. Half-lives are given in Table I.

TABLE I. Decay properties of new isomers observed in the irradiation of ^{9}Be with 80 MeV/nucleon ^{238}U. The number of photons per fragment for each transition has been corrected for the length of the gamma-ray gate, losses in-flight while transiting the A1900 fragment separator, the efficiency of the HPGe detector, and randomly correlated background events.

Isomer	Half-Life	Total Fragments Detected ($g+m$)	E_γ (keV)	Net Photopeak Counts	Photons per Fragment
^{60}Mn^m	$1.0^{+0.3}_{-0.2}$ μs	6.3×10^3	114	15 ± 4	0.18 ± 0.06
^{78}Ga^m	<500 ns	2.8×10^4	218	14 ± 4	>0.031
			281	19 ± 5	>0.049
			342	7 ± 3	>0.017
^{82}Ga^m	<500 ns	1.6×10^4	141	25 ± 5	>0.089
^{92}Br^m	<500 ns	6.3×10^4	99	63 ± 9	>0.085
			106	58 ± 9	>0.072
			139	21 ± 6	>0.011
			155	104 ± 11	>0.094
			169	16 ± 5	>0.012
			239	13 ± 5	>0.011
			259	86 ± 10	>0.096
			295	7 ± 4	>0.006
			301	12 ± 4	>0.012
			780	8 ± 3	>0.014
			1039	12 ± 4	>0.024
^{95}Rb^m	<500 ns	1.2×10^5	192	137 ± 12	>0.072
			618	94 ± 10	>0.085
			810	67 ± 8	>0.066
			835	7 ± 3	>0.002
^{98}Rb^m	700^{+60}_{-50} ns	3.5×10^4	116	15 ± 5	0.02 ± 0.01
			124	97 ± 11	0.19 ± 0.03
			178	49 ± 8	0.07 ± 0.01
^{92}Y^m	$4.2^{+0.8}_{-0.6}$ μs	3.7×10^3	315	40 ± 7	0.63 ± 0.13
			492	41 ± 7	0.78 ± 0.16
^{101}Y^m	860^{+90}_{-80} ns	9.9×10^4	129	37 ± 9	0.011 ± 0.006
			164	13 ± 5	0.002 ± 0.003
			204	10 ± 4	0.002 ± 0.002
			230	15 ± 5	0.006 ± 0.003
			480	15 ± 5	0.010 ± 0.004
^{112}Tc^m	<500 ns	2.0×10^3	258	12 ± 4	>0.44

MLDS code [32]. Table I gives the half-life, the total number of fragments (ground state and isomer) observed, the gamma-ray energies, the net counts in each peak, and the yield of photons per fragment for each isomer. These data were corrected for the length of the gamma-ray gate, losses in-flight while transiting the A1900 fragment separator (with TOF calculated using the LISE++ program [33,34]), the efficiency of the HPGe detector, and randomly correlated background events.

A. ^{60}Mn

A summary of previous reports on the excited states of ^{60}Mn has been recently published by Liddick *et al.* [35]. These researchers studied the beta decay of ^{60}Cr and observed new excited states in ^{60}Mn, and also assigned a previously known long-lived isomeric state ($E^* = 271.9$ keV, $t_{1/2} = 1.77 \pm 0.02$ s [36]) as the first excited state with $J^\pi = 4^+$. The gamma spectrum observed in coincidence with ^{60}Mn in the present work (see Fig. 4) is very clean and shows a single transition with an energy of 114 keV and a half-life of $1.0^{+0.3}_{-0.2}$ μs. Notably, Liddick *et al.* reported the results of calculations which suggested that two additional states ($J^\pi = 3^+$, $E^* \approx$ 80 keV and $J^\pi = 2^+$, $E^* \approx 170$ keV) should exist between the 1^+ ground state and the first 4^+ state. The energy of the decay observed in the current work is reasonably consistent with the predicted 3^+ state at $\approx$80 keV. Their calculations also indicated the possibility of another 2^+ state $\approx$100 keV above the long-lived 4^+ state; a transition from a short-lived isomer to the long-lived isomer would be consistent with our observations. In either case, the transition would have multipolarity $E2$. Naïvely applying the Weisskopf half-life estimates [37] to an $E2$ transition in ^{60}Mn with an energy of 114 keV results in a calculated half-life of 2.1 μs, remarkably close to our experimental result. Our experiment could not distinguish between these two possibilities so the nature of this isomer must be investigated further.

B. ^{78}Ga

Numerous excited states of ^{78}Ga have been reported [38], although only Lewitowicz *et al.* identified an isomeric state [39]. Those authors published a spectrum of gamma rays in coincidence with ^{78}Ga events produced in a fragmentation reaction but do not propose a level scheme based on their data. In our work we observed three transitions in coincidence with ^{78}Ga fragments with energies of 218, 281, and 342 keV. The latter two are in excellent agreement with the known first two excited states of ^{78}Ga; the first excited state decays by the emission of 281.34 keV gamma rays, and the second excited state decays by the emission of a 342.2 keV gamma ray to the ground state and a 60.24 keV gamma ray to the first excited state. The known branching ratios of the 342.2 and 60.24 keV transitions from this state are 0.51 ± 0.21 and 0.49 ± 0.10, respectively. Although 60.24 keV was above our hardware threshold, we did not observe this transition. The detection efficiency for low-energy gamma rays was poor due to strong absorption by the Si detectors and the Al detector can. Based on the net number of feeding 218 keV gamma rays we observed, the previously reported decay scheme, and the low gamma detection efficiency, we estimate that we should have observed less than ≈0.5 counts of the 60.24 keV gamma rays, so the absence of a peak is not surprising. Lewitowicz *et al.* also observed clear peaks at 157.5 keV and 498.9 keV; in the current work we did not observe these peaks at a level that was statistically significant above background. Their reported peak at ≈46 keV was below our hardware threshold.

We assign the third, 218 keV transition as follows: The isomeric state likely occurs at an excitation energy of ≈560 keV, and decays by the emission of this gamma ray to the 342.2 keV state discussed above. We cannot exclude the possibility that the isomer also decays to the first excited state at 281.38 keV; the energy of this supposed transition would be ≈278 keV. Our HPGe detector did not have sufficient resolution to separate 281.38 keV from 278 keV. The measured yields of photons per fragment do not clarify this question, since both the presence and the absence of the suspected 278 keV transition are consistent with the data within error. Assuming that all three peaks in our gamma spectrum are due to the same cascade, the upper limit on the half-life is <500 ns, consistent with 110 ± 3 ns reported by Lewitowicz *et al.* Our proposed partial level scheme is shown in Fig. 5.

C. ^{82}Ga

Comparatively little information is available on ^{82}Ga. Rudstam and Lund measured beta-delayed neutrons from the ground state and the half-life of 0.60 ± 0.01 s [40]. These measurements were further improved by Kratz *et al.* [41]. Unfortunately, no excited states were reported by either group. In principle, excited states could be populated by the beta decay of ^{82}Zn (which is produced by in-flight fission [1]), but to date no group has made this study. In this work we observed a single gamma-ray peak at 141 keV with a half-life of <500 ns.

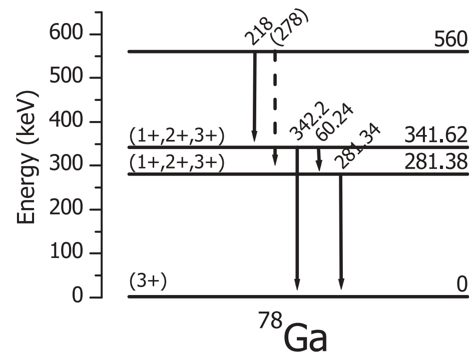

FIG. 5. Proposed partial level scheme for the decay of the ^{78}Ga isomer. The energies of the first two excited states are taken from [38], and the energy of the isomeric state is estimated based on the current work.

D. ^{92}Br

The beta decay of ^{92}Br populates numerous states in ^{92}Kr and has been studied in detail by Graefenstedt *et al.* [42]. The beta-delayed neutron emission probability of ^{92}Br has also been measured [43]. Our isomer decay spectrum showed numerous peaks at a range of energies, indicating a complex decay scheme. Based on summing relationships of the transition energies, we suggest four cases where a single state likely decays via two pathways: 99 keV + 139 keV ≈ 239 keV, 106 keV + 155 keV ≈ 259 keV, 139 keV + 155 keV ≈ 295 keV, and 259 keV + 780 keV = 1039 keV. These relations represent nine of the 11 observed transitions. Unfortunately, we were unable to construct a plausible decay scheme that maintained both the energy relations and intensity balance. The time data were consistent with a single decay component; the upper limit half-life is <500 ns. It is clear that γ-γ coincidence data could clarify the decay of this isomer; a decay scheme of the current complexity indicates the limit of what can be determined using data from a single detector.

E. ^{95}Rb

^{95}Rb is produced with high yield by induced fission of actinides, and numerous measurements of its ground-state decay properties have been made. (See Ref. [44] for a summary.) To date, no excited states have been reported, since the previous work focused on studying beta decay properties and the emission of delayed neutrons. We observed several strong lines, with the most intense transitions having energies of 192, 618, and 810 keV. The intensities of each transition were roughly equal, and since 192 keV + 618 keV = 810 keV, we assume that these three form a sequence of decays among three levels. A proposed level scheme for this isomer is shown in Fig. 6. The ordering of the 192 and 618 transitions may be reversed; the indicated order is in analogy with the decay of the 820.5 keV level in the neighboring nuclide ^{93}Rb [45]. A much weaker transition was observed at 835 keV, and may be the decay of the isomer directly to the ground state. If this transition has a high degree of K- or J-forbiddeness then this may explain the existence of the isomer; the state must

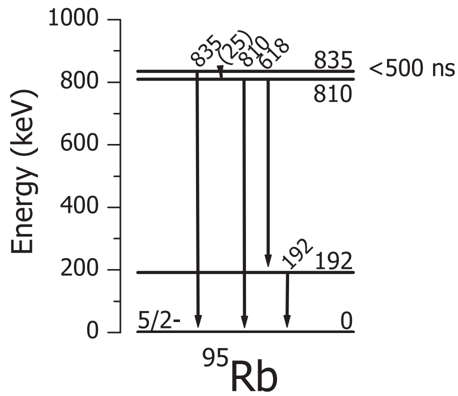

FIG. 6. Proposed level scheme for the decay of the ^{95}Rb isomer. The 25 keV transition was not directly observed in our experiment. See the main text for a discussion.

decay either through a highly forbidden transition or a much lower energy (≈25 keV) unobserved transition to the level at 810 keV. The upper limit half-life is <500 ns. The apparent peak at 114 keV in Fig. 4 is not statistically significant when the background of random correlations is subtracted.

F. ^{98}Rb

As is the case for ^{95}Rb, little information is available on the excited states of ^{98}Rb. The ground state half-life and beta-delayed neutron emission probabilities have been studied in detail. (See Ref. [44] for a summary). A long-lived isomer ($E^* \approx 270$ keV, $t_{1/2} = 96 \pm 3$ ms [38]) was first reported by Pahlmann, Keyser, Münnich, and Pfeiffer [46], and was studied more recently by Lhersonneau *et al.* [47]. Both groups studied the beta decay of the ground state and isomer, but were not sensitive to the decay of a microsecond isomeric state. In the current work we observed two strong transitions with energies of 124 and 178 keV. These data might be interpreted as decaying from a state at 178 keV, with the former populating a second state at 54 keV. Our detection efficiency for a 54 keV transition to the ground state was very low, and the spectrum does not show evidence for a peak at this energy (see Fig. 4). In the neighboring nucleus ^{96}Rb, whose excited states are well-characterized [8,11], the level at 185.4 keV decays by the emission of gamma rays with energies of 37, 126.1, and 185.4 keV to three separate states. A similar scheme could be suggested for ^{98}Rb, but no isomer with such a low excitation energy has been observed in ^{96}Rb. We were unable to assign the weak 116 keV transition observed. The measured half-lives of the 124 and 178 keV transitions were in good agreement, and the overall half-life obtained from combining the data is 700^{+60}_{-50} ns.

G. ^{92}Y

Excited states in ^{92}Y were reported by Parsa *et al.* in the beta decay of ^{92}Sr [48], which has a ground state half-life of 2.71 h. Gilad *et al.* [49] measured the energies of ejectiles in the ^{94}Zr(d, α) reaction and inferred the energies of additional states with an error of ±10 keV. (Similar work was performed by Suzuki, Kawa, and Okada [50], but they reported much larger error bars due to poor target uniformity). It is unlikely that any of these experiments would have been able to resolve the presence of a short-lived isomeric state. Recently, Bucurescu *et al.* observed a rotational band built on a state of unknown excitation energy, but speculated that this state may be a 6^+ isomer [51]. In the current work we observed an isomer, but cannot determine whether this is the bandhead observed by Bucurescu *et al.*

Our data show two clear peaks at 315 and 492 keV. The 492 keV transition is consistent with the 491.27 keV transition depopulating the level at 1383.9 keV, but the more intense 1383.9 keV transition to the ground state reported by Parsa *et al.* was not observed, so this possibility must be discounted. Gilad *et al.* reported the first two excited states of ^{92}Y to be at 310 ± 10 keV and 780 ± 10 keV. These are within one and three standard deviations, respectively, of 315 keV and 315 keV + 492 keV = 807 keV, but this evidence for assigning the isomer to a level at 807 keV (or 780 keV) is weak. Bucurescu *et al.* also observed a 315 keV gamma ray in coincidence with ^{92}Y (see the top panel of Fig. 5 in [51]), but it is not discussed. These data are ambiguous, so we choose not to assign the 315 keV and 492 keV transitions to the decay of a particular state. As with ^{98}Rb, the measured half-lives of the 315 and 492 keV transitions are in excellent agreement, and the combined half-life is $4.2^{+0.8}_{-0.6}$ μs.

H. ^{101}Y

The neutron-rich nucleus ^{101}Y was produced in significant yield by fission of ^{238}U at 80 MeV/nucleon (≈1.6 s^{-1} observed at the focal plane). We were able to observe several gamma rays consistent with the band structure of ^{101}Y, which has been studied in detail by several groups [52–54]. Luo *et al.* [52] studied, among others, the band based on the ground state, which has a $\pi 5/2^+$ [422] configuration, up to the $23/2^+$ state at 2396.1 keV. We observed four transitions corresponding to the four lowest-energy transitions in this band. A fifth transition at 480 keV is not consistent with any known transition in this nucleus. Therefore, we assign the 480 keV transition to the decay of the isomeric state into the ground state rotational band. Although we did not observe any additional higher-energy transitions above the 724.9 keV level in this band, we cannot exclude the possibility that the isomer decays into a higher excited state. Regardless, our data suggest that the energy of the isomeric state is approximately 1205 keV. Assuming that all five transitions we observed constitute a single cascade, the measured half-life is 860^{+90}_{-80} ns. A proposed partial level scheme is shown in Fig. 7.

In the neighboring nucleus ^{99}Y, an 8.6-μs isomer at 2141.7 keV was first reported by Monnand *et al.* [55]. Meyer *et al.* assigned this isomer to a three-quasiparticle $\pi 5/2[422]\nu 3/2[411]\nu 9/2[404]$ configuration with $K^\pi = 17/2^+$ [56]. The latter group also reported evidence for another high-spin (approximately 15/2) isomer at either 1202.9 keV or 1644.8 keV, and speculated that it may be due to a $\pi 5/2$ [422] $\nu 1/2$ [541] $\nu 9/2$[404] configuration. (See the footnote

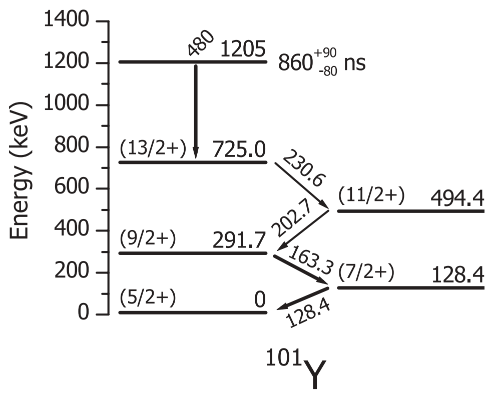

FIG. 7. Proposed partial level scheme for the decay of the ^{101}Y isomer. Energies of the first four excited states are taken from [52], and the energy of the isomeric state is estimated based on the current work.

to Table I in [56]). The proposed isomer at 1202.9 keV in ^{99}Y is very close to the 1205 keV excitation energy that we suggest for the isomer we observe in ^{101}Y; the latter may be due to a similar excitation. Unfortunately, without establishing the detailed decay scheme of the ^{101}Y isomer we are unable to make a definitive level assignment.

I. ^{112}Tc

Like many of the nuclides studied in this work, comparatively little information has been published on ^{112}Tc. This nuclide was first observed by Äystö *et al.*, who measured the ground-state half-life and used its beta decay to study excited states in ^{112}Ru [57]. Further experiments by Mehren *et al.* [58] and Wang *et al.* [59] improved the half-life (290 ± 20 ms) and measured the delayed neutron emission probability. To date, no reports of excited states in ^{112}Tc have been published. We observed a single transition in the gamma ray spectrum with an energy of 258 keV that we assigned as the decay from the isomer to the ground state. The upper limit isomer half-life is <500 ns. ^{112}Tc is also notable for its large number of isomeric decay photons per fragment, >0.44.

IV. SUMMARY AND CONCLUSIONS

Eight new microsecond isomeric states have been observed that were populated by in-flight fission of an 80 MeV/nucleon ^{238}U beam on a ^{9}Be target. In some cases (^{92}Y and ^{101}Y) the isomers were observed to decay into previously known level schemes so that the energy of the isomer could be estimated. Additionally, a level scheme for the decay of the ^{78}Ga^{m} isomer was proposed for the first time. Even though the fraction of a single isotope in the beam was very low, we were able to resolve all the fission fragments and combine the atomic charge states to reduce statistical uncertainty. The yields of photons per fragment encompassed a wide range, from less than ≈0.01 to ≈0.70 for ^{92}Y. In all cases, the new isomers were observed with less than 24 h of beamtime, indicating that detailed studies of these isomers are possible using γ-γ coincidences obtained with a high-efficiency HPGe array such as SeGA [60] or the new segmented tracking arrays that are expected to come online in the next few years.

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