REPORT TO USERS OF ATLAS

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This series of reports concerning the Argonne Tandem-Linac Accelerator System (ATLAS) is aimed at informing users about the operating schedule, user policies, and recent changes in research capabilities. The reports are issued approximately three times annually.

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I. STATUS OF THE ATLAS ACCELERATOR

The ATLAS facility has provided a total of 5749 hours of beam for research in FY1998. The accelerator operation had a very high 93% reliability factor during that period. With the startup of Gammasphere in January, our schedule has attempted to minimize scheduled downtime and maximize beam-time for research. Our best performance so far occurred during the month of May when a total of 639 hours was provided for research.

From the accelerator point-of-view, recent major highlights have included first operation of a new production configuration for our ^{17}F beams which increased the beam current on-target to 2×10^6 ^{17}F ions/sec. The ^{17}F production target was moved approximately 4 meters upstream and a new superconducting solenoid was added to the system to refocus the highly divergent secondary beam. This new location also places the target upstream of a new superconducting resonator which was used to reduce the energy spread of the beam delivered to the spectrograph to less than 300 keV (FWHM). An improved, liquid nitrogen cooled, multiple gas cell has also significantly contributed to better performance.

The new ATLAS ECR ion source and injection beamline system is complete and provided the first beam for the research program on September 7. A beam of $^{16}\text{O}^{5+}$ ions with an intensity on-target of 100 pA was used for the in-flight production of ^{17}F for six days beginning September 7. This milestone had been delayed

approximately 3 months due to shield problem in the high-voltage isolation transformers which required they be returned to the vendor for a design change. Then upon receiving and reinstalling the modified transformers, we discovered a noise problem with the unfiltered SCR high-current power supplies for the main ECR solenoid coils. The supplies performed adequately when connected directly to the building power grid. Now that they are connected to the low impedance of the isolation transformers they create so much high-frequency switching noise that other devices for the source will not operate correctly. We have implemented a short term fix, but replacing both supplies may be required later.

A prototype of a new traveling-wave transmission line chopper/sweeper has been built and tested for use in conjunction with the beams from both ECR ion sources. The goal of this project is to develop a beam chopper which will provide excellent beam chopping (removal of unbunched beam tails) without the emittance degradation associated with sine-wave choppers that we presently use. The initial tests of the prototype showed that excellent chopping with less than 10% emittance growth can be achieved with this device. These tests were performed at only a 10% duty cycle. The next step is to go to CW operation and install an improved transmission line with better vacuum properties. The final version of the chopper should be ready for installation in the Fall, 1998.

II. SUCCESSFUL TEST OF LOW-CHARGE-STATE RFQ FOR INJECTING EXOTIC BEAMS INTO ATLAS

At Argonne's ATLAS facility on May 22, a two-meter long, 12 MHz RFQ was operated CW at an intervane voltage above 100 kV, the voltage required to accelerate singly charged ions of mass 132. The prototype unit is the first of three that will be required to provide for efficient injection of exotic beams into the existing ATLAS heavy-ion linac. Development of a very low frequency RFQ capable of CW operation was required to provide a low-charge-state injector which could maintain the high beam quality characteristics of ATLAS beams.

The room-temperature, normal conducting RFQ utilizes indium gasketed joints, originally developed for the superconducting resonators of ATLAS, to maintain good vacuum, thermal, and

rf properties while permitting a highly modular design. Another unusual feature of the design is the use of aluminum for the main structure, which was electroplated with 100 microns of silver to minimize rf losses in critical areas. The RFQ (Fig. 1) exhibits a very high shunt impedance, requiring only 18 kW of rf power to operate at 100 kV, a field level that provides a total of more than 1.2 MV of acceleration over the two-meter length.

The successful voltage test culminates nearly two years of design and development. Preparations are now underway for beam tests of the RFQ later this year using a low-energy xenon beam from the Physics Division Dynamitron facility.

Fig. 1. Installation of the vertical vane pair in the 12 MHz RFQ.

III. HIGHLIGHTS OF RECENT RESEARCH AT ATLAS

1998 has been a very successful year for ATLAS research. Gammasphere experiments have taken the biggest share of beamtime, with more than 4000 hours of operation, but considerable progress has also been made in our other major programs to study proton radioactivity and conduct radioactive beam physics. Research related to Astrophysical issues has become a prominent theme. Developing the Penning trap and its connection for "online" operation has reached an advanced stage.

More than 30 Gammasphere PAC approved projects have been completed and we have had

more than 100 visitors involved in these experiments. Gammasphere has run very reliably, and always with the maximum number of gamma-ray detectors allowed by the experimental configuration, usually more than 100 HpGe counters. One of the new initiatives has been the study of excited states in the heaviest nuclei. A large collaboration was involved in the study of the $Z=102$ isotope ^{254}No . Figure 2 shows a photograph of some members of the international team who were involved in these experiments.

- A. STUDY OF THE $^{56}\text{Ni}(d,p)^{57}\text{Ni}$ REACTION AND THE ASTROPHYSICAL $^{56}\text{Ni}(p,\gamma)$ REACTION RATE** (K.E. Rehm, F. Borasi, C.L. Jiang, D. Ackermann, I. Ahmad, F. Brumwell, C.N. Davids, P. Decrock, S.M. Fischer, J. Greene, G. Hackman, B. Harss, D. Henderson, W. Henning, R.V.F. Janssens, G. McMichael, V. Nanal, D. Nisius, J. Nolen, R.C. Pardo, P. Reiter, J.P. Schiffer, D. Seweryniak, A.H. Wuosmaa, ANL; B.A. Brown, Michigan State Univ.; J. Görres, M. Wiescher, Univ. of Notre Dame; M. Paul, Hebrew Univ.; and R.E. Segel, Northwestern Univ.)

In the nuclear shell model, the magic number 28 is the first one that requires the introduction of a strong spin-orbit interaction. Indeed, as was recognized in the formulation of the shell model, in the absence of spin-orbit coupling the magic numbers 2, 8 and 20 would still occur, but 28 would be absent. The special character of the $N=Z=28$ ^{56}Ni nucleus also accounts for the fact that ^{56}Fe is the most abundant heavy element in the universe. Yet, ^{56}Ni is the first doubly-magic $N=Z$ nucleus that is not stable ($T_{1/2}=6.1\text{d}$). Over the years, this feature has hampered studies of the properties of nuclear levels relevant to the $N=Z=28$ shell gaps.

Reactions with ^{56}Ni are also of considerable interest in astrophysics. ^{56}Ni is produced via helium burning in the core of massive stars, in supernova explosions and in explosive hydrogen burning (rp process) where in a series of radiative proton capture reactions followed by β^+ decays nuclei up to ^{56}Ni and beyond are produced. The small Q-value ($Q=0.695\text{ MeV}$) for the proton capture reaction on ^{56}Ni makes this nucleus a 'waiting point' for the reaction flow towards heavier nuclei. For a realistic determination of the astrophysical reaction rate, detailed information on the structure of nuclei around $A=56$ is required. We have therefore measured the inverse $d(^{56}\text{Ni},p)^{57}\text{Ni}$ reaction using a radioactive ^{56}Ni beam to determine the spectroscopic factors of low-lying states in ^{57}Ni .

The ^{56}Ni material was produced via the $^{58}\text{Ni}(p,p2n)^{56}\text{Ni}$ reaction with a 50-MeV proton beam from the injector of the Intense Pulsed Neutron Source. A small ^{58}Ni pellet was bombarded for 24 hours with a $16\text{ }\mu\text{A}$ proton beam. Taking into account the cross section for the $(p,p2n)$ reaction and the 12 mm diameter of the beam spot, a fraction of about 5×10^{-6} of the ^{58}Ni nuclei was converted into ^{56}Ni . The sample, already mounted in a Cu insert for the SNICS negative ion sputter source was installed in the ion source of the tandem injector at ATLAS. The use of a negative-ion source and the selection of mass 56 strongly reduces the contribution of the stable isobar ^{56}Fe in the ion beam because of the low yield of Fe^- ions. The other isobar, ^{56}Co ($T_{1/2}=78.8\text{ d}$), which is produced in the sample through the $^{58}\text{Ni}(p,2pn)$ reaction, is difficult to remove in the accelerator, since the mass difference $\Delta M/M$ between ^{56}Ni and ^{56}Co is only 3.5×10^{-5} .

The experiment was performed with a $500\text{ }\mu\text{g}/\text{cm}^2$ CD_2 target located in the scattering chamber of the Fragment Mass Analyzer (FMA). The protons emitted at backward angles from the $d(^{56}\text{Ni},p)^{57}\text{Ni}$ reaction were detected in a large Si detector array consisting of a position sensitive annular detector and six $5\times 5\text{ cm}^2$ Si strip detectors (strip width 1 mm), covering a total solid angle of 2.8 sr. To separate the (d,p)

Fig. 2. A photograph of scientists from Finland, France, Germany, Norway, U.K. and U.S.A. performing a successful experiment on level structure of $^{254}_{102}\text{No}$ using Gammasphere and Fragment Mass Analyzer.

reactions on ^{56}Ni from those induced by the ^{56}Co and ^{56}Fe beam impurities, the reaction products were identified by their mass and nuclear charge at the focal plane of the FMA in coincidence with protons. For the Z identification of the reaction products it was necessary to use a passive absorber consisting of a stack of ten Au foils with a total thickness of 7 mg/cm^2 (mounted 39 mm downstream from the target) that slowed down the Fe, Co and Ni particles differently.

A Q-value spectrum for protons from the $d(^{56}\text{Ni}, p)$ reaction as measured with the annular Si detector that covers the angular range $\theta=147^\circ$ - 162° in coincidence with ^{57}Ni ions detected in the FMA is shown in Fig. 3a. In the center-of-mass

system, this range corresponds to forward angles for a (d,p) reaction, where transitions to low-spin states $\ell=0,1$ should be strongly populated. Indeed, the spectrum is dominated by the transitions to the $3/2^-$ ($E_x=0 \text{ MeV}$) and the $1/2^-$ ($E_x=1.113 \text{ MeV}$) states in ^{57}Ni while the yields for states at $E_x=2.5$ and $E_x=3.8 \text{ MeV}$ are considerably smaller indicating little single-particle strength for low-spin states in ^{57}Ni at higher excitation energy. The spectrum is quite different from the one obtained for the $d(^{28}\text{Si}, p)^{29}\text{Si}$ calibration reaction, where a strong population of the high-lying $2p_{3/2}$ single-particle state at $E_x=4.9 \text{ MeV}$ is observed (see Fig. 3b).

Fig. 3. a) Q-value spectrum measured with the annular detector for the $d(^{56}\text{Ni}, p)^{57}\text{Ni}$ reaction at $E(^{56}\text{Ni})=250 \text{ MeV}$. b) Q-value spectrum for the $d(^{28}\text{Si}, p)^{29}\text{Si}$ reaction. In this angle range only $\ell=0,1$ states are strongly populated.

From a comparison of the measured angular distributions with DWBA calculations spectroscopic factors for first three levels in ^{57}Ni could be obtained. It was found that these three states are indeed well characterized as $2p_{3/2}$, $2p_{1/2}$ and $1f_{5/2}$ single-particle states.

The observation of the single-particle structure in ^{57}Ni allows us to make predictions for the strength of the $^{56}\text{Ni}(p, \gamma)^{57}\text{Cu}$ reaction leading to the mirror nucleus ^{57}Cu , which is crucial for the production of heavier proton-rich nuclei in explosive nucleosynthesis [1]. Because of the low Q-value, the yield of the radiative capture reaction depends on the excitation energies and the spectroscopic strengths of specific low-lying states in ^{57}Cu . The excitation energies of these states were determined recently [2]. At the temperatures occurring in typical nova and supernova explosions and in X-ray bursts

($T_9 \sim 0.5-1$, where T_9 is the temperature measured in 10^9 K) the main contribution comes from the low-lying ($E_x \sim 3 \text{ MeV}$) $5/2^-$ and $1/2^-$ states. Assuming charge symmetry and using the same spectroscopic factors C^2S as measured for the mirror nucleus ^{57}Ni , we estimate the proton widths Γ_p for proton-unbound mirror states in ^{57}Cu from the expression

$$\Gamma_p(E, \ell) = C^2S \cdot \Gamma_p^{\text{sp}}(E, \ell).$$

The calculated astrophysical reaction rates are shown in Fig. 4 as a function of the temperature T_9 . The dashed lines in Fig. 4a represent the results for the astrophysical reaction rate obtained in Refs. [2] and [3], respectively. Since these authors used a smaller proton width for the $1/2^-$ state [2] or a higher (p, γ) threshold [3], their estimates of the reaction rate for the $^{56}\text{Ni}(p, \gamma)^{57}\text{Cu}$ reaction are lower by more than an order of

Fig. 4. a) Astrophysical reaction rates $N_A \langle \sigma v \rangle$ for the $^{56}\text{Ni}(p, \gamma)^{57}\text{Cu}$ reaction. Also shown are the results from Refs. 2 and 3, respectively. b) Lifetimes of ^{56}Ni calculated using the results from the present experiment and Ref. 3.

magnitude in the critical temperature region below $T_9=1$.

The mean life of ^{56}Ni with respect to the (p, γ) reaction as a function of the temperature T_9 is shown in Fig. 4b (thick solid line) in comparison with the results of [4]. As can be seen, a considerable decrease in the lifetime of ^{56}Ni is observed in the critical temperature region between $T_9=0.3-1$. This shorter lifetime should result in an increased production rate of elements

and isotopes above ^{56}Ni on the proton-rich side of the mass valley.

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- [2] X.G. Zhou et al., *Phys. Rev. C* **53**, 982 (1996).
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B. SUPERDEFORMATION IN THE $N=Z$ NUCLEUS ^{60}Zn

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Motivated by the recent observation of superdeformation in the $A \sim 60$ mass region [1], a Gammasphere experiment was conducted in March to search for the predicted [2] superdeformed band built on the "doubly-magic" configuration in the $N=Z$ nucleus ^{60}Zn . This configuration, which involves two $f_{7/2}$ holes and two $g_{9/2}$ particles in both the proton and neutron subsystems, corresponds to filling the single-particle energy levels up to the large SD shell gaps at $N, Z=30$. The identification of the band built on this configuration is necessary to establish the natural reference core for the study of $A \sim 60$ superdeformation.

High-spin states in ^{60}Zn were populated via the $^{40}\text{Ca}(^{32}\text{S}, 3\alpha)^{60}\text{Zn}$ reaction with a 134-MeV ^{32}S

beam provided by the ATLAS facility. Although the 3α evaporation channel leading to ^{60}Zn represented only $\sim 0.1\%$ of the total fusion cross section in this reaction, clean selection of these events was accomplished by a combination of charged-particle detection with the Microball array and total gamma-ray energy measurements enabled by removing the Hevimet collimators from the Gammasphere detectors. This experiment, combined with data from an earlier Gammasphere + Microball experiment in which ^{60}Zn was populated (again at the $\sim 0.1\%$ level) via the $^{40}\text{Ca}(^{28}\text{Si}, 2\alpha)^{60}\text{Zn}$ reaction, has led to the identification of the doubly-magic SD band in ^{60}Zn . A gamma-ray spectrum obtained by summing coincidence gates set on the members of this band is shown in Fig. 5.

Fig. 5. Gamma-ray spectrum measured with Gammasphere and obtained by summing single gates on the members of the ^{60}Zn SD band (circles). Diamonds in the inset label linking transitions connecting the SD band to the yrast line.

In addition to observing the ^{60}Zn SD band, three single-step linking transitions connecting this band to the yrast line have been identified (labeled by diamonds in Fig. 5 inset). These linking transitions provide the first spin, parity, and excitation energy measurements for A~60 SD states. The lowest observed ($I^\pi=8^+$) state of the ^{60}Zn SD band is established at an excitation energy of 9.620 MeV (4.328 MeV above the yrast 8^+ state) and a smooth extrapolation of the band to lower spin places the 0^+ SD bandhead at an excitation energy of ~7.5-8.0 MeV.

One particularly interesting aspect of these results is that the properties of the decay out of the ^{60}Zn SD band differ substantially from those which have been observed in the decay out of SD bands in the A~190 region. Unlike the A~190 SD bands, where the decay out is dominated by dipole transitions, angular distribution measurements indicate that the observed single-step links in ^{60}Zn have stretched E2 character. Furthermore, a measurement of the transition quadrupole moment of this band by the thin-target Doppler Shift attenuation method has enabled the decay-out B(E2) values to be estimated from measured in-band to decay-out branching ratios. The deduced transition strength for the strongest of the single-step links is almost 1 Weisskopf unit, considerably larger than upper limits set on the decay-out E2 strengths in, for example, ^{194}Pb [3]. Some differences in the decay-out process are expected due to the much lower level density in the A~60 mass region and

isospin suppression of $\Delta T=0$ dipole transitions may significantly affect the competition between dipole and quadrupole decay-out transition in this N=Z nucleus. The large decay-out B(E2) values observed in ^{60}Zn are, however, difficult to reconcile with the statistical model [4] which has proved so successful in describing the decay out of A~190 SD bands. These results indicate that a non-statistical mechanism, such as the model proposed by Bonche et al. [5], may be necessary to describe the decay-out of SD bands in the A~60 mass region.

*Researchers from the following institutions collaborated in this work: Argonne National Laboratory, Lawrence Berkeley National Laboratory, Lund University, McMaster University, Oak Ridge National Laboratory, Staffordshire University, Universität zu Köln, University of Tennessee, and Washington University.

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C. OBSERVATION OF DEFORMED PROTON RADIOACTIVITIES AT THE FMA

(C.N. Davids, D. Seweryniak, A. Sonzogni, M.P. Carpenter, D.J. Henderson, R.V.F. Janssens, J. Uusitalo, ANL; P.J. Woods, T. Davinson, Univ. of Edinburgh, UK; J.C. Batchelder, UNIRIB collaboration, C.R. Bingham, R. Grzywacz, Univ. of Tennessee; J.J. Ressler and W.B. Walters, Univ. of Maryland)

As described in the previous newsletter (ANL-ATLAS-98-1), the new proton radioactivities ^{141}Ho and ^{131}Eu have been observed at ATLAS. They were both produced via the p4n evaporation channel, using the $^{54}\text{Fe}+^{92}\text{Mo}$ and $^{40}\text{Ca}+^{96}\text{Ru}$ reactions, respectively. Since the half-lives calculated using the spherical WKB approximation did not agree with the observed experimental values, it was concluded that these nuclides are most likely deformed [1]. This supports calculations of the macroscopic-microscopic mass model, which predict deformations of $\beta_2 \sim 0.3$ for these nuclei [2].

A multiparticle theory of proton decay of deformed nuclei has been developed by Bugrov and Kadmsky [3]. We have shown that their results can also be obtained with the DWBA method of Ref. [4], by using deformed potentials and Nilsson wavefunctions. Figure 6 shows the results of half-life calculations for ^{141}Ho and ^{131}Eu , using various assignments for the Nilsson orbital of the emitted proton in the parent wavefunction. It can be seen that good agreement is obtained for ^{141}Ho using the $7/2^-$ [523] orbital and deformation β_2 near 0.3. Both the $3/2^+$ [411] and $5/2^+$ [413] orbitals give good agreement with the experimental half-life for values of $\beta_2 > 0.3$.

In a recent ATLAS experiment, the recoil-decay tagging technique was used to observe prompt gamma-rays in ^{141}Ho detected in Gammasphere correlated with protons detected at the FMA focal plane. A large number of gamma rays were observed feeding the ^{141}Ho ground state, and gamma transitions were also observed feeding the proton-emitting isomeric state in ^{141}Ho recently observed at Oak Ridge. These data are currently under analysis, and will hopefully result in an independent measurement of the deformation parameter for both ground and isomeric states in ^{141}Ho . Searches for new proton-emitters in the predicted region of high deformation are planned for the near future.

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Fig. 6. a) Calculated proton decay half-life for ^{141}Ho based on the $7/2^-$ [523] Nilsson orbital. The observed half-life lies in the band between the dashed lines. A β_2 value of 0.29 is predicted by Ref. [2] for ^{141}Ho . b) Calculated proton decay half-life for ^{131}Eu based on the $3/2^+$ [411] and $5/2^+$ [413] Nilsson orbitals. The observed half-life lies in the band between the dashed lines. A β_2 value of 0.33 is predicted by Ref. [2] for ^{131}Eu .

- D. STUDY OF EXCITED STATES IN ^{167}Ir : PROBING STATES BEYOND THE PROTON DRIP LINE** (M.P. Carpenter, R.V.F. Janssens, T.L. Khoo, D. Seweryniak, A. Sonzogni, I. Ahmad, L.T. Brown, C.N. Davids, G. Hackman, T. Lauritsen, C.J. Lister, P. Reiter, S. Siem, J. Uusitalo, I. Wiedenhofer, ANL; P.J. Woods, Univ. of Edinburgh; J.A. Cizewski, Rutgers Univ.; W. Reviol, L.L. Riedinger, Univ. of Tennessee; S.M. Fischer, Univ. of Pennsylvania; J.J. Ressler, W.B. Walters, Univ. of Maryland; and D.G. Sarantites, Washington Univ.)

In the past several years, a number of new proton emitters have been identified using current generation recoil mass spectrometers [1]. These results have greatly enhanced our knowledge of the ground state properties of nuclei which lie beyond the proton drip line. For example, the decay rates for the majority of these proton emitters are well understood using a spherical shell model basis of $h_{11/2}$, $s_{1/2}$, and $d_{3/2}$ states [1]. In the few cases where the spherical WKB model fails, the decay rates can be satisfactorily reproduced if one assumes that the proton is emitted from a deformed state [2].

While a substantial amount of nuclear structure information has been deduced about the ground-state properties of these nuclei which lie beyond the proton drip line, very little, if anything, is known about their excited states due to the fact that the cross-sections to form them via heavy-ion fusion-evaporation reactions is small ($<100 \mu\text{b}$). In fact, the only data on non-isomeric excited states in proton emitters with $Z>50$ have been obtained using the Recoil Decay Tagging (RDT) method, a technique which correlates the charged particle radioactivity of an ion implanted in a position sensitive silicon detector with a previously implanted residue [3]. For the two reported cases, ^{109}I [3] and ^{147}Tm [4], the combined efficiencies of the recoil separator and gamma-ray array were insufficient to allow for a gamma-ray coincidence analysis. Nevertheless, important information regarding the ground-state deformations of these nuclei was inferred from the data.

E. COULOMB EXCITATION OF A ^{78}Rb RADIOACTIVE BEAM

(J. Schwartz,* C.J. Lister, D.J. Henderson, S.M. Fischer, P. Reiter, C.N. Davids, R.V.F. Janssens, D. Nisius, D. Seweryniak, ANL; A. Aprahamian, R. deHaan, Univ. of Notre Dame; J.A. Cizewski, Rutgers Univ. and S.M. Vincent, Univ. of Surrey, UK)

N-Z nuclei can be produced and studied in fusion-evaporation and fragmentation reactions. However, these techniques mainly populate yrast configurations. In contrast, the production of radioactive beams of these nuclei and their subsequent Coulomb re-excitation can be a powerful probe into non-yrast collectivity. At present, radioactive beam accelerators are not widely available, so it is necessary to prepare the radioactive beam as part of any experiment. One method of

With the coupling of Gammasphere to the Fragment Mass Analyzer (FMA) at Argonne, this lack of coincidence efficiency for small cross-section reactions has been overcome. In an attempt to probe excited states in nuclei at the edge of stability, we have measured excited states in the proton-emitter ^{167}Ir [5] populated using the $^{92}\text{Mo}(^{78}\text{Kr}, p2n)$ reaction at a beam energy of 360 MeV. Gamma-rays in coincidence with residues were measured with Gammasphere and the FMA. The assignment of gamma-ray transitions to ^{167}Ir was made using the RDT method. Figure 7a shows a spectrum in coincidence with A=167 residues, and this spectrum is dominated by gamma-rays associated with ^{167}Re (3p) and ^{167}Os (2pn). Figure 7b is the gamma-ray spectrum correlated with the alpha/proton decay of the 11/2 level in ^{167}Ir .

The data are currently being analyzed and a preliminary decay scheme suggests that the states built on the 11/2 isomer are associated with a weakly deformed or spherical shape. This is in agreement with the conclusions of ref. 5.

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production is to use the kinematic properties of a primary reaction to produce a secondary radioactive beam. Beams prepared in this manner generally have low intensity, poor emittance, low beam purity, and high backgrounds due to the natural radioactivity of the beam. There is also little control over the secondary beam energy. Nevertheless, it is an experimental challenge to investigate whether new data can be obtained on non-yrast collectivity from

Fig. 7. a) Gamma-ray spectrum measured with Gammasphere in coincidence with $A=167$ residues measured at the FMA focal plane. b) Gamma-ray spectrum correlated with the alpha-decay of the $11/2^-$ isomeric state in ^{167}Ir .

experiments done with these modest secondary radioactive beams. To date, there have been rather few attempts at re-excitation following fusion-evaporation production of the radioactive beam [1,2]. The experiment reported here represents a considerable development of the technique.

We chose to study the nucleus ^{78}Rb which has been studied in atomic beam and fusion-evaporation experiments, through which the spin and parity of the ground state and excited states have been assigned [3,4]. The ground state of ^{78}Rb has $J^\pi=0^+$ and $T_{1/2}=17.66$ min. ^{78}Rb also has two isomers: $^{78}\text{Rb}^{m1}$ with $J^\pi=4^-$, $E^*=111$ keV, and $T_{1/2}=5.74$ min; and $^{78}\text{Rb}^{m2}$ $J^\pi=4^+$, $E^*=115$ keV, $T_{1/2} \geq 7$ μsec . The spectroscopic quadrupole moment of $^{78}\text{Rb}^{m1}$ has been measured to be $Q_s=-0.814$ eb [3]. Transition rates between yrast states have also been measured [4]. The goal of this experiment was to investigate the relationship between the shapes of these states.

A beam of ~ 20 pA ^{58}Ni at 260 MeV was used to produce ^{78}Rb , through the reaction $^{24}\text{Mg}(^{58}\text{Ni}, 3p)^{78}\text{Rb}$. The ^{24}Mg target had a thickness of 0.82 mg/cm 2 . This inverse reaction was particularly well suited to our requirements. The residues were produced with a cross-section

of 239 mb (29 mb for $^{78}\text{Rb}^{gs}$, 83 mb for $^{78}\text{Rb}^{m1}$, and 127 mb for $^{78}\text{Rb}^{m2}$), in a recoil cone with $\theta_{1/2}^{\text{max}} \sim 3^\circ$ with a mean energy of 150 MeV. The reaction had the added advantage that it provides a stable beam of ^{78}Kr (98 mb) for reference.

After the production target, the recoiling reaction products passed through a charge-resetting foil of 20 $\mu\text{g}/\text{cm}^2$ carbon to equilibrate their charge-state distribution. The residues of interest were separated from the direct beam and other reaction products using the Argonne Fragment Mass Analyzer (FMA) [5].

A 2.5 cm square aperture allowed only particles with $A/q=78/25$ to enter the secondary beam-line. Particles were detected in two 9 cm x 8 cm multi-channel plate (MCP) detectors which were position sensitive in two dimensions with a resolution of 2.2 mm, and which were placed 20 cm apart. The two-MCP combination was used to characterize the secondary beam at the re-excitation target ^{58}Ni (1.1 mg/cm 2 placed 92 cm behind MCP1). The MCP system could handle event rates $\geq 10^5$ Hz. The position of each ion impinging on the target was determined by applying a beam tracking method. The beam spot size at the secondary target was determined to have a FWHM of 2.24 cm. In the data

analysis, ions were required to pass through a circle of diameter 3.7 cm, centered on the beam-line. ^{58}Ni was a mechanically convenient re-excitation foil, which was not easily Coulomb excited, and from which $A=78$ ions were scattered in a recoil cone with $\theta_{1/2}^{\text{max}}=48^\circ$. The scattered ions were detected in a 4-quadrant, position-sensitive multi-wire proportional counter (MWPC), placed 19 cm beyond the target and subtending laboratory angles $6^\circ \leq \theta_{\text{det}} \leq 45^\circ$. Each quadrant of the MWPC was a separate detector, with all four quadrants sharing a common gas

volume of isobutane at 3 Torr. The scattered-ion rate was ~ 3 Hz. The detection of a scattered ion provided the main experimental trigger. Ions scattering at angles less than 3° in the laboratory frame were not intercepted and passed into a beam dump 20 cm behind the MWPC. Photons associated with Coulomb excitation were detected in two 70% HPGe detectors, placed at ~ 7 cm from the target, and at an angle $\theta_{\text{Ge}} \sim 112^\circ$ with respect to the beam axis. From these data, complete event reconstruction was possible, allowing Doppler correction (Fig. 8).

Fig. 8. Event-by-event ray-tracing of $A=78$ ions along the secondary beam-line. For clarity, only ions scattering into the beam-right and upper MWPC's are shown.

After time-random subtraction, a clean γ -ray spectrum was obtained, which is shown in Fig. 9. This spectrum is devoid of characteristic 511 keV γ -rays associated with the β^+ decay of the beam. Coulomb excitation of ^{78}Kr and $^{78}\text{Rb}_{\text{gs},m1,m2}$ are evident. The intense peak at ~ 154 keV corresponds to the excitation and decay of states built on both $^{78}\text{Rb}^{m1}$ and $^{78}\text{Rb}^{m2}$ isomers. Preliminary Coulomb excitation calculations indicate that states built on the $^{78}\text{Rb}^{\text{gs}}$ have a similar collectivity to that measured for $^{78}\text{Rb}^{m1}$. The collectivity of $^{78}\text{Rb}^{m1}$ and $^{78}\text{Rb}^{m2}$ also appear to be similar, in agreement with recent in-beam measurements [4]. A quantitative analysis is in progress.

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Fig. 9. The time-random subtracted spectrum of γ -rays associated with re-excitation of $A=78$ ions. Peaks associated with re-excitation of ^{78}Kr and $^{78}\text{Rb}^{g.s., m1, m2}$ are all evident.

F. LONG-TERM MEASUREMENT OF ^{44}Ti HALF-LIFE

(I. Ahmad, S.M. Fischer, ANL; G. Bonino, G. Cini Castagnoli, CNR, Torino, Italy; W. Kutschera, Univ. of Vienna, Austria and M. Paul, Hebrew Univ.)

The half-life of ^{44}Ti plays an important role in determining the amount of ^{44}Ti produced by cosmic rays in meteorites, and supernova explosions. For this reason an accurate half-life of ^{44}Ti is needed. Although several measurements of the ^{44}Ti half-life were made before we started our experiment, these values did not agree with each other. We started a measurement of ^{44}Ti half-life by following the decay of ^{44}Ti activity relative to that of ^{60}Co at three laboratories (Argonne National Laboratory, Hebrew University and CNR Torino). The gamma ray spectra of a mixed source of ^{44}Ti and ^{60}Co were measured with high-resolution Ge spectrometers and the decay was followed for 5 years. From the decay of the ^{44}Ti activity relative to that of ^{60}Co activity and using a half-life of 5.2714(5) y for ^{60}Co decay, the ^{44}Ti half-life was

determined at the three laboratories. A weighted mean of the three measurements gave a value of 59.0 ± 0.6 y [1] for the half-life of ^{44}Ti . Our value is in good agreement with the two other recent measurements, [2,3]. This precise value of the half-life places a constraint on the amount of ^{44}Ti ejected in the Supernova explosion [4]. The counting measurement is still continuing.

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- [2] J. Görres et al., Phys. Rev. Lett. **80**, 2554 (1998).
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IV. PROGRAM ADVISORY COMMITTEE

The ATLAS Program Advisory Committee has met once since the January 1998 report to users in a closed session on May 8 and May 9, 1998. There were 52 proposals requesting beam time for a total of 273 days. In addition, there were three proposals for source measurements using Gammasphere "off-line". Of the submitted proposals, 30 were approved for a total of 123 days. More detailed information which concerns the PAC recommendations follows.

The Program Advisory Committee members for this cycle were:

David Balamuth	Univ. of Pennsylvania
Russell Betts	ANL
David Fossan	SUNY @ Stony Brook
Bernard Haas	Inst. de Recherches Subatomiques
I-Y. Lee	LBL
Witek Nazarewicz	Univ. of Tennessee
Peter Paul (chair)	SUNY @ Stony Brook
Bradley Sherrill	Michigan State Univ.

**Summary of the May 1998
ATLAS PAC Meeting**

• Number of proposals submitted	55
• Total number of days requested	273
• Total number of proposals approved	30
• Total number of days approved	123
• Number of scientists involved in approved experiments	252
• Number of institutions represented	68
• Number of countries represented	17

**List of Proposals Approved at the
May 1998 PAC Meeting**

Exp. No.	Spokes-person	Title	Days Approved				
				710	Fischer	¹⁰⁹ I with Recoil-Decay Tagging Technique	4
						Spectroscopy of the N=Z Nucleus ⁶⁸ Se	3
				711	Sanders	Study of the J ^π =38 ⁺ $\hbar$ Heavy-Ion Resonance in ⁴⁸ Cr	6
				713	Sonzogni	Measurement of ⁴⁶ Ti(α,n) ⁴⁹ Cr and ⁴⁶ Ti(α,p) Cross Sections as the First Step to Study the ⁴⁴ Ti(α,p) ⁴⁷ V Reaction	4
				714X	Hofman	Test of LEPPEX Fission Detectors	2
433-9	Miller	Ion Irradiations of Anisotropic High-Tc Superconductors: Probing Dynamics of Magnetic Vortices	2	716	Clark	Spectroscopy of ⁹⁸ Cd	5
				717	Beausang	A New Magnetic Roter: ²⁰⁶ Rn Conversion Coefficients for a Dipole Band in ²⁰⁶ Rn	5
651-2	Paul	Accelerator-Mass-Spectrometry Measurements of Natural ²³⁶ U Concentrations with the ECR-ATLAS System	4	719	Davids	Deformation and Proton Decay in ¹⁸⁵ Bi	6
667-2	Janssens	Unsafe Coulex of the ^{238,239} Pu Nuclei	4	722	Rudolph	Spectroscopy of Proton-Decay Links from Superdeformed Minima in Mass 60 Nuclei	6
669-2	Carpenter	Excited States Associated with Different Shapes in ¹⁷⁸ Hg and Neighboring Odd-A Nuclei	4	725	Gerl	Study of K-Forbidden Transitions in ¹⁷⁸ Hf by Coulomb Excitation	4
				727	Herskind	Search for Hyperdeformation and Triaxial-Superdeformation in ¹⁶⁸⁻¹⁷⁰ Hf by use of the Very Cold Semi-Symmetric Reactions, ⁷⁶ Ge + ⁹⁶ Zr → ¹⁷² Hf	5
673-2	Lister	A Study of Radiative Decay from High Lying States in ²⁴ Mg	5				
689-2	Freeman	Spectroscopy of Odd Tin Isotopes Approaching ¹⁰⁰ Sn	5	728	Harss	Measurement of the ¹⁷ F(p,α) ¹⁴ O Reaction	8
693-2	Reiter	Structure and Formation Mechanism of Heavy Elements – Request for additional beam time for Experiment 693 –	6	729	Lister	Exploring Methods to Measure the Missing 3 ⁺ -State in ²⁶ Si	1
706	Kwok	Heavy-Ion Lithography on High Temperature Superconductors	2	730	Rubio	Mirror Symmetry in ⁶⁵ As and ⁶⁵ Ge	4
708	Yu	In-Beam Spectroscopy Study of the Proton Emitter		735	Lane	Spectroscopy of Exotic, Neutron-Rich Nuclei at and	

above the Doubly-Closed
Shell at ^{208}Pb

4

**Approved Source Experiments
(Depending on Gammasphere Availability)**

			Exp. No.	Spokes- person	Title	
740	Savard	High-Accuracy Mass Determination of Neutron-Deficient Hg Isotopes: On-Line Commissioning of the CPT Spectrometer				
			736	Bhattacharyya	Gamma-Ray Studies of Few-Valence- Particle Nuclei Around Doubly Magic ^{132}Sn . Proposal for Follow- Up Measurements at Gammasphere using a ^{248}Cm Source	10
745	Lauritsen	A New Search for Hyper- Deformation and the Determination of the SD Excitation Energy in the A=150 Region				
			737	Ahmad	Off-Line Studies in very Heavy Nuclei with Gammasphere	15
746	Cederwall	Superdeformation, Shell Structure and Neutron- Proton Correlations at A~90, N-Z				
			738	Ramayya	Dynamics of the Ternary Fission of ^{252}Cf with Gammasphere	14
750	Devlin	Spectroscopy of Neutron- Rich $50 < A < 90$ Nuclei via Fusion-Fission Reactions				

**The next meeting of the ATLAS Program Advisory Committee will be held on November 9-10, 1998.
The deadline for the proposals is October 13, 1998.**

V. ATLAS USER GROUP EXECUTIVE COMMITTEE

The current members of the ATLAS User Group
Executive Committee are:

David Fossan	SUNY@Stony Brook
E. Frank Moore	NC State Univ.
Michael Wiescher	Univ. of Notre Dame
Frank Wolfs (Chair)	Univ. of Rochester

Frank Wolfs can be reached through the User
Information page on the World Wide Web
(<http://www.phy.anl.gov/atlas/index.html>) or
directly via email at [wolfs@nsrl31.nslr.
rochester.edu](mailto:wolfs@nsrl31.nslr.rochester.edu). Users are encouraged to
communicate with the Executive Committee
about ATLAS issues.