COO-498-82

I. TECHNICAL PROGRESS REPORT

A. Experimental Program

We have continued to obtain high-resolution spectra of radioactive isotopes (primarily in the rare-earth region) with sources produced in a reactor, the Argonne National Laboratory cyclotron (α or d activations), or in our tandem accelerator (d or p activations). In addition, coulomb excitation experiments using an O^{16} beam are now being run regularly after considerable effort in producing a beam and fabricating enriched, metallic, oxygen-free targets. The overall program involves singles and coincidence spectra, directional correlation measurements, determination of nuclear level half-lives in our radioactive decay work, complemented by the coulomb excitation data.

During the year a number of important experimental improvements have been carried out. We have acquired a premium quality 40 cc Ge(Li) detector and a 4096 channel analyzer which are used in both the coulomb excitation experiments at the accelerator and our radioactivity studies. A scheme was developed for detecting very weak γ-ray transitions by reducing the problems due to electronic pileup, an effect which is present at even nominal counting rates. One needs to count at rates of 10^4/sec or more to obtain good statistics on weak higher energy γ-rays. No known scheme can discriminate against the perfect overlaps of two pulses, giving a "sum" peak, but we have developed a technique which discriminates against the partially overlapping pulses which give rise to the extreme "tailing" and sharply rising background in the spectrum. The usual unipolar Gaussian pulse adjusted for optimum energy resolution is stored in a linear gate/stretcher which is dc coupled to the ADC of a PHA. A constant fraction timing pickoff on the leading edge of the preamplifier output generates the start signal for a TAC, while the stop signal is generated by a zero-crossing discriminator fed by a bipolar Gaussian pulse in parallel with, and of the same total width as, the unipolar energy pulse. This measurement of the leading-edge to zero-crossing time difference allows pileup to be analyzed as a deviation from the "prompt" TAC peak. A single-channel analyzer set on this peak strobes the linear gate/stretcher, allowing only pulses with "perfect" time overlap to reach the ADC. The resultant sharp peaks then consist of pure "sums" or real γ-rays, and the amount of each can be determined by appropriate calibrations.

We have completed construction of our Si(Li) detector (3 mm x 80 mm^2) system which consists of a "Kevex-Kit" incorporated into our vacuum system. This system works very well for conversion electrons (resolution < 2.4 keV for the 1064-K line in Bi^{207}) and low energy photons (< 500 eV for 6 keV x-rays). This detector has been carefully calibrated and has been in

constant use, both for singles spectroscopy and coincidence measurements.

Certain improvements have been made on our Nuclear Data 3300-digital gate system which is used for coincidence and directional correlation measurements to allow higher counting rates and greater stability.

The coulomb excitation experiments which now are run regularly have yielded a considerable amount of data which are now being analyzed. In general, a 56 MeV, 60 nanoamp beam of O^{16} (7^+ charge state, 7.0 MV on terminal) is employed. The γ-rays from the coulomb excited levels are detected in a 40 cc Ge(Li) detector and are coincidence-gated by the back-scattered O^{16} ions detected in an annular Si surface barrier counter. Fast timing is used to reduce chance coincidences. Particle and γ-ray timing signals start and stop a TAC, allowing windows to be set on real prompt and chance coincidences, and the prompt and delayed spectra are routed into the two halves of a 4096 channel analyzer. Target fabrication is difficult since oxygen cannot be tolerated. The general technique consists of using lanthanum metal to reduce the enriched rare-earth oxides (at temperatures of 1000-2000°C). A crucible with a mixture of La and the oxide is heated by electron bombardment and the rare earth is evaporated onto a thin Ta foil; the Ta is dissolved away with a mixture of HF_3 and HNO_3 and the metal is mechanically rolled to a thickness of 2-3 mg/cm . Targets of various isotopes of Yb and Tm have been fabricated and run in the beam.

The Copenhagen computer program for analyzing these coulomb-excitation data has been modified for use on the Notre Dame computer. Meanwhile, a turntable for the detector has been designed and is now being constructed in the shop; we shall shortly be able to do angular distribution measurements on the γ-rays de-exciting the levels reached through coulomb excitation

B. Results

It has become quite evident that a given nucleus must be studied in different ways in order to obtain definitive information about the properties of its levels. The achieving of a successful coulomb excitation program with O^{16} ions is a powerful corollary tool when combined with our careful studies of radioactive nuclei with high resolution detectors involving coincidences, directional correlations, fast half-lives, etc. These data, when analyzed in the light of other available experimental data (such as one- and two-particle transfer reactions, neutron capture γ-rays) and extant theory, permit a rather sophisticated description of the nuclear states, including the types of wave functions needed to explain the data.

The coulomb excitation process in the case of the doubly-even Yb isotopes excites states up to the 8^+ level in the ground-state band. Extraction of the B(E2) strengths to these states will tell much about the purity of the ground-state band; there are some inconsistencies in the values published to date. The quadrupole vibrational states lie at fairly high energies in this mass region and one would expect the ground-state band to be fairly pure. The 2^+ state of the K = 2 bands is well populated in these experiments and the B(E2) strength which these data are yielding will be quite important. The excitation of the K = 0 bands is also of great interest since the collectivity due to quadrupole shape vibrations should be distributed over several or many of these excited K = 0 and K = 2 bands, and a measure of this distribution should provide a sensitive test of nuclear models. The coulomb excitation of Yb^{172} (we have already run all the even mass Yb's from 170 through 176) excited several of the K = 0 bands in the 1-2 MeV region (these having been previously observed in n, γ experiments). These data are being analyzed.

At the same time we have conducted radioactivity experiments, studying the neutron deficient isotopes of $Lu^{170, 172, 174, 174m}$ which decay to the even mass Yb's. (These results are all being prepared for publication.) In the case of Yb^{172}, the considerable amount of good available data allows one to propose the configurations of a large number of states. Special attention has been given to the well-known K = 3 band at 1172 keV. The properties of the members of this band are generally explainable, except for the 4^+ state. Even very extensive calculations fail to explain the nature of this state, and it is one of the present-day enigmas of nuclear physics. It may be that, since to first order, γ-ray decay to the ground state is K-forbidden, the results of small mixings with many other levels may make it impossible to account for the ratios of the intensities of the depopulating transitions.

Our work on the complex decay of Lu^{170} is completed and a manuscript is in the final stages of preparation. The large available decay energy permits many states to be populated in Yb^{170}, and since the spin of the parent is 0, these are low spin states. At least four 0^+ states are observed, in addition to a large number of 1^- and 1^+ states. Despite the complexity of the spectrum, we have obtained considerable coincidence and γ-γ directional correlation data and thus have been able to strengthen many of the level assignments. As mentioned before, the coulomb excitation data are still being analyzed.

Studies of the short-lived activities of Ho^{160} and Ho^{162} are very near completion. Sources of these nuclides were produced by the (d, 2n) reaction in the beam of our tandem accelerator. The Dy^{160} and Dy^{162} nuclei which are being studied are especially interesting because they have well-formed negative parity bands which are fairly well populated in the Ho decays. These bands may result from the splitting of the spherical octupole vibrations into the K = 0, 1, 2, and 3 components. We have added the I = 5 member to the previously known K = 2^- band in Dy^{162} and have had some success in explaining the strengths of the K-forbidden transitions to the ground-state band. It appears that a simple mixing of this band with the K = 0^- mode is responsible. Some fairly crucial data on a K = 0 level in Dy^{162} were obtained with our new Si(Li) spectrometer. Coulomb excitation experiments will be done when the target-making problem is solved.

In Dy^{160}, the K = 1⁻ and 2⁻ bands were previously observed and rather detailed mixing calculations were performed to explain the properties of these bands. Our work has yielded a branching ratio from the 1⁻ member of the K = 1 band, a value which was previously unattainable due to close lying γ-ray peaks. Also, we have very probably located two members of the K = 0⁻ band. Information on this band is necessary so that its effect on the K = 1⁻ and 2⁻ bands can be more closely analyzed.

A number of problems on which we had been working have been reinvestigated with our new large detector in order to improve the quality of the data. Our results on the decays of Tb^{152} and Eu^{150} both of which decay to 88 neutron daughters are being combined. Some preliminary data have been obtained for the decay of Pm^{150}(3 h) to Sm^{150} and we are considering continuing these measurements. New data have been obtained for the decays of Tb^{154} and Tb^{153} and these investigations are nearing completion. The decay of Tb^{154} to Gd^{154} is particularly interesting since Gd^{154} has 90 neutrons and should be quite deformed in contrast to the 88 neutron cases. The level structure below 1.8 MeV has been well studied through the Eu^{154} decay but the higher lying states are reached only in the Tb decay. This problem is extremely difficult due to the fact that there exist two isomers (8 and 22 h) which give rise to literally hundreds of γ-rays. We feel that the effort spent on it will be well worth it.

The important case of W^{182} was discussed in last year's report and is still under study using Ta^{182} and Re^{182} sources. Conversion electron spectra (using our new Si(Li) detector) and γ-ray spectra are being obtained in both singles and coincidence modes. It is not yet clear that γ-γ directional correlations are technically possible (to the desired degree of accuracy) in this case which involves a "1157" keV doublet which proceeds between 4^- and 4^+ and 2^- and 2^+ states (both the final states of the ground-state band). ce^--γ coincidence measurements indicate that the former transition is primarily E1. The second transition, which originates at a 2^+ level, has been conjectured to be part of a K = 0 band and to contain considerable E0 radiation. Recent Oak Ridge coulomb excitation experiments indicate some enhanced E2 strength to the state. However, our intensity of the 1157-K conversion line does not appear to agree with the values in the literature and thus the agreement is not yet certain. Further work should resolve the differences. Several problems appear in this (although well-studied) puzzling nucleus, namely, the E0 question just mentioned, the 2⁻ band (we are looking at the systematics of 2⁻ bands), the possible E3 mixtures in some of the K-forbidden γ-transitions, and the fact that the relative γ-ray intensities from certain levels fed in the decays of both Ta^{182} and Re^{182} are different, indicating that perhaps some of these transitions are composite. The half-life of the 1374 keV state in the 2⁻ band is also a source of controversy, different laboratories obtaining quite different values.

A problem which arises in the case of Ta, particularly, is the determination of the attenuation of the angular correlation of radiations where the intermediate state has a half-life of ~ 1 nsec. This attenuation is very sensitive to the chemical form of the source, and Ta is not particularly tractable chemically. The obvious use of the $4 \rightarrow 2 \rightarrow 0$ cascade in the ground-state band is just not sensitive enough to the A_4 term. As the energy resolution of the available counters improves, these effects become very important in looking at correlations which do not have large coefficients.

The interesting problem of E0 transitions has arisen in another case, namely, the transitions between two $K = 1/2$ bands in Lu^{173} (populated by the decay of Hf^{173}(23 h). The internal coefficients between levels of the same spin appear to be quite large, and are consistent only with E0 admixtures. If this is indeed the case, this is quite important. Another case involving large experimental internal conversion coefficients is that of Eu^{147} decaying to levels in Sm^{147}. Here the data could be consistent with M2 admixture and γ-γ directional correlation measurements will be required.

We have attacked the case of Tm^{169} in two ways, first of all, by decay studies of Yb^{169} employing the pileup rejection equipment previously mentioned, and by coulomb excitation of Tm^{169} (with O^{16} ions). Tm^{169} has a 1/2-spin in the ground state and the rotational levels up to 19/2 have probably been observed. In addition, a number of vibrational states may have been excited. These data are being analyzed.

We are continuing our program of determination of short half-lives. A number of measurements have been carried out and a brief precis is given here.

Yb^{174} (1319 keV state): Lx-ray-γ measurements yield slopes of 20-30 nsec using Naton and NaI (for the L x-rays) which is essentially prompt. Experiments which are now being carried out using Sn-loaded phosphors indicate a half-life of ~0.5 nsec for the 1319 keV state.

W^{182} (1554 keV state): A discrepancy had existed in the literature. A triple coincidence experiment yielded $T_{1/2} \sim 1.26$ nsec, in agreement with Meiling and Stary, who obtained 1.30 nsec.

Dy^{160} (283 keV level): Using NaI for preceding γ-rays and then Naton for 197-K conversion electrons, the prompt slope was 0.07 nsec and the $T_{1/2}$ was found to be 0.106 nsec. This agrees with Li and Schwarzchild, who had worried about interfering transitions. The measurements for the (1264,, 1286), 1357, and 1397 keV levels yielded $T_{1/2} < 0.081$ nsec (which is prompt).

Lu^{173} (425 keV state): $T_{1/2} \sim 0.60$ sec using 1" x 1" Sn-loaded NE 102 for K-x rays and 1.3 mm x 1" Naton for conversion electron lines. The half-life of the 434 keV state was measured to be ~0.30 nsec. An attempt was made to measure the $T_{1/2}$ of the 128 keV state which is depopulated by a 4.6 keV transition using a freshly cleaved NaI crystal. No half-life greater than the instrumental slope of 30 nsec was obtained.

Lu^{175} (343 keV state): Preliminary results indicate a $T_{1/2} \sim 0.28$ nsec.

Some developmental work was carried out in the general field, including the construction of a preacceleration device for low energy electrons. Studies were made of Tin-loaded NE 102 and it was found that the energy resolutions varied from 75% at 22 keV to ~23% at 279 keV. The ratio of photopeak height to compton distribution height varied from 0.4 at 122 keV to 0.06 at 279 keV. The results of timing measurements indicate that the response is not much worse than pure Naton 136 which means that these will be very useful phosphors, indeed.

C. Publications

The following paper which was in press at the time of our last report has been published.

"Half-Life Measurements and Transition Probabilities in ^{172}Yb," Belt, Kugel, Jaklevic, and Funk, Nucl. Phys. <u>A134</u>, 225 (1969). COO-498-74.

The following papers which had been submitted for publication at the time of our last report have been published.

"The Decay of ^{182}Re(13 h and 64 h) and ^{182}Ta(115 d) to ^{182}W," Sapyta, Funk, and Mihelich, Nucl. Phys. <u>A139</u>, 161 (1969). COO-498-75.

"The Decay of ^{158}Tb(150 y) to Levels in ^{158}Gd and ^{158}Dy," Paperiello, Funk, and Mihelich, Nucl. Phys. <u>A140</u>, 261 (1970). COO-498-76.

The following papers have been submitted for publication in Nuclear Physics.

"Half-Life and Angular Correlation Measurements in the Decay of ^{147}Eu," Belt, Kugel, Funk, and Mihelich. COO-498-80.

"Coincidence and Directional Measurements on the Decay of ^{170}Lu," Paperiello, Funk, and Mihelich. COO-498-81.

The following paper was presented at the American Physical Society meeting in Chicago, January 1970.

"Decay of ^{170}Lu," Paperiello, Funk, and Mihelich. COO-498-79.

The following manuscripts are in preparation.

"A Study of the 88 Neutron Nuclei ^{150}Sm and ^{152}Gd from the Decays of ^{150}Eu(6.2 y) and ^{152}Tb(18 h)," Zolnowski, Guttmann, Riedinger, Funk, and Mihelich.

"The Decay of ^{172}Lu Studied with Coincidence and Directional Correlation Techniques," Seremak, Riedinger, Funk, and Mihelich.

"The Decay of As^{71}," Van Hise, Rainis, and Ivey (a cooperative problem with the group then at Andrews University).

The following research problems which were underway at the time of the last report are nearing completion.

"The Decay of ^{153}Tb to ^{153}Gd," Zolnowski, Sousa, Funk, and Mihelich.

"The Decay of ^{173}Hf to ^{173}Lu," Belt, Madden, Funk, and Mihelich.

"The Decay of ^{154}Tb to ^{154}Gd," Sousa, Riedinger, Funk, and Mihelich.

"The Decay of ^{160}Ho and ^{160m}Ho to ^{160}Dy," Rainis, Riedinger, Funk, and Mihelich.

"The Decay of ^{162}Ho and ^{162m}Ho to ^{162}Dy," Rainis, Riedinger, Funk, and Mihelich.

"The Decay of ^{174}Lu and ^{174m}Lu," Seremak, Madden, Funk, and Mihelich.

"A Scheme to Reduce the Effects of Pileup in High Resolution Spectra," Schilling and Lubozynski.

Internal Reports

70-1 Notre Dame Nuclear Spectroscopy Spectrum Analysis and Manipulation Program OLBERG, by R. N. Oehlberg.

D. Personnel

During this contractual period, four students have completed their work and taken employment elsewhere. These are C. Paperiello (New York State Board of Health), W. Seremak (Illinois Valley College), R. Belt (Postdoctoral appointment at Wright Field), and A. Rainis (Tri-State College). Dr. Gerd Schilling, who completed his two-year appointment (supported by the NSF Science Development grant), has gone to the Institute for Plasma Physics in Munich, West Germany.

Dr. Lee Riedinger will be completing his first year of a two-year postdoctoral appointment supported by contract funds.

Permanent faculty members on the project continue to be J. W. Mihelich, Principal Investigator (40% of academic year salary derived from the project), and Associate Professor E. G. Funk.