Deexcitation Processes in Nuclear Reactions

Norbert T. Porile, Principal Investigator

Progress Report for the period May 1, 1974 to April 30, 1975

MASTER

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Purdue University
West Lafayette, Indiana

PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT
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Norbert T. Porile

**Purdue University
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ABSTRACT

The following studies of charge dispersion and recoil properties in the interaction of ^{197}Au and ^{238}U with 1-300 GeV protons are described: an investigation of the charge dispersion and recoil properties of $A=131$ nuclides formed in the interaction of ^{197}Au with 11.5 GeV protons; comparative measurements at 11.5 and 300 GeV of cross sections of products in the $A\approx 130$ mass region formed from both gold and uranium; differential ranges of ^{131}La , ^{131}Ba , and ^{140}Ba from the reaction of ^{238}U with 11.5 GeV protons; energy dependence of recoil properties and cross sections of various scandium, gallium, and $A=131$ nuclides produced in reactions of ^{238}U with 1-300 GeV protons. A study of the interaction of silver with 25 GeV ^{12}C ions is described. Results of a study of ^{24}Na production in reactions of intermediate-energy pions and protons are presented. Studies of isospin mixing in the decay of ^{64}Zn and ^{111}In compound nuclei are described. The relative importance of compound and precompound mechanisms in the (p,p') , (p,α) , (α,p) , and (α,α') reactions of even- A zinc isotopes is being examined by means of measurements of energy spectra and angular distributions of the emitted particles.

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I. Research Activities

This report summarizes the research performed during the past year on nuclear reactions. Included are investigations of the mechanisms of reactions of high-energy protons with heavy elements, a survey of the reactions of relativistic ^{12}C ions with silver, fragmentation reactions induced by intermediate-energy pions, isospin conservation in compound nuclear reactions, and compound and precompound mechanisms in low-energy reactions.

In recent years we have devoted considerable effort to charge dispersion and recoil studies of products in the $A \sim 130$ mass region formed in reactions of heavy elements with 1-300 GeV protons. Two such studies were completed this past year. The first involved a study of the charge dispersion and recoil properties at $A=131$ from the interaction of ^{197}Au with 11.5 GeV protons. The irradiations were performed at the Zero Gradient Synchrotron (ZGS). The combination of these two types of measurements has turned out to be a powerful tool in unraveling the mechanisms of high-energy reactions and thus allowed us to find a $\sim 0.2\%$ fission contribution to the isobaric cross section. Details of this work have been presented elsewhere¹⁾. We have also completed some comparative measurements of cross sections and recoil properties of products in the $A \sim 130$ mass region formed in reactions of uranium and gold with 300- and 11.5- GeV protons. The 300 GeV measurements were performed at the Fermi National Accelerator Laboratory (FNAL). Except for some rather small specific differences described in detail elsewhere²⁾ the results are independent of bombarding energy.

We are at present engaged in a number of additional high-energy proton studies. Measurements of the differential ranges of independently formed products with $A \sim 131$ emitted at 90° to the beam in the interaction of ^{238}U

with 11.5 GeV protons are in progress. This project was motivated by the results of our earlier thick-target recoil studies³⁾ which indicated that the range of ^{131}Ba was midway between those of ^{131}La and ^{131}I , which are formed by deep spallation and fission, respectively. This suggested that ^{131}Ba might be formed to a comparable extent by both processes. Such a supposition, which has never before been experimentally verified, can be checked by differential range measurements. The range of independent ^{131}Ba should thus consist of fission and deep spallation components. If the resolution of the experiment is sufficiently good and if the two curves turn out to be sufficiently narrow one might hope to observe a double-peaked differential curve. The experiment is a difficult one since it requires very thin and fragile targets to be inserted into the ZGS vacuum and flipped in and out of the beam for some 30 minutes without breaking. After irradiation the catcher foils must be rapidly dissolved to permit a La-Ba chain-breaking separation to be performed prior to significant decay of 61 min. ^{131}La . Finally, the irradiation must be intense enough to permit the assay of 11 day ^{131}Ba in each of the catcher foils.

We have recently performed a successful preliminary experiment which shows that the project is indeed feasible. In this experiment the target consisted of $300\text{ }\mu\text{g}/\text{cm}^2$ UF_4 evaporated onto $3\text{ mg}/\text{cm}^2$ Al and the catchers were Mylar foils with an areal thickness of $0.9\text{ mg}/\text{cm}^2$. All these foils are too thick for the ideal experiment and we have since successfully tested a $100\text{ }\mu\text{g}/\text{cm}^2$ target evaporated on both $160\text{ }\mu\text{g}/\text{cm}^2$ and $600\text{ }\mu\text{g}/\text{cm}^2$ Al. Our next experiments will be performed with $250\text{ }\mu\text{g}/\text{cm}^2$ thick Mylar catchers, which should provide adequate resolution for our purpose. The results of our first experiment are shown in Figure 1 and consist of differential range curves for ^{131}Ba (independent), ^{131}La , and ^{140}Ba . ^{131}La is a deep spallation product,

^{140}Ba is a fission product, and ^{131}Ba presumably includes contributions from both these processes. It is seen that the ^{131}Ba curve is much closer to the ^{131}La than to the ^{140}Ba curve and a decomposition indicates only a $\sim 15\%$ fission contribution. This result appears to be at variance with that of the thick-target range study and may be indicative of substantial differences in the angular distribution of deep spallation and fission products. This possibility will be explored in future experiments.

A study of the energy dependence of the cross sections and recoil properties of independently formed ^{131}Ba and ^{131}La as well as cumulatively formed ^{131}Ce in reactions of ^{238}U with 1-300 GeV protons is in progress. This study is motivated by a previous experiment⁴⁾ in which we found that the ranges of cumulatively formed ^{131}Ba decreased by over a factor-of-two between 2 and 4 GeV while the forward-to-backward (F/B) ratio went through a concomitant peak. These results were construed as evidence for a transition from a fission mechanism to deep spallation. Since our earlier measurements were performed on cumulatively formed products they represent the average behavior of several isobaric nuclides. In the present work we are obtaining similar results on independently formed products in order to determine how this as yet poorly understood transition depends on the composition of isobaric nuclides.

A similar investigation of cross sections and recoil properties of scandium and gallium nuclides formed in the interaction of ^{238}U with 1-300 GeV protons is also in progress. The purpose of this study is to determine whether the transition between fission and deep spallation, which was previously also found for ^{83}Sr ⁴⁾, occurs for lighter nuclides as well or whether a single mechanism can account for the formation of these products at all energies. Recent results on ^{24}Na and ^{28}Mg ⁵⁾ show the presence of a peak in F/B but no sharp dropoff in ranges.

In conjunction with this study we have explored the suitability of γ - γ coincidence spectrometry in the assay of irradiated foils. In this exploratory study we concentrated on the detection of nuclides having $A \leq 130$ and were able to determine cross sections and recoil properties of some 12 nuclides. The technique promises to be a useful adjunct to singles γ -ray spectrometry in the assay of targets irradiated by high-energy protons.

The availability of relativistic heavy ions at the Bevalac has opened up a new field of study. We have begun a series of experiments on the interaction of silver with 25 GeV ^{12}C ions. The experiments involve the assay of irradiated targets by gross Ge(Li) γ -ray spectrometry followed by computer analysis of the spectra and are designed to yield information on the charge dispersion and mass yield curves. The results will be compared with those obtained in reactions induced by high-energy protons. Silver is a particularly good choice of target in this respect because we have recently completed an investigation of the reactions of this element with 11.5- and 300- GeV protons^{6,7)} using essentially the same techniques.

The analysis of the data from our first irradiation has been completed and we have obtained some 30 relative cross sections. These will be put on an absolute basis as soon as a suitable monitor reaction cross section has been measured at the Bevalac. Comparison of the relative cross sections with those measured in high-energy proton reactions shows some significant differences, particularly for products that are either very close or very far from the target. We are reluctant to go into details at this time because the ^{12}C experiment required a rather thick target (0.01 inch) due to the low beam intensity. This is an order of magnitude thicker than the targets used in our high-energy proton experiments and so the observed differences could be due to secondary effects. We are presently checking this possibility by assay of

a 0.01 inch thick silver target irradiated by 300 GeV protons at FNAL.

A study of fragmentation of heavy elements by pions is in progress at the Los Alamos Meson Physics Facility (LAMPF). This research involves a measurement of the cross section for the formation of ^{24}Na in reactions of heavy elements with pions and a comparison with similar data obtained for incident protons. If fragmentation occurs as a result of pion absorption in a local region of the struck nucleus the production cross section should be higher for pions of a given energy. On the other hand, if this process results from the correlated motion of cascade nucleons, the cross section should be higher for protons. A relatively straightforward choice between mechanisms is thus afforded.

In the course of the past year we have measured the excitation function for the formation of ^{24}Na in the reaction of gold with 200-800 MeV protons. The results are shown in Figure 2. The excitation function is fairly steep, particularly at low energies. This should permit a rather sensitive comparison with the pion experiments and a straightforward determination of whether pions or protons of a given energy have a higher probability of forming products such as ^{24}Na .

In the course of the past year we completed the measurements of energy spectra of charged particles emitted in low-energy reactions at the Purdue tandem Van de Graaff. Much of this work deals with the consequences of isospin conservation in compound nuclear reactions and the determination of isospin mixing between the $T^>$ and $T^<$ states of the compound nucleus. In the course of the year we completed and published an article⁸⁾ on isospin mixing in the decay of ^{49}V , ^{52}Cr , and ^{55}Mn . In collaboration with S. M. Grimes we developed a reformulation of isospin mixing in compound nuclear reactions in which "upward" mixing of the $T^<$ into the $T^>$ states is included and the mixing

matrix element extracted from the data. An article based on this research is due to be published shortly⁹⁾.

In addition to these completed studies there are several other projects that are in various stages of data reduction or interpretation. The determination of the isospin mixing parameter and mixing matrix element in the decay of ^{111}In is in progress. This experiment involves measurements of the differential cross sections for the $^{107}\text{Ag}(\alpha, p)$, $^{107}\text{Ag}(\alpha, \alpha')$, $^{110}\text{Cd}(p, p')$, and $^{110}\text{Cd}(p, \alpha)$ reactions. The resulting spectra are integrated over energy and angle to yield evaporation cross sections. The quantities of interest are obtained from the data by means of an analysis described elsewhere⁹⁾. The ^{111}In compound nucleus lies in a heavier mass region than the other compound nuclei for which the mixing matrix elements have been determined⁸⁻¹¹⁾. These previous studies have shown that the matrix element depends on both the proton evaporation width and the mass number of the compound nucleus. Since these two quantities are related, i.e. the proton decay width decreases with increasing A , it is difficult to determine from the rather narrow mass region covered in the previous work which of these variables has the primary effect on the matrix element. The ^{111}In data will provide results that will extend the previously studied mass interval from about 20 to 60 amu and thereby permit an unraveling of these two effects. Since very little is known about the factors that determine the magnitude of the mixing matrix elements at high (~ 20 MeV) energies such information is of importance.

A study of the energy dependence of isospin mixing in the decay of ^{64}Zn excited to 17.6-23.5 MeV is nearing completion. This study is similar to our previous work on ^{69}Ga ¹¹⁾ in which the first measurements of the energy dependence of isospin mixing were reported. In this earlier work we found that the isospin mixing parameter increases with energy whereas general considerations

appeared to indicate that the opposite behavior would be more reasonable. The research on ^{64}Zn was undertaken to provide further evidence on the energy dependence of isospin mixing. In more recent work^{9,12)} it has been shown that the behavior of the mixing matrix element influences that of the mixing parameter making the determination of the former important.

The results of this study are summarized in Figure 3, where the energy dependence of the mixing parameter, μ , and the mixing matrix element, $|H_c|$, are shown and compared with the corresponding values for ^{69}Ga . It is seen that the μ values vary in the opposite way with energy while the matrix elements display essentially the same energy dependence. The difference in the behavior of the μ values reflects the relative behavior of the mixing and decay widths and depends in a rather complex way on the factors that determine the magnitudes of these widths. The mixing matrix element is a more fundamental quantity and it is interesting to note that it varies inversely with energy for both nuclides. This decrease in $|H_c|$ is consistent with the corresponding values obtained at much lower energies from beta decay studies¹³⁾ in that the latter are an order-of-magnitude larger than the present values.

A systematic study of proton and α -particle emission in the reactions of ^{64}Zn , ^{66}Zn , ^{68}Zn , and ^{70}Zn with 12.5 MeV protons and 18 MeV α -particles is in progress. The purpose of this study is to determine the effect of neutron number on the magnitude of the cross sections and on the relative importance of compound and precompound emission. Figure 4 shows the energy spectra of protons (integrated over all angles) emitted in (α, p) reactions. The differential cross sections are seen to decrease with increasing neutron number. In addition, the curves for the heavier Zn isotopes are distinctly broader; the position of the maximum in the ^{70}Zn spectrum is, in fact, shifted to higher energies. This result appears to be a consequence of increasing contribu-

tion of precompound emission. We have evaluated the magnitude of this contribution in two different ways: first, from the forward-backward asymmetry in the angular distribution and second, by means of a hybrid model calculation of the precompound cross section¹⁴⁾. The results are summarized in Figure 5 which shows that the precompound emission contribution to the (p,p') and (α,p) reactions increases with target A. The agreement between these two completely different ways of estimating the precompound contribution is remarkably good considering that there has been no parameter adjustment in the calculation.

The research performed this past year closely followed the outline submitted in the last renewal proposal and further effort will be devoted to these projects during the remainder of the present contract year. The principal investigator has devoted approximately 50% of his time and effort to this project during the present contract year. It is expected that this figure will be maintained at the same level for the remainder of the year.

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Figure 1

Differential ranges in Mylar of nuclides emitted at 90° to the beam in the interaction of ^{238}U with 11.5 GeV protons.

Figure 2

Excitation function for the production of ^{24}Na from gold by 200-800 MeV protons.

Figure 3

Energy dependence of isospin mixing parameter (top panel) and mixing matrix element (bottom) in the decay of ^{64}Zn (closed points) and ^{69}Ga (open points). The lines show the trend of the data. The $|H_c|$ for ^{69}Ga have been multiplied by a factor of 5.

Figure 4

Energy spectra of protons emitted in (α, p) reactions of ^{64}Zn (-----), ^{66}Zn (.....), ^{68}Zn (----), and ^{70}Zn (——). The bombarding energy is 18 MeV.

Figure 5

Percent precompound emission in (p,p') and (α,p) reactions of even Zn isotopes. $\bullet$ - experimental values for (p,p') reaction; $\circ$ - experimental values for (α,p) . Solid curve - calculated values for (p,p') ; dashed curve - calculated values for (α,p) .

II. Publication Abstracts

Abstracts are given for articles published or submitted to journals during the period covered by this report.

Nuclear Reactions of ^{118}Sn , ^{121}Sb , and ^{127}I with Argon Ions. H. Gauvin, Y. Le Beyec, and N. T. Porile, Nucl. Phys. A223, 103 (1974).

Excitation functions have been measured for a number of ($^{40}\text{Ar}, \text{xn}$), ($^{40}\text{Ar}, \text{pxn}$), ($^{40}\text{Ar}, 2\text{pxn}$), and ($^{40}\text{Ar}, 3\text{pxn}$) reactions induced in ^{118}Sn , ^{121}Sb and ^{127}I over the laboratory energy interval 150-280 MeV. Values of the total fusion cross section are obtained and J_{crit} is deduced. J_{crit} increases with energy and becomes as large as 110-140 $\hbar$, in reasonable agreement with the yrast limit deduced from the ellipsoidal liquid drop model. The competition between proton and neutron emission from the compound nucleus is examined and Γ_p/Γ_n is found to increase rapidly with the number of emitted nucleons, thereby imposing severe limits on the production of very neutron deficient nuclides via compound nuclear reactions. The effect of very high angular momentum on the excitation functions is examined.

Energy Dependence of Isospin Mixing in Compound-Statistical Reactions.

N. T. Porile, J. C. Pacer, J. Wiley, and C. R. Lux, Phys. Rev. C 9, 2171 (1974). The ^{69}Ga compound nucleus was formed at excitation energies ranging from 17 to 22 MeV in the reactions $^{65}\text{Cu}+\alpha$ and $^{68}\text{Zn}+p$ and energy spectra of the emitted protons and α -particles were measured between 30° and 150°. The extent of isospin mixing between the T_+ and T_- states of the compound nucleus was determined by comparison of the quantity $\sigma(p, p')\sigma(\alpha, \alpha')/\sigma(p, \alpha)\sigma(\alpha, p)$ with theory and the fractional mixing was found to increase from 0 to 0.3 over the above

energy range. The mixing width shows a corresponding increase from 0.2 to 16 keV. The independence hypothesis was verified at all energies by measurements of the α and np exit channels. The various spectra were compared with the spin-dependent statistical theory. It was not possible to fit the data for various energies with energy-independent parameters in the Fermi gas model level density expression suggesting that this expression is inadequate.

Interaction of ^{238}U with 300- and 11.5-GeV Protons: Cross Sections and Recoil Properties in the $A \sim 130$ Mass Region. Y. W. Yu and N. T. Porile, Phys. Rev. C 10, 167 (1974).

Formation cross-sections and thick-target recoil properties of 13 products in the $A \sim 130$ mass region from the interaction of ^{238}U with 300 and 11.5 GeV protons have been determined. The values of $\sigma_{300}/\sigma_{11.5}$ are consistent with unity for $A > 130$ and decrease with decreasing A below this mass number, a trend that is most notably exhibited by neutron deficient iodine nuclides. The recoil ranges and F/B values are essentially the same at both energies.

Level Densities of ^{63}Cu and ^{65}Cu from the Analysis of Evaporation Spectra. J. C. Pacer, J. Wiley, C. R. Lux, and N. T. Porile, Nucl. Phys. A226, 413 (1974). The levels of ^{63}Cu and ^{65}Cu were populated in (p,p'), (p, α), (α ,p) and (α , α') reactions induced by 12.5-16.0 MeV protons and 16.8-21.3 MeV α -particles. Energy spectra were measured between 30° and 150° and the evaporation spectra were compared with the spin-and isospin-dependent statistical theory. The comparison permitted the determination of the level density parameter, a , and the pairing energy parameter, δ , in the Fermi gas model level density expression. It was found that while a given set of parameters could give a good fit to

the spectra obtained at a given energy, the energy dependence of some of the differential cross sections was not very well reproduced. The implications of this disagreement for the validity of the Fermi gas model level density are discussed.

Nuclear Reactions of Silver with 11.5 GeV Protons. G. English, N. T. Porile, and E. P. Steinberg, Phys. Rev. C 10, 2268 (1974).

The interaction of silver with 11.5-GeV protons was studied and formation cross sections of 72 radionuclides were determined by direct assay of the target with a Ge(Li) γ -ray spectrometer followed by computer analysis of the spectra. The data were used to construct charge-dispersion and mass-yield curves. Comparison with previous radiochemical studies performed with 29-GeV protons indicates good agreement between the two techniques. The data are compared with Rudstam systematics. This formulation predicts a much steeper decrease in isobaric cross sections with decreasing A than is observed experimentally.

Nuclear Reactions of Silver with 300 GeV Protons. G. English, Y. W. Yu, and N. T. Porile, Phys. Rev. C 10, 2281 (1974).

The interaction of silver with 300-GeV protons was studied and compared with that of 11.5-GeV protons. Cross section ratios, $\sigma_{300}/\sigma_{11.5}$, were determined for 74 nuclides ranging from ^7Be to $^{106}\text{Ag}^m$. The weighted average value of $\sigma_{300}/\sigma_{11.5}$ is 1.01 ± 0.10 . A detailed examination of the dependence of the ratios on product A and N/Z reveals that the only difference occurs in the A $\sim$ 20-30 mass region, where a $17 \pm 5\%$ increase in cross sections is observed at 300 GeV.

Isospin Conservation and the Independence Hypothesis in the Decay of ^{49}V , ^{52}Cr , and ^{55}Mn . N. T. Porile, C. R. Lux, J. C. Pacer, and J. Wiley, Nucl. Phys. A240, 77 (1975).

Energy spectra and angular distributions of protons and α -particles emitted in the decay of ^{49}V , ^{52}Cr and ^{55}Mn produced by 14 MeV protons and 12-16 MeV α -particles were measured between 30° and 150° . The evaporation cross sections of the (p,p') , (p,α) , (α,p) and (α,α') reactions were used to deduce the isospin mixing fractions, μ , between the $T^>$ and $T^<$ states of these compound nuclei and values of 0.2 - 0.3 were obtained. The ratio of upward to downward mixing was calculated to be ≈ 0.02 . Values of the Coulomb matrix elements were deduced and found to range from ≈ 30 to 120 eV. Measurements on the α and $\tilde{p}$ exit channels allowed for a test of the independence hypothesis and the latter was verified for ^{49}V and ^{55}Mn .

Inclusion of Upward Mixing in the Determination of Isospin Mixing in Highly Excited Nuclei. N. T. Porile and S. M. Grimes, Phys. Rev. C (in press).

The formalism for the analysis of isospin mixing in the decay of compound nuclei has been reformulated to include "upward" mixing of the $T^<$ into the $T^>$ states as well as the usual "downward" mixing of $T^>$ into $T^<$. The ratio of isospin mixing parameters for these two processes, $\mu^\uparrow/\mu$, is evaluated for compound nuclei in the $A \sim 50-70$ region and is ~ 0.03 . The mixing matrix element has an average value of $\sim 70 \pm 40$ eV in this mass region.

Charge Dispersion and Recoil Properties at $A=131$ from the Interaction of ^{197}Au with 11.5- and 300-GeV Protons. Y. W. Yu and N. T. Porile, submitted to Phys. Rev. C.

Cross sections and thick-target recoil properties of five nuclides with $A=131$ as well as those of a number of neighboring nuclides have been deter-

mined for the interaction of ^{197}Au with 11.5 GeV protons. The charge dispersion at $A=131$ has a single peak at $Z_A - Z = -3.5$ and the total isobaric cross section is 8.9 ± 0.8 mb. The ranges indicate that only $\sim 0.2\%$ of this value can be ascribed to fission, the bulk of the cross section involving a deep spallation process. Similar data have been obtained at 300 GeV. Within the limits of error the results are the same at both energies. The systematics of deep spallation reactions are examined.

Nuclear Reactions of ^{238}U with 300- and 11.5-GeV Protons: Formation of Nuclides in the $A=110-140$ Mass Region. Y. W. Yu, S. Biswas, and N. T. Porile, submitted to Phys. Rev. C.

Cross sections for the formation of a number of iodine, tellurium, and cadmium nuclides in the interaction of ^{238}U with 300- and 11.5-GeV protons have been determined. Including previously obtained results on cesium and barium nuclides we obtain a weighted average value of 0.92 ± 0.14 for $\sigma_{300}/\sigma_{11.5}$ based on 34 values for nuclides in the $A=110-140$ region. The cross section ratios show little dependence on $Z_A - Z$.

III. Personnel

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Dr. Y. W. Yu^{*}, Research Associate

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^{*} Terminated in the course of the contract year.

IV. Publications, Theses, and Talks

Nuclear Reactions of ^{118}Sn , ^{121}Sb , and ^{127}I with Argon Ions. H. Gauvin, Y. Le Beyec, and N. T. Porile, Nucl. Phys. A223, 103 (1974).

Energy Dependence of Isospin Mixing in Compound-Statistical Reactions. N. T. Porile, J. C. Pacer, J. Wiley, and C. R. Lux, Phys. Rev. C 9, 2171 (1974).

Interaction of ^{238}U with 300- and 11.5-GeV Protons: Cross Sections and Recoil Properties in the $A \sim 130$ Mass Region. Y. W. Yu and N. T. Porile, Phys. Rev. C 10, 167 (1974).

Level Densities of ^{63}Cu and ^{65}Cu from the Analysis of Evaporation Spectra. J. C. Pacer, J. Wiley, C. R. Lux, and N. T. Porile, Nucl. Phys. A226, 413 (1974).

Nuclear Reactions of Silver with 11.5 GeV Protons. G. English, N. T. Porile, and E. P. Steinberg, Phys. Rev. C 10, 2268 (1974).

Nuclear Reactions of Silver with 300 GeV Protons. G. English, Y. W. Yu, and N. T. Porile, Phys. Rev. C 10, 2281 (1974).

Isospin Conservation and the Independence Hypothesis in the Decay of ^{49}V , ^{52}Cr , and ^{55}Mn . N. T. Porile, C. R. Lux, J. C. Pacer, and J. Wiley, Nucl. Phys. A240, 77 (1975).

Inclusion of Upward Mixing in the Determination of Isospin Mixing in Highly Excited Nuclei. N. T. Porile and S. M. Grimes, Phys. Rev. C (in press).

Charge Dispersion and Recoil Properties at $A=131$ from the Interaction of ^{197}Au with 11.5- and 300-GeV Protons. Y. W. Yu and N. T. Porile, submitted to Phys. Rev. C.

Nuclear Reactions of ^{238}U with 300- and 11.5-GeV Protons: Formation of Nuclides in the A=110-140 Mass Region. Y. W. Yu, S. Biswas, and N. T. Porile, submitted to Phys. Rev. C.

Tests of the Spin-Dependent Statistical Model for Compound Nuclear Reactions. John C. Pacer, Ph.D. thesis, Purdue University, August 1974.

Nuclear Reactions of Silver with 11.5- and 300-GeV Protons. Gerald A. English, Ph.D. thesis, Purdue University, December 1974.

"Interaction of ^{238}U with 300- and 11.5-GeV Protons," given by N. T. Porile at the American Chemical Society meeting, Atlantic City, September 1974.

"Nuclear Chemistry at the New Accelerators," given by N. T. Porile at the Physical Chemistry seminar, Purdue University, November 1974.

"Isospin Mixing in Compound Nuclear Reactions," given by N. T. Porile at the Nuclear Chemistry seminar, Argonne National Laboratory, December 1974. Also presented at the Nuclear and Intermediate Energy Physics seminar, Purdue University, January 1975.

"High-Energy Nuclear Reactions," given by N. T. Porile at the Chemistry Honors seminar Purdue University, March 1975.

"Low-Energy Nuclear Reactions of Zn Isotopes," given by C. R. Lux at the Nuclear Chemistry seminar, Purdue University, April 1975.

"Compound and Precompound Emission in the Reactions of Zn Isotopes with 12.5 MeV Protons and 18 MeV ^4He Ions," given by N. T. Porile at the American Physical Society meeting, Washington, D. C., April 1975.