CONF-800870--1

MASTER

THE HELIUM-JET COUPLED MASS SEPARATOR - ADVANCES AND DIRECTIONS

D. M. Moltz

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830 U.S.A.

ABSTRACT

Results from the RAMA-88 system at the Lawrence Berkeley Laboratory are being used to design a new helium-jet and ion source system for the UNISOR project. This system should complement the existing integrated target-ion source to extend UNISOR's capabilities to include a majority of the chemical elements. This fast transport helium-jet system should permit studies of nuclides with half-lives down to 50 ms.

1. Introduction

The helium-jet technique has been used extensively in the study of nuclei far from beta stability. Such studies have also been aided by many isotope separator on-line (ISOL) systems. The coupling of these two techniques as originally proposed by Nitschke[1]) was manifested with the successful advent of the RAMA-88 system at the Lawrence Berkeley Laboratory.[2]) Other helium-jet systems have been coupled to ISOL systems utilizing reactors[3,4]) and off-line sources[5]) to study fission products. RAMA, however, represents the only operating accelerator-based system. The Chalk River helium-jet system[6]) has been designed to operate with their tandem-based ISOL system, but at this time has not been coupled and is currently operating with an integrated target-ion source.[7,8]) The UNISOR[9]) system presently is also an integrated target-ion source system[10,11]) on-line with the Oak Ridge Isochronous Cyclotron (ORIC) and the soon-to-be completed Holifield Heavy Ion Research Facility (HHIRF) at Oak Ridge. An advanced-design helium-jet system is presently being constructed to add this versatile option for performing on-line experiments at UNISOR.

2. Coupled Helium-Jet Techniques

The helium-jet technique is endowed with several properties which make it extremely attractive as a method for studying nuclei far from stability. It enables fast transport of produced radioactivities away from the intense radiation associated with the bombardment region. This transport is reasonably universal for all nongaseous elements produced in many differing target-projectile combinations. Clusters containing the stopped recoil product nuclei exiting from the helium-jet possess thermal energies (eV) rather than the large nuclear recoil energies (MeV). All of these properties are desirable, but the general universality in fact stresses the need for mass separation. Coupling of the helium-jet to an ISOL system adds several more criteria for stable and reproducible operation. These have been investigated thoroughly2,12) and have led to the existing RAMA system.13) All of these considerations have led to the design of a coupled system for UNISOR.

The most important conceptual change from the RAMA system is the use of a small chamber contained within a larger vacuum chamber depicted schematically in fig. 1. This design will permit the selective cooling of both the chamber (and thus the internal gas) and the nitrogen-cooled foil windows needed for increased beam intensity. The importance and design of a multiple-target multiple-capillary system has been discussed previously12) and has been included along with easy external target-change capabilities. The four-target system shown will be used for light-ion induced reactions, while another two-target system has been constructed for heavy-ion induced reactions. The gas mixture of helium plus additives (generally ethylene glycol) will be precooled before introduction into the temperature controlled chamber. Other major differences from the RAMA system are the operation of the system at the extraction potential (~ 55 kV) and the shorter capillary tube (~ 1.5 m compared with 6 m). Similar gas flow rates should permit approximately a factor of four decrease in transport time. This time decrease is very important, since the relatively slow acceleration to sonic velocity of the clusters formed in the helium2) creates an absolute transport time constant which must necessarily reduce the observed reaction yield by an amount which may be calculated by the standard exponential decay formula.

To further illustrate this transport time importance, let us consider the cases of the long-lived nuclide ^{20}Na ($t_{1/2}$ = 446 ms) and the short-lived nuclide ^{20}Mg ($t_{1/2}$ ~ 95^{+80}_{-50} ms).14) If we assume a transport time of ~ 200 ms12) for the RAMA system and ~ 50 ms for an equivalent configuration in the UNISOR system, then the observed yield for ^{20}Na in this new system is only 1.3 times greater. This ratio increases to 3.0 for the 95 ms ^{20}Mg. If we further consider the lower error bar limit for a 45-ms half-life, then this ratio increases to 10.0. Table 1 summarizes these considerations.

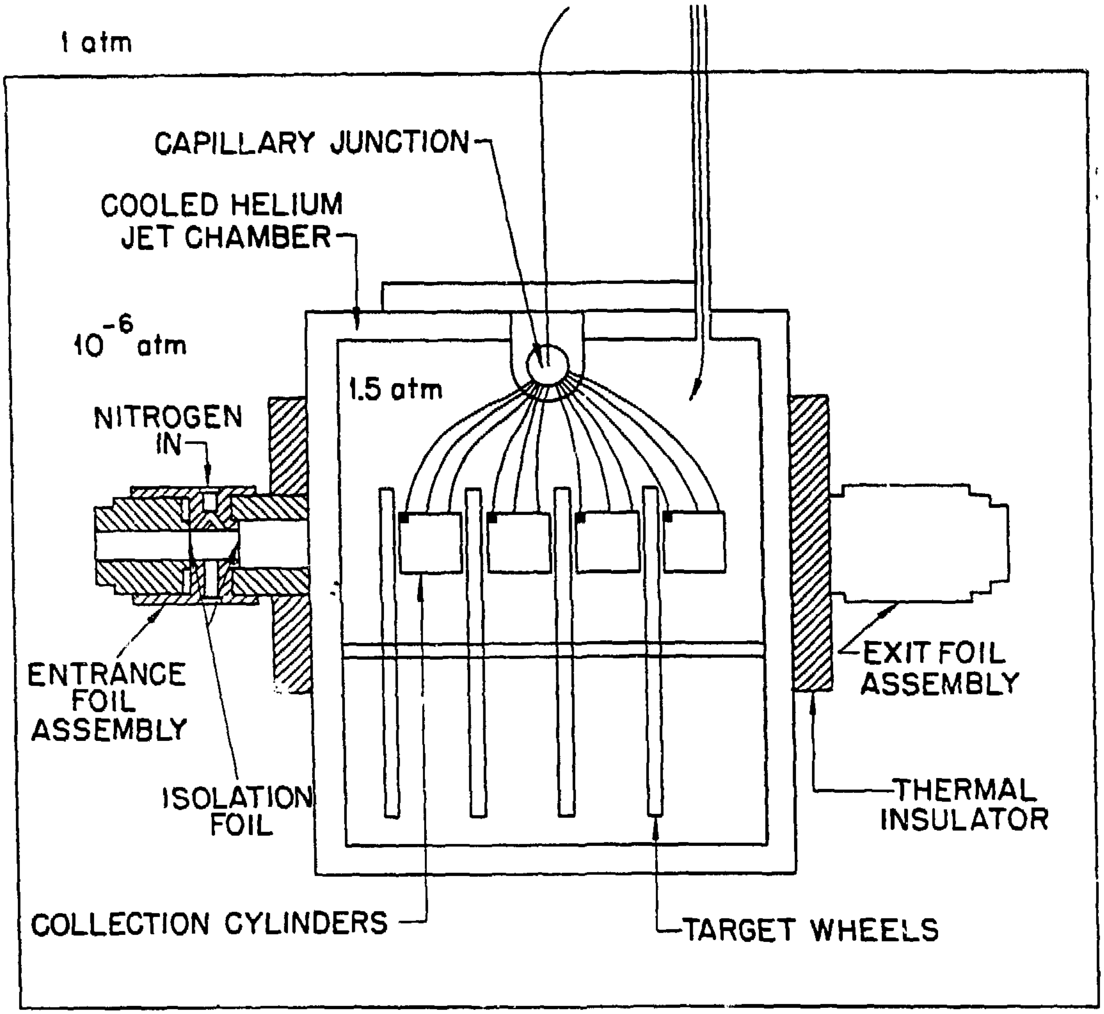

Fig. 1. Schematic diagram of the helium-jet box and chamber which will be coupled to the UNISOR system.

Table 1
Theoretical Maximum Yields for Various Activities and Multiple Capillary Systems.

	Transport Time		
	200 ms	50 ms	Ratio $\equiv \frac{\%_{200}}{\%_{50}}$
Half-Life	Theoretical Yield (%)		
446 (^{20}Na)	73.	93.	1.3
95^{+80}_{-50} (^{20}Mg)	23.	69.	3.0
175 (95 + 80)	45.	82.	1.8
45 (95-40)	4.6	46.	10.

3. Ion Source Coupling

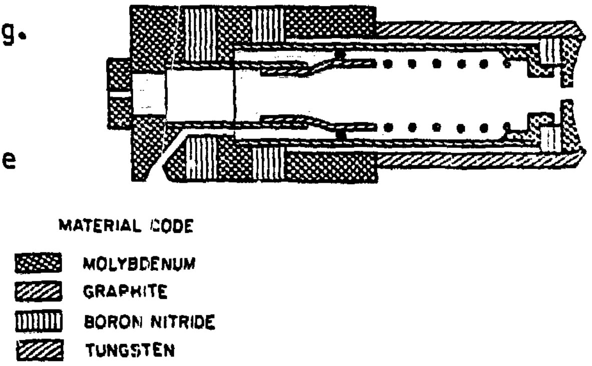

Fig. 2. Schematic diagram of the hollow-cathode anode-extraction ion source to be used in coupling the helium-jet to UNISOR.

Coupling of the helium-jet to an ISOL system has long presented the greatest problem. Even though ion sources have not always been used (see ref. 15), they are still the most prevalent form of coupling. The need for a fast and chemically universal ion souce led to hollow-cathode ion sources for the RAMA system.2,12,13) The hollow-cathode anode-extraction source has been found to be very reliable and reproducible, and thus the very simple version shown in fig. 2 is being constructed. The general purpose holder for this ion source and the skimmer region is shown schematically in fig. 3. The shorter capillary-plasma distance (~ 7 cm) permitted by maintaining the skimmer-capillary potential at 55 kV, and the higher plasma density should permit a factor of 5-10 increase in yield. Even though this source works well,12) development of improved sources is clearly of interest. Since the coupling efficiency is hidden away in the ion

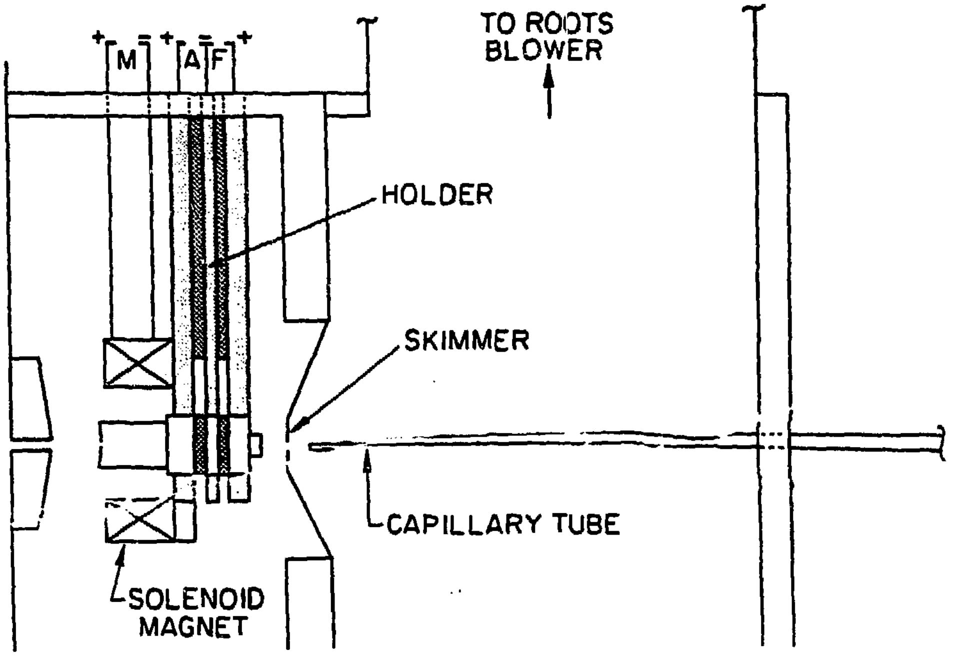

Fig. 3. Schematic diagram of the new ion source and skimmer region.

source efficiency, it is often difficult to decouple it from the efficiency of particles extracted as a percentage of those introduced into the plasma. Efforts are thus needed on both fronts. A newer, higher temperature hollow-cathode cathode-extraction ion source is being designed, in addition to a very simple thermal source consisting of only a heated tube. Both designs are being coordinated with results from the RAMA system.13,16) Attempts will also be made to increase the plasma density and the ion source output (particularly He^+ which will indicate a higher throughput). This latter test will be somewhat initially constrained by unknown beam current limitations of the UNISOR separator.

4. Experimental Assets, Liabilities, and Comparisons

The UNISOR system has been reliably operating for the past eight years in an integrated target-ion source mode10,11) and has produced much excellent work on spectroscopic decay studies of nuclei far from stability. These studies have concentrated on longer-lived (> 1 s) lower-melting-point (< 1000° C) elements. A new DC heated thermal-ionization source is currently being tested17) which will hopefully permit higher-melting-point elements (e.g., the rare earths) to be extracted in good yeild (> 1%). Although the normal operating ion sources have inherently higher efficiencies (> x 10) than the hollow-cathode sources initially proposed for the helium-jet coupled mode, there exist two major obstacles which this helium-jet will help overcome. These are ion source retention time and target limitations.

The normal integrated system stops nuclear reaction recoil products in a graphite felt catcher foil. These nuclei diffuse from this foil into the plasma region for extraction. Although the extraction efficiency for ions in the plasma is high, the diffusion times out of the catcher foil can be quite long (> a few seconds, depending upon the temperature and element). One is continually faced with decreasing half-lives and production cross sections as one proceeds further from stability. The successful observation of alpha-particle decay of ^{184}Tl and ^{185}Tl18) produced in ^{180}W(^{14}N,xn) reactions with UNISOR demonstrated a high extracted yield for thallium. Systematics suggest a high alpha-particle decay branch for the more neutron-deficient nuclides ^{183}Tl and ^{182}Tl. Attempts19) to observe them with UNISOR were unsuccessful. Lower production cross sections were expected, but alpha-particles from ^{182}Hg (11 s) and ^{183}Hg (9 s) were observed,19) indicating that the thallium isotopes had half-lives which were too short vis-a-vis the ion source holdup time. Recent results20) have indeed identified ^{183}Tl to have a half-life of 60 ms. The new helium-jet coupled system shown schematically in fig. 4 with its short, ~ 1.5 m, capillary tube should involve total transit times of 40-75 ms when coupled with a hollow-cathode ion source and thus open a whole new regime of half-lives for study at UNISOR. It should be noted that the RAMA system has been used successfully to observe several members of the A = 4n, T_z = -2 series of beta-delayed proton emitters,14,21,22) all with half-lives ~ 100 ms.

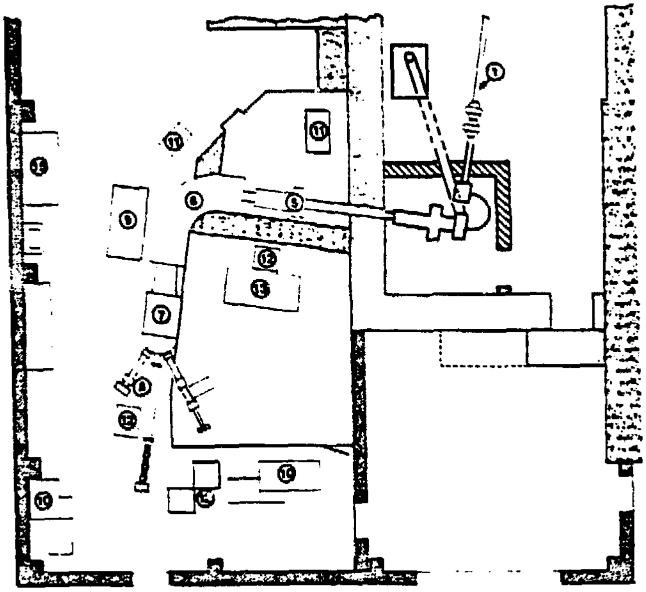

Fig. 4. Revised overall UNISOR schematic diagram depicting the helium-jet coupled mode.

Targets for the integrated UNISOR ion source system must have melting points > 1000°C because of their close proximity to the hot filament. Many proposed investigations have been hampered because of target limitations with available ORIC beams. The new HHIRF tandem should alleviate part of this problem with many new heavy-ion beams.[23]) As one proceeds to study even more neutron-deficient nuclei, however, lower production cross sections may require particular target-projectile combinations. The helium-jet, when coupled with a mass separator, has no elemental target limitations. Some compound of the lower-melting-point elements may always be found which can be attached to some backing foil. For instance, rare-earth oxides and nitrates on copper backing foils have proven to be excellent targets.[2]) Because of the general cooling effect of the surrounding helium, higher beam currents may be used with more targets to produce more nuclei per unit time, thereby negating some of the overall efficiency advantage of the integrated system. It should be noted that rare-gas targets are possible if the carrier gas is also utilized as the target (e.g., ^{20}Ne in ref. 14).

5. Summary and Directions

The ultimate test and the initial motivation for constructing such an experimental apparatus is the nuclear physics measurements performed. Because of the large number of UNISOR participants, the experimental interests are quite diverse, requiring very versatile techniques. These interests cover the entire mass spectrum and include various mass measurements and spectroscopic studies. The large interest level in the latter category led to a trial experiment with the RAMA system to show the viability of performing γ-γ coincidence measurements on a heretofore inaccessible (to UNISOR) nucleus. The singles and coincidence spectra obtained in one of the detectors during a 3-hour bombardment period at the mass 148 position are shown in fig. 5. Gamma rays from both ^{148}Dy (ref. 24) and ^{148}Tb (ref. 25) were clearly detected. The reaction studied was ^{142}Nd(^{12}C,xn-yp) at 108 MeV with a production cross section of ~ 100 mb (from systematics) for ^{148}Dy.

The new helium-jet system should prove to be very complementary to the existing integrated target-ion source system. Although the existing system will be used whenever possible because of its higher total efficiencies, many experiments will require the helium-jet system because of unique target limitations or very short half-lives. Along with the Chalk River on-line mass separator,[8]) UNISOR will be the first to have both operating capabilities, making it a very versatile tool for studying nuclei far from beta stability.

I wish to thank K. S. Toth for general support and editing of this manuscript and J. Wouters, M. Cable, R. Parry, J. Äystö and J. Cerny for information and use of the RAMA system. I further wish to express my gratitude to E. Spejewski, R. Mlekodaj and H. K. Carter for support from the UNISOR project. Special thanks go to UNISOR members E. Zganjar, F. Avignone and C. Bingham, in addition to many others within the Physics Division of Oak Ridge National Laboratory for support of the helium-jet system. This research was funded by the Department of Energy under Contract No. W-7405-eng-26 with Union Carbide Corporation.

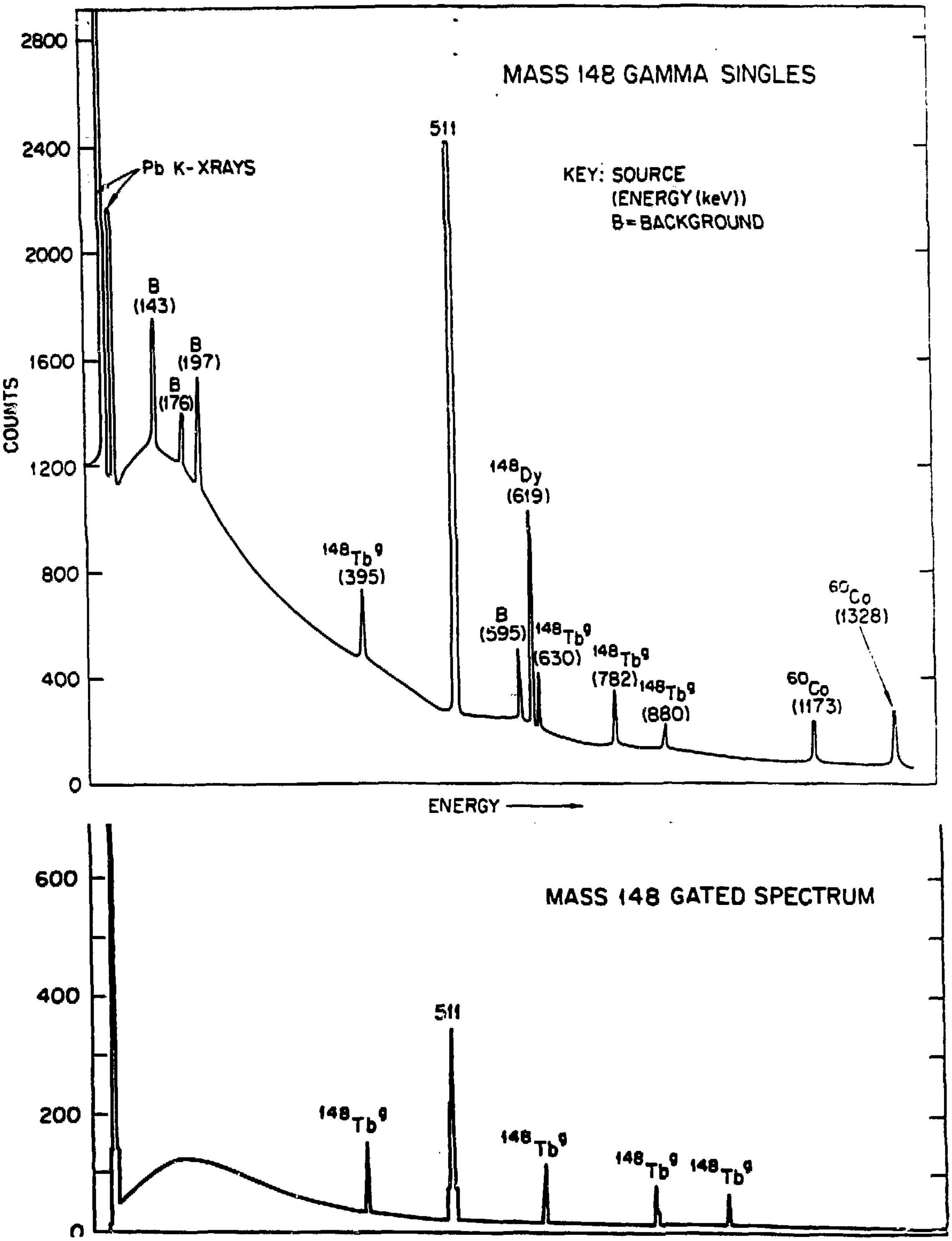

Fig. 3. Mass 148 gamma spectra resultant from the ^{142}Nd(^{12}C,xn-γp) reaction at 108 MeV detected by a single Ge(Li) counter: a) singles; b) total coincidence spectrum with a second counter. Gamma rays associated with the decay of ^{148}Dy and ^{148}Tb (refs. 24 and 25, respectively) are clearly observed.

References

1) J.M. Nitschke, in Proceedings of the International Conference on the Properties of Nuclei Far from the Region of Beta-Stability, Leysin, Switzerland, 1970 (CERN, Geneva, 1970) Vol. 1, p. 153.
2) D.M. Moltz, R.A. Gough, M.S. Zisman, D.J. Vieira, H.C. Evans and J. Cerny, Nucl. Instrum. Meth. 172 (1980) 507.
3) J.P. Zirnheld, L. Schutz and F.K. Wohn, Nucl. Instrum. Meth. 158 (1979) 409.
4) A.K. Mazumdar, H. Wagner, W. Walcher, M. Brügger and N. Troutmann, contribution to this conference, No. B12.
5) R.A. Anderl, V.J. Novick and R.C. Greenwood, contribution to this conference, No. B16.
6) H. Schmeing, V. Koslowsky, M. Wightman. J.C. Hardy, J.A. Macdonald, T. Faestermann, H.R. Andrews, J.S. Geiger and R.L. Graham, Nucl. Instrum. Meth. 139 (1976) 335.
7) H. Schmeing, J.C. Hardy, E.G. Hagberg, W.L. Perry and J.S. Wills, contribution to this conference, No. B2.
8) J.C. Hardy, private communication.
9) University Isotope Separator at Oak Ridge, a consortium of 13 member institutions.
10) E. Spejewski, in Proceedings of the Isotope Separator On-Line Workshop, R.E. Chrien, editor, Brookhaven National Laboratory, Upton, New York, Oct. 31-Nov. 1, 1977, BNL 50847, p. 149.
11) E.H. Spejewski, contribution to this conference, No. B4.
12) D.M. Moltz, J.M. Wouters, J. Äystö, M.D. Cable, R.F. Parry, R.D. vonDincklage and J. Cerny, Nucl. Instrum. Meth. 172 (1980) 519.
13) D.M. Moltz, J. Äystö, M.D. Cable, R.F. Parry, J.M. Wouters, P.E. Haustein and J. Cerny, contribution to this conference, No. B14.
14) D.M. Moltz, J. Äystö, M.D. Cable, R.D. vonDincklage, R.F. Parry, J.M. Wouters and Joseph Cerny, Phys. Rev. Lett. 42 (1979) 43.
15) J. Ärje, J. Äystö, A. Hautojärvi, J. Honkanen and K. Valli, contribution to this conference, No. B15.
16) M.D. Cable and J.M. Wouters, private communication.
17) E.H. Spejewski, contribution to this conference, No. E5.
18) K.S. Toth et al., Phys. Lett. 63B (1976) 150.
19) K.S. Toth, M.A. Ijaz, C.R. Bingham, J. Lin, E.L. Robinson and H.K. Carter, Phys. Div. Ann. Prog. Rep., June 30, 1977, ORNL-5306, p. 83.
20) U.J. Schrewe et al., Phys. Lett. 91B (1980) 46.
21) J. Äystö, D.M. Moltz, M.D. Cable, R.D. vonDincklage, R.F. Parry, J.M. Wouters and Joseph Cerny, Phys. Lett. 82B (1979) 43.
22) J. Äystö, M.D. Cable, R.F. Parry, J.M. Wouters, D.M. Moltz and Joseph Cerny, Report No. LBL-11193, submitted to Phys. Rev. C.
23) HHIRF Users' Manual, R.L. Robinson, editor, Feb. 1, 1980.
24) K.S. Toth, E. Newman, C.R. Bingham, A.E. Rainis and W.-D. Schmidt-Ott Phys. Rev. C11 (1975) 1370.
25) E. Newman, K.S. Toth, D.C. Hensley and W.-D. Schmidt-Ott, Phys. Rev. C9 (1974) 674.