UNISOR ON-LINE NUCLEAR ORIENTATION FACILITY (UNISOR/NOF)

I. C. Girit[1], G. D. Alton[2], C. R. Bingham[3], H. K. Carter and M. L. Simpson[4], J. D. Cole[5], W. L. Croft[6], J. H. Hamilton, E. F. Jones, P. M. Gore and J. Kormicki[7], B. D. Kern[8], K. S. Krane and Y. S. Xu[9], P. F. Mantica, Jr. and B. E. Zimmerman[10], W. G. Nettles[11], E. F. Zganjar and M. O. Kortelahti[12], and W. B. Newbolt[13]

TO BE PUBLISHED IN THE PROCEEDINGS,
WORKSHOP ON ON-LINE NUCLEAR
ORIENTATION AND RELATED TOPICS,
OXFORD, ENGLAND, AUGUST 31-SEPTEMBER 4, 1988

The UNISOR on-line nuclear orientation facility (UNISOR/NOF) consists of a ^{3}He-^{4}He dilution refrigerator on line to the isotope separator. Nuclei are implanted directly into a target foil which is soldered to the bottom accessed cold finger of the refrigerator. A 1.5 T superconducting magnet polarizes the ferromagnetic target foils and determines the axis of symmetry. Up to eight gamma detectors can be positioned around the refrigerator, each 9 cm from the target. A unique feature of this system is that the k=4 term in the directional distribution function can be directly and unambigously deduced so that a single solution for the mixing ratio can be found. The first on-line experiment at this facility reported here was a study of the decay of the ^{191}Hg and ^{193}Hg isotopes.

1. INTRODUCTION

Low temperature nuclear orientation has been a very productive experimental technique for studying nuclear structure from radioactive decays. Since about 1980, the combination of an on-line isotope separator and dilution refrigerator has reduced the half-life limit from several hours to several seconds, thus increasing the applicability of low temperature nuclear orientation to a wide range of short-lived nuclei far from stability. The four other existing facilities are in Bonn, Leuven, Daresbury (a comprehensive review of these systems has been given by Herzog/1/), and in CERN. The one in Bonn is not 'on-line' to the accelerator. The common feature of these four systems is that the separated ion beam is directly implanted onto the target through a side access.

The UNISOR/NOF described in this paper differs in design that the beam access to the target is from the bottom of the refrigerator. This configuration allows up to eight detectors to view the target. Also, the construction of the heat shields enables the eight detectors, four at 45°, to view the target with essentially the same solid angle. The external field direction which determines

[1]Vanderbilt University, Nashville, TN 37235 and UNISOR, Oak Ridge Associated Universities, Oak Ridge, TN 37830; [2]Oak Ridge National Laboratory, Oak Ridge, TN 37831; [3]University of Tennessee, Knoxville, TN 37996; [4]UNISOR, Oak Ridge Associated Universities, Oak Ridge, TN 37830; [5]INEL, Idaho Falls, ID 83415; [6]Mississippi State University, Mississippi State, MS 39762; [7]Vanderbilt University, Nashville, TN 37235; [8]University of Kentucky, Lexington, KY 40506; [9]Oregon State University, Corvallis, OR 97331; [10]University of Maryland, College Park, MA 20742; [11]Mississippi College, Clinton, MS 39058; [12]Louisiana State University, Baton Rouge, LA 70803; [13]Washington and Lee University, Lexington, VA 24450

the axis of symmetry lies in the equitorial plane (for a schematic summary of these differences see Fig. 1). In the light of the briefly mentioned differences, the features of the UNISOR/NOF are:

a) Three independent angles enable us to deduce the k=4 terms unambigously in the directional distribution function. This is important for nuclear structure experiments since it allows us uniquely to determine the multipole mixing ratio.
b) The cylindrical geometry of detectors allows us to correct small fluctuations in beam positioning.
c) The additional detectors increase the counting statistics.

The UNISOR/NO facility is now operational. In this paper, Section 2 will describe the main relevant technical features. Section 3 will cover data acquisition, and Section 4 will concentrate on the data analysis of this multi-detector system. Finally in Section 5, recent results will be presented.

ON-LINE SYSTEMS

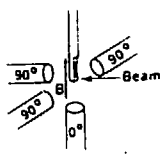
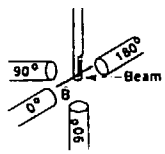
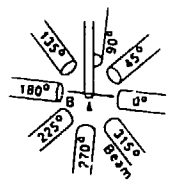
LEUVEN	DARESBURY/NICOLE	UNISOR/NOF
		
NO OF DETECTORS		
1 - 0 3 - 90	2 - 0 2 - 90	2 - 0 4 - 45 2 - 90
SOURCE TO DETECTOR DISTANCE		
5,6 cm	7 cm	9 cm
MAX. MAGNETIC FIELD & DIRECTION		
0.5, 1.5 T vertical	1.5 T horizontal	1.5 T horizontal
FIRST ON-LINE IMPLANTATION		
November 1980	November 1983/ July 1988	June 1986

Fig. 1. A schematic comparison of the four fully on-line systems.

2. EXPERIMENTAL SETUP

A schematic dual plane view of the UNISOR/NOF is shown in Fig. 2. The Holifield Heavy Ion Research Facility (HHIRF) 25 MV Tandem accelerator (TM) provides the primary beam which is focused on a target in a modified FEBIAD ion source (IS). The ionized reaction products are then accelerated (typically at 50 kV) and mass separated by a 90° bending magnet. The chosen mass beam is

focused (see Section 2.2) before entering the cold beam tube (CBT) which is part of the refrigerator cryostat. The ferromagnetic foil (T) on which the activity is implanted is soldered to the cold finger of the ^{3}He-^{4}He dilution refrigerator (DR) which should maintain the temperature at about 12 mK with 4 K baffle open. The magnetic domains in the target foils (usually Fe) are polarized by a 1.5 T superconducting magnet (SM).

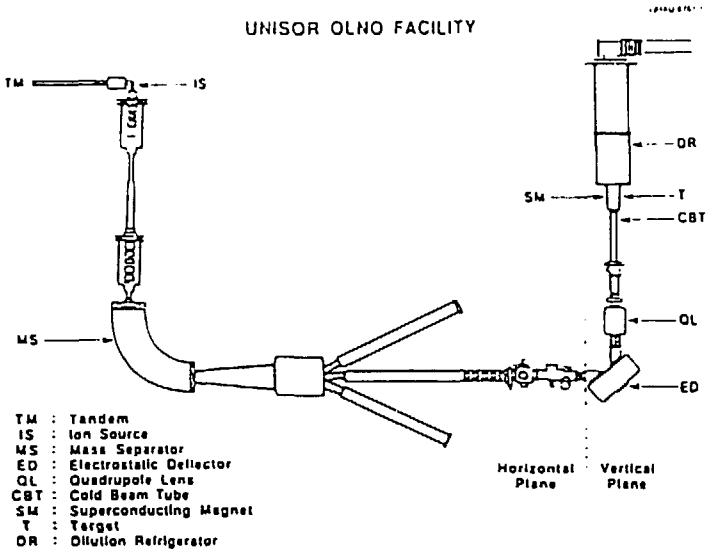


Fig. 2. An overall view of the experimental set-up.

2.1 THE ^{3}He-^{4}He DILUTION REFRIGERATOR

The refrigerator and the bottom access beam assembly were manufactured by Oxford Instruments. The refrigerator is a standard design, but in order to allow bottom access, the tail section and the magnet are modified. The tails are cylindrical; the outer one is 18 cm in diameter, so that the closest source-to-detector distance is 9 cm. At this distance, for detectors with 5 cm crystal diameter, the magnet allows 1.65, 1.29, and 1.07 percent solid angle for 0°, 45°, and 90° detectors respectively. There is also a 2.2 cm opening at the bottom of the magnet for beam entrance. The refrigerator is equipped with a "top load" facility to change target material while the refrigerator is operational. The cooling power of the refrigerator, at a circulation rate of 500 μmol/s is given by the power relation: $Q = 0.017(T^2-44.9)\,\mu W$, where T = target temperature.

The target foils and thermometer sources are soldered on the face of a 0.9 cm diameter cylindrical, copper sample holder which is screwed into the mixing chamber of the dilution unit by the top loading rod. The sample holder is made of high purity oxygen-free tellurium copper and lies at the center of a 1.5 T Helmholtz type superconducting magnet which can also be run in persistent mode. The field direction is horizontal and the beam direction is perpendicular to this field. The refrigerator cryostat and the detectors are accommodated by a 6 m high platform. A separate platform for detection electronics, experimentalists, and for cryogenic liquid transfer surrounds the inner one (Fig. 3).

The recent experiments have shown that when all the baffles are closed, a base temperature of 7.6 mK can be reached. Modifications are presently being made which should permit 12 mK operation in the on-line mode with a base temperature of less than 6 mK.

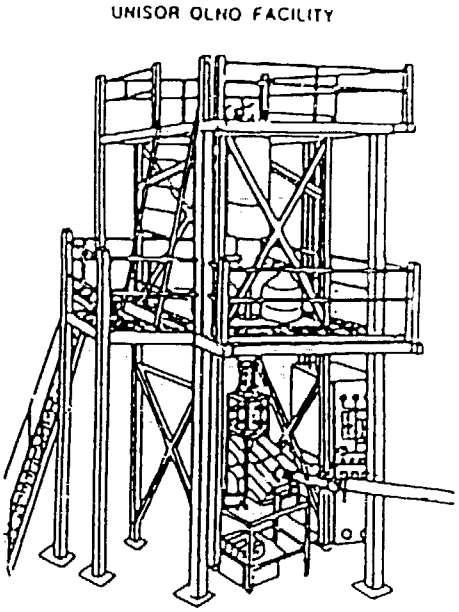


Fig. 3. The UNISOR/NOF.

2.2. THE BEAM LINE

The 50 kV beam from the separator is controlled and monitored by several lenses and deflector assemblies. At first, the separated beam is focused in the dispersion chamber of the separator in which a beam profile monitor and a Faraday cup check the shape and intensity of the beam before it enters the horizontal beam line. A compressor lens at the beginning of the beam line narrows the beam; an Einzel lens at the end focuses it to the entrance of the 90° electrostatic deflector. The transmission through the horizontal beam line is checked by a removable Faraday cup. An x-y beam scanner can also be used to monitor the beam shape before it is bent up. A 90° electrostatic deflector consisting of seven equally spaced parallel plates deflects the beam. A quadrupole triplet lens just after the deflector provides the final focusing before the beam enters the cold beam line. The final steering of the beam is achieved by a set of x-y deflectors placed just before a cooled iris which is used to control the beam striking the target. The intensity of the beam at this stage is monitored by a Faraday cup mounted on the 4 K baffle.

The transmission from dispersion chamber to the target with the present FEBIAD ion-source and all the beam monitoring and steering devices is measured to be 70 to 96% for many different beams. It is possible to keep the beam not deposited on the cold target below 0.05%.

3. DATA ACQUISITION SYSTEM

Currently the UNISOR/NOF data acquisition system is based on a Tennecomp TP 5000 and the HHIRF Concurrent computer. On the Tennecomp, up to six ADC's, display, disk storage, etc. are interfaced to a Digital Equipment Corporation PDP 11. A special high-level language (TIL) provides necessary commands to set live/real time, to start/stop ADC and to manupulate the spectral data which can be stored either on hard disk or magnetic tape. The Tennecomp system is linked to a HHIRF Concurrent main frame computer through a CAMAC interface. The spectra can be transferred to the main frame where they are stored again either on high capacity disk drives or magnetic tapes. Depending on the work load of the CPU, it takes about one to three seconds to transfer six 8192 channel spectra from the Tennecomp to the Concurrent computer.

The software control of both computers provides the selection of collection time of the acquisition, number and length of spectra to be transferred, and type of data storage. Spectra are automatically transferred to the selected storage devices. A separate program accesses the data in the disk and is used to monitor the base temperature of the refrigerator, and calculate the anisotropy of up to three peaks in the isotope of interest. Thus, the experimenters can monitor the alignment of the sample in real time.

4. DATA ANALYSIS

We define the anisotropy as

$$A(\theta) = 1 - W(\theta,I)/W(0,I)$$

where $W(\theta,I)$ is the distribution function as defined in [2] and I is temperature

Experimentally, it is convenient to choose the ratio of this function in the following way:

$$A(\theta) = 1 - \frac{[N(\theta,c)/t(\theta,c)]}{[N(\theta,w)/t(\theta,w)]} \Big/ \frac{[N(0,c)/t(0,c)]}{[N(0,w)/t(0,w)]}$$

where θ refers to 6 possible 45° or 90° positions and where 0° means 0° or 180°. N refers to the number of counts observed by a detector at θ taken at high temperature, w (T=1 K), and low temperature, c, for a time t. This definition is independent of varying beam intensities and of decay time effects. Due to differences of dead time of each detector, live times should be known quite accurately.

The advantage of the present system is that from any pair of A(45°) and A(90°), it is possible to obtain directly values of $a_2(=B_2U_2A_2)$ and $a_4(=B_4U_4A_4)$. Furthermore, by averaging results from pairs of diametrically opposite detectors, systematic effects associated with movement of the beam are reduced. For example, averaging a_k calculated from A(45°) and A(90°) with a_k calculated from A(45°) and A(270°), we correct for movement along the line connecting the 90° and 270° detectors.

In the six-detector system now in use, it is possible to obtain a_k from eight different combinations of detectors (0° or 180°; 90° or 270°; 45° or 225°). In these eight combinations, each detector is used four times, so in the final statistical average of the 8 a_k values, the uncertainty is increased by $\sqrt{4}=2$. In the final analysis, if the orientation coefficients B_k are known from information based on the parent ground state, the main source of error on distribution coefficients A_k, then would be due to those of U_k coefficients.

5. THE ON-LINE NUCLEAR ORIENTATION OF ^{191}Hg

In 1980, Iachello suggested that dynamical supersymmetries may be present in the spectra of complex nuclei /3/. The ^{193}Au described in Ref. /4/ was studied as a candidate for a supersymmetry structure generated by a single particle with j=3/2 and L=0,2 bosons with O(6) symmetry. Likewise, the nuclide ^{191}Au has a j=3/2 ground state and lies in a region of even-even nuclei with a O(6) symmetry /4/, so it was chosen for the first UNISOR/NOF on-line experiment to determine whether its low-lying spectrum can be described by this classification scheme. Among others, one criterion to test supersymmetry in ^{191}Au is to determine whether the E2 transitions satisfy the selection rules appropriate to the scheme. This criterion requires precise values of δ(M1/E2) to be measured, since for the heavier Au isotopes the measured B(E2) of the τ forbidden transitions are often only about 10% of the B(E2) of the allowed transition. Also the allowed transition itself may have only a 5-10% E2 component and the selection rules apply to E2 transitions only.

The excited states of ^{191}Au studied by the radioactive decay of the ^{191}Hg high spin isomer (T(1/2)=51min) which was produced by a C beam with an energy of 110 MeV from the HHIRF Tandem on a natural W target. Throughout the experiment, the beam intensity was at 2×10^5 ion/sec at the target. The data were collected in eight cycles. A typical cycle is illustrated in Fig. 4. Data were acquired from six detectors placed at 0°, 45°, 90°, 180°, 225°, and 270° in 12-14 runs, each of 10 min. duration. At the end of each cycle, the sample foil was replaced by a new iron foil in order to avoid buildup of daughter activity.

Table 1 shows a small subset of the 102 preliminary $a_k=B_kU_kA_k$ values based on the analysis of only two cycles. The errors on k=4 terms would be reduced by at least a factor of two when the results from other cycles were averaged to obtain final values.

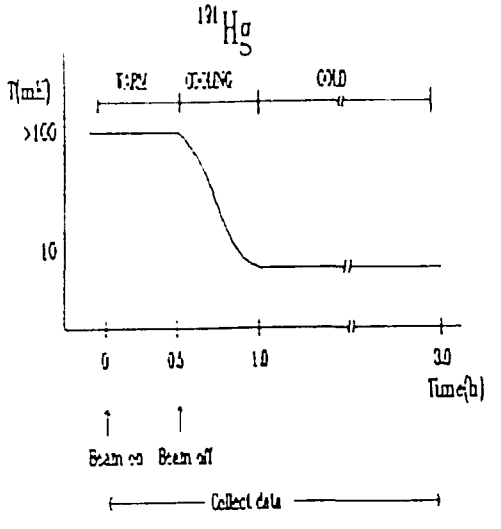


Fig. 4. A typical experimental cycle.

AVERAGE ak VALUES

ENERGY	B2U2A2	ERR	B4U4A4	ERR
158.80	-0.0004	0.1232	0.0007	0.1200
196.50	0.1038	0.0338	-0.0127	0.0438
214.60	0.4108	0.1194	0.0705	0.1383
224.60	-0.0638	0.0232	-0.0161	0.0262
240.50	-0.1585	0.0376	-0.0665	0.0435
247.80	0.1025	0.2915	0.5340	0.3177
252.70	0.3362	0.0089	-0.0220	0.0124
274.20	0.0270	0.0139	-0.0277	0.0170
⋮				
1503.70	0.2981	0.0773	-0.0703	0.1154
1509.60	0.0457	0.1345	0.0307	0.1544
1525.10	-0.0970	0.1337	0.0377	0.1529
1532.30	-0.1447	0.0830	-0.1007	0.1002
1548.90	-0.1063	0.1856	0.0264	0.1260
1632.90	-0.1886	0.1180	-0.0191	0.1379
1739.50	0.1274	0.0485	-0.0566	0.0686
1863.60	0.4276	0.1089	-0.2147	0.1678
1908.40	0.2910	0.0411	0.1210	0.0582

Table 1

6. CONCLUSIONS

The UNISOR/NOF system has now succesfully demonstrated a new symmetrical geometry for on-line nuclear orientation refrigerators whereby the beam enters the system from bottom. The possibility to place detectors at 45° angles around the target, a unique feature of the system, enables us to determine uniquely the multipole mixing ratios, and reduces some of the systematic errors like count rate fluctuations due to beam movement, change of distance between the sample holder and bottom 90° detector due to thermal contractions at low temperatures, etc. The necessary technical changes to achieve this extra feature did not by any means affect the performance of the refrigerator nor will it affect the incorporation of a NMR system and particle detectors. But unambiguous determination of multipole mixing ratios with a high degree of accuracy will enhance our understanding of nuclear structure.

References

/1/ P. Herzog, H.R. Folle, K. Freitag, A. Kluge, M. Re[illegible]bach and E. Bodenstadt, Nucl. Instr. and Meth. 155 (1978) 421.
/2/ K. S. Krane in Low-Temperature Nuclei Orientation, ed. N. [illegible]tone and H. Postma, (Elsevier Science Publishers B.V., 1986), p.31.
/3/ F. Iachello, Phys. Rev. Lett. 44 (1980) 772.
/4/ J.L. Wood, Phys. Rev. C24 (1981) 1788.
/5/ R.F. Casten and J.A. Cizewski, Nucl. Phys. A309 (1978) 477.

UNISOR is a consortium of universities, State of Tennessee, Oak Ridge Associated Universities, Oak Ridge National Laboratory, and is partially supported by them and by the U.S. DOE under Contract No. DE-AC05-OR00033. This work was supported by the U.S. DOE Contract Nos. DE-AS05-76ER05034 (Vanderbilt University), DE-AC05-84OR21400 (Oak Ridge National Laboratory), DE-FG05-87ER40361 (University of Tennessee), DE-AC07-76ID01570 (INEL), DE-FG06-87ER40345 (Oregon State University), DE-FG05-88ER40418 (University of Maryland), and DE-FG05-84ER40159 (Louisiana State University).

DISCLAIMER