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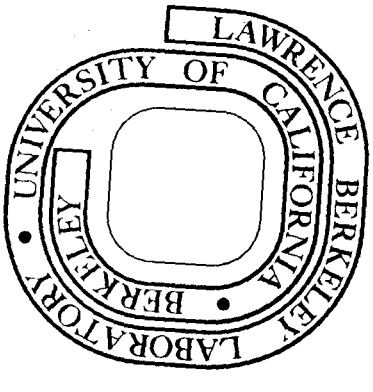

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DISCLAIMER

AN INTERACTIVE COMPUTERIZED SYSTEM FOR THE ANALYSIS OF GAMMA RAY SPECTRA FROM HEAVY ION NUCLEAR REACTIONS*

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ABSTRACT

A system for the yield analysis of radionuclides produced in heavy ion nuclear reactions is presented. The system is based on gamma ray spectroscopic measurements of the induced activities, automatic peak identification and fitting with the SAMPO code, and an interactive decay curve identification process. A computer code has been developed which facilitates this process by binding together an updated gamma ray catalogue, the measured decay curves and the ability to fit varying components to the data.

INTRODUCTION

Gamma ray spectrometric methods have been developed to deduce mass yield distributions for heavy ion induced nuclear reactions at incident particle energies ranging from 5.0 MeV/A to 8.5 MeV/A and 0.4 to 2.1 GeV/A. These nuclear reactions produce radioactive, gamma ray emitting nuclides that cover the entire chart of the nuclides. In a single heavy ion reaction such as ~960 MeV $^{136}Xe + ^{238}U$[1] or 25.2 GeV $^{12}C + ^{238}U$[2] over 100 neutron excessive and neutron deficient nuclides ranging from ^{7}Be to ^{238}Np were produced and identified by their characteristic gamma ray transitions between 40 keV and 2 MeV from spectrometric measurements of the target.

The object of the analysis is to translate the complicated gamma ray spectra into a data set consisting of the partial cumulative and independent yield production cross sections from which isobaric mass yield distributions can be deduced. In the development of a computer aided interactive analysis system the following criteria were established.

a. The energy resolution and the linear and differential stability of the spectrometer system should be extremely good. In practice this means we require a system in which the photopeaks are nearly Gaussian in shape and unchanging with time, because single samples have been counted up to one year after the end of bombardment. The absolute efficiency of the detector system has to be well known for the many counting geometries that are used during the spectrometric measurements of different chemical fractions from a single target.

b. Given the above energy stability and photopeak shape requirements the counting geometry and counting schedule should be adjusted so that production cross section information can be obtained on the greatest number of nuclides, and therefore, the gamma spectrometric measurements should span the largest range of half-lives possible.

c. All routine data handling and processing should be made completely automatic. This includes data acquisition, photopeak analysis and preparation for an interactive decay half-life analysis.

d. In those areas of analysis where a large number of factors must be considered, such as in the assignment of known gamma ray transitions to the measured decay curves of the observed gamma rays, the system should be an interactive one. It is at this point, also, that the experimenter should be able to evaluate the quality of the data and be able to recognize any systematic errors that the previous automatic part of the analysis may have introduced.

METHODS

The first criterion above can be met with many commercially available systems today and this aspect will not be discussed. With respect to the second criterion a counting strategy has been developed that takes into account first, the problem of high count rate distortions of the peak shape associated with a very radioactive target that is continuously decaying, and second, the wide range of half-lives of the gamma ray emitting products in the target. This strategy is based on the observation that the gamma rays from a given radionuclide will only be observable in that period of time when that given radionuclide is going through its second, third and fourth half-lives. That is, a given radionuclide is usually not visible during its first half-life because it will be obscured by short lived activities. It is also not generally visible at longer times because of the prominence of longer lived species.

The gamma ray spectra are automatically recorded onto magnetic tape along with the start and stop times of the measurement and an alpha-numeric tag. A typical gamma ray spectrum is shown in Figure 1. The identification and analysis of photopeaks in the spectra is done with a modified version of the program SAMPO[3]. The modified automatic mode of this program which was written for the CDC machine at the Lawrence Berkeley Laboratory has proven to be very successful. Desirable features that are built into this code include exact, energy dependent, calibration of the detector efficiency, polynomial energy cali-

brations, and particularly energy dependent peak line shape calibration. The count rates for each identified peak, corrected for efficiency, are output on magnetic tape in blocks which are labeled with the spectrum tag and the time from the end of bombardment to the midpoint of the measurement.

After the SAMPO analysis is complete the next step of the analysis is to sort the observed gamma ray peak areas so that decay curves can be constructed. For each gamma ray the code TAU1 was written to perform this sorting. The code starts with the magnetic tape output from SAMPO and searches first on the spectrum identification tag and then on gamma ray energy. Throughout the analysis the chronological order of the original measurement schedule is preserved. Thus, the SAMPO analysis is performed on spectra in chronological order, which TAU1 preserves, thereby eliminating the need for any chronologic sorting in TAU1. The code is able to collect the data from up to 40 spectra for each of 10 samples. The code then generates a new magnetic tape as output that contains the gamma ray intensities sorted by energy for each of the samples. The code also provides a printed output of all the accepted gamma rays for each sample along with the results of the least square estimate of the half-life and the identity of the spectrum in which the gamma ray was observed.

The next stage of the analysis is to bring the measured decay curves for each gamma ray together with a compilation of the known gamma ray transitions in order to identify the radio-

nuclides present in the sample. For this task we have written the computer code TAU2 which is an interactive decay curves analysis program that constructs decay curves and also presents relevant data on the 20 nearest known gamma ray transitions to facilitate the identification. The code has been designed to run on the CDC-6000 machine at LBL with a Tektronix 4014 terminal. Input data for this code is the sorted gamma ray data from TAU1 and a listing of the updated compilation of Binder et al.[4] of the MacMurdo-Bowman gamma ray tables[5], both on magnetic tape. The code begins with the lowest energy gamma ray observed in the first sample and plots a semi-logarithmic decay curve, time unit of days, on the CRT of the terminal. Simultaneously the code searches the gamma ray table for a known gamma ray transition nearest to the average measured gamma ray energy. Finding the closest known gamma ray, the code presents the energy, isotope, half-life, relative intensity and parents (if any) for the 20 gamma rays nearest to the measured energy. A typical display is shown in Figure 2. The operator is then able to choose any single known line or combination of known lines to be least squares fitted to the measured decay curve, or arbitrary half-lives may be fit to the data. The possible combinations are presented in Table 1. When an acceptable identification of the decay curve has been made by the operator the graphical display is recorded on microfiche and the A_0 value along with its error, energy and radionuclide identification is output on a punched card. This A_0 value has the units of decays per minute having been corrected for the

branching ratio of the parent nuclide. Nuclear reaction cross sections are calculated on weighted average of all the observed gamma rays for each product nuclide after the identifications have been screened for duplicate or erroneous identifications and for self consistency. Once a set of partial cumulative and independent yield cross sections has been obtained an iterative procedure is used to deduce the mass and charge distribution for the nuclear reaction under study.

RESULTS AND DISCUSSION

We believe that the analysis system that we have described represents a relatively unique combination of analytical methods and programs for the analysis of complex gamma ray spectra. Since no prior knowledge of which radionuclides are contributing to the spectra is required it is hoped that this approach may be applicable to a broad range of problems in the field of activation analysis and gamma ray spectroscopy. Most important to the analysis system that we have developed is the interactive graphics display program which makes it possible to identify reaction products based on their half-lives and known gamma ray transitions. Although this interactive program is presently run on a CDC 6000 machine with a Tektronix 4014 Terminal it could be easily adapted to a smaller computer such as the PDP 11. Fortran versions of the computer codes described in this work are available on request to the authors.

REFERENCES

*Work supported in part by the Division of Physical Research of the Department of Energy.

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TABLE 1

Decay Curve Component Analysis Options

Single Component	(a) Known gamma ray transition from table
	(b) Arbitrary straight line
Multiple Components	(a) Known gamma ray plus constant background
	(b) Straight line plus constant background
	(c) Sum of two known gamma rays
	(d) Sum of known gamma ray plus straight line
	(e) Sum of two arbitrary straight lines
	(f) growth of known gamma ray from its known parent

FIGURE CAPTIONS

Fig. 1. Typical gamma ray spectrum observed in this work. A gold target was irradiated with 1140 MeV ^{136}Xe ions and the gamma radiation measured directly with a range of 75 to 2000 keV in a 4096 channel spectrum. XBL 776-8998.

Fig. 2. Graphics terminal display showing the fit of two components (solid lines) to the measured decay curve of a 604.4 keV gamma ray (open circles) the ordinate is the logarithm of the count rate and the abscissa the time after the end of bombardment in days. Also shown on the CRT display are 20 gamma rays, nearest in energy to the measured 604.4 keV, from the Binder et al. gamma ray catalogue.[4] These entries, numbered 1 to 20, contain information on the energy, chemical property, isotope, half-life in days, percent abundance of the transiton and chemical symbol of the parents, if any. XBL 776-8887.

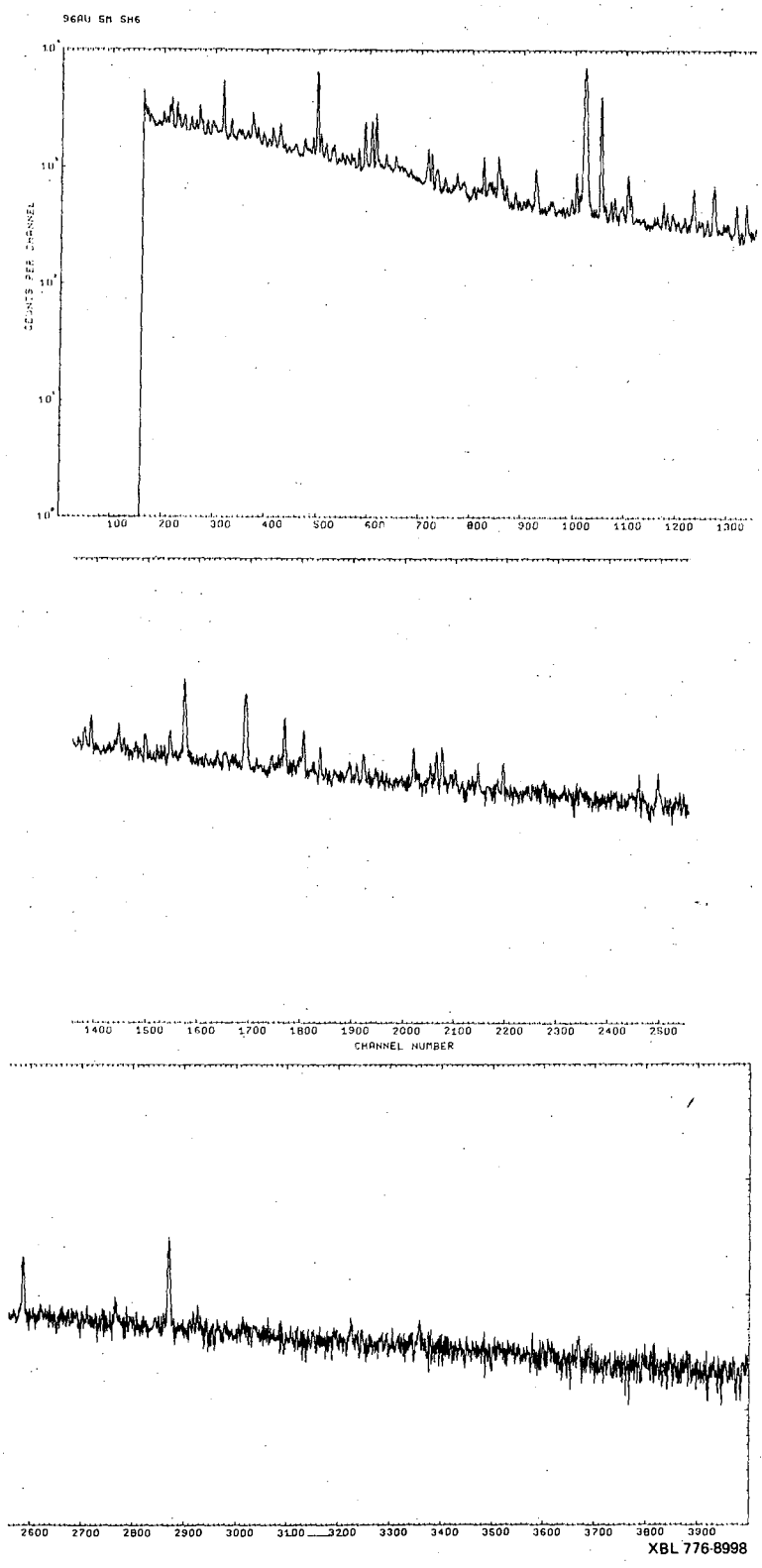
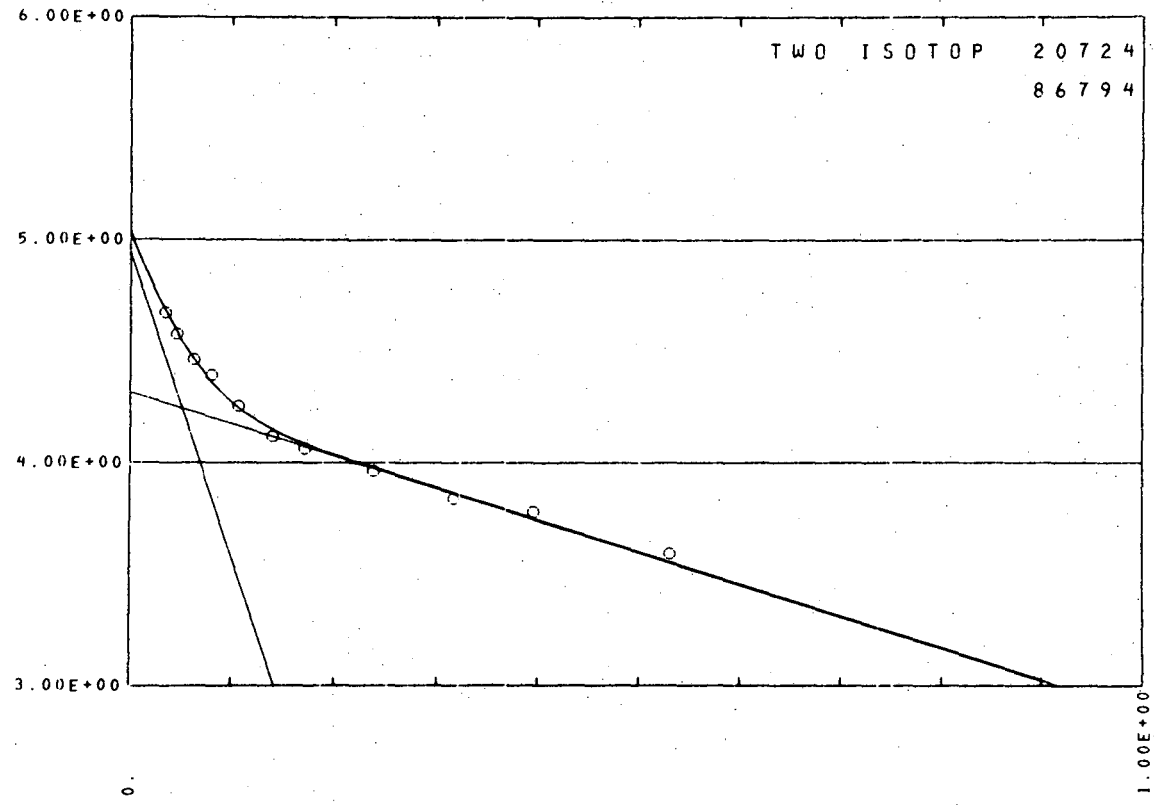


Fig. 1

AU64 X 604.4KEV 604.3 SH AU-192 .210
604.8 I BR- 84 .022

X OK	(1)	603.2	DI	TE-115A	.005	1.0	I	0	(11)	604.8	I	BR- 84	.022	1.7	SE	5105552
X SUM	(2)	603.2	DI	TE-115B	.004	5.0	I	0	(12)	604.9	LA	LA-134	.005	5.1	CE	0
X BACKGR.	(3)	603.2	PB	RB- 79	.016	.7	SR	0	(13)	604.9	LA	CE-134	3.000	100.0	PR	0
X GROWTH	(4)	603.6	SH	AG-102	.009	1.7	CD AG	0	(14)	605.1	LA	AM-238	.068	7.8	CM	0
X FIT	(5)	603.6	I	I -130	.517	.6		0	(15)	605.2	I	I -118	.010	95.0	I	0
X OMIT	(6)	603.8	DI	SB-127	3.850	4.4	SN SN	0	(16)	605.2	I	I -118M	.006	10.0*		0
X DOUBLE	(7)	604.2	LA	GA- 74	.006	2.9		0	(17)	605.3	SH	IR-190	12.100	37.8	IR	0
X HALVE	(8)	604.3	SH	AU-192	.210	1.6	HG	1295256	(18)	605.3	SH	RE-190M	.117	15.1		0
X RESET	(9)	604.4	SH	IR-192	74.000	8.1	IR	0	(19)	605.4	LA	SB-126	12.400	1.4	SB	0
X UP	(10)	604.6	U	CS-134	751.900	98.0	CS	0	(20)	605.5	LA	TB-151	.750	1.0	DY	0
X DOWN																
X SKIP																



XBL 776-8887

Fig. 2

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