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PAC SPECTROMETER WITH SIX-BAF$_2$-DETECTORS

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ABSTRACT

A Perturbed Angular Correlation (PAC) spectrometer with six conical BaF_2 detectors was built. The increased number of detectors in relation with the current configuration of the spectrometer (with four detectors), extends the number of delayed γ–γ coincidence spectra from 12 to 30 obtained simultaneously, reducing the time of PAC measurements. The standard multichannel analyzer (MCA) commonly used in these types of spectrometers was replaced with an ultra fast analog to digital converter (8715 ADC - CANBERRA®) and a high speed digital input-output (I/O) board (6534 Aquisition system – NATIONAL INSTRUMENTS®). The experimental data consisting of relevant information about the delayed γ–γ coincidence events generated from different combinations of detectors (for example: the timing information, start and stop detector identification, coincidence validation etc.) are stored in a file-mode in the hard disk of a computer. This information can be processed at a later stage by background data processing to generate and periodically refresh individual PAC spectra without interruption of the data collection process. The coincidence spectra are generated in real time by using LabVIEW software. The increased number of simultaneous spectra generated in this spectrometer improves the hyperfine parameters deduced from the TDPAC measurements. More important, the new spectrometer would be used for application of some interesting radioactive nuclei that can be used as probes in several hyperfine interaction studies.

1. INTRODUCTION

Measurement of Perturbed Angular Correlation (PAC) of gamma rays is a microscopic technique to determine the hyperfine fields or electric field gradients at the site of probe nucleus generated by neighboring ions and electrons. The method can also provide information on dynamic properties of the local environment. The radioactive nuclei are introduced into a host material where they eventually decay to an excited state of the daughter nucleus which subsequently decays to the ground state by emission of two successive gamma rays γ_1 and γ_2. The interaction between nuclear moments and extra nuclear electromagnetic fields perturbs the angular correlation between the emitted gamma rays in a way which can be used to determine the properties of the host material on a microscopic scale. A detailed analysis of these perturbations reveals the electronic properties of the host material such as: crystalline and magnetic structure, structural defects, phase transitions, etc. Further details about the PAC technique and experimental procedure can be found elswhere [1]. Currently the PAC experiments at the Laboratory of Hiperfine Interactions (LIH) at IPEN are made in a gamma spectrometer consisting of four BaF_2 scintillator detectors arranged in a planar configuration with 90° between them and an electronic system to measure the time differential delayed γ–γ coincidences. In this arrangement the time distribution of coincidence events for combination of γ_1 (start) and γ_2 (stop) detected in each pair of detectors are measured. There are 12 valid combinations, four from detectors at 180° each other and eight from detectors at 90°. A "slow-fast" coincidence circuit validates the signals from each detector and the pair of detectors responsible for the coincidences is identified by using a special routing circuit module [2,3]. For an accepted coincidence the time to amplitude converter (TAC) provides an amplitude signal proportional to the time difference between arrival of γ_1 and γ_2. The multichannel analyzer (920-16 ADCAM - ORTEC®) stores the digital information in each memory block, and generates real time spectra using ORTEC MAESTRO software. All of the electronic modules used are commercially available except the router. A couple of 6-detector spectrometers using this type of system are already in use in some of the laboratories in Europe [4].

In this work it was decided to maintain the basic architecture of 4-detectors spectrometer including the basic routing circuit. The main innovations are the analog to digital converter (ADC) and an input-output (I/O) board to replace the MCA. The relevant information for each coincidence event such as digitalized TAC output and their detector pair is stored in file -mode in a computer. Specific software has been developed to process the accumulated data. This study also introduced a new router module to connect six detectors to the electronic system and to handle 30 possible coincidence combinations between the detectors.

2. GENERAL DESCRIPTION OF THE 6-DETECTOR SPECTROMETER

A block diagram of the 6-detector spectrometer is illustrated in figure 1. The most practical set up is obtained when the cube is positioned with one of its main diagonals is in the z-axis (figure 2) and the detectors are positioned on each of the six faces of the cube. Necessary space for introducing the auxiliary systems such as cryostat for cooling the samples and small furnace for heating is from top or under the detectors (figure 3).

Each BaF_2 detector yields two types of signals. Two distinct signals from the detectors carry information about the gamma radiation energy and the detection timing respectively. The energy signal (from dynode photomultiplier tube) is amplified and the energy selection is performed by the timing single channel analyzers (TSCA), defining the windows on γ_1 or γ_2 of the gamma cascade ("slow branch"). The timing signal (from anode of photomultiplier tube) goes to a constant fraction discriminator (CFD) and is delayed by about 2.5 μs ("fast branch"). The coincidence between the slow and fast signals is established by a coincidence circuitry (AND). The output of AND circuitry is a pulse that provides information about the photon energy and the instant of its detection. This signal goes to a time to pulse height converter (TAC) and it is connected to "start" or "stop" depending on γ_1 or γ_2. The linear output pulse from TAC goes to an analog to digital converter (ADC) circuitry. The "router" provides a 5 bits output going to an input-output (I/O) board which addresses the digital data to a PC. The experimental data obtained in this way corresponds to 1 of the 30 possible combinations of the detectors and can be stored in the computer in a file mode using a LabVIEW software as well as for constructing histograms (figure 4). The I/O board has additional 14 digital inputs for connections to other instruments that may be used in the experiment, as for example, controller of sample temperature in the cryostat and furnace, servo motors for programmed positioning of the detectors as the radioactive source decays during the course of experiment, etc.

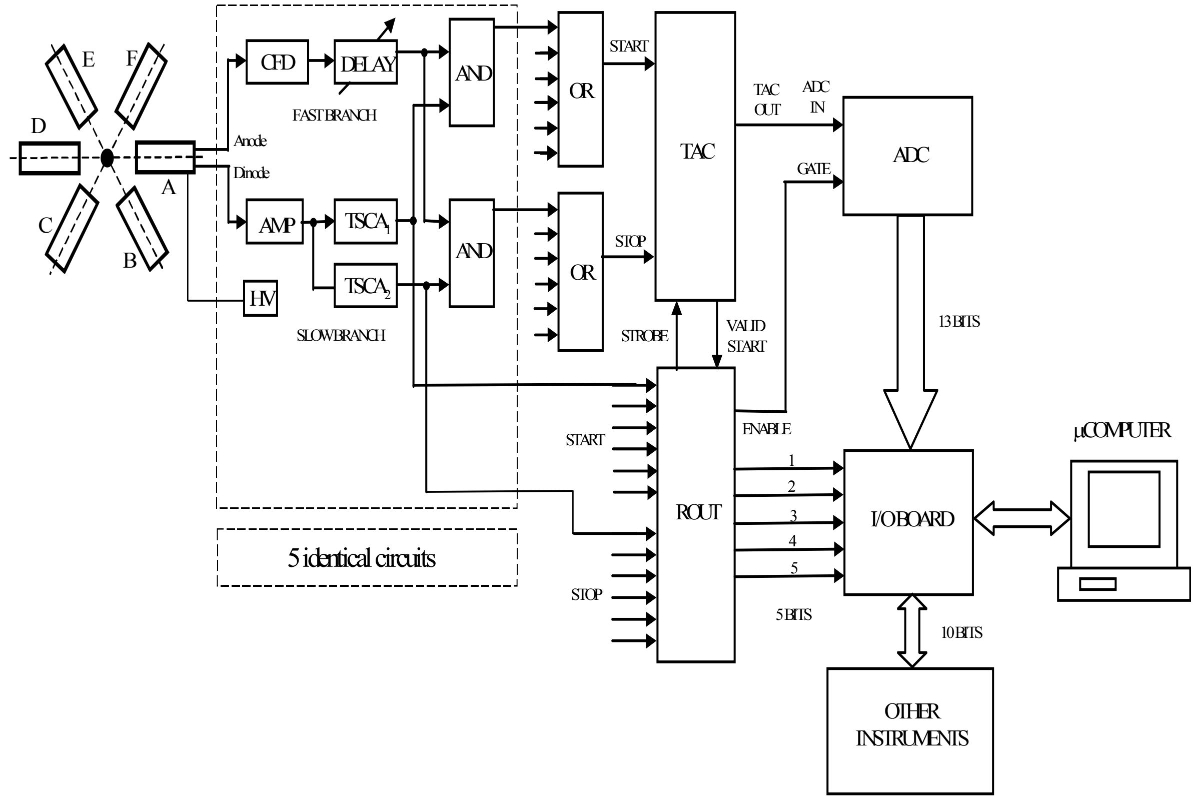

Figure 1. Block diagram of the 6-detectors spectrometer.

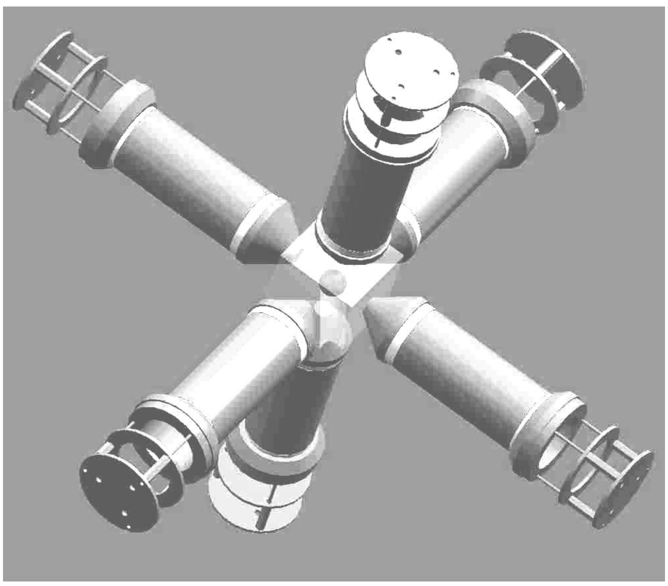

Figure 2. Cubic arrangement of the 6-BaF_2-detectors.

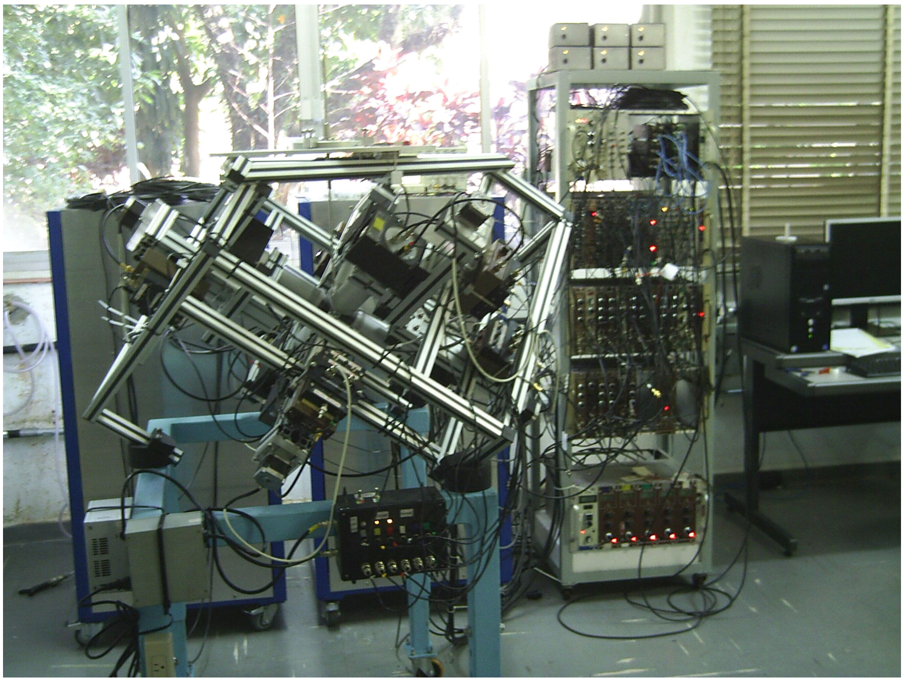

Figure 3. PAC Spectrometer with six-BaF_2-detectors.

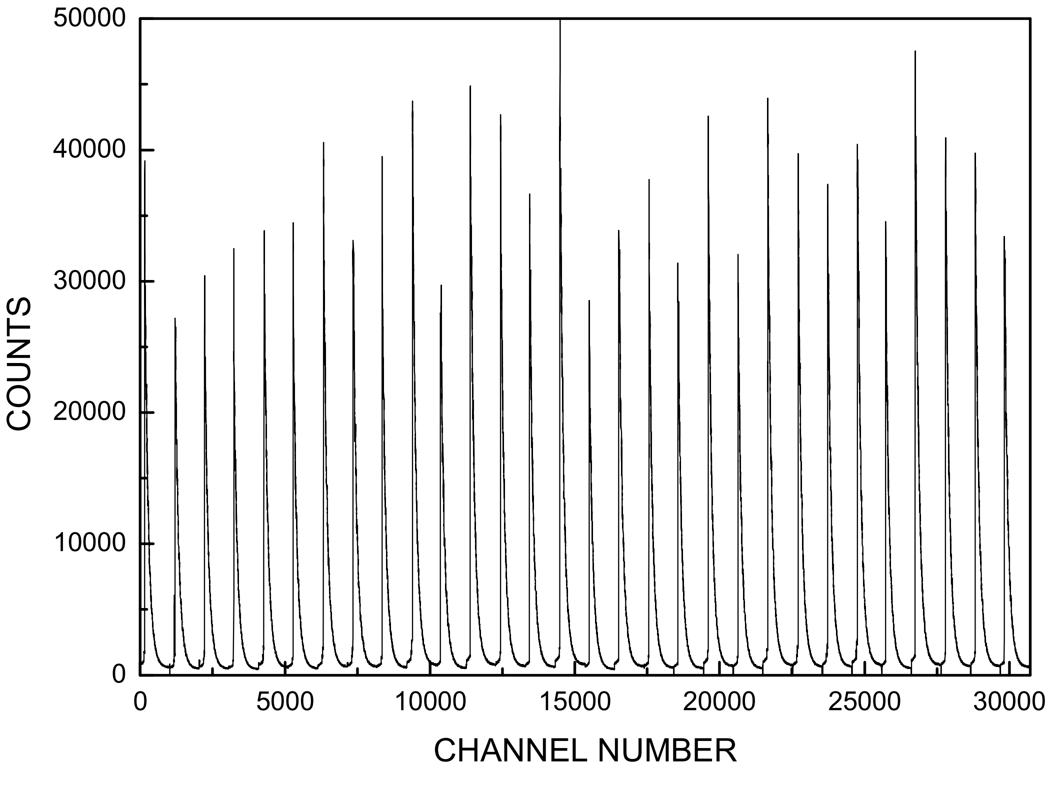

Figure 4. Typical PAC espectra.

3. RESULTS

The performance of the spectrometer was evaluated through a test PAC measurement in a sample of ^{111}Cd(Ni) prepared by arc melting of Ni foil on which about 20μCi of carrier free ^{111}In activity was deposited. PAC spectra were recorded with the spectrometers of four as well as six detectors. The results are shown in figure 5. The PAC spectra show magnetic interaction of ^{111}Cd in Ni. The magnetic hyperfine field in this case is well known from the literature and the present results are in accord with the literature value. Since the measurements were made for the same period of time in the two spectrometers, the statics of the data (calculated from error bars) for the six detector spectrometer was determined to be about 50% superior as compared to the data from four detector system.

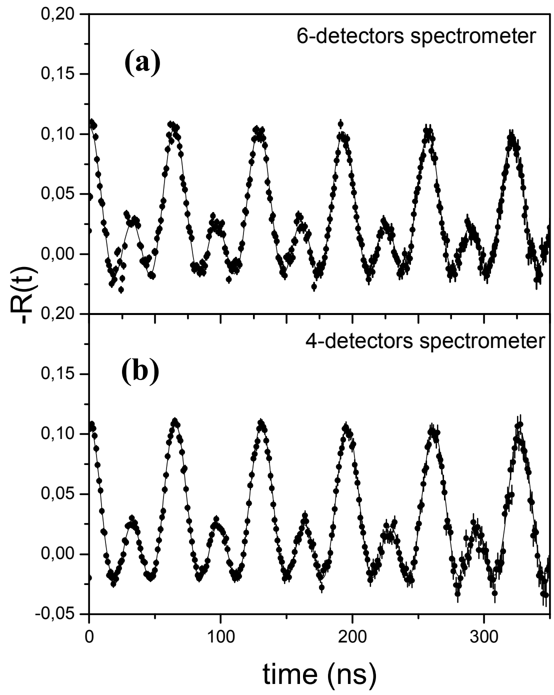

Figure 5. PAC espectra of ^{111}Cd(Ni) measured with: (a) 6-detectors spectrometer and (b) 4-detectors spectrometer.

4. FUTURE APPLICATIONS

Several applications of this spectrometer in the near future are expected. The use of ^{111m}Cd with a relatively short half-life ($T_{1/2}$ = 49 min.) in the study of insulator compounds where the use of ^{111}In is not recommended due to strong "after affects", which often appear due to electronic sub-shell rearrangement following the electron capture decay process of ^{111}In. The radioisotope ^{111}Ag, which decays by the emission of β^- ($T_{1/2}$ = 7,5d) and populates a gamma cascade through the same intermediate state of ^{111}Cd could in principle be used for measurements, however only a small fraction (~6%) of beta decays feed the gamma cascade requiring extended period of time for data acquisition even with a four detector spectrometer. Both isotopes ^{111m}Cd as well as ^{111}Ag are produced in the nuclear reactor while ^{111}In is produced in a particle accelerator.

Another example ^{199m}Hg ($T_{1/2}$ = 43 min.) as a nuclear probe in the in-situ study of corrosion in metallic monocrystals at high temperatures, study of coordination compounds of mercury with important applications in biology and bioinorganic chemistry. The isotope ^{187}W ($T_{1/2}$ = 24h) has been used in several studies of chemical compounds of tungsten and presents a typical example where the use of six-detector spectrometer is very useful. The gamma cascade of 480-72 keV in ^{187}Re in the β^- decay of ^{187}W has a very small value of the unperturbed angular correlation coefficient (A_{22} = 0,07) and this requires exceptionally high counting statistics (several millions of counts) to extract meaningful physical information from experimental data.

Apart from significant economy of time achieved with the use of six detectors spectrometer, cubic arrangement, where each detector is fixed on one of the faces of the cube, allows to detect inhomogenities or effects of texture in polycrystalline samples. This arrangement allows independent determination of the angular correlation coefficients from the data collected with the spectrometer using different four-detector arrangements in distinct orthogonal planes.

5. CONCLUSIONS

The new PAC spectrometer with six conical detectors of BaF_2 was built. The initial tests show significant increase in the efficiency of the data acquisition (approximately by a factor of 1.5 compared to four detector arrangement) and good precision in the final results of hyperfine interactions parameters compared with the spectrometer of four detectors.

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