

FAST SPECTROMETER FOR ANALYSIS OF CONCENTRATION PROFILES OF THE HYDROGEN ISOTOPES IN MATERIALS

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Determination of the concentration profiles of the hydrogen isotopes in various materials is very actual problem now since hydrogen, if presents, rather strongly affects on physical, chemical, electrical, mechanical and other properties. In the INP AS (Uzbekistan) the specific method of hydrogen isotopes' profiling (Neutron-induced Elastic Recoil Detection (NERD) method) has been developed. Measured energy spectrum of H-ions that are knocked out by fast neutrons gives the information on the depth and concentration of hydrogen in a sample. The method allows obtaining of the concentration profiles for all hydrogen isotopes simultaneously and has the analysable depth up to 1,5 mm for ¹H. Improving of analytical characteristics of the method is achieved by decreasing, as much as possible, of the gamma and charged particles background in the measured energy spectra. That is made in the NERD-installation by choosing the constructional materials and geometry factors at its construction and manufacturing, as well as by using of the specific fast electronics set-up. To decrease the false coincidences count rate and worsening of energy resolution we turned down traditional fast - slow arrangement of the spectrometer and used fast branch of the electronics down to the last spectrometric amplifier that produces the spectrometric signal for ADC. In this report the specific developed electronic modules (charge sensitive preamplifiers, linear gates and coincidence schemes) as well as the set-up diagram of the spectrometer are described.

1. Introduction

Determination of the content and profile of concentration of the hydrogen isotopes in various materials is very actual problem now because presence of hydrogen importantly affects on their physical, chemical, electrical, mechanical and other properties. The hydrogen problem arises in such areas as mechanical engineering (fragility of surfaces of friction details), gas and oil industry (fragility of inner surfaces of pipelines), hydrogen energetic and accumulators, constructional materials for nuclear technologies, thermonuclear reactors etc.

A lot of experimental methods exist now for material-hydrogen systems study. Nevertheless, only a few, such as the ion beam analysis (IBA) [1, 2], are able to probe the hydrogen directly and measure its distribution in near-surface region without destruction of the sample.

The method of hydrogen profiling (Neutron-induced Elastic Recoil Detection (NERD)) has been developed in the Institute of nuclear physics of Academy of Sciences (Uzbekistan) [3]. The method uses the information on the depth and concentration of hydrogen in a sample that is contained in the energy spectrum of H-ions knocked out by monochromatic fast neutrons produced in the neutron generator (NG). The method allows measuring of the concentration for all hydrogen isotopes simultaneously along the thickness of the sample and has the maximal analysable depth.

To achieve the best characteristics of the method the following technical problems should be solved:

(i) – increasing, as much as possible, the neutron flux on the analysed sample aimed at achieving of reasonable statistical uncertainty;

(ii) – decreasing, as much as possible, the background in the measured energy spectra of the knocked particles which is caused by intense gamma quanta, electron and charged particles irradiation that arise under the neutrons interactions with the constructional materials of the spectrometer;

(iii) – providing the energy resolution being good enough for correct particles identification and achieving of reasonable uncertainty at depth profiling.

Note that all these problems are tightly connected and some complex optimisation should be carried out at the NERD installation development. It is particularly necessary: to develop the tritium targets having high tritium concentration for the NG and to optimise the measurement geometry; to use for the detectors chamber "low background" material; to develop the electronic modules that enable to carry out primary treatment of the detector's pulses as fast as possible, as well as to develop the software for handling of the spectrometer and data processing.

Previously we have essentially reduced the background of charged particles by choosing the constructional materials and geometry factors at construction and manufacturing of the NERD-installation units [4]. That has led somewhat also to reducing of the intensity of gamma rays on spectrometer's semiconductor detectors. However, there remains a source of strong background of gamma ray, which cannot be removed in principle – the NG tritium target so it is necessary to make additional background rejection by using fast pulse's treatment.

So the set of fast electronic units were developed to improve the NERD-spectrometer characteristics. To minimise the false coincidences count rate and corresponding worsening of energy resolution [5] we turned down traditional build-up of the spectrometer as a fast - slow arrangement of circuits and use only fast branch of the electronics down to the last spectrometric amplifier that produces the spectrometric signal for amplitude-digital conversion. In the report we describe developed electronic modules and block scheme of the spectrometer. The photos of the output pulses shape for the most important assemblies of the spectrometer are presented. The method of the energy spectra forming is described and the spectrum of alpha particles of the ^{226}Ra alpha source is displayed illustrating operation of the spectrometer as a whole.

2. The set-up of the spectrometer

Schematic layout of the spectrometer is shown in Fig. 1. Distinctive feature of the spectrometer is use of fast output signal of the charge-sensitive preamplifier allowing to operate at high count rates.

The scheme contains a number of standard CAMAC modules: 1501 FA, FPA - fast amplifier (fast post-amplifier), 1502 FSCA - fast discriminator (single-channel analyzer), 23 DL - cable delay line, 1101 SA - spectrometric amplifier, 712 ADC (E, ΔE)- analogue-to-digital converter; and the blocks that were developed for the spectrometer: CSPA - charge-sensitive preamplifier with a fast output, CS – fast coincidence scheme, LG - linear gate, DL – delay line.

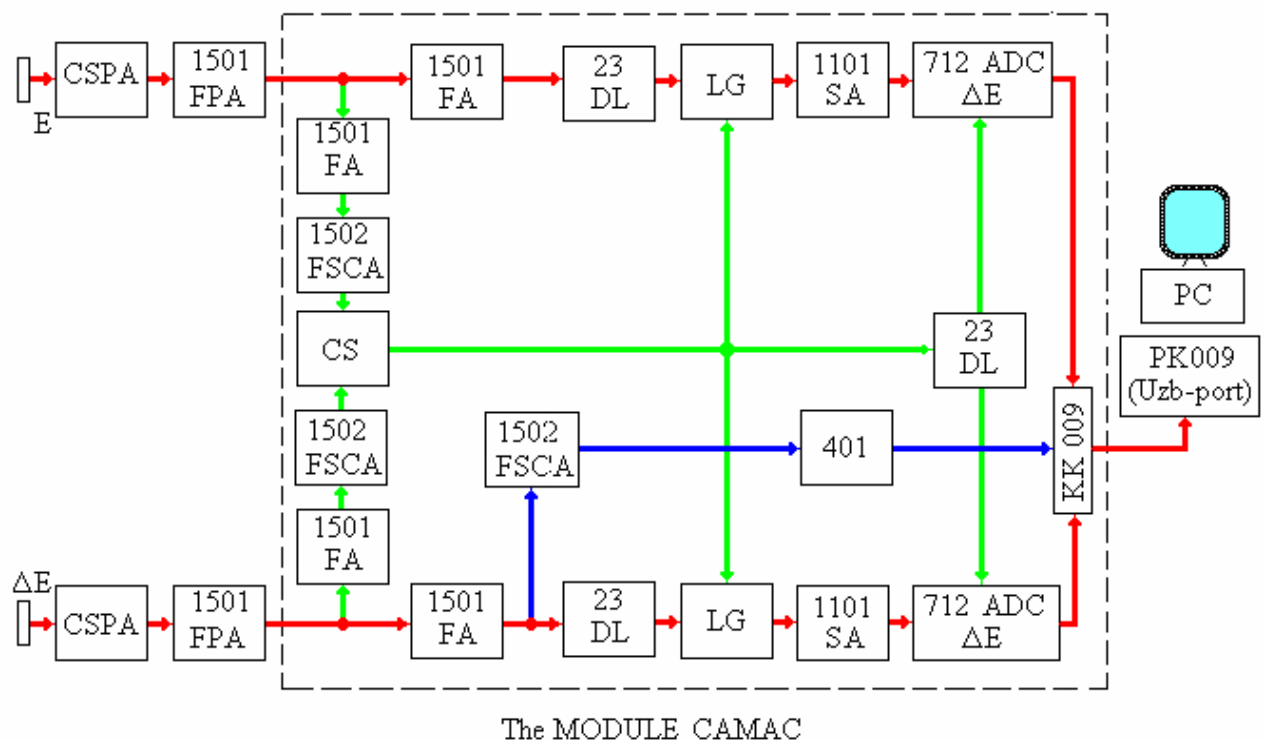


Fig. 1 Schematic layout of the NERD spectrometer.

The spectrometer operates by the following way. Fast ΔE and E signals of CSPAs are shaped and gained by fast amplifiers 1501 and then are transmitted through a cable to the measuring room. There signals are shaped and gained again by other amplifiers 1501 for optimal operation of the fast discriminators 1502 and the linear gates LG. Discriminators 1502 generate logic signals for the coincidence scheme CS.

If ΔE signal coincides with the E signal in the time interval of 50 ns, CS produces the logic pulse which opens inputs of both linear gates LG, and so signals are transmitted to the spectrometric amplifiers 1101. The amplifier shapes and gains short signals that passed through LG to adapt the shape of pulses for an input of

the ADC. The delay lines DL allow synchronizing of the spectrometric signals and gating signal (strobe) for ADC operating. The pulse stretchers and analogous summing units of ΔE and E signals are excluded in the spectrometer. Summation and treatment of $\Delta E + E$ signal is carried out by PC code NERD-EDE that has been developed for the spectrometer.

All electronic modules are adjusted on impedances and time synchronisation. The shapes of pulses of are shown in Figs. 2, 3, 4.

One can see from these figures that time resolution of the selection of events in fast part of spectrometer is about 100 ns. The 1101 SA pulses for the amplitude analysis are shaped and have larger rise time. Shape of the pulse is shown in Fig. 5.

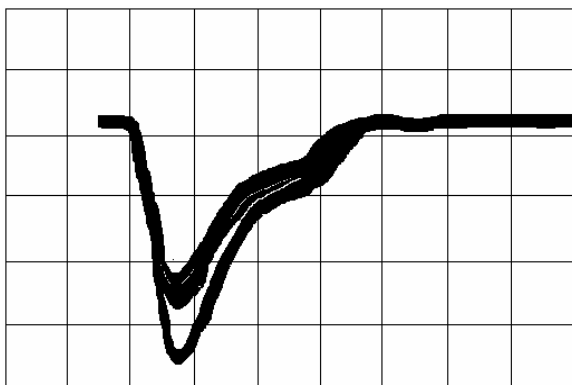


Fig. 2 The pulse shape of post-amplifier output signal. Rise time of the pulse is of 70 ns.

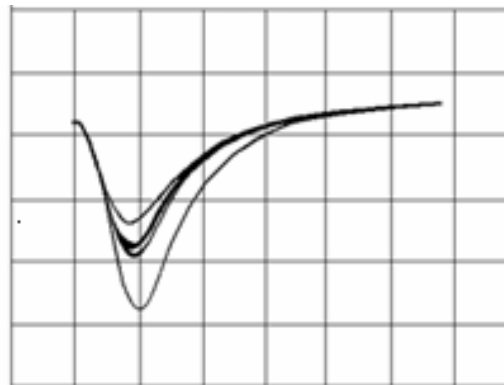


Fig. 3. The pulse shape of output signal of the amplifier 1501. Rise time of the pulse is 70 ns.

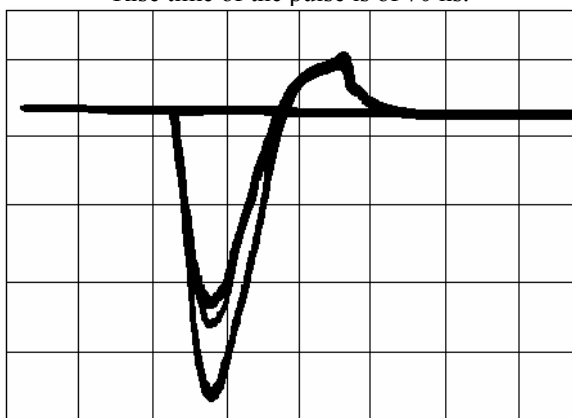


Fig. 4. The pulse shape of the fast gate output signal. Rise time of the pulse is 70 ns.

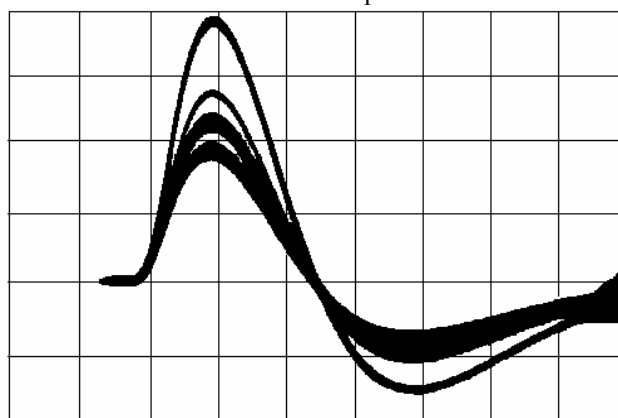


Fig. 5. Shape of the pulses on output spectrometer amplifier 1101. Rise time of the pulse is 1 μ s.

Accumulation and treatment of the energy spectrums are made under on-line PC control. The corresponding software consists of basic program NERD-EDE (written on "C"- language) and of some additional service programs. Program NERD-EDE carries out accumulation, processing and adjusting of the spectrometric information, as well as some service functions, and supports the standard graphic interface with the user. Its specific feature is the opportunity of accumulation of the information at high count rates of the spectrometer [6].

The procedure of the spectrometric information accumulation allows to build in memory of a computer both two-dimensional (ΔE , E) and linear spectra relating to various kinds of registered particles.

Marking of the loci of different detected particles in the two-dimensional (ΔE , E) matrix is carried out in an interactive mode by the keyboard or with help of the "mouse". The program allows to form also two-dimensional (ΔE , $E + \Delta E$)-spectra. After marking the loci the mode of simultaneous formation of the two-dimensional spectrum and corresponding energy spectra can be used. The energy spectra (spectra of projections to the abscissa axis) are formed by summation of channel contents along ΔE -axis of the two-dimensional (ΔE , E) or (ΔE , $E + \Delta E$) spectrum inside the marked area (locus).

The program contains various modes of accumulation of the spectrometric information. To control the value of the pulse omission owing to dead time of "CAMAC - IBM PC" system, permanent comparison of the amount of registered by the program (ΔE , E) events with the amount of strobes from the coincidence

module is carrying out. It allows choosing of suitable count rates at the measurements by adjusting of the neutron flux intensity.

The subsystem for the collected data processing works in the "off-line" mode. It includes a number of procedures, allowing making the full analysis of spectra. It gives the user the following opportunities:

marking of loci of the two-dimensional spectrum and formation of the energy spectra corresponding to various kinds of particles;

calibration of the energy scale of linear spectra by using the energy values of alphas of standard α -source ^{226}Ra ;

performance of kinematic calculations.

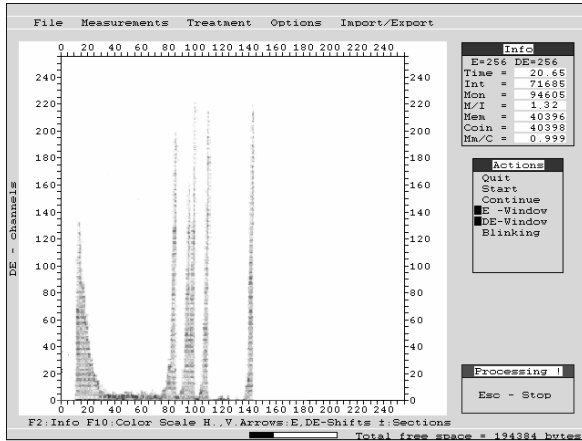


Fig. 6 Energy spectrum of alpha-particles from the α -source Ra-226.

The information presented by program NERD-EDE, can be displayed on the monitor as one-dimensional, two-dimensional and three-dimensional pictures. The $(\Delta E, E)$ -matrix size is of 256×256 channels. Volumetric display of a set of events in a two-dimensional matrix gives evident representation about intensities of various kinds and energy groups of registered particles. The practice of the use of the program has shown its convenience to the user both in the modes of adjustment of parameters of experiment, and of the data collection and treatment at the measurement. The energy spectrum of alpha particles of α -source Ra-226 together with menu of the NERD-EDE program is shown in Fig. 6.

3. Fast charge-sensitive pre-amplifier

The schematic diagram of developed charge-sensitive pre-amplifier (CSPA) for semiconductor detector of nuclear particles is shown in Fig. 7. CSPA consists of input stage with the bipolar amplifier section (BAS), which is a fast noninverting amplifier, and the signal pulse shaper (PS), intended for the transformation of CSPA output signal into the triangular spectrometric pulse.

The special feature of CSPA application in this case is the fact that the detector with the relatively high leakage current and high capacity can be used, and high count rates (up to 10^3 kps) are assumed. For eliminating the CSPA saturation by the detector leakage current, the detector is separated from the CSPA by input capacitor.

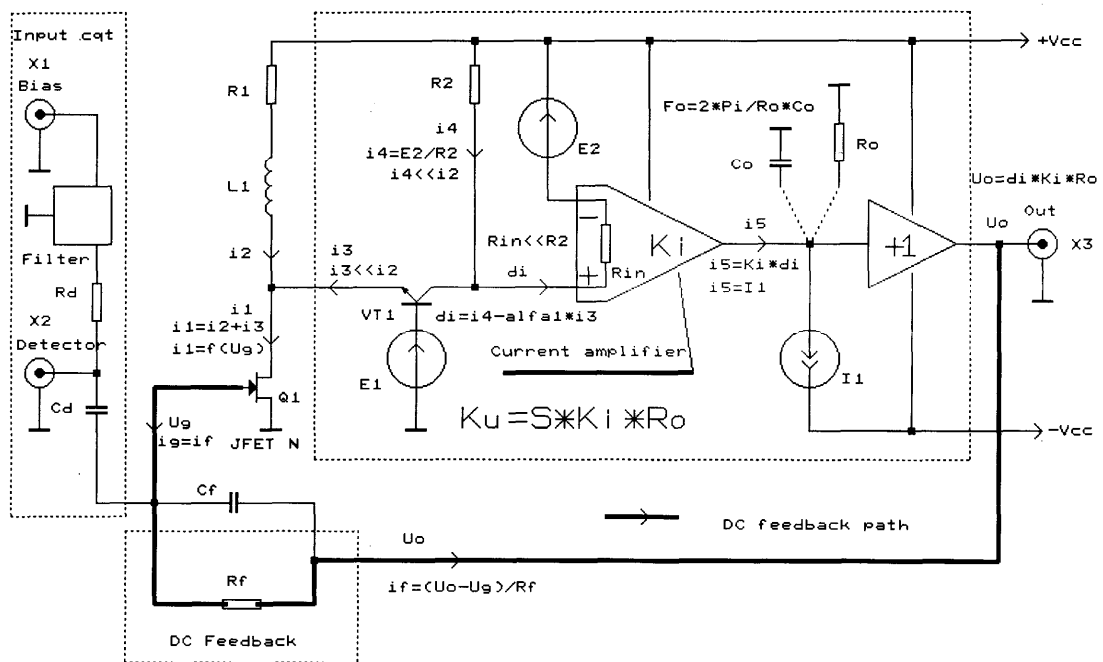


Fig. 7. CSPA block diagram.

The CSPA was tested by using pulsed laser imitator (PLI). The output light pulses of the PLI have following parameters:

the pulse amplitude range: from 50 keV to 5 MeV (energetic equivalent at 40 mV/MeV);

the pulse frequency: up to 10^6 ;

the light pulse width, not more 50 ns, i.e. something like the time of charge collection in the detector at a some charge particle detection.

Reaction of CSPA prototype with input isolating capacitor to the pulse loading is shown in Fig. 8 at laser frequency 10^5 Hz. It follows from these data that CSPA conversion coefficient doesn't change practically for the energy conversion level up to 10^5 MeV·s⁻¹. Spectrum on the right side of the α -peak is formed by pulses pile-up in comparatively slow amplifier.

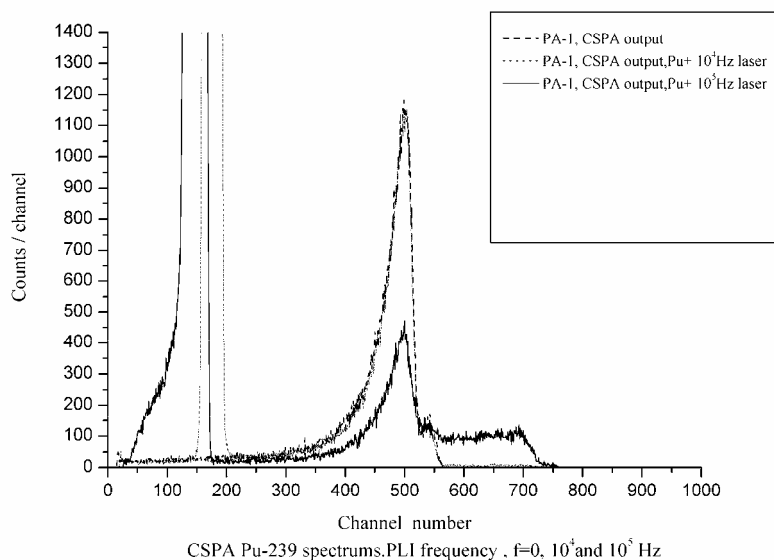


Fig. 8. Alpha-spectrum for ²³⁹Pu α -particles and 1 MeV equivalent laser pulses. Laser frequency is 0, 10^4 and 10^5 Hz. CSPA + amplifier BUI-3K are used. BUI-3K molding time is 1 μ s.

4. Design and manufacture of the fast linear gate and the coincidence circuit

Linear time gate. The pilot LG version developed on this stage of the project utilizes commercial microcircuit – very high quality analogue multiplexer having bandwidth 150 MHz (at level -3 decibel) and the switching time “channel-to channel” less then 25 ns. Through this time peak value of the switching noise is not more 50mV. LG provides gating of positive and negative pulses having minimal time width 120 ÷ 150 ns in the range 0 ÷ 2,5 V. Control pulses should be consistent with TTL level.

Developed LG module consists of two identical linear gates (channels) A and B that are placed in one CAMAC module. The LG circuit diagram is given in the Fig. 9

The scheme of another variant of the fast linear gate is shown in Fig. 10. This LG version is manufactured on basis of the fast integral multiplexer of electrical potential IC-1 (series K590 KH13). Multiplexer KH13 contains the 4-channel MOS key with interior control schemes of keys in TTL logic. The turn on/off time of the linear gate is equal 30 ns. Microchip D1 allows adapting input control signals from an input of the IC - 1. One can choose the polarity of an input control pulse by switch S1. INP1-INP4 and OUT1-OUT4 are inputs and outputs of the spectrometric signal and inp1-inp4 are the relevant guiding inputs of LG [7, 8].

At driving of the analogue linear gate based on the MOS-transistors there is “pedestal” conditioned by the driving signal. This pedestal sums with the input analogue signal and distorts it. There are the following ways to eliminate the pedestal:

- 1) using MOS-transistors with a small transmission capacitance (usually the value of it is a portion of the microfarad) as the pedestal penetrates into a chain of an analogue signal through this capacity;
- 2) using driving signal with large rise time and large fall time of the signal;
- 3) using the minimal values of resistances of a signal source and loading;
- 4) using the screen between elements of transistors;
- 5) using the consecutive-parallel modulators.

Conclusion

A number of technical developments were carried out aimed at improving of the NERD method metrological characteristics, first of all – aimed at decreasing of the statistical and spatial uncertainties. These objectives are achieved as the result of reduction of both - charge particle (mainly relates to statistical uncertainty) and gamma- quantum (mainly relates to spatial uncertainty) backgrounds in the pulses entering to ADC for further data processing. To reduce the particles and gamma-ray fluxes through detectors, the telescope box was made of graphite having comparatively small cross- sections of interactions with fast neutrons, and mass of the chamber was made minimal to diminish the yield of gamma quanta. Using fast electronics carries out further background reduction. Here two approaches were applied. On the one hand for the NERD installation special electronic unites, i.e. charge – sensitive pre- amplifiers, linear gates and coincidence scheme were developed, on the other hand instead of traditional fast - slow arrangement of circuits the fast branch of the electronics is used up to the last spectrometric amplifier. The pilot version of the electronic modules was tested by pulse laser background imitator that allows simulating of “particles” and “quanta” detection practically for any given energy range and for frequencies up to 10^6 Hz. The pilot units have rather good characteristics:

CSPA module with output pulse shaper has the pulse width on the 0.1 amplitude level not more 380 ns on the input range 50 keV - 30 MeV. Special stabilisation scheme that is used in the CSPA enables support the conversion coefficient stability at the “energy count-rate product” up to 10^5 MeV·s⁻¹ and for detectors having capacity up to 1000 pF. That provides the NERD spectrometer work with overlapping not more then 10% at the count rates up to $4 - 5 \cdot 10^5$ s⁻¹;

linear gate module has switching time near 20 ns and pulsed/DC control modes and allows transmit analogue pulses in the dynamical range not less the 10^2 . In the NERD installation the couple of LG modules is used, in the installation both LG are placed in one CAMAC module and may be switched by one pulse (here - from the CS). This pulse starts internal LG time interval in regulable range 300 - 1000 ns.

Now for all modules the documentation for its mounting on the printed plats is developing for completing of the final version of NERD installation and possible (semi-) industrial production.

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ОПТИМИЗАЦИЯ МЕТОДА ЯДЕР ОТДАЧИ ДЛЯ АНАЛИЗА ПРОФИЛЯ КОНЦЕНТРАЦИИ ИЗОТОПОВ ВОДОРОДА В МАТЕРИАЛАХ

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Профилирование концентраций изотопов водорода в различных материалах сегодня весьма актуально, так как уже в относительно малых концентрациях водород сильно воздействует на физические, химические, электрические и другие свойства материала. В ИЯФ АН Узбекистана разработан метод профилирования на основе измерения спектров рассеянных ядер водорода при облучении образца быстрыми монохроматическими

нейтронами (Neutron-induced Elastic Recoil Detection (NERD) method). Метод дает возможность одновременного измерения профилей концентрации всех изотопов водорода до глубины 1,5 мм для ^1H . Улучшение аналитических характеристик метода достигается в экспериментальной установке при снижении, насколько это возможно, фона гамма-квантов и заряженных частиц в измеренном спектре путем оптимизации конструкции и выбора материалов с малым сечением взаимодействия с нейтронами при разработке и изготовлении механических блоков установки, а также при оптимизации электронной схемы. Чтобы уменьшить вклад ложных совпадений и соответствующее ухудшение разрешения, мы отказались от традиционной быстро-медленной схемы спектрометра и используем быструю ветвь электроники вплоть до финишного спектрометрического усилителя, сигнал с которого уже непосредственно подается на блок амплитудного преобразователя. В докладе приведено описание блок-схемы спектрометра, а также специально разработанных быстрых схем первичной аналоговой обработки импульсов – зарядово-чувствительного предусилителя, линейных входов и схемы совпадений.

ОПТИМІЗАЦІЯ МЕТОДУ ЯДЕР ВІДДАЧІ ДЛЯ АНАЛІЗУ ПРОФІЛЮ КОНЦЕНТРАЦІЇ ІЗОТОПІВ ВОДНЮ В МАТЕРІАЛАХ

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Визначення розподілу концентрацій ізотопів водню по глибині залягання (профільювання) в різноманітних матеріалах має сьогодні актуальне значення, оскільки, навіть у відносно малих величинах, водень значно впливає на фізичні, хімічні, електричні та інші властивості матеріалу. В Інституті ядерної фізики АН Республіки Узбекистан розроблено метод профільювання на основі вимірювання спектрів розсіяних ядер водню під час опромінення зразка швидкими монохроматичними нейтронами (Neutron-induced Elastic Recoil Detection (NERD) method). Це дало можливість провести вимірювання профілів концентрації одночасно всіх ізотопів водню до глибини 1,5 мм для ^1H . Покращення аналітичних характеристик методу було реалізовано на експериментальній установці при зниженні, наскільки це можливо, в отриманих спектрах фону від γ -квантів і заряджених частинок. Цього було досягнуто шляхом оптимізації конструкції та вибору матеріалів із малим перерізом взаємодії з нейтронами під час розробки та виготовлення механічних блоків установки, а також модернізацією її електронної схеми. Щоб зменшити вклад помилкових збігів, що приводить до погіршення роздільної здатності, ми відмовилися від традиційної швидко-повільної схеми спектрометра й використовуємо швидкодіючий електронний тракт аж до фінішного спектрометричного підсилювача, сигнал з якого безпосередньо подається на блок амплітудного перетворювача. У доповіді наведено описання блок-схеми спектрометра, а також спеціально розроблених швидкодіючих схем первинної аналогової обробки імпульсів: зарядо-чутливого попереднього підсилювача, лінійних воріт і схеми збігів.