

CHOICE OF ION LINAC AS NEUTRON GENERATOR FOR CONTRABAND-DETECTION SYSTEM

Yuri Svistunov, Michael Vorogushin (NIEFA, St. Petersburg)
 Dmitri Semenov, Boris Vodennikov (Res. Sci. Institute of Pulsed Technology, Moscow)

Abstract

8 MeV proton linac and 4 MeV deuteron linac with working frequency 433 MHz are considered as neutron generator for detection systems of explosive and fission. Required beam parameters, target materials, pulsed modulation and detection methods are discussed. Possible schemes of accelerating system of contraband detection complex are proposed. One supposes using RFQ for deuteron linac and RFQ with IH-cavity as proton one. Choice is determined by some few criterions: cost, sizes, safety, hardness of manufacturing and tuning.

INTRODUCTION

All methods of nuclear physics to a certain extent use element analysis of material. Basic elements of chemical composition of commercial and military explosives are nitrogen, oxygen, hydrogen, carbon. These elements are part of typical food-stuffs, textiles, polymers too. But explosives have special characteristics:

- relatively high density;
- rich content of nitrogen and oxygen and relatively poor content of carbon and hydrogen.

Exposure such specificity under small quantity explosives in object which filled up big quantity of substance, need information about nuclear concentrations inside each elementary volume of researched object. Gamma quanta of inelastic scattering of neutrons on N, C, O nuclei are measured with help time-of-flight technique. PFNA is perhaps best method of nuclear physics to detect explosives and fission [1],[2]. According to information detection complex using PFNA technique had been created in USA and will be tested in 2006. At present explosive detection systems in airports of USA and Russia use TNA (Thermal Neutron Activation) or API (Associated Particle Interrogation) methods. In case of TNA method presence of explosives is determined by content of nitrogen only. It gives big quantity of false alarms. In case of API method one measures gamma quanta of neutron scattering on N, O, C nuclei (neutrons from $T(d,n)^4He$ reaction), but there is principal limit of source intensity so far as time of measuring cannot be short. In contrast of these installations detection complex on base linac with PFNA may provide average neutron flux at least by factor 10^2 more and pulsed flux up to 10^{14} n/s. So it is possible to provide real time regime of baggage examination under passing velocity up to 450 units/hour.

COMPARISON (d,n) AND (p,n) REACTIONS

To obtain monoenergetic neutrons usually one use (d,n) and (p,n) reactions on light nuclei. Main characteristics of neutron source (depending of yield and neutron energy on angle of departure and energy accelerated particles) are determined by reaction's properties and laws of conservations of energy and momentum. Following requirements must be fulfilled:

- accelerated particles must have small energy spread because neutrons repeat this spread. This suggest target thickness must be very small ($d \approx \Delta E / (dE/dx)$), where ΔE - admissible spread of charged particles; dE/dx - specific ionization lost of charged particle of energy E;
- residual nucleus must not have low -lying exited levels, otherwise neutron energy is not determined one-to-one and it depends on nuclear state;
- another nuclear reactions must not take place, which could give neutron yield with different energy;
- reaction's cross-section must be big enough to provide required neutron flux.

Analysis of the most spreaded reactions which may be used for obtaining neutrons of required energy shows there are only two right reactions for producing of 7-9 MeV monoenergetic neutrons: $D(d,n)^3He$ and $T(p,n)^3He$. First of reactions is used in generally accepted version of PFNA [1]. Under 4.3 MeV deuterons it gives neutron energy 7.5 MeV for outgoing neutrons at null angle. Deuteron energy 4.3 MeV is near optimal one. It's increasing opens reactions of deuteron splitting which add to monoenergetic neutrons a new ones with different energy. Reaction $T(p,n)^3He$ gives 7.5 MeV neutrons at null angle under proton energy 8.32 MeV. This energy is near optimal too. One cannot increase it strongly because opening of three-particle reaction's channel $T(p,pn)D$ where neutrons have continuum spectrum. Depending of neutron energy on emission angle in laboratory coordinate system is given in table 1.

Table 1: Neutron Energy (MeV) depending on Flight Out Angle

Neutron flightout angle in laboratory coordinate system (grade)		0	10	30	60	90	120	150	180
$D(d,n)^3He$ under $E_d=4.3$ MeV		7.55	7.47	6.85	5.20	3.52	2.39	1.81	1.64
$T(p,n)^3He$ under $E_p=8.32$ MeV		7.55	7.47	6.86	5.24	3.59	2.46	1.88	1.70

Differential section of forward scattered neutrons under consideration of monoenergetic neutron producing offers

the greatest interest. Let one consider depending of neutron yield on deuteron energy in $D(d,n)^3\text{He}$ reaction. Under decreasing deuteron energy up to 3.5 MeV (energy of forward-scattered neutrons will be 6.7 MeV) forward-scattered neutron yield decreases slightly. But possibilities of using deuteron linacs of 4.3 and 3.5 MeV for PFNA-method realization are comparable. Sections of reactions $D(d,n)^3\text{He}$ for $E_d=4$ MeV and $T(p,n)^3\text{He}$ for $E_p=8$ MeV are given in table 2.

Table 2. Sections of $D(d,n)^3\text{He}$ and $T(p,n)^3\text{He}$ Reactions

Reaction	Total cross-sections, mbarn	Differential section of forward-scattered neutrons, mbarn/steradian
$D(d,n)^3\text{He}$ under $E_d=4.3$ MeV	99	65
$T(p,n)^3\text{He}$ under $E_p=8.32$ MeV	223	28

Comparison of these values shows preference of $D(d,n)^3\text{He}$ reaction. Forward-scattered neutron yield from thin target bombarded by equal fluxes of falling particles (proton and deuteron accordingly) is 2.5 times as much for $D(d,n)^3\text{He}$ reaction. In addition background radiation conditions created by neutron source of $T(p,n)^3\text{He}$ reaction is worse because total neutron yield of this reaction two times as much than $D(d,n)^3\text{He}$ reaction's yield. Without considering technology of manufacturing and exploitation of deuterium and tritium targets one may see peculiarity of neutron yield from target. Special ionization losses of deuteron with energy E are equal ionization losses of proton with energy $E/2$ that is 4 MeV deuteron losses is according to 2 MeV proton losses in one and the same medium. Using data of proton paths and stopping powers one can see that relation $(dE/dx)_{E=2\text{MeV}} / (dE/dx)_{E=8\text{MeV}}$ is:

- 3.17 in hydrogen isotope medium;
- 2.18 in tantalum which are used frequently as underlying material under manufacturing of solid deuterium and tritium targets.

Target thickness is determined by relation $d \approx \Delta E / (dE/dx)$. It follows that when reaction $T(p,n)^3\text{He}$ is used target providing acceptable energy spread of sounding neutrons ΔE may be two-three times as much than deuterons are. As result yield of monoenergetic 7.5 MeV forward-scattered neutrons having the same energy spread for both reactions practically is the same but total yield in case of $T(p,n)^3\text{He}$ reaction will be five times as much than yield of $D(d,n)^3\text{He}$ one. This makes background radiation conditions in proton case worse and it may have decisive importance in detection time. Therefore reaction $D(d,n)^3\text{He}$ is more promising when PFNA-method is used for element analysis of object with explosives. As regards the fission registration one may note that observation of neutrons of forced fission under background radiation of sounding neutrons is hopeless task if fission is small part of inspected object. Therefore all methods are based on dividing of sounding and secondary radiations by time, either by energy or specific indications (for example, multiplicity of fission neutrons).

Most universal methods of inspection of broad class objects are method of differential damping and method of measuring of delayed neutrons. Detection of fission in complex objects with help instantaneous and delayed gamma quanta is connected with difficulties because big quantity of background quanta appeared as result inelastic scattering and nuclear capture of incoming neutrons in researched object.

COMPARISON OF PROTON AND DEUTERON LINACS

Possible inspection's scheme with particle acceleration by 432 MHz linac is shown on fig.1. In case of deuteron linac accelerating resonator is RFQ, in case of proton linac it is RFQ plus APF cavity. Efremov Institute project is supposed acceleration of deuterons from 150 keV up to 4 MeV by RFQ and acceleration of protons from 60 keV up to 2 MeV by RFQ and from 2 MeV up to 8 MeV by APF cavity. It is possible in proton case to provide average accelerating gradient higher than in deuteron variant. Both variant provide energy spread near 5% because bunches of small phase length are injected into accelerator. Proton accelerator is more compact. It has more simple alignment and manufacture. But proton accelerator must work with tritium target. Deuteron linac must work with deuterium target which has thickness providing deuteron energy loss not more than ΔE . Neutron yield on one deuteron is near $(1 \cdot 10^{-4} \text{ neutron/steradian} \cdot \text{MeV}) \cdot \Delta E$. Proton linac works with tritium target providing proton energy loss not more than ΔE . Forward-scattered neutron yield on one proton is near the same. But total neutron yield in proton case is by factor 10 more. Therefore background radiation conditions in this case can be much worse.

CONCLUSION

Comparative analysis of possibilities of use of 4 MeV deuteron linac and 8 MeV proton linac as sources of nanosecond monoenergetic neutron pulses with energy near 7 MeV shows that deuteron accelerator is better. There are other detection methods which need fast neutron source of broad energy spectrum. Then one may use both linac types. A thick beryllium target is fitted for both cases (8 MeV proton linac and 4 MeV deuteron one). But the target thickness for proton beam must be 0.2 g/cm^2 opposite 0.02 g/cm^2 in case of deuteron beam.

REFERENCES

- [1] Tsani Gozani and Patrick M. Shea, SAIC. Nuclear based Explosive Detection System 1992 Status. Proceedings of the 4th International Symposium on Analysis and Detection of Explosives, Jerusalem, Israel, September 7-10, 1992.
- [2] Lee Grodzins, "Nuclear techniques for finding chemical explosives in airport luggage," Nuclear Instruments & Methods in Physics Research. B 56/57 (1991), 829-833.

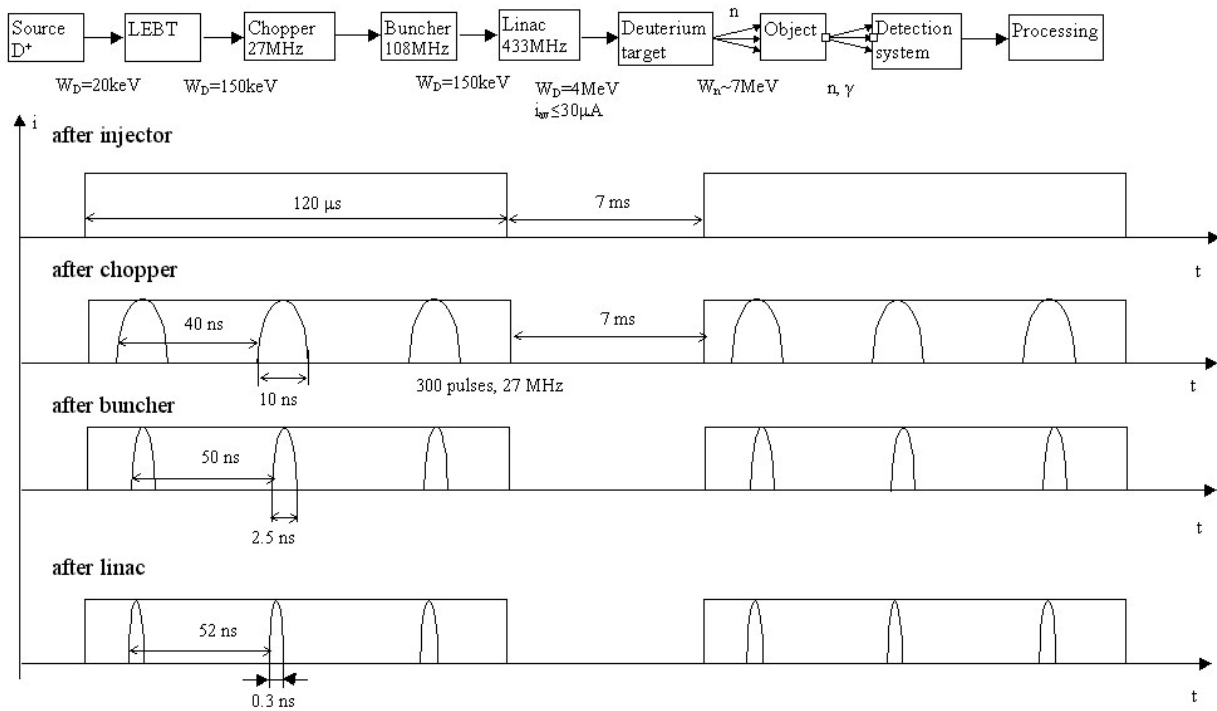


Figure 1: Scheme of deuteron obtaining on the target.