APPLICATION OF NUCLEAR METHODS

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PRODUCTION OF PHOSPHORUS-32 AT A NEUTRON GENERATOR AND IT'S SEDIMENTARY ISOLATION

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Phosphorus-32 is a β-emitter with a maximum energy of 1.7 MeV (such radiation is completely absorbed in a layer of water or biological tissue up to 1 cm thick) and a half-life of 14.29 days can find application in medicine to study the circulation of substances. This isotope is best obtained from sulfur by the reaction ^{32}S (n, p) ^{32}P, followed by precipitation using neutron generator.

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INTRODUCTION

Radioactive phosphorus is used to study the functional state of the kidneys, to detect superficial tumors, to determine breast cancer metastases, blood flow rate, phosphorus distribution in various structures of the eye, in the tissues of the salivary glands and dental tissue. Radioactive phosphorus is selectively deposited in bones. In some malignant tumors, especially of the brain, P-32 is concentrated 10-100 times, and sometimes up to 500 times, than in normal tissue. For radiation therapy P-32 with activity calculated in millicurie units (mCi) is used in the form of soluble disubstituted sodium phosphate ($Na_2H^{32}PO_4$) or as insoluble chromium phosphate ($Cr^{32}PO_4$). ^{32}P is considered the best known remedy for the treatment of the hematopoietic system. ^{32}P refers to substances of average radiotoxicity, when working with an activity not exceeding 10 mCi in the workplace, it does not require special protective measures. It is used for brachytherapy, in particular for the treatment of capillary hemangiomas as applications [1], for the treatment of cancer of the pancreas and prostate [2].

1. WAYS OF OBTAINING RADIOACTIVE PHOSPHORUS

This isotope can be obtained in two main ways: from sulfur ^{32}S (n, p) ^{32}P and from stable phosphorus ^{31}P (*n*, γ) ^{32}P. It is better to use the first way so as not to have a mass of inactive phosphorus, but then it is necessary to separate phosphorus from a large amount of sulfur. In general, phosphorus-32 can be obtained by other reactions: ^{31}P (d, p) ^{32}P; ^{35}Cl (n, α) ^{32}P; ^{34}S (d, α) ^{32}P; ^{29}Si (α, p) ^{32}P. However, in our conditions they are difficult to implement. The most attractive way is to obtain radioactive phosphorus from natural sulfur, since there are no harmful fumes of carbon disulphide. It is not possible to carry out an easy way to isolate phosphorus-32 from the mass of inactive natural phosphorus. As a neutron source, we offer a compact generator that includes a deuteron accelerator and a metal target.

2. NEUTRON GENERATOR

In the neutron generator, neutrons with an energy of 10 MeV will be obtained when deuterons interact with lithium according to the reactions:

$$^2H+^7Li \rightarrow ^8Be+n+15.028 \text{ MeV};$$

$$^2H+^7Li \rightarrow 2^4He+n+15.122 \text{ MeV};$$

$$^2H+^7Li \rightarrow ^4He+^5He+14.165 \text{ MeV};$$

$$^5He \rightarrow ^4He+n+0.958 \text{ MeV}.$$

The neutron generator [4] (Fig. 1) is a container lined with graphite for neutron reflection; at the bottom of the container there is a quartz glass vessel filled with powdered sulfur or liquid carbon disulphide. Deuterons are preliminarily accelerated in a linear accelerator. The production of phosphorus-32 is carried out for at least 1 day.

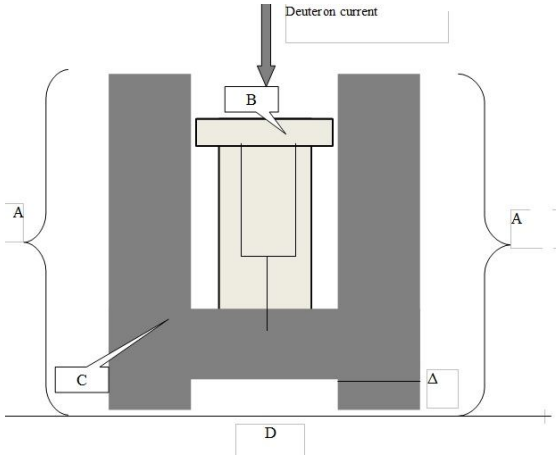

Fig. 1. The main elements of the target location and neutron motion:
A – primary fast neutrons; B – target block (deuterons interact with beryllium or lithium nuclei); C – the target for neutrons is a vessel with carbon disulphide CS_2 or pure sulfur S; D – retarder-reflector (graphite),
Δ is the width of the layer of a substance containing sulfur (CS_2 or elemental sulfur)

3. ISOLATION OF PHOSPHORUS FROM THE TARGET

To facilitate the release of the accumulated phosphorus, it must be oxidized to orthophosphate ion (PO_4^{3-}). To do this, a few drops of bromine are added to the liquid target, the oxidized phosphorus is extracted with dilute nitric acid, which is subsequently distilled off. We chose sulfur as a target to ensure safe working conditions. A solid sulfur target was treated with hot concentrated nitric acid. The sulfur was removed by filtration, and the orthophosphate ion was precipitated from the

solution. Precipitates with orthophosphate ion can form many metal ions, but the best method is selective precipitation in the form of yellow phosphoromolybdate

$$(NH_4)_3PO_4 \cdot 12MoO_3 \cdot 2HNO_3 \cdot H_2O \text{ [4]}$$
or $(NH_4)_3PO_4 \cdot 12MoO_3 \cdot 6H_2O$ [5].

To accelerate the precipitation, the presence of 5…10% ammonium nitrate in the solution is useful; the nitric acid content can also vary within 5…10%. The resulting precipitate contains molybdenum, which must be disposed of. For this, the precipitate was dissolved in hydrochloric acid and phosphorus was precipitated in the form of magnesiumammonium-phosphate ($MgNH_4PO_4$). For deposition, a magnesian mixture ($MgCl_2$; NH_4Cl; NH_4OH) was used:

$$HPO_4^{2-} + Mg^{2+} + NH_4OH = MgNH_4PO_4 \downarrow + H_2O.$$

The most complete release of radioactive phosphorus will be provided by the collector – phosphoric acid. Other reactions can be used to isolate orthophosphate ions. With accurate pH adjustment (6.6), a white crystalline precipitate $ZnNH_4PO_4$ is formed. Metatin acid gel absorbs orthophosphate ion quantitatively from aqueous solutions. Concentrated nitric acid and a few tin granules are added to the solution, stirred while heating:

$$3Sn + 4H^+ + 4NO^{3-} + H_2O = 3H_2SnO_3 + 4NO,$$
$$nH_2SnO_3 + mPO_4^{3-} \rightarrow nH_2SnO_3 \cdot mPO_4^{3-}.$$

In the gel particles, hydrogen ions are likely to be counterions. Iron hydroxide also quantitatively sorbs phosphorus from solution. The use of sediments other than phosphoromolybdate and magnesium ammonium phosphate requires additional study.

CONCLUSIONS

The production of the promising medical isotope phosphorus-32 is hampered by the lack of an available neutron source and a simple method for chemically separating phosphorus from the target matrix. The design of a neutron generator proposed by us for obtaining a radioisotope of phosphorus, as well as a sedimentary method for extracting phosphorus, can find application.

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ПОЛУЧЕНИЕ ФОСФОРА-32 НА НЕЙТРОННОМ ГЕНЕРАТОРЕ И ОСАДОЧНОЕ ЕГО ВЫДЕЛЕНИЕ

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Фосфор-32 – это β-эмиттер с максимальной энергией 1,7 МэВ (такое излучение полностью поглощается в слое воды или биологической ткани толщиной до 1 см) и периодом полураспада 14,29 суток, он может найти применение в медицине для изучения круговорота веществ. Этот изотоп лучше всего получать из серы по реакции ^{32}S (n, p) ^{32}P с последующим осадочным выделением с помощью нейтронного генератора.

ОТРИМАННЯ ФОСФОРУ-32 НА НЕЙТРОННОМУ ГЕНЕРАТОРІ ТА ОСАДОЧНЕ ЙОГО ВИДІЛЕННЯ

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Фосфор-32 – це β-емітер з максимальною енергією 1,7 МеВ (таке випромінювання цілком поглинається в шарі води або біологічної тканини до 1 см завтовшки) і періодом напіврозпаду 14,29 доби, він може знайти застосування в медицині для вивчення круговерті речовин. Цей ізотоп краще отримувати за реакцією ^{32}S (n, p) ^{32}P з наступним осадочним виділенням за допомогою нейтронного генератора.