

Review for the project
“Study of Deeply subcritical accelerator driven systems and features of their application for energy production and Transmutation of spent nuclear fuel (E&T-TSNF) ”

To realize the potential of nuclear energy as the main source of future energy, it is necessary that it be safe and has effective technologies for waste processing.

The problem of the spent fuel can be solved in a fundamentally different way when processing fuel and fractionating (separating) of radioactive elements.

This new approach developed in recent years is the creation of new nuclear processing technologies, in particular nuclear transmutation - the transformation of long-lived radionuclides into stable or short-lived nuclides under the action of n , p , α , $-e$ and other particles irradiation.

It is assumed that neutron transmutation of long-lived radioactive materials using synergistic systems will be the most promising direction of nuclear transmutation.

Synergistic systems involve the unification of various technologies, including nuclear technologies (fission, synthesis and splitting of nuclei by high-energy particle beams), to develop an integrated system of energy and the implementation of energy-producing systems.

In the 1990s of XX century, the concept of using high-energy accelerators for the large-scale use of splitting reactions began to be intensively developed in order to generate neutrons in heavy extended targets, which, when multiplying in a subcritical ($k_{\text{eff}} \sim 0.9-0.98$) blanket, induce fission reactions of uranium or thorium nuclei (Accelerator Driven Systems - ADS). There were proposed three basic projects by Prof. C. Bowman (ADS with thermal neutron spectrum for fission products transmutation); Prof. H. Takahashi (ADS with fast neutron spectrum for minor actinides transmutation) and Nobel prize winner C. Rubbia (ADS with resonance neutron spectrum for fission products transmutation and minor actinides incineration).

Such a system makes it possible to obtain sufficiently high neutron fluxes ($\Phi \sim 10^{15-17}$ neutrons/(cm²·s)), generating energy, transmuting radiotoxic isotopes, generating tritium for thermonuclear facilities or plutonium for fast reactors.

To implement ADS-systems it is necessary to solve a number of physical and technical problems:

1. Select the energy and current of the proton beam and create an accelerator with the required parameters;
2. Select the target material and create a target design for obtaining the fission neutrons;
3. To develop a scheme of heat extraction in the target block;
4. To develop a scheme and design of a subcritical blanket and to solve issues of nuclear safety;
5. To develop a scheme for heat extraction in a subcritical blanket;
6. To determine the reaction rates of transmutation of long-lived nuclides and the rate of their formation.

To date, despite a rather large number of theoretical papers, the problem of choosing the most optimal energy spectrum of neutrons for transmuting of long-lived fission fragments of iodine, cesium, strontium, zirconium and minor actinides of neptunium, plutonium, americium, curium persists one of the most urgent.

First of all, this is due to insufficiently accurate data on the interaction cross sections of neutrons with radioactive nuclei over a wide energy range from electron volts to tens of thousands of mega-electron-volts.

In this context, it is of significant interest the possibility of experimental studies of various aspects of the ADS using existing accelerators.

The first part of the proposed project was carried out at JINR (Dubna, Russia) in 2001-2013 years on the target of natural uranium (setting "Quinta") irradiated with deuterons (energy 0.5 - 4 GeV / nucleon).

Within the framework of the research, methods for measuring various neutron-physical characteristics (beam parameters, impulse characteristics, fission and capture numbers, neutron output, etc.) were tested.

These techniques and the created equipment will be used in the proposed project, and can also be used in other installations of this type.

In recent decades, studies of subcritical systems controlled by accelerators have been actively conducted in the nuclear centers of the EU (Mazurka, Guinevere, MYRRHA), Japan (CUCA), Belarus (YALINA), China (VENUS) and other countries.

Such work is carried out mainly on subcritical systems of zero power using the available low-energy accelerators and neutron generators.

The first subcritical 100 kW reactor will be a neutron source (Kharkov, Ukraine).

The project "Study of Deeply subcritical accelerator driven systems and features of their application for energy production and Transmutation of spent nuclear fuel (E&T-SNF) will be devoted to experimental and theoretical studies of various neutron-physical characteristics after irradiation of a large uranium target with high-energy deuteron beams.

In the process of passage of high-energy particles and nuclei through different substances two stages are distinguished. The stages differ in the time and nature of the interaction.

The first stage is associated with intensive generation of particles in high-energy splitting reactions, fission, and their propagation in matter, which ends in the formation of neutrons with energy $E_n \leq 20$ MeV.

The second stage is associated with the propagation of low-energy neutrons.

Thus, the main part of the neutron spectrum in heavy targets is made up by neutrons in the energy range $E < 20$ MeV, which was shown by theoretical and experimental studies.

When irradiating targets containing fissile (Th, U, Pu, ...) nuclei, fission reaction neutrons will give a significant contribution to the neutron component.

The energy distribution of the neutron flux density will undoubtedly be determined by the material composition of the medium (environment).

It is obvious that as the size of the target increases, the fraction of high-energy particles decreases due to a reduction in both elastic and inelastic interactions.

The energy spectrum of the neutrons formed in the uranium target basically will be determined by neutrons with energy $E_n < 20 \text{ MeV}$

In a large uranium target, a rigid neutron spectrum will be formed due to the absence of light nuclei. This will make it possible to measure the spectral characteristics and cross sections of various reactions in this energy range.

The experimental data that can be obtained within the framework of this project are of great interest from the viewpoint of the connection between the accelerator and the subcritical reactor, the development of neutron measurement techniques, the verification of computer codes and the libraries of the estimated nuclear data in the high-energy range.

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