CONDITIONS FOR EFFECTIVE UTILIZATION OF THE ELECTRONUCLEAR BLANKET SYSTEM AS A NEUTRON SOURCE

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The efficiency of an intermediate-energy electronuclear setup with a blanket as an alternative source of neutrons is discussed on the basis of experience in designing the electronuclear neutron generator at the Institute of Theoretical and Experimental Physics. A classification of electronuclear setups is introduced. The factors determining the efficiency of the driver-target-multiplying blanket scheme at low and intermediate driver energies are examined. To obtain high neutron fluxes, the possibility of compensating an inadequate driver current by decreasing the subcritical store is examined and the conditions for realizing such a possibility while preserving the fundamental requirement of nuclear safety are formulated. The concept of the criterion of dynamical safety, in contrast to the criterion of static safety ordinarily assumed for subcritical systems, is introduced. A program of precision investigations for studying operating regimes of a blanket under conditions of a low store of subcriticality is formulated on the basis of the criterion of dynamical safety. The results of an implementation of this program are important for the assessment of the technological possibility and desirability of replacing research reactors with subcritical setups based on an accelerator. 2 figures, 6 references.

Classification of Systems and the Components of the Efficiency. Electronuclear systems are ordinarily classified according to power: low-power systems, demonstration systems, and power-generating systems. They can also be nominally classified according to the target material and the energy of the driver particles. Tritium and deuterium targets and deuteron-based drivers with energies up to 2 MeV are low-energy systems; targets consisting of light metals for protons with energies up to 100 MeV or deuterons up to 30 MeV are intermediate-energy systems; targets consisting of heavy metals predominantly in a liquid form with protons from 100 to 600 MeV are medium-energy systems; targets consisting of heavy elements in the form of melted salts or lead-bismuth eutectics and protons from 600 MeV up to 2 GeV are high-energy systems.

The boundaries of these classes can be adjusted or other types of targets can be added, but the difference in their purpose is obvious. Low-energy installations function as neutron sources. At intermediate energies radionuclides can also be produced on the basis of both neutrons and protons. Setups in this range can be used to simulate operational algorithms for control, diagnostics, and protection systems for other ranges. At medium energies, it is possible to solve, besides the problems enumerated above, the problems of simulation and testing of real units and subsystems for installations belonging to the next energy class. High-energy systems are intended primarily for reprocessing radioactive wastes, but they can also be equipped with equipment for standard research problems, for example, with a neutron moderator and channels for extracting neutrons.

A scheme with a blanket that multiplies thermal neutrons can be used in low and intermediate energy systems to compensate a low driver current and a low neutron yield from the target. A two-section blanket, multiplying in the first section fast neutrons from the target and in the second section thermal neutrons is also possible. Either scheme can be implemented for an intermediate-energy installation with two target variants. The first variant employs a stable material with a low neutron absorp-
tion cross section, for example, beryllium or $^7$Li. In the second variant a fissioning element is used, for example, an isotope or a mixture of isotopes of uranium in a specially selected matrix. The second variant is preferable with respect to neutron yield. However, in this variant replacing the target unit is comparable to removing a spent fuel channel. A spent target unit requires a special repository and further reprocessing, which makes the installation more complicated to operate. Medium- and high-energy systems produce tens of neutrons per proton, and they do not require blankets.

In the present paper, only intermediate-energy setups with stable light-metal targets surrounded by a blanket with a channel structure and fuel based on highly enriched uranium are considered.

The efficiency of an intermediate-energy system includes the following:

the efficiency of the accelerator from the standpoint of achieving high operational efficiency, a high current of accelerated particles, the stability of the beam position on a target or a system of targets; and automation of beam control for stabilization of the beam on the target:

the efficiency of the target unit, which means a high target resource (high proton and neutron fluence); this is necessary in order to prevent frequent overloads of the target unit:

an optimal relative arrangement of the fuel channels in the blanket, the channels for introducing the driver beam, and the target reloading channels; in an optimal structure the beam input channel does not prevent access to the fuel channel and the fuel reloading channel, the target can be reloaded remotely and automatically as the service life is depleted, irrespective of the state of the beam transport and fuel channels:

a high neutron flux density in the experimental channel, which made possible the required changes in the reactor from the standpoint of not only safety but also setting up precise experiments; and

convenient access to the core and reflector for placement of service lines for the cryogenic moderators and experimental setups.

The first three components are not considered in the present paper. The present analysis is confined to a discussion of the efficiency of the blanket. We note that the optimal procedure would be to determine first the most effective structure of an electronuclear setup from the standpoint of standard operation and then to examine questions concerning transport of the beam to the target. In analyzing the efficiency, we proceed from experience in designing an apparatus in which the proton channel is also the channel for loading the target unit [1].

**Blanket Efficiency.** To substantiate the feasibility of switching from a reactor to an electronuclear setup, it is necessary to show that the thermal-neutron flux in the experimental channel does not decrease in enhanced-safety setups. We shall estimate it according to the formula

$$F = JY\epsilon(1 - K_{eff})^{-1},$$

where $J$ is the beam current on the target, mA; $Y$ is the neutron yield from the target in a $4\pi$ solid angle per unit current; $\epsilon$ is the efficiency of conversion of neutrons from the target into thermal neutrons that give rise to fissioning of the fuel; and $K_{eff}$ is the effective coefficient of multiplication of the blanket, which depends only on the structure and composition of the blanket. For practical assessments, we shall replace the quantity $Y\epsilon$ by its value for optimized heavy-water blankets [1] and 36 MeV protons incident on a beryllium target: $F = 1.5 \times 10^{11}(1 - K_{eff})^{-1}$. We shall estimate the real proton beam current as 5 mA. Then an effective coefficient of 0.985 is required to obtain a flux density of $5 \times 10^{13}$ sec$^{-1}$ cm$^{-2}$. This signifies 1.5% subcriticality.

Hence it is clear that even for an average beam current of 10 mA and higher, the effective coefficient of multiplication of the blanket should not be less than 0.97 in order that the thermal-neutron flux density not be less than $5 \times 10^{13}$ sec$^{-1}$ cm$^{-2}$. We note that in modern setups, a flux density in the range $10^{15}$–$10^{16}$ sec$^{-1}$ cm$^{-2}$ is attained. Such a current means that under normal heat-removal conditions (with water as the coolant) the target surface must be increased to 0.5 m$^2$. In this case, a compact target unit becomes a multicomponent target zone. The arrangement of the compound elements of this zone and the possibility of reloading them as the resource is depleted are a separate problem.

The high-current Istra-36 accelerator, constructed at the Institute of Theoretical and Experimental Physics [2], is intended for currents up to 1 mA, though in principle the construction of the resonators makes it possible to accelerate 5–10 mA currents. To determine the structure of the target-blanket composition and the accelerator requirements, it is important to understand the level of subcriticality of the blanket $(1 - K_{eff})$ that is admissible for obtaining a high neutron flux density in a real accelerator.