An Active Target for the Accelerator-Based Transmutation System

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Abstract. Consideration is given to the possibility of radical reduction in power requirements to the proton accelerator of the electronuclear reactor due to neutron multiplication both in the blanket and the target of an active material. The target is supposed to have the fast-neutron spectrum, and the blanket - the thermal one. The blanket and the target are separated by the thermal neutrons absorber, which is responsible for the neutron decoupling of the active target and blanket. Also made are preliminary estimations which illustrate that the realization of the idea under consideration can lead to significant reduction in power requirements to the proton beam and, hence considerably improve economic characteristics of the electronuclear reactor.

In recent time quite evident became the interest again to the idea of the electronuclear reactor (ENR), especially as applied to the problem of long-lived radioactive wastes transmutation. The basic ENR components are the high-current proton accelerator, the target made of material with high atomic number that is responsible for the protons-to-neutron transformation, and the subcritical blanket that multiplies neutrons leaving the target. The subcritival mode of the ENC operation gives grounds to hope that the elevated safety level can be achieved. But because of the accelerator high cost, the ENR-generated electric power cost, by some estimations [1], can appear to be considerably higher, if compared with traditional nuclear reactors. So, the search for methods of reducing power requirements to the ENR accelerator is of principal importance, and a progress in this direction could have changed present look at the perspectives of ENR practical usage.

Evidently, the power requirement to the ENR accelerator can be reduced by a trivial way, i.e. by increasing of the coefficient of neutron multiplication in the blanket. Then the major advantage of the electronuclear approach i.e. operation at a deep subcritical mode will be lost, and the ENR will have practically no differences from usual nuclear reactor in this respect.

The main purpose of this report is call to attention to the practical possibility of radical reduction in power requirement for the ENR proton accelerator due to neutron multiplication performed both in the blanket and in the target (active target). If the neutron flux from the blanket into the target is suppressed, these two subsystems will operate practically independently, and instead of the neutron multiplication in the blanket, which is $1/(1 - K_{eff})$, in the active target-blanket system it is possible to obtain the multiplication being equal to the product of neutron multiplications both for the blanket and for the active target. Of principal significance is the fact that in this case the target, the blanket and the system as whole will be deeply subcritical, and because of this the safety of the system with the active target will not practically degrade, i.e. the system transfer into the nearly-critical state is as just unlikely as in the ENR with the inert nonmultiplying target.

The idea of the sectioned blanket with one-way neutron coupling between its components is well-known [2,3] and has been investigated in detail as applied to the pulsed aperiodic nuclear reactor [4]. Recently, some suggestions have been made regarding sectioned blanket usage to reduce the requirements to the accelerator for ENR [5,6].

Neutron one-way coupling of the active target and the blanket can be easily made, if the target has a fast-neutron spectra and the blanket has a thermal one, and the blanket and the active target are separated by the layer of a thermal neutron absorber. Hence, the target can be of an uranium oxide or MOX solid fuel rods and cooled by an liquid-metal coolant, e.g. the lead or lead-bithmuth one. Not only traditional absorbers, but materials undergoing transmutation with rather large thermal absorption cross-sections can be used as the thermal-neutron absorber. The problem of the absorber cooling can be solved by the forced circulation of the absorber solution through the core or by the coolant forced circulation through this zone. The active target reflector and the blanket shell of the hastelloy or other structural material could be used to create the one-way coupling, too.

Estimations show, that leaving the target fast neutrons absorption in the thermal neutrons absorber surounding the target will be not so large and these neutrons will efficiently cause fission in the blanket, where the neutron reverse flux from the blanket into the active target will be suppressed.

Let us estimate the proton beam current necessary to obtain 500 MWt of thermal power in the blanket proposed by LANL [7] with the active target. In order to obtain the given thermal power in the blanket, the neutron flux from the target should be

$$F_t = (1-K_b)\bullet(\nu - 1)\bullet P_b \,,$$

where

F_t - neutron flux leaving the target,
K_b - multiplication coefficient of the blanket,
ν - mean number of the secondary neutrons per fission,
P_b - blanket power (fissions/sec).

For the obtaining the mentioned above blanket power at $K_b = 0.9$, the neutron yield from the target of about $4{\cdot}10^{18}$ neutrons/sec is required.

The target power P_t (fissions/sec) providing the specified value of the neutron flux going from it, is

$$P_t = F_t / \alpha \,,$$

where α is the neutron yield from the target per one fission in it. For estimations we assume that $\alpha = 1$, then the target thermal power resulting from the neutron multiplication in it will be about 50 - 100 MWt and well over the the energy deposition from the proton beam.

Preliminary estimations have illustrated that the active target for the 500MWt blanket [7] can have the following parameters:

The target power		50 MW(th)
Volume of the target core		0.5 m^3
Fuel rodes		UO_2 or MOX
Fuel enrichement	up to	20 %
K_{eff} of the target/blanket system	up to	0.95
Accelerator power (800Mev protons)		
- with active target		3 - 5 ma
- without active target		15 ma.

The specific power in the active target will be near 100 MW/m^3 , that is no more than at existing fast reactors. So, the possibility to perform the active target cooling as well as to solve the problem of radiation stability of the materials is quite evident. Nuclear fuel burnup in the target will be close to this at the fast reactors, hence the active target fuel elements can be reloaded one or two times a year as for usual reactors. The active target is simply subcritical heavy-metal cooled reactor and it can be costructed at the present level of tecnologhy.

So, the estimations show the possibility of the essential reduction (some times) in the power and efficiency requirements to the accelerator for ENR due to usage of the active target essentialy multiplicating neutrons. The idea is worth to be developed in detail including neutron-physical and thermophysical simulations, experiments with coupled cores, thermophysical experiments, materials selection , safety analysis and preliminary designing. It is planed to perform this work in the nearest future.

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