ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-97-304

V.S.Barashenkov*, A.Polanski[1], A.N.Sosnin**

APPLICATION OF LOW-ENERGY ACCELERATORS IN ELECTRONUCLEAR SYSTEMS

Submitted to «Kerntechnik»

[1]Soltan Institute for Nuclear Studies, Otwock–Swierk n. Warsaw, 05-400 Poland; e-mail: polanski@cyf.gov.pl
*E-mail: barashenkov@lcta30.jinr.dubna.su
**E-mail: sosnin@decimal.jinr.dubna.su

1997

Барашенков В.С., Полянски А., Соснин А.Н. E2-97-304

Применение низкоэнергетических ускорителей в электроядерных системах

В электроядерных системах с большим коэффициентом мультипликации ($K_{eff} > 0{,}94$), где тепловыделение в реакциях деления во много раз превосходит энергию управляющего пучка ускоренных частиц, ионизационные потери становятся относительно менее важными. Это позволяет использовать ускорители протонов и легких ионов с энергией всего лишь в несколько сотен МэВ, что существенно удешевляет систему и позволяет иметь значительно большие токи, чем в случае высокоэнергетических машин.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1997

Barashenkov V.S., Polanski A., Sosnin A.N. E2-97-304

Application of Low-Energy Accelerators in Electronuclear Systems

In electronuclear systems with high neutron multiplication factors, $k_{eff} > 0.94$, where the heat generation due to fission reactions essentially exceeds that obtained due to the driving beam of accelerated particles, ionization losses appear to be relatively less important. This allows one to use proton and light ion accelerators with energies just about several hundred MeV, which significantly simplifies the system, makes it cheaper and provides a possibility of getting much higher currents than those in high energy machines.

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1997

Over many years discussion of the features of electronuclear technology was fixed mostly on the breeding of nuclear fuel in uranium and thorium targets with neutron multiplication factor $K_{eff} \simeq 0.3$ — 0.5. In these cases optimal energy of the primary proton beam is $E \simeq 1$ GeV because the energy cost of the produced neutron N_{tot}/E (here N_{tot} is the total amount of neutrons escaping the reactor volume and those neutrons which initiated capture and fission reactions, see also Table below) increases at larger energies, capital costs of accelerators raise impressively up, while shifting to lower energies leads to a decrease in production of ^{239}Pu and ^{233}U due to increasing ionization losses and reduced amount of neutrons generated in inelastic $p-U$ and $p-Th$ collisions. For example, when the estimated energy spent at $E = 1$ GeV on production of one ^{239}Pu nucleus in a very large (practically infinite) natural uranium target is $E/N_{Pu} \approx 9.6$ MeV, at $E = 0.4$ and 0.2 GeV this value reaches already about 17 and 40 MeV [1].

Simultaneously, the neutron yield and the coefficient of energy amplification $K_{amp} = Q_{tot}/E$ (here Q_{tot} is the total amount of heat delivered in the target-blanket system) in subcritical electronuclear reactors with $K_{eff} \simeq 0.94 - 0.97$ keep large even at low energies, therefore energy losses by ionization appear to be not that important as for the systems with low K_{eff} values.This is evident, in particular, from Table where the values of relative losses on ionization Q_{ion}/E and the coefficient of energy amplification are shown for one of the versions of electronuclear system with plutonium blanket based on construction elements of the core of the impulse fast reactor IBR - 30 available in Dubna (see Fig . 1 [3]) [2]. Even at $E = 0.1$ GeV when only 5% of initial energy is spent to produce neutrons, heat generation exceeds the energy of the incoming beam by a factor of four.

[1] It is assumed that the proton beam is introduced into the target through the gap because otherwise large fraction of the neutrons escapes the target volume due to the scattering at large angles. Here and below all calculations are performed by means of Monte Carlo simulation based on assumptions discussed in detail in the papers [1, 2].

[2] 2000 proton histories are simulated for each energy.

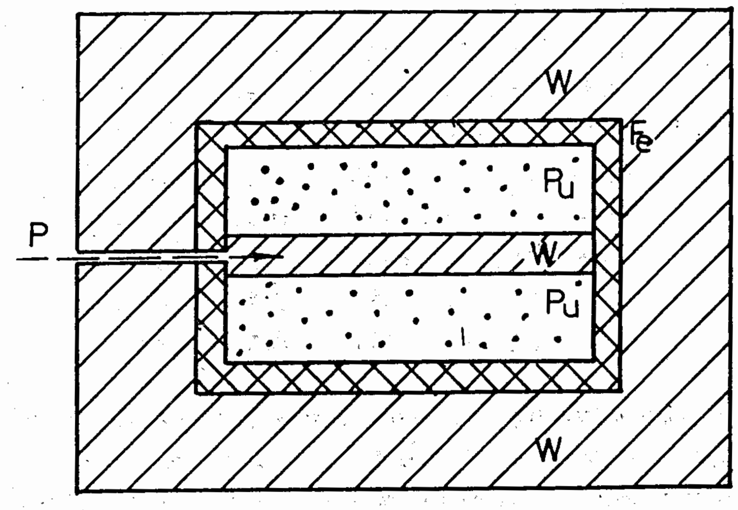

Fig. 1. The target reactor assembly is shaped as a multilayer cylinder with a tungsten primary target with a radius $R = 1.5$ cm, length $L = 14$ cm which is covered by a plutonium blanket with the dimensions $R \times L = 7.2 \times 14\,cm^2$ and the average density of plutonium $\rho = 8$ g/cm^3. Plutonium pins are clad with the tungsten (0.1 mm thick) and stainless steel (0.3 mm thick) casings. The reactor is surrounded with a steel reflector with thickness $\Delta L = 10\,cm$ and with the tungsten reflector 2.4 cm thick. The beam of the accelerated protons is introduced into the target through the axial channel to the depth of 1 cm. Space distribution of the proton beam is shaped as a gaussian with the half-width $R = 1$ cm

In subcritical electronuclear systems driven by accelerators with energy $E \gtrsim 0.2$ GeV, energy amplification Q_{tot}/E and relative neutron yield N_{tot}/E decrease due to a large contribution of fission reactions only by a factor of two in comparison with high energy accelerators. That is

Объединенный институт ядерных исследований
БИБЛИОТЕКА

Table
Parameters of the electronuclear system at various proton beam energies E

E, GeV	K_{eff}	N_{tot}/E	Q_{ion}/E	Q_{tot}/E
0.1	0.939	64	0.95	4.3
0.2	0.941	210	0.85	11.2
0.3	0.943	276	0.80	15.5
0.5	0.944	378	0.69	20.8
0.65	0.943	393	0.58	21.4
0.8	0.946	396	0.47	21.4
1.0	0.946	409	0.41	22.1
1.5	0,945	379	0.34	20.4
2.0	0.942	347	0.30	18.7

accompanied also by essentially smaller accelerator costs and the possibility to increase significantly the intensity of the beam [3].

Ionization losses in the energy region equal to several hundred MeV could be reduced significantly when the deuteron beam is used instead of the proton one. The neutron yield in the very large natural uranium target mentioned above increases by 50% at $E = 0.3$ GeV and by 60% at $E = 0.2$ GeV. The neutron yield and the heat generation in subcritical electronuclear assemblies increase in a similar manner as well.

As one can deduce, employment of accelerators especially deuteron accelerators with energy about several hundred MeV appears to be more advantageous in comparison with the 1 GeV proton machines. Such approach seriously changes the strategy of electronuclear technology.

It is seen from Table that the value of the K_{eff} grows weakly with the beam energy reaching similarly to the K_{amp} and N_{tot}/E values its maximal level at $E \simeq 1$ *GeV* as a result of neutron spectrum variations. At the same time fluctuations of the multiplication ability of the electronuclear installation are possible during its operation due to different thermal effects related to variations in the coolant flow, acceleration regimes etc. It is shown, as an example, in Fig. 2 how the heat generation and neutron yield are changing depending on the value of the K_{eff} in the reactor presented in Fig. 1 for the proton beam at 650 MeV available at Joint Institute for Nuclear Research [4].

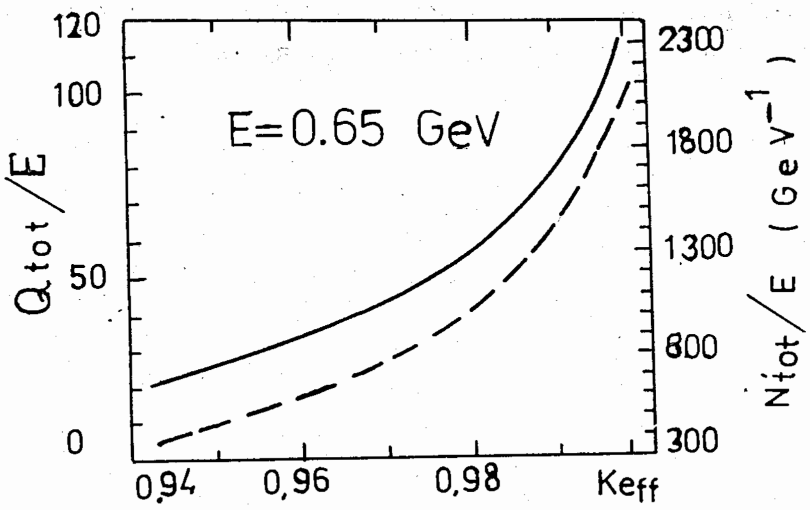

Fig. 2. Dependence of the heat generation (solid curve) and neutron yield (dashed line) on the neutron multiplication factor

In the region of $K_{eff} = 0.94 - 0.97$ fluctuations $\Delta K_{eff}/K_{eff} \simeq 1\%$

[3] In the case of the electronuclear installation which is being developed in Dubna and is based on the combination of the core of the plutonium reactor IBR-30 and the 650 MeV phasotron the decrease of the K_{amp} in comparison to the 1 GeV beam is equal to only 3 — 5 %. We would like to stress specifically the importance of studying the properties of ecologically safe and economically effective electronuclear utilization of the rapidly growing stock of "technical" plutonium from the nuclear power plants because such plutonium as is well known today could be used to manufacture nuclear weapons which is seriously dangerous from the proliferation point of view.

[4] Variation of the K_{eff} value is obtained by respective variation of the plutonium blanket radius.

change the K_{amp} by 25 — 30%. This is the region of quite safe operation of the electronuclear installation. Sharp (~50 %) changes in the heat generation and neutron yield appear only at $K_{eff} > 0.99$.

References

[1] *Barashenkov V. S. et al.:* Mathematical modeling of radiation damages of microelectronic devices. Phys. Part. Nucl. 24 (1993) 246.

[2] *Barashenkov V. S. et al.:* Neutron production in fissile targets under the ion beam irradiation. Kerntechnik 61 (1996) 103.

[3] *Barashenkov V.S. et al.:* Application of the JINR low-current accelerators for modeling of ecologically safe utilization of plutonium. JINR Comm. E2-97-245, Dubna, 1997.