Power Production by Atomic Power-Station Based on High Intensity Accelerator and Subcritical Nuclear Reactor.

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Abstract

Physics and economic aspects of a power station, based on tandem: "high intensity accelerator - subcritical reactor" hane been discussed. The chain nuclear reaction in subcritical reactor is induced by neutrons, generated in the uranium or lead target by high energy protons. Physics principles of power facility completely exclude reactive accidents. The acceptable renge of the main parameters of the facility has been evaluated. The economic analysis shows the cost of electric power, produced by this power installation, will increased by on 10÷15%.

1 INTRODUCTION

The most dangerous accidents of nuclear power station are connected with a self-maintaining chain fission reaction in nuclear reactor. The control system damages or errors of operators can lead to uncontrolled run-away of a reactor and accidents of the Chernobyl type. The causes of such accidents will be completely exclude by using the energy of fission reaction in a deep subcritical reactor. The chain nuclear reaction is induced by neutrons, generated in the uranium or lead target by proton beam, accelerated to the energy of some hundreds MeV [1-3].

2 POWER STATION WITH SUBCRITICAL REACTOR

A hadron cascade, induced by proton beam in the target, generates neutrons with spectrum similar fission one. The number of neutrons depends on proton beam energy, target sizes, it construction and composition. The energy dependence of the neutrons yield from uranium target, calculated with MOSKIT code [4], is presented in table 1. Due to multiplying characteristics of the core, determined by the multiplication factor (k_{eff}), a total number of neutrons will be increased by $1/(1-k_{eff})$ times.

Table 1: Neutron yield from cylindric uranium target (d=20.4cm, h=61cm), neutron/proton

E,GeV	0.1	0.25	0.47	0.72	0.96	1.47
our calc.	0.93	6.9	17.3	28.	38.	54.
calc.[6]	0.6	3.9	14.	29.	42.	60.
exper.[7]	-	-	18.1 ±0.9	29.1 ±1.5	40.5 ±2.0	56.8 ±2.8

The thermal power of electronuclear reactor can be evaluated by formula [1]:

$$W_t = \frac{I_p k_{eff} \omega n_0}{\nu(1-k_{eff})q} \tag{1}$$

where ω=200 MeV is total energy emmited by fission of U^{235}; ν is the average number of neutrons per fission; I_p is the particle beam current; n_0 is the number of neutrons, generated by a proton with the energy E_p in the target; q is the proton charge.

The thermal energy, released in the core, is transformed into electricity using the usual scheme of power station.

3 K_{EFF} RANGE

The upper boundary of k_{eff} is always less than 1. The safety electronuclear facility is due this fact. It is obviouse that the nominal power of the subcritical reactor is higher, when k_{eff} is close to 1. However the upper boundary of k_{eff} is determined by excessive reactivity reserved for power effects, steady state poisoning by Xe and Sm, as well as for fuel burn up compensation [5]. The maximum safety k_{eff} for Light Water Reactor is 0.90. For the fast reactor with metalic U-Pu fuel and metalic or gas coolant it is 0.98.

Evaluation of k_{eff} admissible minimum can be derived from obvious relation, which takes account of the balance of generated and consumed energy. It can be writen as:

$$k_{eff} = \frac{1}{1+\frac{\omega n_0 k_1 k_2}{(1+\alpha)E_p \nu}} \tag{2}$$

where k_1 is transformation efficiency of heat into electric energy; k_2 is transformation efficiency of electric energy into energy of partical beam; α is parameter, which accounts effectiveness of energetical system and shows how much the energy for external consumer is greater than that for inner consumption.

Calculated dependences of k_{eff} on the energy of proton beam and parameter α are presented in fig.1. The efficiencies of energy conversion used here are as follows: k_1= 0.35, k_2= 0.3. As is shown on fig.1, the electronuclear reactors with $k_{eff} > 0.8$ become energeticaly adventageous. Such values of k_{eff} allow one to develope thermal subcritical reactor with U^{235} concentration less than 0.7% It significantly decreases fuel ingradient of power production cost and excludes uncontroled distribution of enriched nuclear fuel, which can be used for criminal purposes. The

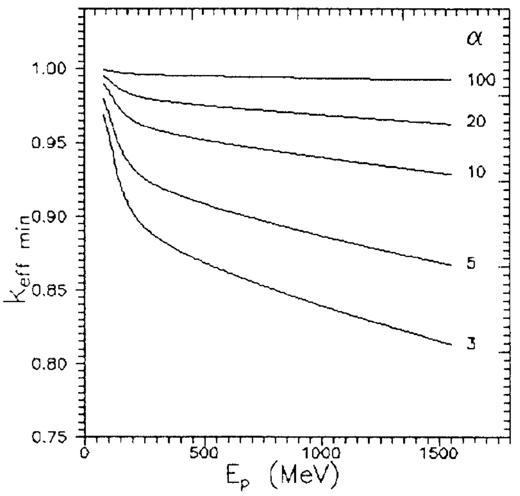

Figure 1: Minimal k_{eff} as a function of proton energy and α.

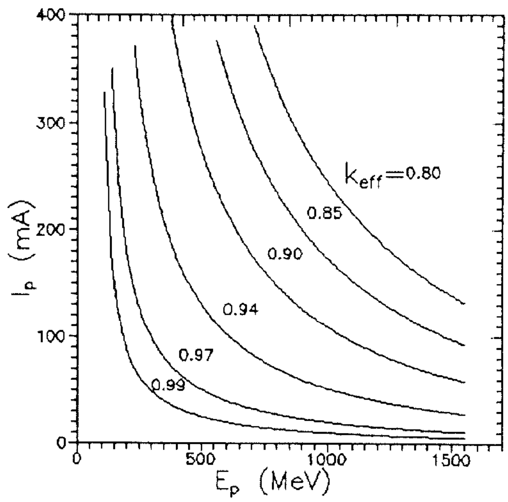

Figure 2: Accelerator current as a function of proton energy and k_{eff} for 1GWt facility.

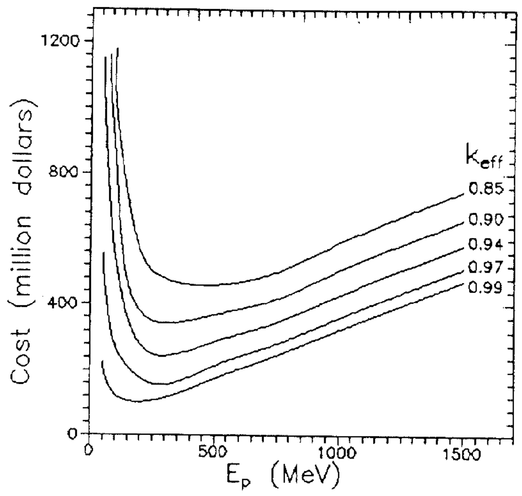

Figure 3: Cost of accelerator as a function of proton energy and k_{eff} for 1GWt facility.

main difficulty in creating the electronuclear system with thermal reactor is a rather big value of proton current. (It is about 300÷400 mA). The situation with electronuclear system with fast reactor is opposite. It operates with highly enriched U^{235}, but it is not required very high proton current (about 10 ÷ 20 mA). Besides this system will have very deep burn up and a long period of time before fuel loading.

4 HIGH INTENSITY ACCELERATOR

The most appropriate accelerator for energy production in electronuclear system is the linear accelerator, because the problems of beam dynamics and radiation safety can be solved easier, than for isochronous cyclotron. The capital investments into accelerator building (with no account of expenses to power radio engineering) can be evaluated from the experience of operating LINAC building and current project of high intensity LINACs[8]. Some data for new LINACs are presented in table 2. The economic evaluation of high frequency radio-technical system can be derived by using specific cost of an equipment - 1 doll./Wt.

We consider that building expenses for other equipment (without power radio engineering) should be proportional to the accelerator energy. According to the above data the average value of this part of expenses is equal about 0.2 mill.dol./MeV. The power of RF-system must be sufficient both to accelerate the beam with current Ip and compensate for the energy losses in the walls of accelerator structure.

$$C = E_p[a + b(I_p + I_e)] = E_p[a' + b'\frac{1 + k_{eff}}{k_{eff} n_0} W_t] \quad (3)$$

The cost (C) in formula (3) is given in millions dollars, currents in ampers, energy (E_p) in MeVs, thermal power (W_t) in MWt, a,a',b,b' are dimensional constants: a=0.2[mil.dol./MeV], a'=0.3[mil.dol./MeV], b=1[mil.dol./(MeV Z)], $b' = 1.510^{-2}$ [(mil.dol. A)/(MWt Z)], where Z is a unity charge of proton (Z=1). The walls energy losses are presented here by means of equivalent accelerated current I_e.

The calculated energy dependences of current and cost of accelerator for W_t=2.86 GWt are presented on fig.2,3. A choice of subcritical level of reactor is limited by the accelerator power consumption. In a practice, the total power, consumed by the accelerator is used by power radio engineering and can be calculated by the formula:

$$P = E_p (I_p + I_e) / k_{RF} \quad (4)$$

where k_{RF} is RF-generators efficiency. The dependence of P on accelerator energy for reactor with 1 GWt electric power is presented in fig.4 for warm accelerator structure (I_e = 0.1 A) and criogenical (I_e = 0) one.

One can see that the load on electric net less then 20% for warm accelerator structure with k_{eff} > 0.93 and for

Table 2: Parameters of new LINACs

Laboratory	Energy, GeV	Current, mA	Cost of accel.system, mill.dol.	Cost of RF-system, mill.dol.	Total cost, mill dol.
Chalk-River,Can.	1	300	105	287	392
Livermor,USA	1	300	60	176	235
BNL,USA	1	300	5.5	385	467

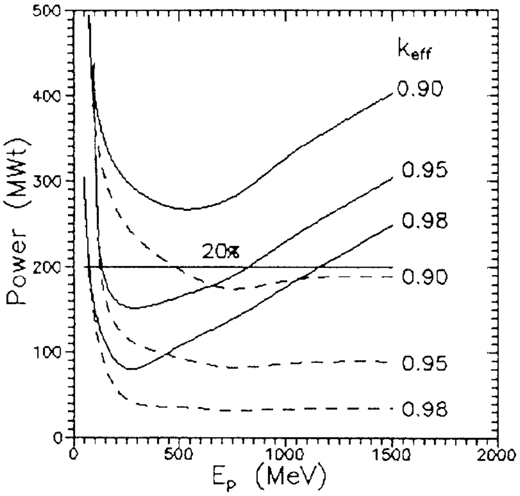

Figure 4: Power consumed by accelerator as a function of proton energy and k_{eff} for 1GWt facility and 200 mA current

criogenic one with k_{eff} >0.87.

5 CONCLUSION

An electronuclear method of power production offers few advantages over traditional critical reactors:

-the origin of reactive accidents of nuclear reactor can be completely eliminated;

-the natural uranium can be used as a nuclear fuel in electronuclear system with thermal reactor;

-the "closed" fuel cycle with uranium as well as thorium can be realized in electronuclear system with thermal reactor. It allows one to solve the problem of non-prolifiration of fissiable matter. Besides this cycle is more ecologycally pure;

-although the electronuclear system with fast reactor operates with highly enriched $U^{235}(orU^{233})$, it has big advantages: it is not requiered very high proton current (about $10 \div 20$ mA), and has very deep burn-up and long period of time before fuel loading.

As for now, there are no technical and physics limitations for realization of electronuclear method of energy production.

6 REFERENCES

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