THE PROS AND CONS OF SAFE ELECTRONUCLEAR STATION WITH ACCELERATOR AS A DRIVER

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Creation of 200 MW compact safe energetic installation on a base of a high-temperature, gas-cooled, subcritical reactor was discussed in paper [1]. Chain reaction was initiated by the outer neutron flow. It was proposed to obtain such a source by irradiation of different substances with an intensive proton beam from the linac. Now possibilities of such a scheme are considered in more details. Structure of the reactor active zone is discussed. The use of the cyclotron as a driver is considered as an alternative variant. Problems of reliability, radiation safety and cost of installation are taken into account too.
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1 INTRODUCTION

Over the past few years, there has been a strong interest in the possibility of using high- power accelerators for energy production and transmutation. Such a system requires a beam power of 10 MW in the 16 eV energy range. Programs of producing several-MW proton beams for the accelerator-driver are developed with USA, France, Italy, Japan, Corea, and in CERN. These projects are durable and very expensive. But proposals of creation of a relatively small-scale safe electronuclear power station are unknown. In paper [1] one determined the parameters of the rf linac as a driver for the subcritical reactor of a 200 MW safe electronuclear station (SES). The rf proton linac with an average current of 5 mA and output energy of 200 MeV can produce a sufficient quantity of neutrons to provide the 200 MW thermal power of SES under conditions of using the cascade active zone.

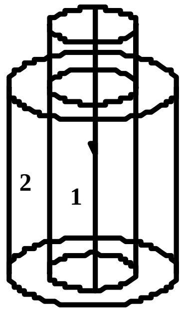
2 CHOICE OF ACTIVE ZONE

Thermal power N_t which is picked out in the active zone of a subcritical reactor with an outer neutron source and effective multiplying factor K_{ef} is determined by the formula

$$N_t = \frac{I_p \omega}{e} \frac{K_\infty}{1-K_{ef}} \frac{E_f}{\nu} \qquad (1)$$

where E_f - energy which is picked out under fission of fuel nucleus; ν - average number of neutrons that act only on fission; K_∞ -multiplying factor of the infinite reactor; I_p – average current of the accelerator; ω - average yield of neutrons which is due to only an accelerated particle (conversion factor).

It is supposed now that for the sake of nuclear safety *Kf* must be no more then 0.98 in an operation period. During the active zone campaign K_{ef} can decrease due to the change of the fuel isotope composition (fuel burning out, toxic effects etc.). One can expect that K_{ef} will decrease to 0.95 for the fast neutron reactor. Electronuclear station with a homogeneous active zone, U^{235} as a fuel and proton linac as an outer neutron source (a uranium target is suggested) may provide a 40 MW thermal power if E_p=200 MeV; I_p=5 MA; K_{ef}=0.95; ν=2.5l; E_f=200 MeV. If K_{ef}=0.98 then one can obtain a thermal power of SES of 100MW. Possibility of increasing N_t for constant beam parameters and target composition is appeared when cascade zone is used [2]. The scheme of the cascade zone is given in Fig. 1.



1 - inner subcritical zone (fast neutron spectrum)
2 – outer subcritical zone (thermal neutron spectrum)

Fig.1. Scheme of cascade zone.

Neutron source obtained under irradiation of the target with a charged particle beam is placed inside of the inner subcritical zone (fast neutron zone, where a retarder is absent). The outer zone has a thermal spectrum (there is a retarder and can be a neutron reflector). To exclude fission of fuel nuclei at the inner zone due to diffusing neutrons from the outer zone, the inner zone has absorbers of thermal neutrons (for example, samarium or gadolinium). Absorbers may be installed on the border between the inner and outer zones too. In this way the inner part of a cascade active zone is, according to the homogeneous active zone of the electronuclear station, transferred from the inner part of the active zone and is a source of primary neutrons for the outer part of the active zone. Since the neutron feedback between the inner and outer parts is broken the active zone having two subcritical parts is remained a subcritical one. The power of cascade zone can be determined as

$$N_{tc} = N_{ti}\left(1 + \frac{1 - K_{ef1}/K_{\infty 1}}{1 - K_{ef2}}\frac{K_{ef2}}{K_{ef1}}\right) \qquad (2)$$

where index "1" relates to the inner zone parameters and N_{t1} is determined by the formula (1), where K_{ef} was substituted with K_{ef1}. Relation $p = K_{ef1}/K_{\infty 1}$ is a probability to avoid a neutron leakage from the active zone. Relation N_{tc}/N_{t1} demonstrates a power gain under transition from the homogeneous zone to cascade one. According to [3] a maximal value of K_∞ can not exceed 2.73 (if the fuel is 100% Pu^{239} and for the fast neutron spectrum) or 1.65 (if the fuel is 100% U^{235} and for the intermediate neutron spectrum). Neutron absorption in real active zones is produced by nonfissionable materials therefore the value of K_∞ is less then the maximal K_∞ for a zone with pure fissionable materials. Let assume that the homogeneous active zone with a fast neutron spectrum has $K_{ef}=0.95$. Transition from such a zone to cascade one with $K_{ef1}=0.95$; $K_\infty=1.65$; $K_{ef2}=0.95$ gives according to (2) the power gain N_{tc}/N_{t1} =9.5. This value will be somewhat lower due to neutron leakage under transition from zone one to zone two, but one can rate at a thermal power of such SES of 200 MW or more for an average linac current of 5 mA and beam energy of 200 MeV.

3 CHOICE OF LINAC

A probable scheme of such a proton linac and key block were discussed in papers [1,4]. A relatively small overal dimension of the linac is provided by a working frequency of 433 MHz and using H-resonators as initial and main parts of the accelerating system. To provide a pulsed current of 50 mA and average current of 5 mA at 433 MHz frequency is a hard problem of course. But the pulsed current of 100 mA was obtained in LANL at 425 MHz RFQ and accelerated particle energy of 2 MeV [5]. Accelerating of protons up to 20 MeV is supposed to be provided by IH-resonators with a drift tube and alternating-phase focusing. Accelerating from 20 to 200 MeV may be provided under constant synchronous and additional magnetic focusing. Focusing lenses can be placed inside the drift tubes or supports of drift tubes. A field intensity on the axis of cavities of 180 kV/cm is equivalent to accelerating gradients of 5-7 MeV/m (it depends on the β value), so the length of the accelerating system can be 35-40 meters or 17-20 with a 180^o beam turn at 80-100 MeV particles energy. A gas-cooled reactor and two 200 MeV ion linacs can be placed inside the volume of 35-40 m length and 9-12 m diameter. A probable scheme of equipment disposition of is given in Fig. 2. Accelerator blocks and reactor facilities are divided. Such disposing makes easier a solution of the problem of servicing, radiation safety and reliability of SES.

4 OTHER POSSIBILITIES

Alternative variant of the proton linac for the energy amplifier was proposed by B.P. Murin [6]. He discussed a possibility to use a superconducting proton linac as a driver, but one can expect that such a 200 MeV accelerator will be less reliable and much more expensive then the usual one. Competitors for the rf ion linac as a driver are an electron linac and a cyclotron. To obtain such effective conversion "electron-neutron" as "proton-neutron" for the energy of about 100 MeV one must have an average current of the electron linac at least of 0.2 A. So, the power consumption with such an accelerator will be too great for a compact 200 MW electronuclear station.

There are some proposals to use cyclotron as an energy amplifier. A workshop on Critical Beam-Intensity Issues in Cyclotron was hosted by LANL in Santa-Fe in December 1995, with primary aim of assessing the feasibility of using cyclotrons to obtain 10 mA cw proton beam of 1 GeV [7]. Machines considered included: separated-orbit, separated-sector and conventional integrated-sector cyclotrons accelerating either protons or H^- ions. Various injectors were also dc- devices, RFQs and small cyclotrons under consideration – the latter having already produced internal beams of 5 mA cw. With the overall major concern being minimization of the beam loss, the detailed concerns discussed included space-charged effects, clean extraction, rf beam loading, beam loss detection and control and reliability. It appears that cyclotrons offer a feasible, and probably the most economical, route the desired beams (they mean 1 GeV accelerator), but researches and development will be needed on rf systems, collimation and high space-charge beam dynamics.

Among contemporary cyclotrons PSI (or such type cyclotron) only may provide 1 MW beam and required conversion "proton-neutron". But cost of such machine (both injector and main cyclotron) will be well higher then 200 MeV, 5 mA proton linac. On the other hand cyclotron with energy 200 MeV and current 5 mA may be considered as alternative of rf linac for stationary nuclear power station. Conclusions of workshop [7] show that at present creation of 5 mA cyclotron has more problems then creation of rf linac with the same current.

Other problem of SES creation is necessity of uninterrupted operation during at least 5000 hours. Contemporary accelerators don't operate in such regimes. But there is information that cyclotrons may operate up to 7000-7500 hours during a year under beam power a few tens KW. Reliability of LAMPF which one can consider as SES driver-prototype is no more then 85%. Ways for enhance of reliability of power proton linacs are discussed in [8]. Reservation of separate blocks or accelerator as whole is necessary.

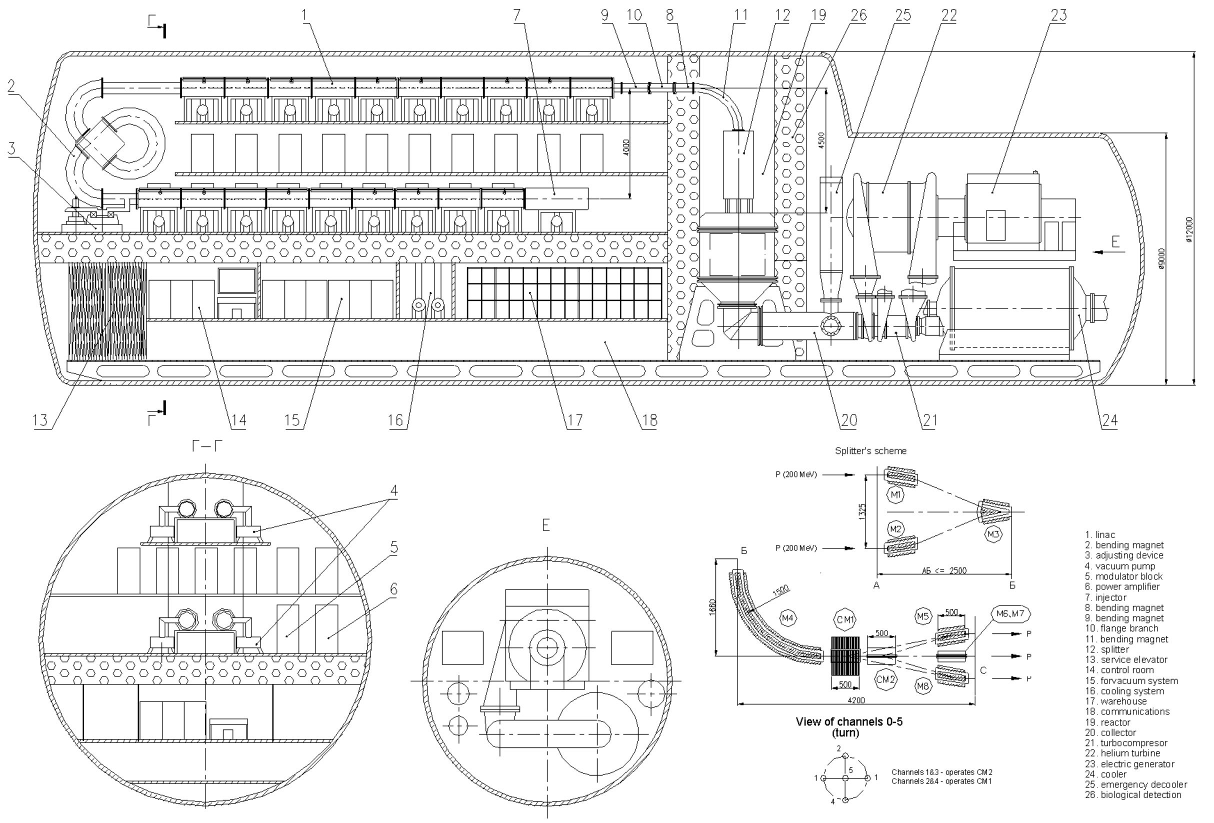


Fig. 2. Disposition of SES equipment.

5 CONCLUSION

1. At present creation of a proton linac as driver of subcritical reactor of 200 MW SES is more practicable plan then working out of cyclotron for the same purpose.
2. Problem of reliability for SES is main problem. But contemporary accelerator technologies and reservation must prove interrupted operation of SES during 5000 hours.

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