THE FEASIBILITY OF LOW-ENERGY ELECTRONUCLEAR POWER PLANT

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Abstract

There are examined prospects and challengers associated with the development of low-energy electronuclear power plant eliminating any possibility of uncontrolled chain fission reaction through fission in subcritical reactor with an additional neutron source. The neutron source is anticipated to be a heavy-element target irradiated with a beam of protons accelerated to several hundreds of megaelectron-volts. The intensity of external neutron source for an electronuclear reactor rated under 200-400 MW may be much less than for greater ones, and that allows reducing accelerator performances to limits that are already run in the world industry. Potential applications of such electronuclear plants include municipal, industrial and other electricity, and heat supply utilities in remote areas. The same engineering philosophy may be used on solving of the nuclear waste transmutation problem.

INTRODUCTION

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

$$N_t = \frac{I_p n_0}{e} \cdot \frac{K_\infty}{1-K_{ef}} \cdot \frac{E_f}{\nu} \quad (1)$$

where E_f - energy which is picked out under fussion of one fuel nucleus; υ - average number of neutrons from one act of fission; K_∞ - multiplying factor of infinite reactor; I_p - average current of accelerator; n_0 - number of neutrons which are produced by one particle after interaction with target. It is supposed now that for save of nuclear safety K_{ef} must be not more than 0.98. During the active zone campaign K_{ef} can decrease due to change of the fuel isotope composition (fuel burning out, toxic effect etc.) One expect K_{ef} will decrease to 0.95 for fast neutron reactor. Results of modeling of active zones of gas-cooled reactor with multiplying target and K_{ef} =0.96 give release of thermal power 200 MW for intensity of outer source $4.2 \cdot 10^{17}$ n/s. This intensity may be achieved for I_p =5mA and yield of neutron n_0 =13. Such yield neutrons can obtain from (UN+W) target under proton energy E_p =200-400 MeV. 200 MeV spread depend on incompleteness of experimental data, possibilities to use K_{ef} >0.96, cascade zone etc. There is consider proton linac as outer source of neutrons. Alternative variant is to use cyclotron as energy amplifier. Among contemporary cyclotrons PSI (or such type cyclotron) may provide 1 MW beam and required conversion "proton-neutron". But cost of such machine and weight will be well higher than 200-400 MeV, 5 mA proton linac. On the other hand cyclotron with energy 400 MeV and 5 mA current could consider as alternative of rf linac for stationary nuclear power station. Conclusions of workshop [1] show that at present creation of 5 mA cyclotron has more problems than creation of rf linac with the same current.

LINEAR ACCELERATOR

A probable scheme of such proton linac is given on fig.1 It includes: RF volume source, LEBT, 4-vane spatially-homogeneous strong focusing structure (RFQ), alternating phase focusing structure (APF DTL), coupled cavity linac structure (CCL). APF DTL structure is IH-cavity with thick holders turned on right angle in each following sell and magnetic lenses in drift tubes [2].

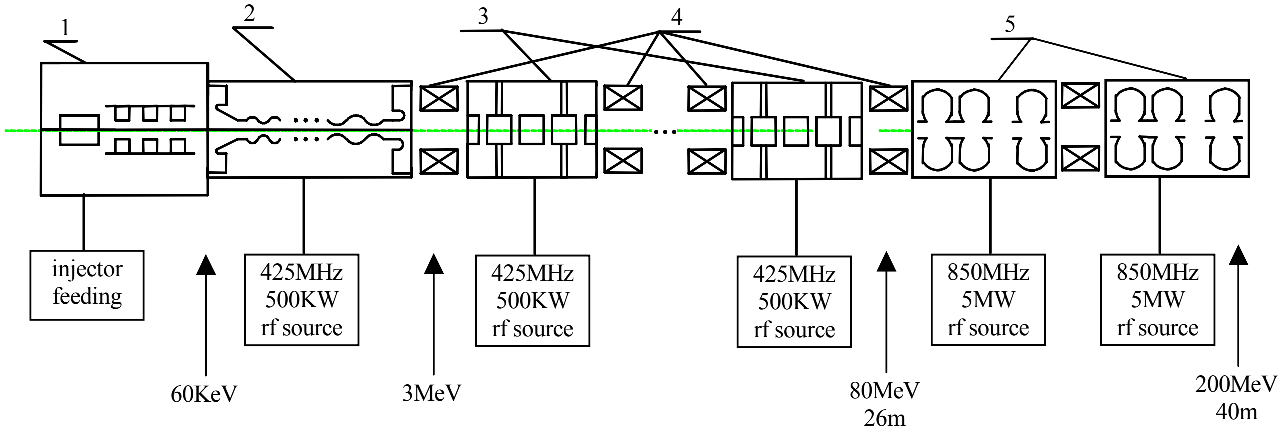

Figure 1: Layout of linac. 1 - ion source and LEBT 2 - spatially-homogeneous strong focusing structure (RFQ) 3 - alternating phase focusing structure (APF DTL) 4 - coupled cavity linac structure (CCL) 5 - focus lenses

Main parameters of linac are given in table 1.

Table 1: Main Parameters of Linac

Output energy, MeV	200-400
Average current, mA	5
Duty Factor, %	10
Possible frequency range of RFQ and DTL, MHz	402.5-433
Beam power, MW	1-2
Working frequency of CCL, MHz	805-866
Number of RFQ	1
Number of APF DTL resonators	20
Number of CCL module	4

Presented parameters are based on achievements of accelerator technologies of the last twenty five years [3], [4], [5].

HIGH TEMPERATURE GAS-COOLED REACTOR

To compensate decreasing of K_{ef} during long reactor working one need increase accelerator current. Therefore it is expediently reactor with hard spectrum of neutrons to use for LEEPP where diapason of K_{ef} change much less than the same in thermal neutron reactors. There is considered high-temperature gas-cooled fast neutron reactor (HTGCR) [6] as reactor of LEEP. Gaseous heat-carrier captures neutrons weakly therefore fuel reproduction is improved and change of reactivity is lowered in fast neutron reactors. So that risk of inlet of positive reactivity because of heat-carrier lost is absent. Helium is chosen as heat-carrier of gas-cooled reactor of LEEPP since helium has best thermal properties than other than other gaseous heat-carriers. Advantages of helium are chemical inertness preventing corrosion of constructional materials and absence of activation under action of neutron irradiation. It raises radioactive safety of LEEPP. HTGCR design of LEEPP is shown on fig. 2. Active zone of LEEPP reactor may be created on base of elements developed for ship HTGCR. Active zone consists of cylindrical heat assemblings (diameter 42 mm) with ball-shaped elements of HRA. Heat releasing elements (HRE) (diameter 2-4 mm) include fuel core from mononitrid of uranium covered by tangsten. HRE take place in inside HRA as backfill in ring gap between two coaxial pipes of niobium. Cooling of HRE is released by transversal stream of helium via ball-shape backfill. Reactor of thermal power 200 MW active zone sizes are: outer diameter 1.6 m, height 1.5 m. These sizes are determined by energy intensity 70 MW/m^3. It proves safe elimination of heat from active zone. Results of modeling show that in active zone with multiplying target (UN+W) (diameter 0.4 m) power heat releasing 200 MW may be achieved for K_{ef} 0.96 and source intensity $4.2 \cdot 10^{17}$ n/s.

NEUTRON-PRODUCING TARGET

In this report one proposes design of target with tubular irradiated elements (fig.3). Three of coaxially-located shells form vessel. Inner carrier shell, connected with ion transport channel, is insulated from heat-carrier and has good vacuum. Target is cooled by heat-carrier of reactor - helium. Middle and outer shells of vessel prove circulation of cooling heat-carrier in the target. The middle shell has holes inside surface which are connected with inner pipe of suitable irradiated elements via adapter. Radial clearances between shells are used as collectors of heat carrier which are cooling neutron-producing target.

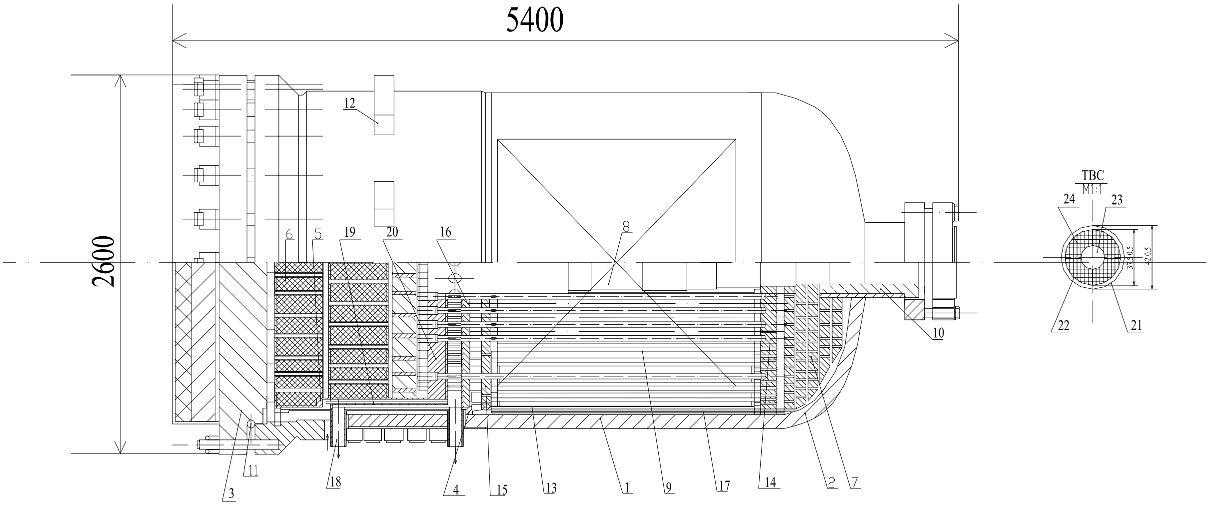

Figure 2: Design of high-temperature gas-cooled reactor. 1 - vessel 2 - bottom 3 - cap 4 - holder of active zone 5 - holder of heat releasing assembling (HRA) 6 - upper shield plug 7 - edge-joint screens 8 - neutron-producing target 9 - active zone 10 - cooled socket for target strengthening 11 - tubular thickening 12 - elements of strengthening of bio-protection 13 - carrying shell 14 - bottom bearing plate 15 - intermediate plate 16 - dividing plate 17 - sidelong screen 18 - sockets "pipe in pipe" type 19 - shell of HRA holder 20 - upper plate of HRA holder 21, 22, 23 - tube of HRA 24 - ball-shaped elements of HRA

Each tubular irradiated element consists of two coaxial pipes with thin walls.

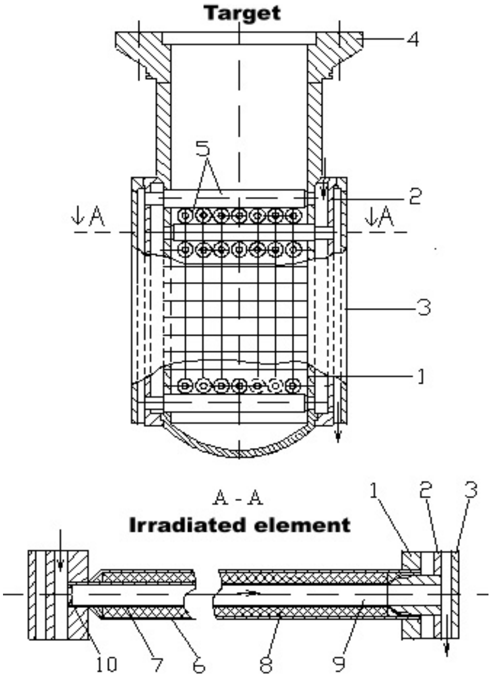

Figure 3: Neutron-producing target. 1, 2, 3 - shells of vessel, forming channel of heat carrier 4 - ion supply channel 5 - irradiated elements of target 6, 7 - shells of irradiated element 8 - neutron-producing material 9 - heat-carriers channel 10 - choke element

Between walls is placed neutron producing material. Such structure of irradiated element allows to use neutron-producing substance in different form (tablets, powder etc.) and to decrease requirements to radiative and heat resistance. It is proposed uranium compound UN to use as neutron-producing material. It is heat-resistance and multiplying target allows to obtain heat power in activ zone 1.5 times as much as unmultiplying one. Experimental data of neutron yields from targets of finite sizes presented in publications have essential distinctions. Modeling of neutron yield from UN 60 cm diameter target for 400 MeV protons gives more than 20 n/p.

CONCLUSION. DESIGN LEEPP

Scheme of principle placement of basic equipment is given on fig. 4. It is possible to place installation in protected container with diameter 10 m and length 25 m. It is according to sizes of atomicship's compartments. linac and power equipment of LEEPP are placed in same enclosed space to reduce length of protected container. Longitudinal size of linac may be reduced under 180° turn of accelerator tract. Turbocompressor with start system, power turbine, heat-exchanger and main electric generator are forming rigid construction. they are placed inside power vessel connected with reactor. Foundation of construction is attached to protected container's vessel. Linac is placed on foundation which is integral whole construction. It help to prevent deformations of beam tract due to vibrations of mechanical equipment of LEEPP. Blocks of linac RF system may be placed in special chambers protected from radiation. It proves possibility of their servicing under working LEEPP.

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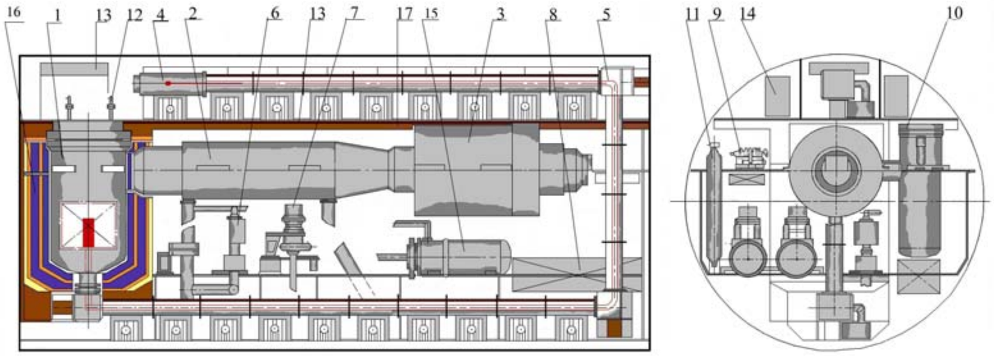

Figure 4: Configuration of electronuclear installation in protecting container. 1 - reactor 2 - turbocompressor with heat exchanger 3 - main electricity-generating 4 - accelerator 5 - bending magnets 6, 7 - pumps of cooling system 8 - water storage tank of cooling system 9 - vacuum aggregate 10 - aggregate of emergency shut-down cooling 11 - helium balloons 12 - monitors 13 - electrical equipment 14 - blocks of RF source 15 - heat-exchanger 16 - bio and heat shielding.