PROJECT OF LOW-ENERGY ACCELERATOR DRIVEN POWER PLANT

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Abstract

Project of low-energy accelerated driven nuclear power plant is considered. It is proposed the accelerated driven system (ads) with subcritical fast reactor, proton linac and fissile target. The main performance data of the ads: proton beam energy 300-400 MeV, accelerator average current 5ma, reactor thermal power 200mw, core effective multiplication factor k_{eff}= 0.98. The principal design features of the power plant is represented.

INTRODUCTION

The accelerator driven system – subcritical reactor driven by high power proton accelerators through a spallation target which is neutronically coupled to the core – have been proposed for addressing certain missions in advanced nuclear fuel cycles [1]. The interest is induced by a number of ADS applications in field of nuclear technologies:

- Transmuting actinides and fission products;
- Producing fissile materials;
- Power generation.

LINEAR ACCELERATOR

For transmuting and large power ADS there are needed high energy proton beams obtained in unique expensive accelerators. For ADS with reactor power 200-400 MW accelerator requirements are much less and traditional proton linac without superconductivity may be used [2].

In Fig. 1 it is shown layout of proton linac with output energy 300 MeV which can be suitable for ADS. Linac consists of multicusp ion source, 4 vane spatially homogeneous strong focusing structure (RFQ), six resonators with alternating phase focusing structure (APF DTL) and working frequency in diapason 424-433 MHz, coupled cavity linac structure (CCL). Injector, RFQ and six APF DTL resonators are LEBT system, eight resonators of CCL with working frequency in diapason 800-861 MHz are MEBT system. APF DTL structure is IH-cavity which have many cells with thick holders turned on right angle in each following cell and magnetic lenses in the drift tubes [3].

Accelerating gradients, collateral disposition of LEBT and MEBT connected by isochronous turning with help of magnetic system (270° bending magnet and focusing lenses).

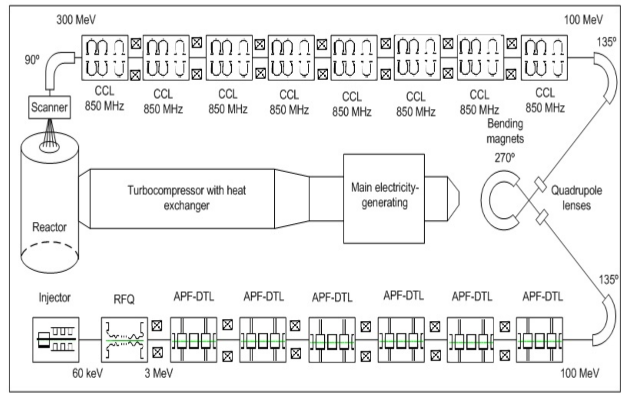

Figure.1: Layout of ADS Power Plant with proton linac.

According to results achieved at SNS accelerator in Oak-Ridge laboratory one can suppose accelerating gradients for LEBT and MEBT 4 MeV/m and 10 MeV/m accordingly [4]. Linac current adjustment can be realized by varying of pulse current repetition frequency. Main parameters of proton linac are given in Table 1.

Table.1: Main parameters of linac.

Output energy	300 MeV
Average current	up to 5 mA
Duty factor	10%
Frequency range of RFQ and DTL	424 - 433 MHz
Beam power	1,5 MW
Working frequency of CCL	805-861 MHZ
Number of RFQ	1
Number of APL-DTL resonators	6
Number of CCL modules	8

TARGET

Neutron yield from the target irradiated by charge particles depends on parameters of particle beam, target composition and it dimensions.

Characteristics of targets were defined with code Geant 4.9.5.

In case of non-fissile target materials spallation neutrons aren't multiplicated inside target and neutron source intensity is specified by leakage from target surface. In target with fissile materials spallation neutrons are multiplicated in target due to fissile processes and neutron source intensity is specified by yield of spallation neutrons inside target.

Calculated values of optimal dimensions of cylindrical non-fission targets are presented in Fig. 2, it also represents neutron yields for them.

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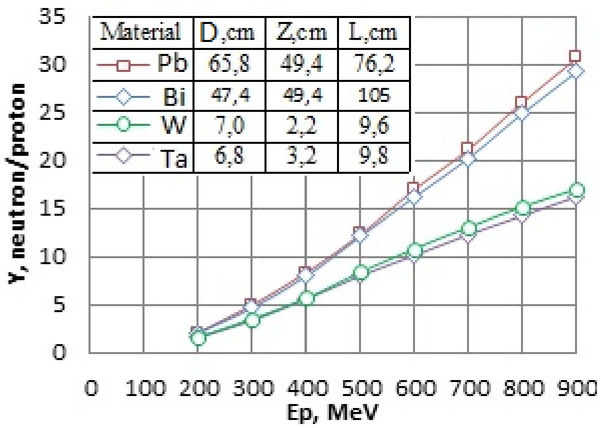

Figure 2: Neutron yield from non-fissile target with table of optimal dimensions for 300 MeV primary protons. D – diameter; L- length; Z – injection point injection point depth.

This is necessary because for small size targets a significant part of secondary particles that can induce nuclear fissions leave the target. For large size – radioactive capture of neutrons by the target plays an important role. In addition, it should be noted that since entering the beam directly at the face surface leads to the large protons and neutrons leakage, it's necessary to deepen input beam penetration point.

Calculated values of spallation neutron source (without fission process) inside uranium target are presented in Fig. 3.

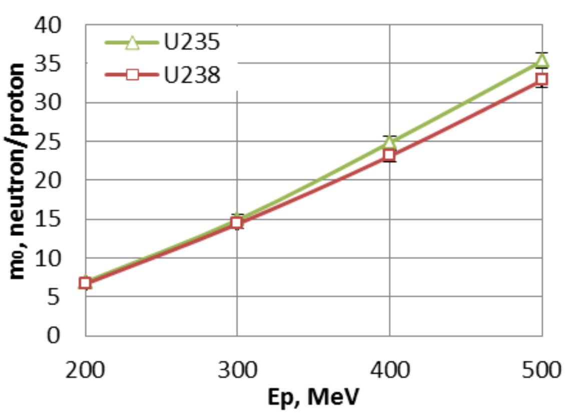

Figure.3: Spallation neutron source inside fissile target.

Obtained dimension of neutron production fissile target demonstrate that spallation source is indifferent to increasing of target diameter and leakage of spallation neutron is insignificant. For Uranium target irradiated by 300 MeV protons the leakage of spallation neutrons is less than 5% for target with diameter 32 cm (3 λ_{in}).

For ADS with 300 MeV proton beam should be used fissile target with diameter $D = 3\lambda_{in}$, which produce $m_0=15$ spallation neutron in fissile material.

Design of target with tube irradiated elements is shown at Fig. 4. Structure of irradiated element allows to implement fissile material in form of tablets, powder etc. The diameter of target is 40 - 60 cm depending on void fraction of fissile material.

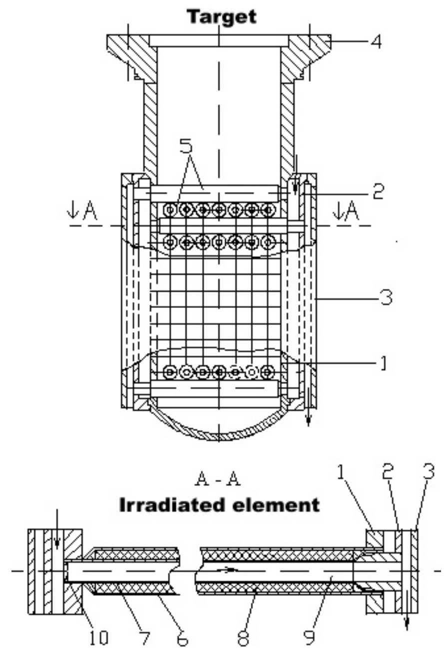

Figure.4: Target. 1, 2, 3 – vessel with channels for coolant; 4 – vacuum ion guide; 5 - irradiated elements; 6, 7 – shells of irradiated element; 8 - fissile material; 9 - coolant channel; 10 – throttle.

SUBCRITICAL REACTOR

The intensity of electronuclear neutron source is defined as

$$S = \frac{I_p m_0}{e}$$

I_p – accelerator current, m_0 – spallation neutron yield per primary particle, e – charge of primary particle.

For gas cooled target with fissile material UN and structural material W spallation neutron source $m_0=12$ n/p and intensity S=4,2·10^{17}n/s for $I_p=5mA$.

Thermal power of sub-critical reactor with external neutron source spatial distribution similar to fission neutron one (reference neutron source) is evaluated as

$$N_T = S_0 \cdot \frac{k_{эф}}{1-k_{эф}} \cdot \frac{1}{\nu} \cdot E_f$$

where S_0 - intensity of reference neutron source, $k_{eff} < 1$ – multiplication factor, ν – mean number of neutrons per fission, E_f – energy released per fission.

To maintain constant power rate of ADS over reactor operation period with decreasing k_{eff} it's necessary to increase accelerator current. Reactivity reduction as a result of nuclear fuel burning and reactor poisoning is about 8% for thermal-neutron reactor and 1- 3% for fast-neutron reactor. Thus, in ADS with fast neutron reactor accelerator current variety during the operation period is significantly less than in one with thermal-neutron reactor. Consequently, using fast core in ADS is more preferable.

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It is possible to increase reactor power locating external neutron source in the center of the core and hence decrease neutron leakage.

High-temperature gas-cooled fast neutron reactor (HTGR) with helium coolant is proposed as sub-critical reactor for ADS. The design of this reactor is shown in Fig. 5.

The thermal power of sub-critical core with fissile target$(S=4,2\cdot10^{17}\ n/s)$ is equal 400MW at $k_{eff}=0,98$ and 200 MW at $k_{eff}=0,96$.

ADS POWER PLANT

The ADS is comprised of a sub-critical high-temperature gas-cooled reactor (HTGR), a linear proton accelerator and a single-circuit gas-turbine installation. Gas-turbine installation efficiency is 20%. With accelerator energy consumption of linac equal to 15 MW the effective electrical output of ADS is 25 MW.

ADS layout and its main characteristics are shown in Fig. 5 and in Table 2. It is possible to place installation in protected container with diameter 10 m and length 30 m.

Table 2: Main characteristics of accelerator driven power plant.

Effective output:	25 MW(el.)
Linac:	
-current	0,5 mA
- proton energy	300 MeV
Target (D)	UN+W (0,4 m)
Reactor:	Fast HTGR
- Thermal power,	200 MW
- Core DxH,	1,6x1,5 m
- k_{eff}	0,98 - 0,96
- fuel	UN
-coolant (P; T_{in}; T_{out})	He(10MPa; 230^{0}C; 900^{0}C)
Gas-turbine efficiency	20%

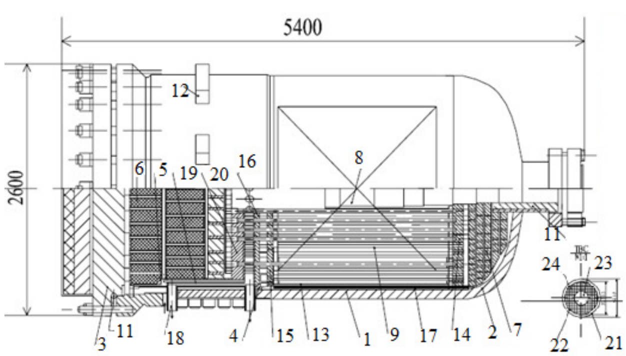

Figure.5: Design of high temperature gas-cooled reactor. 1-vessel; 2 – bottom; 3 – closure head; 4 – core shroud; 5 – fuel assemblies holder; 6 – upper shield; 7 – edge shields; 8 – target; 9 – core; 10 – nozzle ofion guide; 11 – sealing; 12 – reactor vessel fixing elements; 13 – core shroud shell; 14, 15, 16 – core plats; 17 – shield; 18 – output gas nozzle; 19, 20 – fuel assemblies holder shell, plate; 21, 22, 23 – fuel assemblies' tubes; 24 – cylindrical fuel elements.

CONCLUSION

Present-day reactor and accelerator technologies allow to create low energy accelerator driven power plant with electrical output 25 MW.

A promising option of a small-size electronuclear power plant can be based on linear high-frequency proton accelerator, fissile target and sub-critical fast reactor.

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