TEST FACILITY FOR NUCLEAR WASTE TRANSMUTATION STUDIES

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Abstract

Proposal for construction in ITEP the prototype of the electro-nuclear installation for transmutation of long-lived NPP waste is discussed. Combination of the linear proton accelerator "ISTRA" with subcritical accembly on the place of stopped heavy water experimental ITEP reactor is considered.

Introduction

The feasibility study of the transmutation of the long-lived high-level waste of nuclear industry based on the powerful electro-nuclear installation which consists of linear proton accelerator and subcritical assembly have been initiated in scientific centers of USA, Japan and Russia.

The requirements for the accelerated proton beam in such installation isn't yet defined precisely, however, it is clear that the energy of the beam is in the region of 1 GeV with average output current from tens to hundreds mA. It means that beam current is at least two orders of magnitude higher than achieved in present.

The proposal to develop in ITEP prototype of such installation based on the combination of the proton linac and solid light-metal target surrounded by the heavy water blanket with subcritical assembly is discussed in this paper.

For this goal it is possible to use linac "ISTRA" with output energy 36 MeV, which has been designed early as many purposes machine and constructions and elements of the research heavy water reactor which has been stopped due to ecological restrictions. It is necessary to move linac "ISTRA" on a distance 150 m to the reactor building and to increase considerably the power of the RF-system. Nevertheless cost of the prototype development will be relatively small (in comparison with the development completely new accelerator) and all needed work can be made in enough short period.

In the proposed project proton beam (pulse length 150 − 300 µs, repetition rate 10 − 25 Hz) will produce on the target quite long pulse of neutrons (fall time of 20 − 30 ms). Neutrons are multiplied by the assembly. Rather high average beam current (approximately 1 mA) and neutrons multiplying by the blanket (20 − 100 times in dependence of the blanket composition) can give high flux of the thermal neutrons ($10^{12} - 10^{13}$ n/cm^2 s) in the area of the experimental channels.

Installations of this kind have some advantages comparing with reactors by virtue of the nuclear safety. They can be used as a thermal neutrons sources for fundamental and applied nuclear physics.

By using the installation as experimental stand for full-scale modelling of the subcritical blankets one can to optimize this system from the point of view of the maximizing of the neutron flux with certain energies (first of all − thermal). This one based on possibility to choice of the composition and structure of the blanket for effective multiplying of the neutrons emitted by the target in different parts of the spectra, and moderating and multiplying them inside of subcritical assembly. Note that, in such systems problem of the increasing neutron flux will be connected only with increasing of the beam current.

The development in ITEP this installation, called here Subcritical Neutron Generator (SNG), allows to solve a number of problems during its operating and future upgrading. It concerns just as problems of the accelerator, so a problem of the optimization of the blankets for the nuclear-physical experiments with neutrons extracted from the core as a beam or accumulated in the special traps installed in blanket.

Main parameters of the installation

In the SNG accelerated proton beam is guided to the target and initiates neutron producing reactions and the direct reactions of the neutron knocking. Beryllium was chosen as a material for the target because it has higher than, for example lithium, yield of neutrons and more preferential mechanical and thermal characteristics. Target is made as a cone (see Fig.1) and placed inside the existing frame and biological shielding of the stopped ITEP heavy water reactor near the center of the multiplying assembly.

The range of 36 MeV proton is 1.426 g/cm^2, density of beryllium is 1.84 g/cm^3, therefore the linear range is equal 7.75 mm. There is evidence for the possibility of beryllium cooling up to 15 kW/cm^2. In our case power of the beam (30 − 40 kW) will be distributed on the target surface, so that the heat operation will be not stressed.

Main multiplier consists of the channel type heat-released assemblies based on the high-enriched U^{235} and neutrons reflector section in which experimental, irradiational and special channels are placed (Fig.2). According to the estimates loading of U^{235} is 1.17 kg and 16 − 17 heat-released assemblies with a length of

1.11 m are used. Diameters of the experimental channels are from 100 to 240 mm. Expected full neutron flux will be approximately 10^{14} n/sec.

The following problems can be solved by the SNG using :

- define optimal parameters of the heavy water blanket for the transmutation installation;
- measure parameters of the full-scale models of the blanket without of critical regime hazard;
- research relation between neutron-physical parameters of the blanket and time-depended characteristics of the pulse neutron flux;
- check codes for calculation of the neutrons multiplying;
- justify the conception of the subcritical system control from the point of nuclear safety;
- use SNG as neutrons source in investigation of the fundamental problems of neutron physics.

Linear accelerator

Linear proton accelerator ISTRA [1] has been designed as additional injector for the ITEP synchrotron and as pulse prototype of the high current accelerator. ISTRA consists of the 90 keV injector, 3 MeV RFQ section and two Alvarez resonators : DTL-1 (10 MeV) and DTL-2 (36 MeV). Average beam current up to 4 mA can be used in accordance with possibilities of the heat removal.

Initial part of the linac, which includes first version of the RFQ structure and first Alvarez resonator DTL-1 is now in operation at low duty cycle with design value of the output pulse current 150 mA. Experimental confirmation of the physical and technical decisions which were used by ITEP specialists in the linac development has been achieved.

Optimal choice of the RFQ section parameters provides practically 100% transmission up to current 100 mA. The using of the frequency 297 MHz for DTL resonators twice higher than for the RFQ section allows to decrease size of the DTL resonators and RF power losses without decreasing maximal beam current.

Original construction of the permanent magnet quadrupoles (PMQ) and their using in the focusing channel of the DTL resonators excludes the need for the special system for the lens energize and facilitates thermal conditions of the drift tubes.

In the DTL-1 resonator, which now in operation, 33 drift tubes are positioned. 33 drift tubes (among 54) of the DTL-2 resonator now have been controlled on all magnetic and mechanical parameters. Field distortion in the measured drift tubes is approximately 0.7% and root-mean displacement of the PMQ magnetic axis from the geometrical axis of the linac is less than 30 μ m. Measurements was made in universal stand which allows to define spatial distribution of the magnetic field configuration.

Most part of the linac equipment including of additional RF output stages and new high d.f. RFQ structure has been manufactured, nevertheless completion of the linac construction with simultaneous transformation it to the intensive beam operation needs a solving of a number special problems. Most technically serious ones are upgrading of RF modulators, generating and fast controlling high level RF power.

The estimations and testing of our modernized for operation up to 300 MHz power tube GI-27AM show that it allows to develop RF-system with parameters shown in the Table 1.

TABLE 1
RF system parameters

Parameters	RFQ	DTL-1	DTL-2
RF frequency, MHz	148.5	297	297
Pulse RF power losses in Cu, kW	440	430	1110
Pulse RF power for the beam, kW	440	1090	3910
Power control ratio	2.0	3.6	4.5
Average RF power consumption, kW	4.4	7.6	25.0
Average RF power losses, kW	2.2	2.2	5.6

Duration of RF pulse and its repetition rate are chosen for the best utilization the possibilities of GI-27AM triode at rising of d.f. Compromise mode for producing at first the average beam current 0.5 mA in our case is the follow:

RF pulse length — 500 μsec
Beam pulse length — 350 μsec
Duty factor — 0.5%

As it is seen from the Table 1, RF power feeding into resonators in dependence on the beam current has to change in wide area (up to 4.5 times for the DTL-2). Clearly it takes not only large regulation of the anode voltage at the RF generators output stage but also the using of the different kinds of the feedback. Resonators thermostabilization with summed RF power losses 10 kW can be made without problems.

Planned placement of the linac ISTRA at the two floors in the existing reactor building provides beam transportation from the first floor to the second with rotation it on 180° (Fig.3). Calculations show that it is possible to construct the transport channel which insures identical transversal and longitudinal parameters of the beam at the DTL-1 output and DTL -2 input. This channel has to consists of the two bending magnets, two-gap buncher and four drift spaces in which PMQ's are placed. The maximum of the transversal beam size in this channel isn't higher than 2 cm.

Proposed linac placement allows to eject easily parts of the beam pulses with energies 10 or 36 MeV for the applied goals.

Conclusion

Possibility of the combination linac ISTRA-36 with subcritical target-blanket complex based on the stopped heavy water reactor ITEP is shown. It is necessary to rise linac beam intensity as it's described above. This project is economically beneficial and can be finished at comparatively modest financial grounds approximately in 2.5 years.

The full neutron flux in SNG is much higher than it is necessary for precise measurement all characteristics of blanket at different geometries of active zone and quite enough for many experiments on the field of neutronic physics. The possibility of instantaneous beam intensity control checked in SNG will help to develop a new NPP safety conception.

Projects of the high power researching and energetic subcritical installations can be justified by checking of design configuration on flexible SNG structure.

References

1. V.A.Andreev, I.V.Chuvilo, I.M.Kapchinsky at al "ISTRA-10 Linear Proton Accelerator Start-up", Proc. of the 1990 Linac Conf., LA-12004-c, p.782.

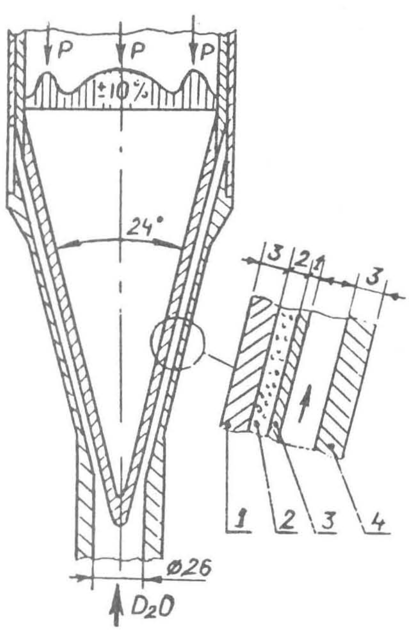

Fig.1. Neutron producing Be target. ① - Be cone thickness 6 mm. ②-Binding layer. ③-Al jacket. ④-Outer Al tube.

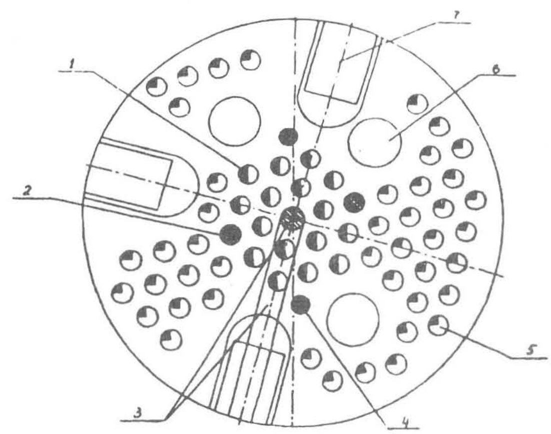

Fig.2. Blanket of the subcritical neutron generator. ①-Fuel channel (16 ones). ②-Compensating and regulating rod (2 ones). ③-HEBT and Be target. ④-Shut-down rod (2 ones). ⑤-Special channel (44 ones). ⑥-Vertical experimental channel (3 ones). ⑦-Horizontal experimental channel (3 ones).

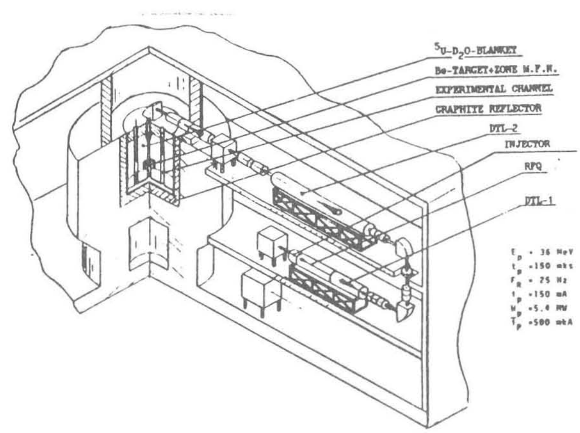

Fig.3. Layout of the linac in reactor building.