B.2.6. ACCELERATOR DRIVEN HEAVY WATER BLANKET ON CIRCULATING FUEL

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B.2.6.1. INTRODUCTION

A conceptual design of a heavy water blanket with circulating fuel is described. Radiation safety for a reactor with fluid fuel is provided by the same means as in traditional nuclear power, namely by security in depth and control. As compared with fixed fuel reactors, the radiation situation in the suggested system can be improved, for, on the one hand, activity of the fission products is reduced through the continuous removal of the irradiated fuel for reprocessing, and, on the other hand, there is no need to open the reactor for reloading.

A design of a heavy water blanket with circulating fuel has been proposed in ITEP [1]. A lattice of power channels is placed inside a cold heavy water tank under about normal pressure. The channels made of proven Zr-Nb alloy isolate the fuel from the moderator and keep it constantly exposed to irradiation. Inside each channel there are two loops: a fuel loop (solution or slurry in heavy water) and a loop of pressurized heavy water coolant. The latter cools the fuel, circulating in the channel, while the fuel is continuously fed and removed in small portions for chemical reprocessing. After reprocessing the actinides come back to the fuel loop, while the remainder is fractionated and further sent for transmutation or storage and burial.

B.2.6.2. GENERAL CHARACTERISTICS OF THE FACILITY

The hybrid system consists of a high-current linear accelerator of protons and 4 targets, each placed inside a subcritical blanket. The plan view of target-blanket and its cross section are presented in Fig. 1 and 2. The accelerator current is 100 mA, the proton energy is 1 GeV and its power is 100 MW. The RF-to-beam conversion ratio is 40-50%.

Control magnets split the beam up into 4 separate beams, each of 25 mA current. After passing through defocusing magnets the beam of 30 cm in diameter goes through a diaphragm (window), isolating the accelerator vacuum from the target space, and strikes a 50 cm diameter target. The thermal power of such a separate beam is about 15 MW. The target consists of coated Pb elements or Pb grains cooled by heavy water flow. The Pb- heavy water volume ratio is 50%. The target, encased in a Zr tube, is surrounded by an inner reflector, made up of pure heavy water 70 cm thick. This heavy water layer is isolated from the blanket by a Zr cylinder wall. Control rods could be inserted into the inner reflector, and in a emergency some neutron poison for example, boric acid could be quickly released into the reflector water.

The subcritical blanket consists of a regular lattice of channels (modules), arranged with a step of 30 cm. The module design is shown in Fig. 3. The channel is constructed from Zr material. Heavy water coolant is pumped through an outer heat exchanger. Fluid fuel circulates inside the channel. The fuel is discharged in small portions for chemical reprocessing. Fresh fuel feeding and spent fuel discharge take place incessantly. The circulating fuel is either a heavy water solution of Pu, MA and fission products (FP) salts or their slurry.

The power of the channel, which is put under maximum load, is 5 MW. The depth of the active part of the channel is 4 m. The power of a channel in the blanket is on average about 3 MW (variation is 1.6). The blanket unit contains about 160 channels, the facility total being 640 channels.

The blanket is surrounded on an outer reflector. The subcriticality of the blanket is close to 5%. The thermal power is 500 MW (for the whole plant 2000 MW). Due to its heat-to-electricity conversion rate, close to 20%, the electric power of the whole plant will be 400 MW. An average thermal neutron flux in the blanket is expected to be about 3.* 10^{14} n/ cm^2 s.

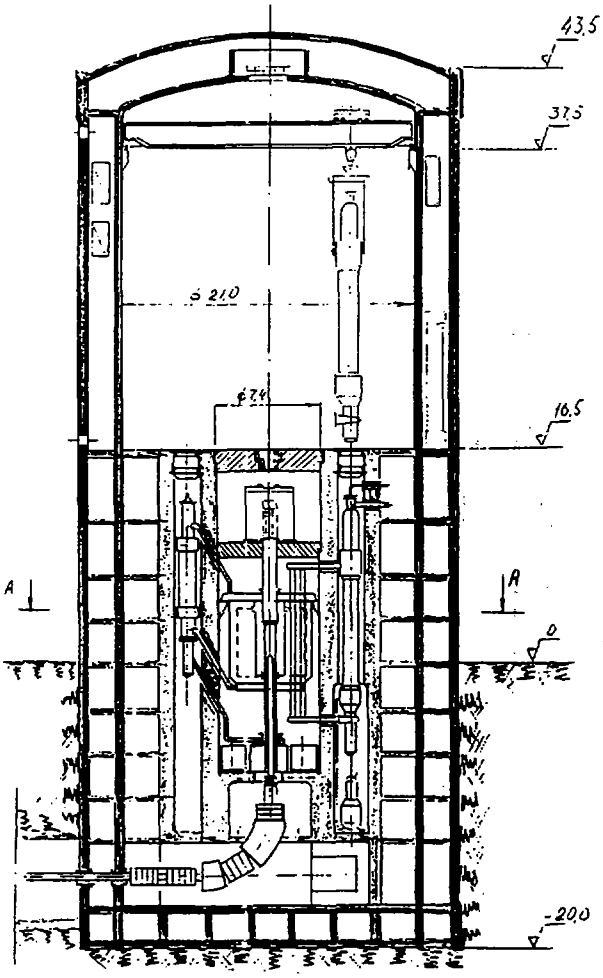

FIG. 1. Vertical cross-section of the accelerator driven heavy-water facility. The numbers show the approximate heights and diamaters in meters. The line A-A shows a cross section presented in Fig. 2

B.2.6.3. GENERAL PRINCIPLES OF THE SUGGESTED FLUID FUEL MODULE

The suggested fluid fuel module (FFM) is a unit of the blanket assembly of the accelerator driven nuclear plant containing circulating fluid fuel within the blanket core. Water solutions of salts or water slurry of oxides could be used as fluid fuel. The proposed design of the fluid fuel module is illustrated in Fig. 3.

The conceptual design scheme of FFM is as follows: the circuit of FFM contains a central 1.5 mm thick lifting tube of 83 mm in diameter (CLT) and 90 outlying 0.5 mm thick lowering tubes of 11 mm in diameter each (OLT). The OLT are joined with the CLT and arranged as a stringer with lattice spacing 13 mm. The forced circulation of the fluid fuel is realized by a centrifugal pump placed in the lower part of the CLT and driven by a hydraulic turbine, which uses the energy of a fluid fuel coolant. The FFM active zone is 4.0 m in height, the external diameter of the coolant channel is 165 mm.

The FFM is installed into an assembly channel, which is a component of the blanket structure.

The design scheme of the FFM also provides :

- continuous withdrawal of the irradiated fuel,
- compensation of the fluid fuel volume by changes of the temperature,
- support of the pressure drop between the coolant and the fluid fuel within hydraulic losses of the coolant,
- guide grids of the heat-exchange tubes.

The initial data for developing the blanket design are determined by the following factors:

- heavy water is the coolant and the fluid fuel carrier,
- production of electrical power for feeding the Linac.

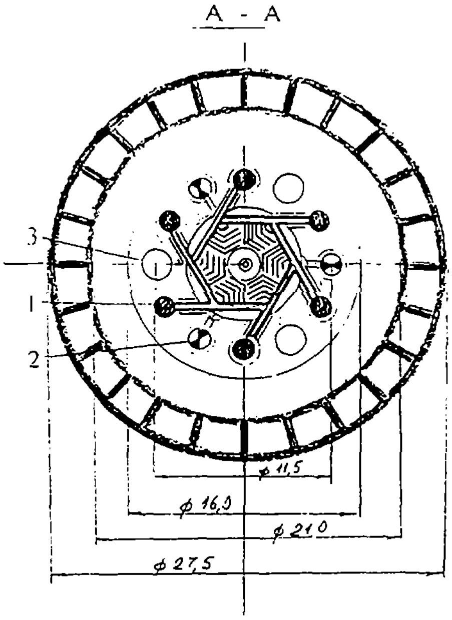

FIG. 2. Cross section of the facility. 1 - steam generator, 2 - heat exchanger, 3 - channel for inlet-outlet of fuel regeneration

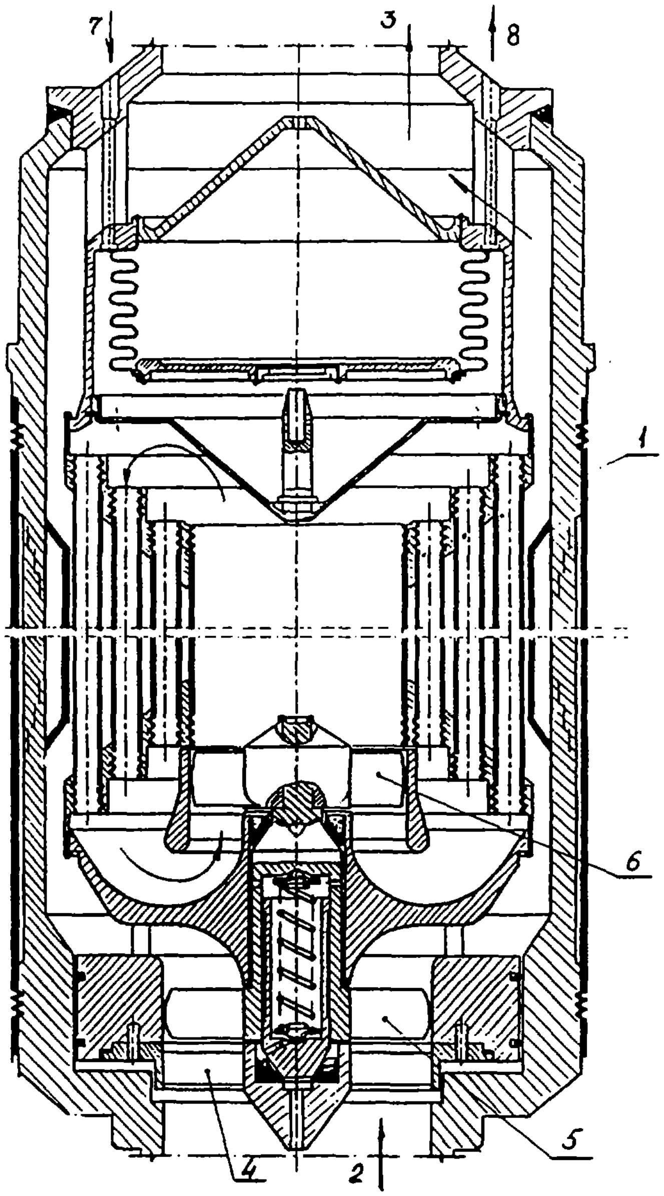

FIG. 3. Vertical cross section of the fluid fuel element. 1 - fluid fuel circuit, 2 - coolant inlet, 3 - coolant outlet, 4 - flow guider, 5 - turbo-drive, 6 - pump, 7 - feed inlet, 8 - fuel regeneration outlet

On the basis of the literature on the subject and the preliminary calculatons of the design characteristics of the FFM, the following starting conditions are accepted:

- maximum temperature of the fluid fuel - 300 ;
- pressure - 10 MPa.

These conditions can provide:

- good enough characteristics for the power circuit of the plant (see an illustration of the suggested scheme on Fig. 4) ;
- practically complete suppression of the radiolytic gas release in the fluid fuel under normal operating conditions, moderate content of bivalent cuprous ions in fluid fuel (0.8 g/dm^3 and accordingly $\Sigma_c \leq 0.29 \cdot 10^{-4} cm^{-1}$);
- use of the Zirconium alloys such as H-1 and H-2 as construction materials;
- reasonable corrosion velocity (to 0.0107 mm\a by 280-300°C);

- good erosion resistance of the materials in the slurry with a flow velocity up to 6 m\sec.

Preliminary module design calculations show that the accepted above-mentioned parameters of the fluid fuel can be realized under the module parameters listed in Table I.

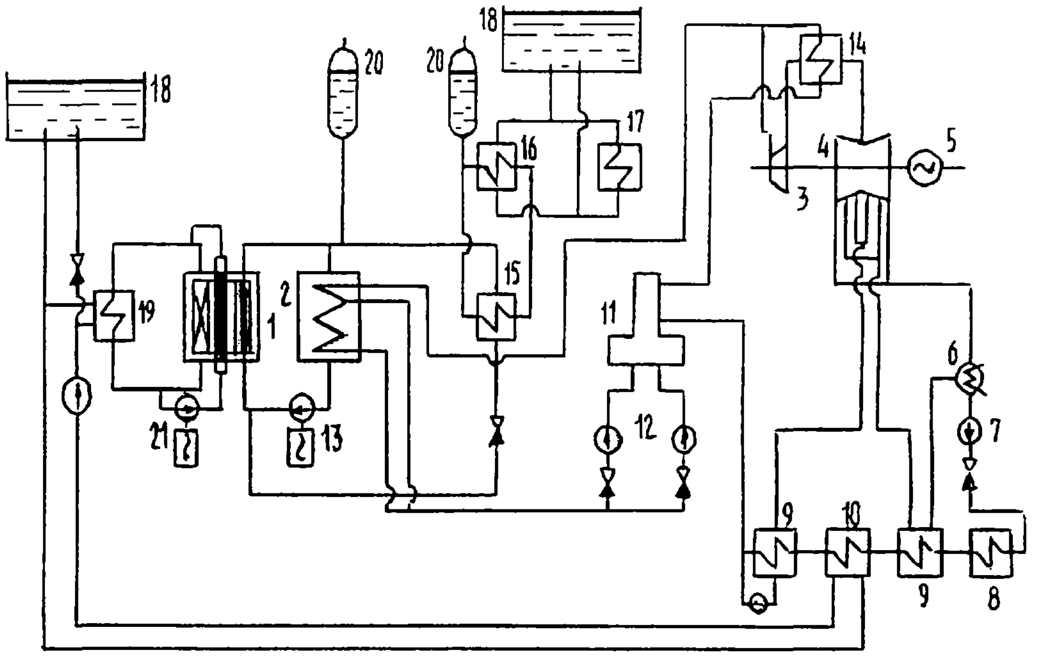

FIG. 4. Schematic thermodynamical layout of the facility. 1- target-blanket, 2 - steam generator, 3 - high pressure cylinder of the turbine, 4 - low pressure cylinder of the turbine, 5- electro-generator, 6 - condensor, 7 - condensation pump, 8 - condensation cooler, 9 - low pressure heater, 10 - heat exchanger of the moderator, 11 - deairator, 12 - water feeding pump, 13 - the first loop circulator, 14 -steam overheater, 15 - heat exchanger of coolant, 16 - water-water heat exchanger ocf coolant, 17 - water-air heat exchanger of coolant, 18 - reservoir of the emergency cooling, 19 - moderator cooling, 20 - comensator, 21 - target coolant circulator

TABLE I. PARAMETERS OF FLUID FUEL MODULE.

Thermal output, MW	5
Fuel circulation rate, kg/s	10
Coolant circulation rate, kg/s	35
Fuel velocity, m/s	2
Coolant velocity, m/s	6
Fuel temperature (av), °C	285
Coolant:	
outlet temperature, °C	250
average temperature, °C	230

Tentative estimates of parameters of the power circuit are shown in Table II. Figure 2 shows relative positions of steam generators and heat exchangers.

TABLE II. STEAM GENERATION SPECIFICATIONS

Steam temperature, °C	200
Feed-water temperature, °C	100
Steam pressure, MPa	1.6
Rankin's cycle thermal efficiency, %	22.6
Efficiency of the power plant, %	17.3

B.2.6.4. FUEL CYCLES

Two fuel cycles are considered: 1) military Pu and MA are loaded, only fission products (FP) are discharged (Cycle 1); 2) the same load, Pu of a worsened isotope composition is discharged additionally to FP (Cycle 2). In the blanket Pu, MA and FP are considered to be in equilibrium. With the given power of the facility equilibrium concentrations are maintained in stable working order with the choice of rates of feeding and discharge. Performance data for two fuel cycles are presented in Table III.

TABLE III. PERFORMANCE DATA FOR TWO CYCLES OF PU CONVERSION AND MA TRANSMUTATION.

	Cycle 1	Cycle 2
Pu load, kg/a	400	750
Pu withdrawal, kg/a	0	500
MA load, kg/a	200	350
FP discharge, kg/a	600	600
Core inventory of Pu and MA, t	4	2.9

It is assumed that the Pu in the load is Pu-239(100%). The composition of MA being loaded is ^{241}Am (47.47%), ^{237}Np(41.81%), ^{242m}Am(0.09%), ^{243}Am(8.57%), ^{244}Cm(1.67%), ^{245}Cm(0.09%). The equilibrium concentrations of Pu and MA mixtures in fluid fuel, which are obtained, are 125 g/l for Cycle 1 and 91.5 g/l for Cycle 2. The isotope composition of Pu is estimated to be as follows: ^{238}Pu(27%), ^{239}Pu(39,4%), ^{240}Pu (20%),^{241}Pu(5.8%), ^{242}Pu(7.8%).

It can be seen that in Cycle 2 the MA incineration rate to be achieved in the facility is approximately doubled due to a failure of complete Pu burn-down. The equilibrium compositions obtained are presented in Table IV. For Pu isolation in Cycle 2 the rate of chemical reprocessing needed, should be 46 l/day.

B.2.6.5. CONCLUSION

The suggested hybrid system offers a chance to fulfill safe and efficient incineration of all built Pu and MA stock. Resources of the facility performance can be considered by a wide variation of the load-withdrawal rate as well as the concentration of Pu and MA in the fluid fuel. Additionally, disposal of Cm to interim storage and its return back to the blanket in 2 years' time are expected to be promising.

TABLE IV. EQUILIBRIUM ISOTOPE COMPOSITIONS (g/l) IN BLANKET CORE.

Element	Atom number	Cycle 1 (g/l)	Cycle 2 (g/l)
Np	237	9.33	17.15
Np	238	0.41E-1	0.76E-1
Pu	238	9.48	8.28
Pu	239	9.77	12.09
Pu	240	10.78	6.13
Pu	241	3.45	1.81
Pu	242	25.5	2.42
Am	241	3.075	5.58
Am	242m	0.33E--1	0.61E-1
Am	242	0.14E-1	0.25E-1
Am	243	7.99	4.15
Am	244	0.41E-3	0.23E-3
Cm	242	2.61	4.80
Cm	243	0.223	0.42
Cm	244	23.54	15.57
Cm	245	0.90	0.61
Cm	246	14.68	9.57
Cm	247	1.08	0.72
Cm	248	2.77	1.86

REFERENCE

[1] V.D.Kazaritsky, P.P.Blagovolin, V.R.Mladov et al. - Fluid Carrier Problem of Blankets on Circulating Fuel, Preprint ITEP 20-1994, M., 1994 (In Rus.).