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AN EXPERIMENTAL ACCELERATOR DRIVEN SYSTEM BASED ON PLUTONIUM SUBCRITICAL ASSEMBLY AND 660 MeV PROTONS ACCELERATOR

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Экспериментальная управляемая ускорителем система,
основанная на подкритической плутониевой сборке
и протонном ускорителе с энергией 660 МэВ

Излагается концепция электроядерного реактора с подкритической плутониевой сборкой и протонным ускорителем с энергией 660 МэВ, которым располагает ЛЯП ОИЯИ. В качестве делящегося материала подкритической сборки предполагается использовать аналог плутониевых стержней, предназначенных для импульсного реактора ИРЕН (ЛНФ ОИЯИ). Тепловая мощность проектируемой электроядерной системы — около 20 КвТ, коэффициент мультипликации $K_{\mathrm{eff}} = 0,94 - 0,95$, энергетический выигрыш — 20. Ток ускорителя 1,6 μ A.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1999

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An Experimental Accelerator Driven System Based
on Plutonium Subcritical Assembly
and 660 MeV Protons Accelerator

We present a Plutonium Based Energy Amplifier Testing Concept, which employs a plutonium subcritical assembly and a 660 MeV proton accelerator operating in the JINR Laboratory of Nuclear Problems. Fuel designed for the pulsed neutron source IREN (Laboratory of Neutron Physics, JINR) will be adopted for the core of the assembly. To make the present conceptual design of the Plutonium Energy Amplifier we have chosen a nominal unit capacity of 20 kW (thermal). This corresponds to the multiplication coefficient K_{eff} ranging between 0.94 and 0.95 and the energetic gain about 20. Accelerated current is in the range of $1 - 1.6$ μ A.

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1999

Introduction

Several electronuclear breeders with natural and enriched uranium have been studied at JINR. However all these systems require high current accelerators. Transition to subcritical assembly with a safe value of the neutron multiplication coefficient K_{eff} = 0.94-0.95 allows one to build experimental accelerator driven systems using proton current of several μA. By means of such experimental but rather powerful set-ups one can investigate many problems of a future electronuclear technology.

Particularly, it is important to study the possibilities of ADS for ecologically safe and economic utilization of weapon grade and technical plutonium accumulated in the course of operating nuclear power plants. The ADS technology looks quite promising to solve this issue. As a first step in the studies of peculiarities of plutonium ADS it was proposed in [1],[2],[3] to combine the core of the plutonium fast reactor IBR-30 and the 660 MeV proton accelerator, operating now at JINR. Now we consider to use a plutonium assembly similar to the IREN -new pulsed neutron source designed in JINR [4].

Main characteristics of the installation

The ADS which is a combination of the core of the IREN with neutron multiplication coefficient 0.94-0.95 and the 660 MeV phasotron with beam power 1kW and extracted beam with 2.0 10^{13} protons/s, can provide a way to get the thermal power of such a set-up about 20 kW . Such a power can be removed by an air and partly by a helium coolant. At the same time it is sufficient to carry out most investigations required for designing a full-scale industrial ADS .

The proposed ADS facility consists of:

- 660 MeV proton accelerator,
- beam bending magnets ,
- tungsten spallation target ,
- plutonium subcritical core based on IREN fuel elements,
- reflectors and concrete shielding,
- control and auxiliary systems.

Fig.1 represents general layout of the phasotron hall with marked position of the assembly.

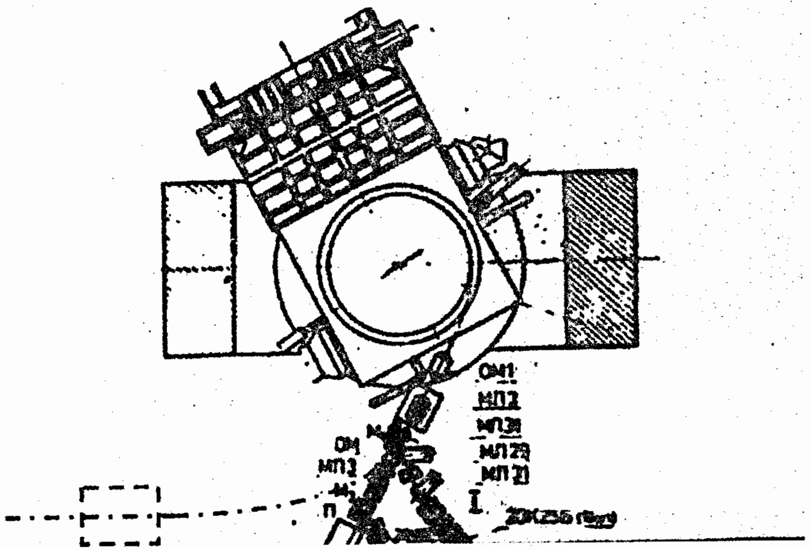

Fig. 1. General layout of the phasotron hall with marked position of the subcritical assembly.

The core is made up of 86 plutonium fuel elements similar in the construction to the fuel elements of the IREN reactor. The fuel elements are shaped as a cylinder with metal plutonium of radius r=5.1 mm, surrounded by Ta (0.1 mm thick) and stainless steel (0.3 mm thick) casings. The rods contain Pu-with density 15.6 g / cm^3. The mass of plutonium in the rod is 229.5 grams. The rods are located in a triangular grid. The full length of a fuel element with its end details amounts to 34 cm, while the core length is 18 cm. The fuel element consists of a stainless steel tube, a tantalum tube with a plutonium pills, iron inserts and details. The hexahedral core is surrounded by a reflector. Both the core and the reflector are placed inside a concrete container. The isotope composition of plutonium rods is shown in Table I.

Table I. Isotopic compositions of Pu

^{238}Pu	0.4 %
^{239}Pu	98.0 %
^{240}Pu	1.0 %
^{241}Pu	0.5 %
^{242}Pu	0.1 %

The fuel elements are cooled by airflow. The target, if required, can be cooled by helium. The estimations of the thermal loads of the target and fuel elements show that permissible values should not be exceeded. If necessary, it can be quickly minimized by decreasing the current of the accelerator. From this viewpoint the designed set-up is safe.

The 660 MeV JINR phasotron is characterized by following parameters:

-max average beam power	1.0	kW
- max. proton energy	660	MeV
- proton energy deviation	6	MeV
- max. average beam intensity	$2 \cdot 10^{13}$	p/s
- number of protons per pulse	$0.8 \cdot 10^{11}$	
- pulse rate.	250	Hz
- pulse length (fwhm)	20	µs
-pulse microstructure:		
- bunch length	10	ns
- interval between bunches	70	ns
- number of bunches per pulse (approx.)	300	

The building housing the phasotron allows one to provide safe radiation conditions. As the multiplication coefficient does not exceed the value of 0,95 the ADS set-up represents a safe subcritical assembly and requires only some additional precautions. In particular, the proposed subcritical assembly is supposed to be installed in the main accelerator hall of the phasotron in a closed location with limited access.

The ADS facility under design will be placed in a hall equipped with radiation shielding. The proton beam will be extinguished completely in the accelerator hall with the help of an additional local concrete shielding of a width of 1 meter that will provide fulfillment of the conditions on radiation safety at all operation modes of the installation. Around the plutonium assembly having a high gamma-radiation level due to fission fragments even when the accelerator is switched off, a lead shielding will be placed that will allow one to perform work at the assembly. The proton beam is transported to the target through a vacuum track passing through the concrete shielding.

In view of the essential variation of radiation fields and the danger resulting from a possible damage of the plutonium rods, an automated system will be installed for radiation monitoring including the volume activity of gases and aerosols in the installation. The experience of monitoring the radiation level obtained at the currently operating JINR pulsed plutonium reactor IBR-30 will be used in this case.

The important advantage of this project is a relatively small size of the reactor and a possibility of its quick realization, as a part of the required equipment is practically available.

The 940,000 US dollars are required to build up such a facility and to carry experiments; 340,000 US dollars will be allocated for this purpose as JINR Member States' grants. The project participants ask to invest the rest of the money (600,000 US dollars).

Physical aspects

The main properties of the designed set up with various variants of the assembly details are investigated by means of computer simulation using the particle transport code CASCADE based on the intranuclear cascade evaporation model developed at the JINR. The general goal of the calculations was to provide proper design assumptions, especially from the viewpoint of the operational safety and measurement accuracy.

By calculation the system with a plutonium blanket of radius 7 cm and tungsten or lead target of radius r=2.0 cm was considered as a cylindrical one. The target was placed in a steel tube of thickness 0.3 cm The blanket was considered also as homogenous taking into account the composition of Fe, and Pu : plutonium (56.5 %) steel (15 %) and air as a coolant (28.5%). The reactor core is surrounded by a steel reflector of thickness 2.0 cm and heavy concrete shielding with thickness about 17 cm. The beam of accelerated protons is directed into an axial split (11 cm. depth), penetrating the facility through the vacuum system of the accelerator tube via a special tungsten window. (Fig. 2).

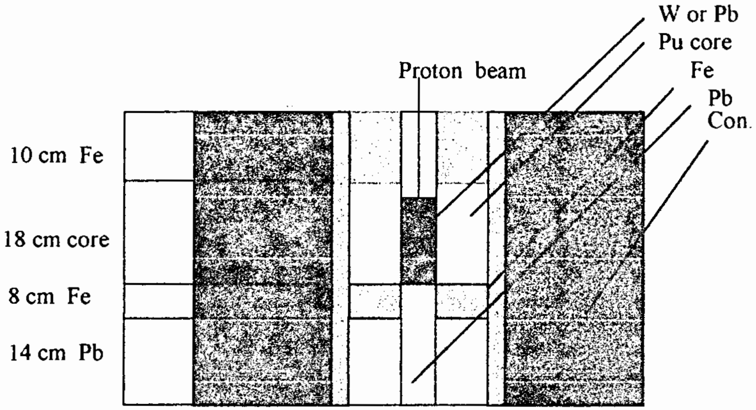

Fig. 2. Cylindrical geometry adopted for the transport calculations

The calculated quantities were the neutron multiplication coefficient and the heat generation in the target and blanket system. Table 2 and Fig. 3 give the dependence of the heat production (ionization and total) and the neutron multiplication at various proton beam energies.

Table 2. Results of CASCADE code calculations.

W target			
E [GeV]	k_{eff}	Q_{ion}/E	Q_{tot}/E
0.4	0,954/0.002/	0.750	20.0
0.5	0,952/0.003/	0.704	21.6
0.65	0,947/0.003/	0.623	23.7
0.8	0.950/0.003/	0.568	24.8
1	0.950/0.003/	0.491	25.4
1.4	0.951/0.003/	0.433	24.1

Pb target			
E [GeV]	k_{eff}	Q_{ion}/E	Q_{tot}/E
0.4	0.955/0.002/	0.762	19.0
0.5	0.956/0.002/	0.704	23.0
0.65	0.955/0.003/	0.627	24.7
0.8	0.953/0.003/	0.503	24.0
1	0.953/0.003/	0.437	23.3
1.4	0.952/0.003/	0.381	22.0

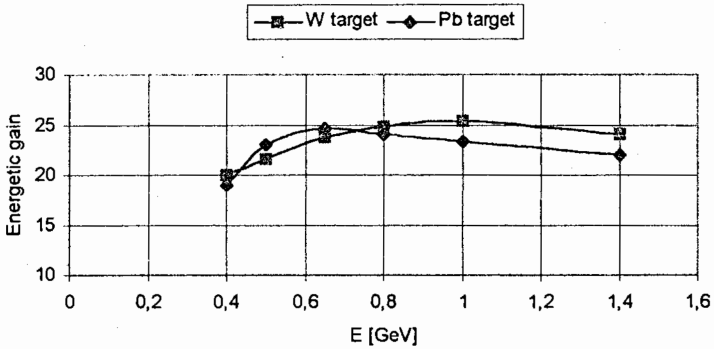

Fig. 3. Energetic gain vs. incident proton energy.

As one can see, the maximum is observed for incident proton energy about 0.6-1GeV. A decrease in energy gain seen at lower energies is caused by ionization losses of the primary protons. For the suggested 660 MeV of proton energy the energetic gain is only 5% less for the tungsten target than for the lead target .At high energies spallation neutron production in the tungsten target is greater then for the lead target.

The results of computer simulations for the proposed assembly at 650 MeV proton energy, in terms of a number of rods, factor k_{eff} ,and energetic gain are presented in Table 3.

Table 3. The results of CASCADE code calculations.

Number of rods	Mass of Pu [grams]	k_{eff}	Q_{ion}/E	Q_{tot}/E
85	19507	0,9344 /0.002/	0.634 /0.013/	17.6 /0.3/
86	19737	0,9411 /0.003/	0.632 /0.013/	19.7 /0.4/
87	19966	0,9474 /0.003/	0.631 /0.013/	23.3 /0.5/

It can be seen in Table 3 that the energetic gain weakly falls with the reduced number of rods. For the assumed multiplication coefficient 0.947 one should use 87 plutonium rods (20 kg of plutonium). At the same time fluctuations of the energetic gain of the ADS set-up are possible during its operation due to different accelerator modes and changes of the neutron multiplication coefficient. For example, Fig. 4 shows the energetic gain depending on the value of neutron multiplication coefficient for the system presented in Fig.2. with 650 MeV proton beam.

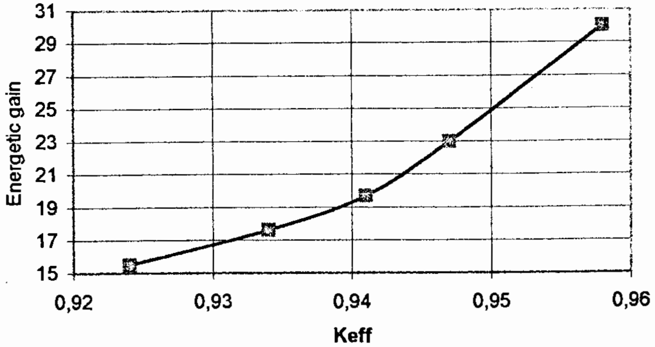

Fig. 4. Energetic gain vs. neutron multiplication coefficient for Pu zone with tungsten target at the incident proton energy 650 MeV.

We see that the energetic gain in the designed set-up for keff=0.94 is equal to 19 and energetic gain for k_{eff}=0.95 is equal to 25.

The above estimates show that one would expect quite a stable behavior of the facility under investigation.

Experimental program

The main goal of the experiment is to demonstrate the possibilities to construct a safe and stable from the operation viewpoint ADS set-up and to verify reliability of theoretical methods to estimate characteristics of such systems.

The installation under design is intended for:

- study of the ADS system's dynamics, in particular, methods for measurement and monitoring of the value of k_{eff} and its fluctuations;
- research in the efficiency of the ADS technology for utilization of the weapon-grade and technical plutonium;
- study of the energetic gain and its variation for different target materials and compositions:
- obtaining data for designing a full-scale incineration of plutonium by means of optimization of the system parameters;
- measurement of integral cross-sections (radiation capture and fission) of fission products and actinide isotopes in various neutron spectra ,
- study of some possibilities to increase effectiveness of the ADS installations on the way of sectioning the breeding assembly (by introducing valve layers, reflectors),
- obtaining data to correct the physical model and software support by means of comparison with computations on neutron yield, spectra and leakage.

The ideas of the measurements have been described also in [5].

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References

[1] V.S. BARASHENKOV, A.POLANSKI, A.N. SOSNIN, "Application of low-energy accelerators in electronuclear systems". Kerntechnik, p.197, Vol.63, No.4 ,August 1998.

[2] S.BARASHENKOV, et al "Physical Aspects of an Electronuclear Assembly Based upon the Subcritical Reactor IBR-30 and the 660 MeV Proton Phasotron",Rep. JINR, P2-98-74, Dubna, 1998.

[3] V.S.BARASHENKOV, et al., "Plutonium Based Energy Amplifier Testing Concept, Proc. Nuclear Energy in Central Europe 98' Catez, Slovenia, p.67, 1998.

[4] W. FURMAN." New pulsed neutron source of the JINR-the IREN project". Rep. JINR, E6,7-97-49, Dubna, 1997.

[5] S.TACZANOWSKI, J.JANCZYSZYN, Experimental Testing of Accelerator-Driven System for Nonproliferating Transmutation of Radwaste and W-Pu in „On the Selected Problems of Accelerator-driven Systems for Transmutation", ed. S.TACZANOWSKI, Rep. Fac. of Physics and Nucl. Techniques, Univ. of Min. & Metallurgy, ISBN 83-905100-6-5 Cracow, 1999.
