GOALS AND OBJECTIVES OF ISTC PROJECT # 3128 "USING LOW-ENRICHMENT URANIUM IN VNIIEF PULSED NUCLEAR REACTORS"

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ABSTRACT

At present All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) operates six unique aperiodic pulse nuclear reactors. The peculiarity of these facilities is in their rather compact core and high-enrichment fuel (90 % of ^{235}U). Practically null burnup and null fission product buildup in operation, as well as relatively low residual background radiation, make these facilities attractive for terrorists from the viewpoint of stealing the strategic fission materials suitable for manufacturing low-power nuclear charges. The authors of this paper and ISTC project # 3128 share the objectives of the RERTR program and propose to consider the possibility of reducing the enrichment of fuel used in the VNIIEF facilities.

The theoretical, design and technological studies on developing the neutron- and gamma-radiation sources based on the pulse nuclear reactors equipped with uranium-graphite and uranyl sulphate aqueous solution (UO_2SO_4) fuel enriched by 20 % are intended being carried out under the project. The characteristics of radiation to be produced in the facilities to be designed should be similar to those of high-enrichment facilities.

Introduction

Since the early sixties, the experts of the RFNC-VNIIEF nuclear reactor department take an active part in searching the ways to design high-power laboratory pulse neutron sources capable of simulating nuclear explosion radiation. These works brought the unique park of aperiodic pulse nuclear reactors into being [1, 2]. The first facilities were placed into operation in 1964. First, the reactor VIR-1, which operated on the aqueous solution of high-enrichment uranium salt as the fuel, was started up. The reactor BIR-1 equipped with the compact metal core was placed into operation almost at the same time. Both facilities were under permanent improvement. Their last modifications operate up to now.

The advanced study of nuclear radiation impact, which was accomplished in the period from 1970 to 1980, brought the special pulsed reactors BR-1 and GIR into being. They were involved in special complexes for synchronous operation together with the high-power pulse electron accelerators [3].

The intent to achieve high intensive energy release resulted in the need to solve the problem on reducing the heat shock effect on the reactor fuel elements. The joint efforts of the designers, theoreticians and experimenters made it possible to find the original and effective solutions. The fuel of the reactor BR-1 was composed of several lays consisted of coaxial rings. This permitted achieving the record-high fission rate in the metal-fuel fast reactors. In the reactors TIBR and GIR the heat shock was eliminated owing to the localized neutron moderator, i.e. to the inner layer of zirconium hydride, introduced in the core in the first case, and to the outer polypropylene reflector in the second case.

The quest for producing the intensive ionizing radiations inside large volumes gave impetus to the development of new materials applied as the pulsed reactor fuel. The manufacturing methods were developed and a unique high-temperature ceramic fuel, i.e. the pressed homogeneous mixture of high-enrichment uranium (90 % in 235U) dioxide and graphite, was fabricated at the plant of chemical concentrates in Novosibirsk. Owing to composition and original design of the fuel components the reactor BIGR has a status of one among the most high-power fast-neutron pulsed reactors in the world [4].

The peculiarity of the VNIIEF facilities is in relatively compact core and high-enrichment (90 % in ^{235}U) fuel. The core, as a rule, is located at the upper part of the reactor bench. The facility can be transported from the storage position to the working position.

The fuel solution of the reactor VIR is contained in the safe steel vessel, which provides storing and confines the solution within the vessel during the fission bursts. The reactor is stationary.

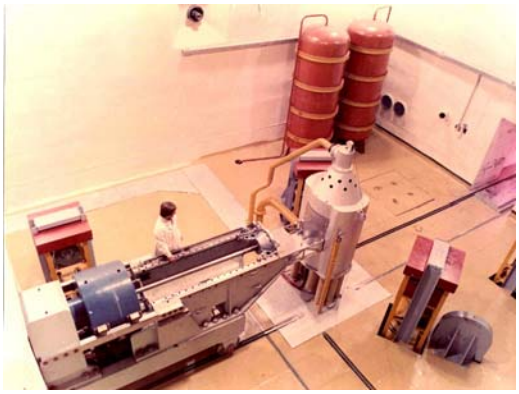
The mentioned reactors are characterized by low reactivity margin needed for regulating and producing the fission pulses. The static operating mode of the facilities (usually a short-term one) is provided in the range from 1 up to 100 kW. The facilities are located inside the safe and secured building, which shields people and environment from the radiation effects.

The current view of the facilities is shown in figure 1.

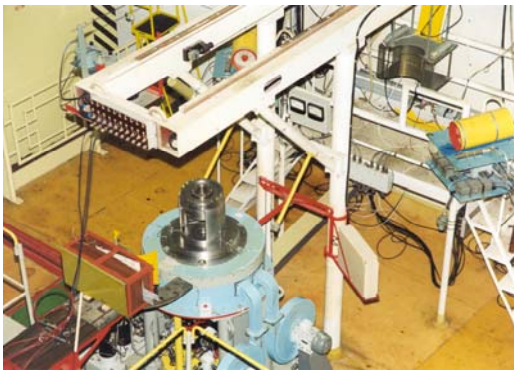
GIR 2

BR-K1

BIR-2M



BIGR



BR-1

VIR-2M

Figure.1. RFNC-VNIIEF pulse nuclear reactors

The characteristics of the reactors are given in table 1.

Table 1 – Characteristics of pulse nuclear reactors designed at VNIIEF

Reactor	VIR-2M	BIR-2M	TIBR	BIGR	BR-1	GIR-2	BR-K1
Commencement of operation: 1st modification Last modification	 1965 1979	 1965 1991	 1970	 1977	 1978 1990	 1984 1993	 1995
State in 2005	In operation	In operation	Deeded	In operation	In operation	In operation	Temporary inoperative
Core material*	$UO_2SO_4+H_2O$ solution	U+6%Mo alloy	U+9%Mo,$ZrH_{1,9}$ multipart	UO_2+C ceramics	U+9%Mo alloy	U+9%Mo multipart	U(36%)+9%Mo alloy
Weight of fuel material in core, kg	160 (150 l)	121	124	833	176	178	1511
Core dimensions, cm	∅55x63	∅22x21.7	∅27.5	∅76x67	∅27x27	∅30	∅62x75
Energy release, MJ	64	3	7	280	11	7	30
Exposure cavity, cm	∅14.2, ∅30.0	∅4.0	∅2.8	∅10.0	∅10.0	-	∅30.8x36.0
Energy release, MJ	64	3	7	280	11	7	30
Fuel maximum temperature, °C	250	300	700	900	700	400	200
Pulse width, μs	2650	55	480	2000	53	300	1000
Neutron fluence, $10^{14}cm^{-2}$: inside cavity at core surface	 7 1	 5 1.5	 10 2.5	 120 10	 10 3.5	 1	 5.1
γ-radiation dose, 10^3 Gy: inside cavity at core surface	 5 0.5	 1 0.15	 2 0.25	 30 2.4	 2 0.5	 0.6	 0.65

* Uranium enriched by ~ 90% in ^{235}U is used as fission material, unless otherwise specified.

The design features of the described facilities, which depend on the separate slugs constituting the core, exposure cavities inside the core, fuel slug jackets and bearing components, make the amount of fission material used in the reactor much greater than the minimum critical mass of the same material. Practically null fuel burning and null fission product buildup in operation, as well as relatively low residual radiation background, make these reactor facilities attractive from the viewpoint of stealing the fission materials suitable for manufacturing low-power nuclear charges. The authors of this paper and ISTC project # 3128 share the objectives of RERTR program and propose to consider the feasibility of reducing the enrichment of fuel used in the VNIIEF facilities.

Discussion

As known, decreasing the fuel enrichment increases the dimensions of critical assembly capable of providing self-maintaining fission reaction. The characteristics of spherical critical systems charged with fuel similar to that of VNIIEF reactors changed due to the decrease of uranium enrichment from 90 % down to 20 % are estimated in table 2.

Table 2 - Characteristics of spherical critical systems charged with various fuels

Fuel	Enrichment in ^{235}U, %	Fuel density, g/cm^3	Sphere radius, cm	Sphere weight, kg	Mean time between fission events, s
Uranium metal containing 9 wt% Mo	89	15	12	102	10^{-8}
	20	17	25	1112	$4\cdot10^{-8}$
Uranium dioxide-graphite homogeneous mixture Nucleus ratio,C/U~16	90	2.9	40	780	$2.5\cdot10^{-7}$
	20	2.9	84	7000	$1.5\cdot10^{-6}$
Aqueous solution of uranyl sulphate 0.23 moles of salt per 1 l of solvent	90	1.07	20	36	$4\cdot10^{-5}$
	20 subcritical system	1.07	≤ 200	≤ 36000	$1\cdot10^{-4}$

As follows from the data presented in the table, decreasing the uranium enrichment (from 90 % down to 20 % of ^{235}U) in the existing reactors increases the critical mass of the material more than by an order, as well as the lifetime of neutrons in the assembly. So, making the nuclear explosive assembly leaves no prospects from the physical viewpoint. However, redesigning of the existing facilities by increasing the weight of low-enrichment fuel actually results in the necessity of creating a new reactor. May be this is the only way for the unmoderated reactor. The mentioned facility to be used as the laboratory physical facility will be larger, more complicated and expensive than the existing metal-fuel reactors.

At the same time the small-size and inexpensive pulsed reactors having the core characterized by the optimal composition of low-enrichment fuel and moderator can be successfully used for research and training purposes. The parameters like energy release in the fission pulse, neutron fluence and gamma-radiation dose in the fission pulse are comparable or superior to the

parameters of the unmoderated reactors operating on high-enrichment fuel. Using the neutron moderator in the reactor core considerably decreases the emergency consequences due to the excess reactivity and enhances the pulsed reactor safety. These facilities producing pulses of various shape and width and providing relatively high static power are rather attractive for commercial application.

Two reactors VIR–2M and BIGR having the cores equipped with moderator have been built at VNIIEF. The fuel composition used in the pulsed reactors should meet the specified requirements. Developing a new type of fuel is rather long and expensive process. So we shall try to use the known and available fuels in our investigations. Theoretical, technological and design studies are planned to be carried out under the project # 3128 aimed at developing the pulsed reactors operating on uranium-graphite and uranyl sulphate (UO_2SO_4) dissolved in the light water enriched to 20 % and having the integral radiation characteristics similar to those of high-enrichment assemblies. As show the preliminary estimates, increasing the concentration of uranyl sulphate (20 % of ^{235}U) from 0.23 up to 1.75 moles per liter of solvent allows creating the spherical critical system having the dimensions similar to those indicated in the table 2 for the high-enrichment solution (R = 20 cm). It is well known that in this case the solution keeps stability and can be used as the pulsed reactor fuel. However the weight of the solution increases up to 50 kg. Using this solution in the reactor VIR-2M changes the efficiency of the control system and increases the dynamic loading of the reactor vessel. The research to be carried out under the ISTC project # 3128 should provide the answer on the possibility of using the new solution in the available vessel together with the existing or partly modified equipment. As for using the low-enrichments uranium-graphite fuel, reducing the fuel weight owing to hydrogenous moderators to be used in the core is very promising. For example, the reactor may be arranged as the common lattice composed of the cylindrical fuel elements immersed in water. In the pulsed reactor the fission pulse energy is accumulated by the fuel material, which gradually transfers the energy to the water due to forced reducing of heat transfer power. The preliminary calculations give some hope and prospects of using the combined low-enrichment metal and uranium-graphite fuel in the pulsed reactor cores.

Conclusions

Making the nuclear reactors practically unattractive for the terrorists and thus eliminating the real terrorist threat by decreasing the enrichment of fuel used in the research nuclear reactors, which will nevertheless retain their physical characteristics essential in the scientific and applied research, can be considered as an urgent problem to be solved in terms of civil liability to enhance the safety of operating hazardous facilities.

References

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