XA0056013

IN-PILE TESTS OF HTGR FUEL PARTICLES AND FUEL ELEMENTS

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Abstract

Main types of in-pile tests for specimen tightness control at the initial step, research of fuel particle radiation stability and also study of fission product release from fuel elements during irradiation are discribed in this paper. Schemes and main characteristics of devices used for these tests are also given. Prinsipal results of fission gas product release measurements satisfying HTGR demands are illustrated on the example of fuel elements, manufactured by powder metallurgy methods and having TRISO fuel particles on high temperature pyrocarbon and silicon carbide base.

Introduction

Development of VGR-50 and VG-400 reactor projects in the USSR /1, 2/ has demanded research of core material behaviour in these reactors under irradiation. The most important element responsible for irradiation situation in the HTGR primary circuit is a fuel element. In the given designs it is a graphite sphere of 60 mm diameter with fuel as fuel particles (FP) /3/. The ability to retain fission products release to gaseous coolant during the whole operation time is one of important requirements to such fuel elements (FE). So, designing structure and technology of FP and FE it's necessary to perform in-pile tests, the main directions of which are:

- control of FP and FE tightness for fission products to detect the initial level of retention capability,
- studies on radiation stability of FP having various structural and technological modifications,
- workability control of FE with FP having sufficient radiation stability under irradiation conditions near operation ones.

Conclusion on FE capability to retain fission products according to the demands can be done, as a rule, from in-pile and out-of-pile experimental results.

Some types of irradiation devices used for HTGR FE in-pile tests, and also some results of experiments are considered in this paper.

Tightness control

One of FP and FE tightness control methods is weak irradiation of specimens to thermal neutron fluence of $\sim 10^{13}$ cm^{-2} followed by annealing till 1100 C in a special furnace and Xe^{135} release analysis /4/. This method advantages are a weak activation of controlled specimens and possibility to work further with them without special shielding. This method is used for controlling initial tightness of FP and FE for long-time reactor tests.

More detailed research of the value of fission gas product (FGP) leakage from FP is performed with the help of the device, schematically shown in Fig. 1a /5/. FP are in the graphite unit in the pebble–bed state, test isothermity being provided with a tungsten radiation heater. Temperature is changed by moving the capsule with specimens along the reactor core height, and FGP release is controlled by blow–through of specimens with inert gas.

A device supplied with additional heater (1000–1100 C) in the upper part topped by a filter is used for in–pile measurements of some solid fission product release. The filter provides trapping of some solid fission products (Cs, Ba, Ag) and periodically is delivered by pneumatic post to the measuring block for analysis.

FP Long–Time Tests.

There are two types of devices used for FP radiation stability research: simple ampouls, in which irradiation is performed without in–pile measurement of FGP release, and channels to control FGP release during irradiation.

Ampouls "MT" and "Karat" /6/ are the first type, their characteristics and schemes are presented in Table 1 and Fig. 1. A large number of different FP modifications (pebble–bed state, coupons, compacts) are irradiated in these devices.

Specimen irradiation temperature is realized in a wide range up to accident level in combination with different burn–ups of the fuel gives the possibility to estimate various type FP irradiation behaviour in a wide parameter range. Information about irradiated FP state is mainly got in post–irradiation examinations. The advantage of this type devices is their simplicity, accelaration of the tests, and also the possibility to irradiate a large number of FP varients.

The second type of devices is more complicated as every capsule with specimens has a gas system for its blow–through with inert gas. Such channels as "Mikrat", "ASU" and "BKS" are of this type (Table 1 and Fig. 1) /5, 7/. Every capsule contains, as a rule, one FP modification, specimens are made in the form of graphite units with FP (Mikrat), sets of 7–10 coupons (ASU) or FE simulators of 45 mm diameter (BKS). In these channels FGP release under FP irradiation under different conditions similar to HTGR operation ones is studied.

FE Tests.

In the process of FE tests a number of questions on operate reliability are considered. They are: FGP release study under various irradiation conditions, FGP transport into the coolant and primary circuit equipment, corrosion interaction of the coolant and FE and others. Simultaneous realization of all HTGR FE project operation condition peculiarities is practically impossible, that's why various FE workability aspects are studied separately in experimental reactors.

FGP release study in FE irradiation process near operation was performed in special channels of "Kashtan", "Vostok" and "RBT" type (Table 1, Fig. 2) /5, 6/. FE are mostly placed in individual capsules each of them has a pumping system for FGP sampling. Capsules are provided with double thin–walled stainless steel shells, the gap between them can be used for FE temperature adjustment by changing gases with different thermal conductivity (helium or neon). Some channels have a sample moving mechanism for additional adjustment of irradiation conditions to move these samples

Table 1. DEVICE CHARACTERISTICS FOR FE AND FP LONG-TIME TESTS

Sample	Device	Quantity			Irradiation Conditions	
		Capsule	Specimen	FP in the specimen	Temperature, C	Thermal Neutron Flux Density $cm^{-2}\,s^{-1}$
FP	MT	3*	~ 50	~ 5x10^2	1000–2000	(3–6) 10^{13}
	Karat	5*	5	~ 10^3	1000–1600	till 1x10^{14}
	Mikrat	5	5	~ 3x10^3	700–1000	till 3x10^{13}
	ASU	3	3	~ 5x10^2	1200	till 7x10^{13}
Model FE φ45 mm	BKS	2	3	5x10^2	1250; 1400	till 3x10^{14}
Spherical FE	RBT	2	3	(5–10) 10^3	1250, 1400	till 3x10^{13}
	Vostok	4	4	(3–10) 10^3	1000–1400	till 1x10^{14}
	Kashtan	6*	6	(3–5) 10^3	800–1600	till 3x10^{13}
	Udar	1	10	(1–3) 10^3	300–1000	till 1x10^{13}
	PG–100	1	19	(3–5) 10^3	800–1200	till 3x10^{13}

* capsules are without control of fission product release under irradiation.

along the core height. FE temperature is controlled by W/Re thermocouples, and neutron flux density is controlled by direct charge detectors (based on emission of electrons by rhodium) or thermo-neutron detectors. FGP release measurement is carried out by gas sampling from capsules with subsequent gamma-spectrometry. According to activity value methods with continuous gas-carrier flow, probe accumulation in the capsule or special sampling vessels are employed. Usage of one of these methods depends upon probe activity and provides R/B value control of 10^{-7} level. FGP release study in transient irradiation conditions is performed in the channel "Udar" (Table 1). This channel has one common capsule with 10 FE. The capsule entrance and its removal from the reactor core provides FE necessary thermocycling in the temperature range of 300–1000 C with about one hour periodicity. FGP release is analysed for all FE in the channel.

FE irradiation under conditions near operation ones by heat characteristics is carried out in helium loop PG–100 /6/. Nineteen FE or their simulators with total FGP release control and solid fission product analysis are simultaneously irradiated in the loop to perfect the technology of work with helium coolant and its cleaning.

Mentioned devices for HTGR FE and FP tests provide wide study of their behaviour in irradiation conditions, the number of examined FP modifications consistently decreasing, and their statistic representativity increasing with complexity of experiments. Irradiated specimens are further subjected to post-irradiation examinations.

Some Test Results

Initial tightness control by weak irradiation performed on a large number of samples shows, that Xe^{135} leakage value at annealing till 1100 C for FP is mainly lower 1×10^{-6}, for FE depending upon fuel concentration is $(1-3)\times10^{-6}$. Major contribution in FGP release is caused by uranium contamination of FP outer coating and FE matrix graphite.

FP long-time tests, carried out in a wide range of irradiation parameters (Table 1) on specimens of various construction and technology, showed, that FGP leakage value at the beginning of irradiation is also determined by the volume contamination of the outer coating and doesn't practically depend upon separate layer thickness for TRISO FP with high-temperature PyC /8/.

With growth of burn-up and fast neutron fluence some FP coating failure accompanied by FGP leakage increase from 10^{-7} – 10^{-6} (at 1000–1200 C) till 10^{-4} – 10^{-3} can occur. The start of failure depends upon irradiation conditions, FP construction and manufacture technology. Carried out research showed, in particular, that TRISO FP with UO_2 kernels and high-temperature PyC have rather high radiation stability, if buffer and carbide layer thickness is not lower 80 and 40 mkm, respectively /8/.

For example, FE manufactured by powder metallurgy methods from artificial graphite and tar pitch satisfying the mentioned demands for FP coating thickness garantee FGP retention at $R/B < 10^{-5}$ till fuel burn-up $\sim$ 10% and fast neutron fluence $\sim 2\times10^{21}$ cm^{-2} at all temperature operation conditions till 1400 C. At most characteristic HTGR FE operation temperatures (800 – 1100 C) leakage rate is in the range of 10^{-7} – 10^{-6} till burn-up 15% and more, this completely satisfies these reactor requirements.

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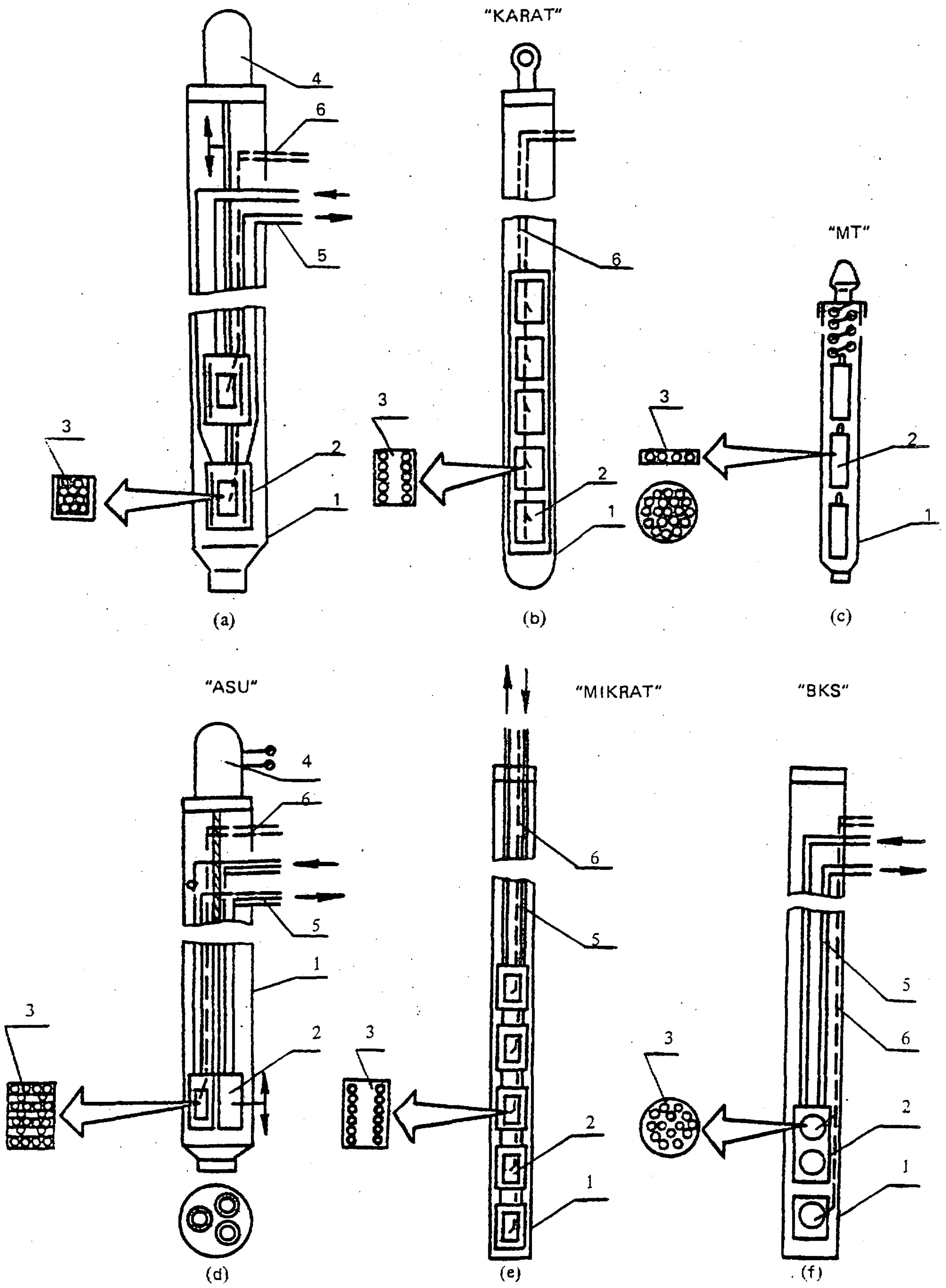
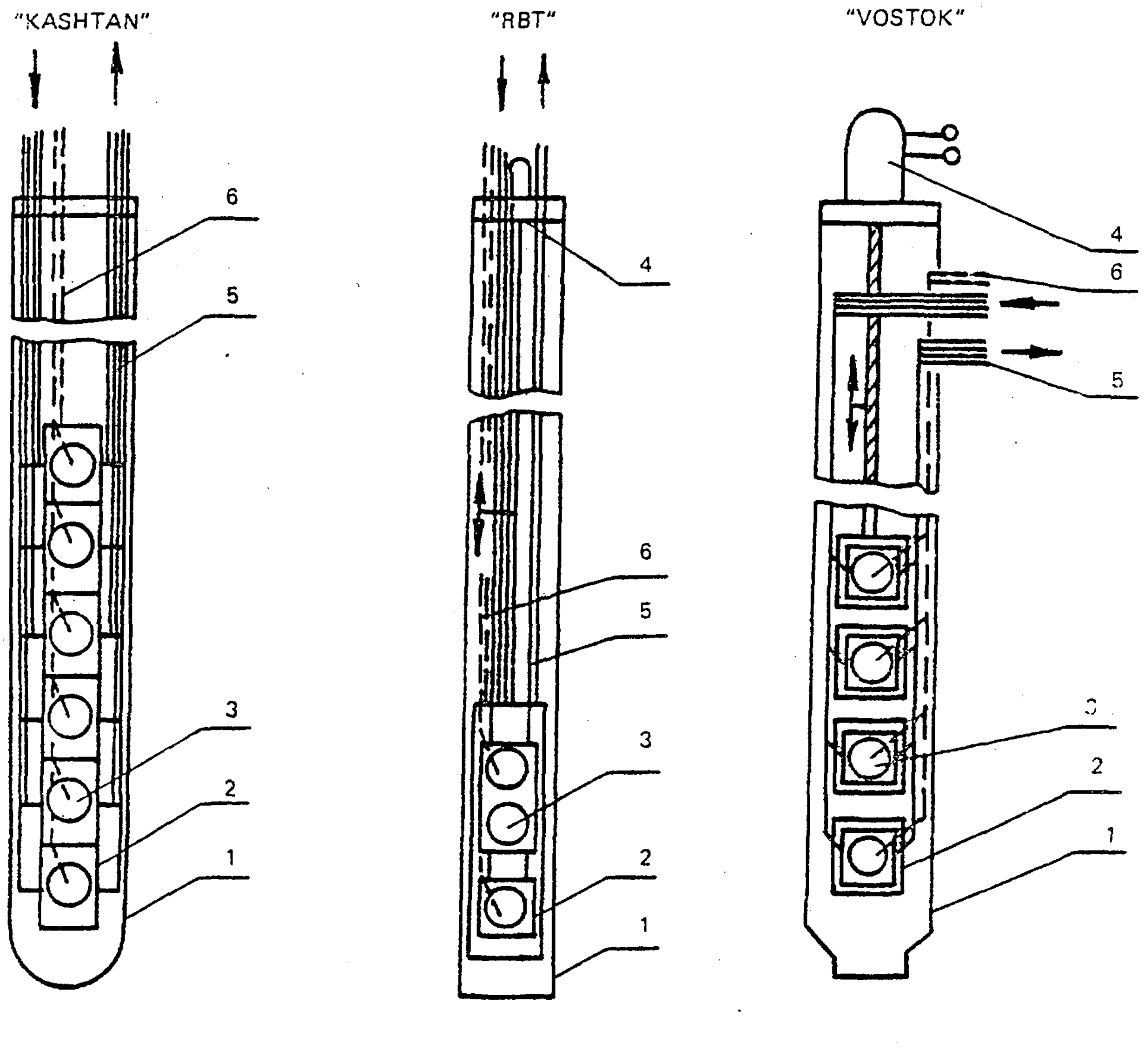
DEVICE SCHEMES FOR FP AND SIMULATOR IRRADIATION



1 – wall
2 – capsule
3 – specimen
4 – sample moving mechanism
5 – gas system
6 – thermocouples and detectors

DEVICE SCHEMES FOR SPHERICAL FE IRRADIATION



1 – wall
2 – capsule
3 – specimen
4 – sampl moving mechanism
5 – gas system
6 – thermocouples and detectors

Fig. 2.