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NUCLEAR FUEL IN THE SHELTER

A. A. Borovoi UDC 621.039.54

The stages of multiyear investigations of the fuel-containing materials remaining in the Shelter after the accident at the Chernobyl nuclear power plant, including the determination of their total amount and the physicochemical properties, are described. Thus far ~150 tons of fuel from the destroyed reactor have been found inside the Shelter. Another ~30 tons could be located in sites which are still inaccessible to investigators. One section of this paper is devoted to the analysis of the possibility of the decomposition of the lava-like fuel-containing materials during a long storage period (ten years) after the Shelter is converted into an ecologically safe system. Questions concerning the development of a system for monitoring fuel-containing materials are discussed.

During the liquidation of the consequences of the accident at the Chernobyl nuclear power plant, one of the most important and difficult questions was converting the nuclear fuel remaining in the destroyed unit (within the boundaries of the object Shelter created) into a controllable state. It was necessary to determine the location of the main accumulations of fuel-containing materials and their physicochemical properties, estimate the degree of nuclear and radiation safety, develop a monitoring system, and prepare the countermeasures required for possible accidents. In the future, the fuel should be removed from the Shelter and buried. Work on solving this problem proceeded from the first days after the accident and throughout all 20 subsequent years. Even though many individual questions were solved successfully, the problem has still not been completely solved. The fuel-containing materials, remaining in the Shelter, are not completely monitored. This makes it necessary to employ superfluous safety measures, based on applications known to be conservative. The present article describes the results of investigations of nuclear fuel, performed over 20 yr, and discusses certain aspects of future work.

At the time of the accident, the reactor core contained 1659 fuel assemblies. Most of them consisted of first-load assemblies with burnup 11–15 MW·days/kg U. The average burnup over the core was 10.9 MW·days/kg U. The core also contained a certain amount of fresh fuel. The mass of the uranium in each holder was ~115 kg, and the total fuel mass loaded into the core was 190.2 tons.

Immediately after the accident a substantial discrepancy was observed between the computed and measured amounts of the main radionuclides accumulated in the fuel in the No. 4 unit over its period of operation before the accident. Consequently, refinements of these calculations were made [1–3]. The main characteristics of the fuel are illustrated in Fig. 1 [1].

1986–1987. The enormous radiation fields, piles of structures and concrete, which was poured into tens of rooms at the time the Shelter was constructed, impeded entry into the destroyed unit and investigations of the accumulations of fuel-containing materials found there. Consequently, in 1986–1987 the main achievement was an assessment of the total amount of fuel remaining in the destroyed unit. The most reliable estimates were made on the basis of a determination of the amount of fuel ejected outside the object during the accident [1, 4–6]. In the present paper, we consider only the main principles of such estimates. After the accident, it became clear that uranium and transuranium elements were ejected in the form of fuel particles, which also contained other nonvolatile radionuclides remaining in the fuel matrix. This made it possible to

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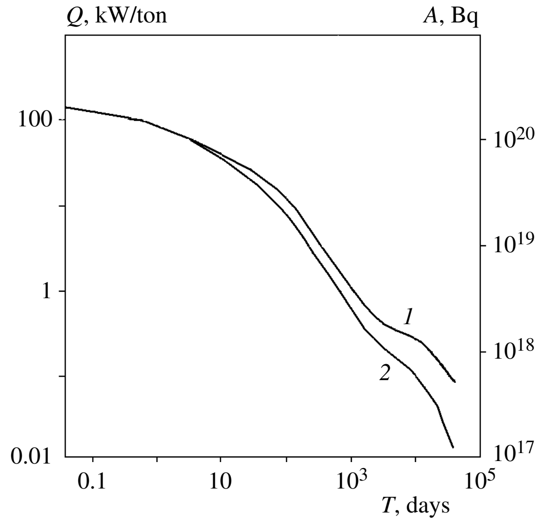

Fig. 1. Variations of the specific heat release from fuel in the No. 4 unit (*1*) and its total activity (*2*) as a function of time elapsed after the accident.

replace the complicated radiochemical analyses of soil samples for uranium and the plutonioum isotopes $^{238–240}$Pu by operational determination of ^{144}Ce in them according to its γ radiation [4]. The following correlation relation was used for this:

$$A(\mathrm{Pu}) = K_{\mathrm{Pu}} A(^{144}\mathrm{Ce}),$$

where A(Pu) is the total α activity of $^{238–240}$Pu; K_{Pu} is the correlation coefficient; and $A(^{144}\mathrm{Ce})$ is the γ radiation from ^{144}Ce in the sample. On April 26, 1986, $K_{\mathrm{Pu}} \sim 9 \cdot 10^{-4}$.

A three-level system for determining the fuel contamination was used in the measurements:

- determination of the γ-ray dose rate using aerial γ surveys (first, “rough” approximation, using the dose rate – fuel amount relation);
- operational investigation of soil samples using semiconductor γ spectrometers (which refined the measurements using the correlation coefficient K_{Pu});
- slow and careful radiochemical analyses (check of the stability of the coefficient K_{Pu}).

By autumn 1986, the measurements performed by specialists at the Russian Science Center Kurchatov Institute, certain research institutes, the services of Goskomgidromet, and military organizations, made it possible to estimate the emission of fuel. It turned out to be 3 ± 1.5% of the total amount present in the core of the No. 4 unit before the accident (see Table 1). Later, in 1987–2000, the analysis of tens of thousands of samples confirmed that the emission of fuel particles was small (less than 5%) [6].

Thus, it can be regarded as established that more than 95% of the fuel in the initial load, i.e., more than 184 tons (with respect to uranium), remained inside the Shelter.

We note that the emission of volatile radioactive substances – radioactive inert gases, iodine, cesium, tellurium, and others – occurred independently. For example, cesium was carried out of the reactor at the active stage of the accident, collecting on light aerosols rising to a substantial height with the warm airflow. The “radioactive clouds” moved over great distances and, because of rain or because of the complicated character of the airflows, contaminated territory located far away from the accident site. It is these contaminations that gave rise to the enormous scales of the accident.

The final estimates [1] are as follows: ^{137}Cs and ^{134}Cs emission outside the confines of the Shelter was 33 ± 10% of the amount accumulated in the core before the accident; the amount of long-lived ^{137}Cs was 2.3 ± 0.7 MCi.