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GRAPHITE STACK DISMANTLING APPROACHES UNDER "DEMOLITION" DECOMMISSIONING OPTION

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"Demolition" decommissioning strategy is currently being followed up for RBMK, AMB and EGP-6 type uranium-graphite commercial reactors. Nevertheless, practical experience on such reactor demolition, including graphite stack dismantlement, is not yet available.

Technologies being developed to enable the dismantlement of nuclear power facilities should be primary based on optimization and feasibility principles. Given the existing setup, this requires that remote techniques are applied to the maximum extent possible. Under the Federal Targeted Program for Nuclear and Radiation Safety-2 (FTP NRS-2), JSC Pilot-Demonstration Center for Uranium-Graphite Nuclear Reactor Decommissioning has carried out R&Ds on the development of graphite stack dismantlement technology for the shutdown uranium-graphite commercial reactor ADE-5. The first stage of the project resulted in a flow sequence of operations and measures ensuring safety during the dismantlement of UGR metal structures located between the upper biological shielding and the graphite stack. Characteristics and the amounts of generated radioactive waste, personnel exposure and time have been evaluated. Engineering solutions on penetrating the upper biological shielding, dismantlement of reactor fuel channel elements, metal structures and graphite blocks in the stack's upper layer have been developed.

Keywords: *uranium-graphite reactor, graphite stack, dismantlement, metal structures, biological shield, technological sequence.*

To date, more than 250 uranium-graphite nuclear reactors of various types have been built around the world. Many of them have already been shut down with most of the currently operated units to be shut down in the next 10—15 years due to the expiration of their operational lifetime.

Management of irradiated graphite from UGR decommissioning is currently considered as a most pressing issue in this area due to the presence of ^{14}C, ^{36}Cl radionuclides in it. Due to their long half-lives ($5.73 \cdot 10^3$ and $3.01 \cdot 10^5$ years, respectively) and radiological properties, these radionuclides pose a significant potential hazard to the environment [1]. Irradiated graphite contains 10^6 times more of ^{14}C (10^5—10^6 Bq/g) compared to the natural carbon.

Moreover, the extent of the problem should be also taken into account. Global inventory of irradiated graphite accounts for over 230—250 thousand tons of this material. To date, 13 production and five commercial uranium-graphite power reactors have been shut down in the Russian Federation (AM, JSC "SSC RF-IPPE"; AMB-100, 200, Beloyarsk NPP; RBMK-1000, Leningrad NPP; EGP-6, Bilibino NPP). 10 RBMK power units at Leningrad, Kursk and Smolensk NPPs and 3 EGP-6 units at Bilibino NPP are still operated. A total of some 60,000 tons of irradiated graphite has been accumulated to date. Irradiated reactor graphite management challenge seems to be relevant not only for Russia, but for other countries as well. For example, more than

77,000 tons of irradiated graphite have been accumulated in the UK; over 50,000 — in the USA and over 23,000 tons — in France.

Currently, for all UGRs, both built in Russia and abroad, the "demolition" decommissioning option has been approved as the decommissioning concept to be followed [2]. The only exception accounts for Russian-built production uranium-graphite reactors (PUGRs), for which the so-called "entombment" concept can be implemented taking into account their design and siting features. However, no practical experience on UGR demolition or graphite stacks dismantlement is available for such reactors.

Large-scale efforts on graphite stack dismantlement involving any operations associated with irradiated graphite handling (blocks, bushings, rings) should be implemented in a way enabling to minimize the formation of radioactive aerosols, as well as to ensure explosion and fire safety of the operations. Graphite stack dismantlement seems to be even more challenging as it is surrounded by massive metal structures subjected to neutron activation at the time of reactor operation. For this reason, at the time of the final shutdown, UGR contains a significant amount of gamma-emitting isotopes (mainly ^{60}Co) resulting in a high dose rate in the reactor space (up to 10 Sv/h).

Relevant managerial and technical measures, engineering solutions and necessary technological equipment enabling remote operations should be developed to ensure the safety of graphite stack dismantlement. Since 2016, PDC UGR, JSC NIKIET and IPCE RAS have been performing R&Ds to develop some engineering solutions and equipment for UGR graphite stack dismantlement executed under relevant state contracts.

ADE-5 PUGR with its design being similar to the one of uranium-graphite power reactors was chosen for practical testing of the proposed dismantlement technology. Not a single serious incident was recorded during its operation, so personnel exposure could be kept at minimum during the dismantlement technology testing.

Prior to the pilot operations performed at PUGR ADE-5, a comprehensive engineering and radiation survey was carried out enabling to identify the penetration area in the upper biological shielding. A flow sequence of operations was developed to arrange for the access to the graphite stack of the reactor and to remove the graphite blocks, as well as a list of measures to prevent dusting during work execution. The dose loads and fire hazard factors were estimated accounting for all the operations provided for in the flow sequence. Using full-scale mock-ups of PUGR structure elements, operations involving standard and non-standard equipment for the dismantlement of process channels' loops and the removal of graphite stack blocks have been worked through.

Graphite stack and metal structures within the reactor shaft were described and analyzed during the R&Ds. A method was developed enabling the dismantlement of nuclear reactor graphite stacks.

Flow sequence of pre-dismantlement operations ensuring the access to PUGR ADE-5 graphite stack provides for the dismantlement of the upper water utilities and cutting of process channels' loops (PC) above the upper biological shielding, cutting of an opening in the upper biological shielding (removed were the fragments of upper and lower sheets of the upper biological shielding with PC loops), installation of a temporary biological shielding above the opening, dismantlement of PC loop elements between the graphite stack and the upper biological shielding, cutting of an opening in the nitrogen box, removal of the floor slabs (Figures 1—3).

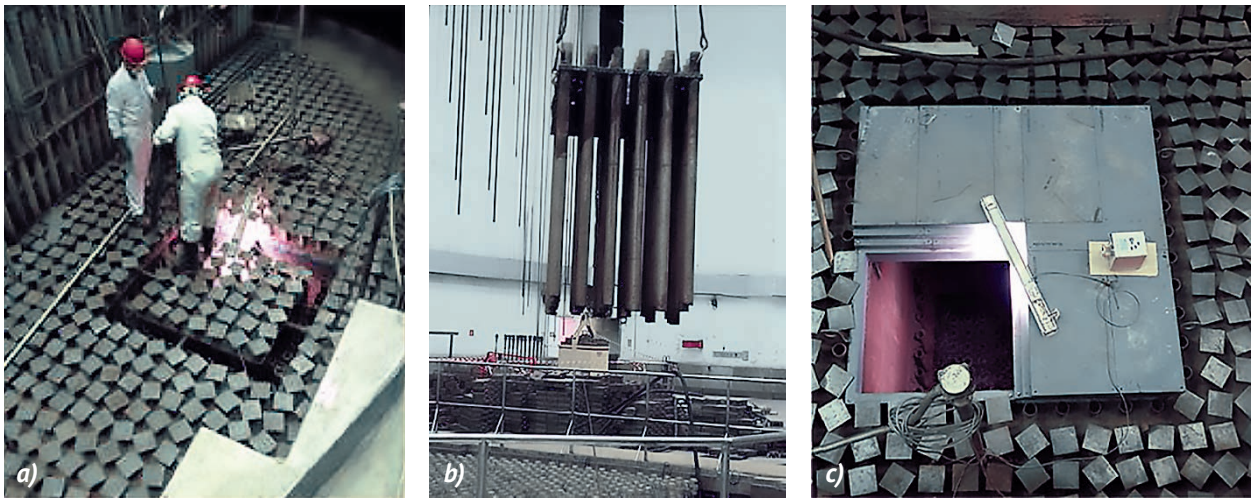

Figure 1. Stages of practical efforts on arranging an opening in PUGR ADE-5: a) cuttings of the upper plate along the penetration perimeter; b) extracting fragments of the upper plate with PC loops; c) installation of a shielding plate

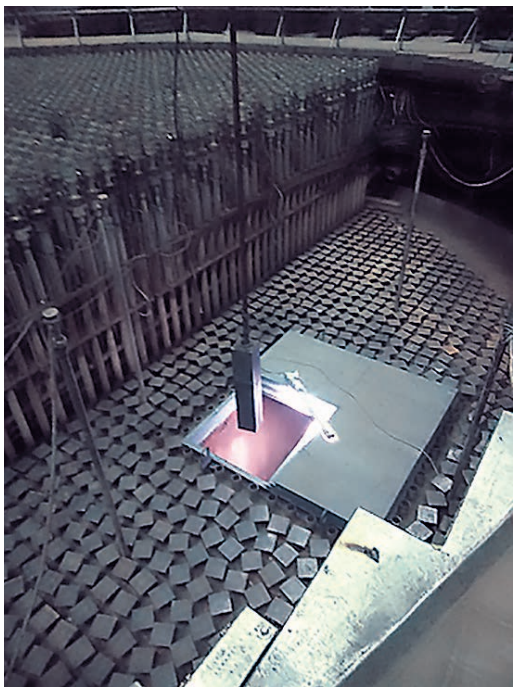

Figure 2. Removal of the upper graphite stack blocks at PUGR ADE-5

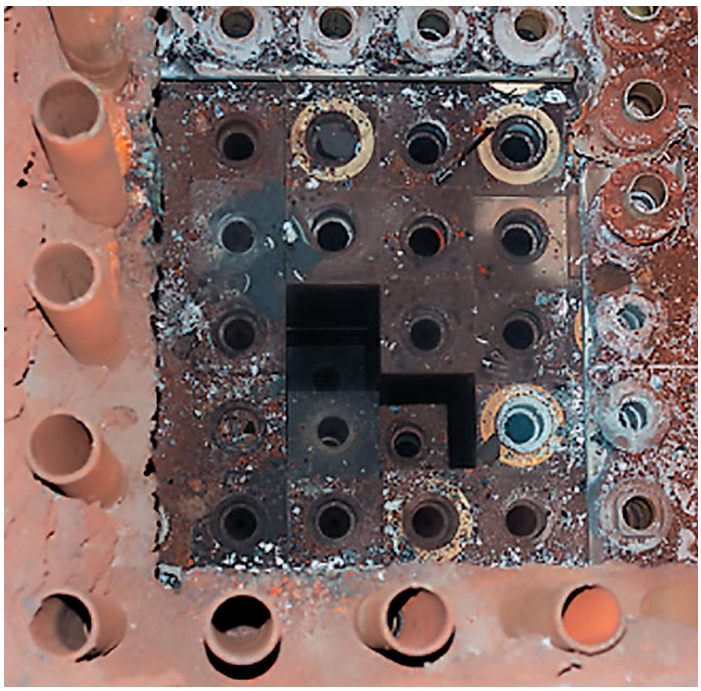

Figure 3. Fragment of the opening after graphite blocks removal

Results of the operations performed can be summarized as follows:

- Feasibility of the proposed approaches for the safe dismantlement of reactor's graphite stack was demonstrated;
- General engineering solutions for graphite stack dismantlement and requirements for non-standard equipment were developed;
- An opening was cut in the upper biological shielding of PUGR ADE-5 to provide access to the graphite stack;
- Non-standard equipment for stack dismantlement was manufactured and tested at a stand unit;
- Several graphite blocks were removed through the opening in the upper biological shielding;
- Recommendations concerning relevant amendments to be introduced to the design documentation for non-standard equipment were provided.

Further development of UGR dismantlement technology covers the following areas:

- development of engineering solutions enabling the dismantlement of UGR metal elements, PC loops located between the upper biological shielding and graphite stack, and stack elements;
- upgrading the robotic complex to increase its functional capabilities for remote-controlled movement and execution of operations on the dismantlement of reactor's metal structures and graphite stack;
- pilot operations on the dismantlement and removal of PC loops and other UGR metal structures located between the upper biological shielding and graphite stack, including PUGR ADE-5 graphite stack blocks, using a purpose-designed tool and a robotic complex;
- metrological certification of the method applied to measure radiation characteristics of graphite RW using blocks removed from the reactor stack;
- refinement of segregation methods applied for graphite RW using the blocks removed from the reactor stack;
- graphite RW packaging and development of relevant certification methods.

Based on the R&D results, a method enabling the dismantlement of nuclear reactor graphite stack was developed and patented [3].

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