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Experience of on-site disposal of production uranium-graphite nuclear reactor

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ABSTRACT

The paper reported the experience gained in the course of decommissioning EI-2 Production Uranium-Graphite Nuclear Reactor. EI-2 was a production Uranium-Graphite Nuclear Reactor located on the Production and Demonstration Center for Uranium-Graphite Reactors JSC (PDC UGR JSC) site of Seversk City, Tomsk Region, Russia. EI-2 commenced its operation in 1958, and was shut down on December 28, 1990, having operated for the period of 33 years all together. The extra pure grade graphite for the moderator, water for the coolant, and uranium metal for the fuel were used in the reactor. During the operation nitrogen gas was passed through the graphite stack of the reactor. In the process of decommissioning the PDC UGR JSC site the cavities in the reactor space were filled with clay-based materials. A specific composite barrier material based on clays and minerals of Siberian Region was developed for the purpose. Numerical modeling demonstrated the developed clay composite would make efficient geological barriers preventing release of radionuclides into the environment.

1. Introduction

Graphite has been used as a moderator and neutron reflector in more than 100 nuclear power plants and in many research and plutonium production reactors. Many of the older reactors were shut down by now, even more approaching the end of their service life. About 250 000 tonnes of irradiated graphite (i-graphite) were accumulated worldwide to date (IAEA, 2004a, 2015; Costes et al., 1990; EPRI, 2006). Only a very small number of those plants were dismantled. For most cases, the final destiny of i-graphite remained unresolved. The International Atomic Energy Agency (IAEA) has decided to support Member States in resolving i-graphite management issues until the industrial implementation of processing technologies by launching an International Project on Irradiated Graphite Processing Approaches (GRAPA) (Wickham et al., 2017; Wareing et al., 2017). The GRAPA program included different approaches to solve i-graphite issues.

The concept of In-Situ Decommissioning (ISD) was not new. ISD was the practice of permanent entombment of a facility where it stands (US Department of energy, 2012).

When applying the Concept for the main reactor facility structures (such as materials of core, the metal support structures, biological shield), meeting the ISD requirements can be achieved by used of barrier materials to prevent radionuclide migration. The Radioactive Waste (RW) burial system in case of UGR decommissioning is a complex of natural geological bodies (enclosing and covering solids), UGR vaults and close-to-reactor rooms (disposal object), RW to be buried (irradiated graphite, which is the main source of activity) and engineering safety barriers. This approach permits coping with i-graphite waste challenges (IAEA, 2015; Costes et al., 1990).

According to the «Concept for Safe In-Situ Decommissioning of Production Uranium-Graphite Nuclear Reactors» developed by the State Corporation of Atomic Energy « Rosatom» of Russian Federation on December 28, 2009, the PUGR decommissioning safety was ensured by reliable isolation of radioactive waste (RW) on the PUGR site, which provides radiation safety of the personnel, public and environment for the whole period for which the RW is potentially hazardous. Duration of the period of potential hazard for each individual radionuclide was not defined by the time of its complete decay, but rather by the time the maximum impact of the radionuclide on the environment and population, such as the radiation exposure and content in environmental objects, was reached under conditions of the given disposal site. In its turn, the conditions of the disposal site impact on the environment and population were characterized by the parameters and properties of objects and medium that governed the dynamics of both the radionuclide release from the disposal site and the following migration in the environment. In particular there were:

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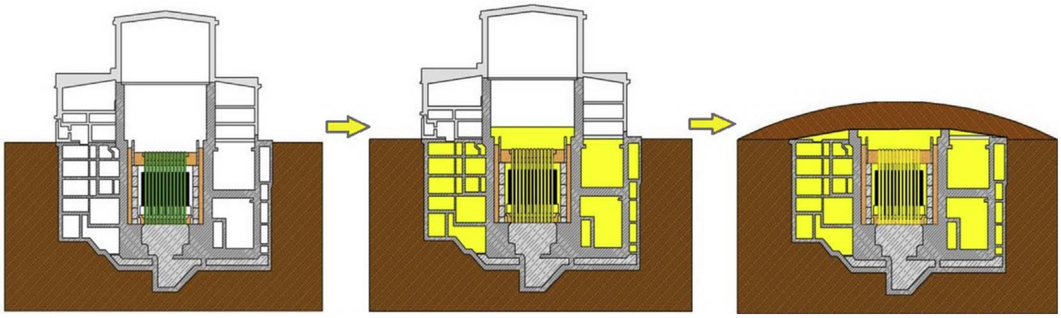

Fig. 1. Stages of the additional safety barriers creation during PUGR decommissioning by means of the safe in-situ disposal option (using the JSC PDC UGR EI-2 PUGR as an example).

- characteristics of RW in the disposal site, namely, the quantity, composition of the material, isotope composition, activity, strength of the radionuclide fixation in the RW matrix, leaching rate, etc;
- configuration and composition of the engineered safety barriers existing by the moment of the reactor shutdown, namely, the RW material, reactor vault, enclosing concrete structures, confining rocks;
- configuration and composition of the additional safety barriers engineered in the process of decommissioning, namely, concrete and clay barriers;
- hydrogeologic, climatic, and demographic conditions of the disposal site and its location.

Depending on the disposal site evolution scenario, the duration values for the period of potential hazard for a given radionuclide may vary. Those values were numerically determined in the course of prediction calculations using models and initial data sets, taking into account the characteristics and specifics of a given disposal site.

In recent years during preparation activities for the EI-2 PUGR decommissioning project, «PDC UGR», JSC, performed a set of R&D and design works aimed at the development and scientific justification of the technologies for safety barrier creation for in situ PUGR decommissioning project implementation. Development included barrier materials design, placement techniques, overall design of the ISD, technology for removal of RW, and monitoring system for the ISD.

2. In situ EI-2 disposal

2.1. Radiation characteristics of the EI-2 PUGR graphite stack

The Russian PUGRs including EI-2 were characterized by the following common regularities of radioactive contaminants formation in irradiated graphite (Bushuev et al., 2015; Bulanenko et al., 1996; Pavliuk et al., 2018).

1. The radionuclides present in irradiated graphite of PUGR could be subdivided into several groups as follows:
   - activation products of the admixture elements present in the initial graphite – ^{14}C, ^{36}Cl, ^{3}H, ^{60}Co, and Eu isotopes;
   - fission products and actinides – ^{137}Cs, ^{90}Sr, isotopes of U, Pu, Am, ^{244}Cm, ^{237}Np, etc.;
   - activation products of nitrogen gas – ^{14}C;
   - activation products of the admixture elements present in the construction materials of supporting structures and materials of the first loop contained in the products of their corrosion got into graphite – ^{60}Co, Eu isotopes.
2. The total activity of graphite was defined by the long-lived beta-emitting isotope of ^{14}C ($T_{1/2}$ = 5730 yr, $E_{\beta max}$ = 156 keV). Its contribution could be as high as $\sim 10^6$ Bq/g.
3. The primary dose-forming element of the bulk graphite stack was the gamma-emitting isotope of ^{60}Co ($T_{1/2}$ = 5.27 yr, $E_{\gamma 1}$ = 1173.2 keV, ω_1 = 99.99%, $E_{\gamma 2}$ = 1332.5 keV, ω_2 = 99.97%). The characteristic value of its activity was $\sim 10^3$–10^4 Bq/g.
4. In some areas of the graphite stack the gamma dose rate could be defined by ^{137}Cs. In the same areas an increased content of other fission products was observed, mainly ^{90}Sr, and actinides U, Pu, Am, ^{244}Cm, ^{237}Np, etc., contained for the most part in the sub-surface layer of graphite blocks. The higher activity of fission products in the sub-surface layer of graphite blocks clearly witnessed they got into graphite from the outside, i.e. from the fuel composition.
5. The radionuclides contained in the sub-surface layer were subject to leaching and the following migration in a greater extent than the radionuclides contained in the deep layers of graphite blocks.

2.2. Main phases of EI-2 PUGR decommissioning

Actual activities on EI-2 PUGR decommissioning were under way during the period of 2008–2015. The works comprised the following (Fig. 1):

- development of the engineering concept;
- development of the design and the safety assessment of work performance;
- dismantling and removal of systems and equipment from the building except the fixed structures in the reactor vault;
- removal of RW stored in rooms and vessels at the EI-2 PUGR location;
- preparation of the building, equipment, and communication lines for the additional safety barrier engineering, namely, cutting of openings, partial dismantling of walls and slabs, laying out communication lines for barrier material handling, electric power, water supply, and air suction;
- creation of additional clay-based safety barriers in the reactor vault and reactor vault surrounding room;
- demolition of the reactor building;
- creation of the safety barrier system made of layers of natural materials (a hill) over the disposal site.

It should be noted that the practical implementation of ISD was stipulated by a wide spectrum of pre-construction activities commenced as long ago as 1990 after the reactor was shut down. The main of them were as follows:

- conversion of the reactor, its systems, equipment and communication lines into the nuclear-safety condition;
- disassembly and dismantling of the equipment and communication lines accessible to decontamination;
- complex engineering and radiation survey of the reactor, equipment, systems, communication lines and the building itself, periodic control of the supporting members condition;
- comprehensive irradiated graphite research studies;
- comprehensive research studies of accumulated RW;