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The optimization of radiation protection composition

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Abstract

The purpose of the study is to develop an algorithm for designing the composition of homogeneous radiation protective materials (RPM) for the radiation protection optimization. Homogeneous radiation protective materials of the Abris type were used in the studies, the manufacturing technology for which makes it possible to obtain the required concentrations of filling agents. The attenuating capacity of a radiation protective material with the barite, lead and tungsten concentrations of 20–80% was estimated using high-precision codes. Experimental studies into the protective properties of the Abris material with different concentrations of filling agents were conducted to verify the calculation results. For the experiment, five sources of gamma radiation (^{60}Co, ^{58}Co, ^{198}Au, ^{54}Mn, ^{24}Na) with typical radiation energies were generated in the IVV-2 M research reactor. A dedicated facility and a DKS-AT1123 measuring device were also used.

As the result of an integrated research, calculated dependences of the attenuation factors have been obtained for the radiation produced by typical radiation sources, and for different RPM compositions and thicknesses. This data forms the input for the optimization of radiation protection. The design of the homogeneous RPM composition is highly promising in terms of the approach to radiation protection optimization. As follows from a comparison of the investigation results for the γ-radiation dose attenuation factors for homogeneous protective materials of the Abris type, depending on composition and thickness, the experimental data differs from the values obtained by calculation by not more than 5%. The Abris-type homogeneous RPM manufacturing technology makes it possible to provide the required protective properties for particular exposure conditions (composition of radioactive contaminants).

Keywords: Exposure dose; Optimization of radiation protection; Homogeneous radiation protective material; Attenuation ratio; Nuclear research reactor.

Introduction

Shielding of ionizing radiation sources plays a key role in reduction of the personnel exposure dose. Today, application of radiation shields is limited by the scarce choice of materials, which are often troublesome in use and difficult to install and remove. For protection against gamma radiation, shields are made from materials with high atomic numbers and densities (e.g., iron, lead and tungsten). In some cases, barite is used for protection (e.g., in X-ray rooms). Among traditional protective materials, the most effective ones are lead and tungsten. These materials are however very expensive. High ductility requires solution of difficult engineering problems regarding the attachment of lead plates with thicknesses of over 5 mm [1].

The absorbingcapacity of a protective material depends on the spectrum of the gamma radiation source. The isotopic composition of radioactive contamination in the water-cooled reactor circuits is approximately the same (^{58}Co, ^{60}Co, ^{54}Mn, ^{59}Fe, ^{51}Cr). In the BN-600-type reactors, the radioactivity of sodium is defined by the radionuclide ^{24}Na during the reactor operation and by the radioactive isotopes ^{22}Na and

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Table 1
Characteristics of obtained γ-radiation sources.

Gamma radiation source	Irradiation time, min	Activity as of the end of irradiation, Bq	Activity as of the measurement time, Bq	Dose rate during measurements at a distance of 90 mm, µSv/h	
				Experiment	Calculation
^{60}Co	20.0	3.40 10^6	3.40 10^6	151	147
^{58}Co	108.0	6.83 10^6	6.83 10^6	144	147
^{198}Au	15.0	3.45 10^7	1.73 10^7	146	141
^{54}Mn	1680.0	9.45 10^6	9.45 10^6	166	168
^{24}Na	60.0	2.77 10^6	9.10 10^5	55	56

^{137}Cs after the reactor shutdown. The greatest contributors to the deposited activity are ^{54}Mn (on the sodium contacting surfaces) and ^{137}Cs (on the argon contacting surfaces) [2].

During the dismantling of NPP units in the course of decommissioning activities, the background radiation is defined by long-lived radioisotopes ^{137}Cs and ^{60}Co. During the reactor operation, repair, upgrading and retrofitting, the radiological conditions may be defined by other isotopes with a variety of the gamma radiation spectra.

Methods and materials

For the investigation on optimizing the homogeneous radiation protection composition, a material of the Abris RZ series, developed by LLC "Plant of Sealing Materials", was taken as the basis. The radiation protective material (RPM) is a homogeneous composition based on a polymer binding agent, a filling agent, a plasticizing agent and processing additives. The material manufacturing technology makes it possible to achieve the required protective properties of the material with regard for the isotopic composition of radioactive contamination. To this end, the required concentration of the filling agent (e.g., barite, lead or tungsten) shall be determined.

One of homogeneous RPMs is mastic. This is a viscous-flow mass with the required content of the absorber (e.g., barium concentrate powder) injected into bundles.

High-precision codes based on Monte-Carlo method (for determining the transport of a group of neutrons, photons, and electrons with a continuous energy in a generalized geometry and depending on time) were used to determine the gamma radiation dose rate attenuation factors for the protective material samples. Monte-Carlo techniques are most realistic in the particle transport problems.

The calculation model includes a gamma radiation source, a gamma radiation detector in the form of a sphere with a diameter of 20 mm, filled with a material most similar to human tissue, and a protective material in the form of a square plate with a given thickness [1].

To verify the estimated protective properties of the RPM, an experimental study was conducted using five gamma radiation sources [3]. The sources were selected with regard for the typical isotopic composition of the radioactive contaminants from reactor facilities of different types.

The gamma radiation sources (^{60}Co, ^{58}Co, ^{198}Au, ^{54}Mn, ^{24}Na) were generated for the experiment in a "wet" channel of the IVV-2 M research reactor (Table 1). Activation detectors, including metallic cobalt (^{59}Co), nickel (^{58}Ni), aurum, aluminum alloy (^{197}Au), iron (^{54}Fe), and aluminum (^{27}Al) from certified sets (AKN-T-10 No.014, SN-60/10, SN-65/11), were used as targets for the source generation.

The gamma dose rate attenuation ratio for protective materials was measured using a dedicated tool and a DKS-AT1123 instrument (X-ray and gamma radiation dosimeter).

Results and discussion

Figs. 1 and 2 present the results of the estimations and experimental studies for the gamma radiation dose rate attenuation ratio (on the example of the isotopes ^{60}Co, ^{198}Au and ^{58}Co) versus the thickness of an Abris-grade protective

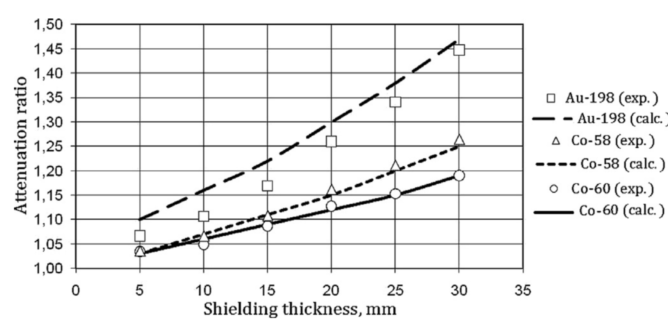

Fig. 1. Calculated and experimental dependencies of the gamma dose rate attenuation ratio (^{60}Co, ^{198}Au and ^{58}Co sources) on the thickness of the Abris RZnk-01 material with 50% of $BaSO_4$ as the filling agent.

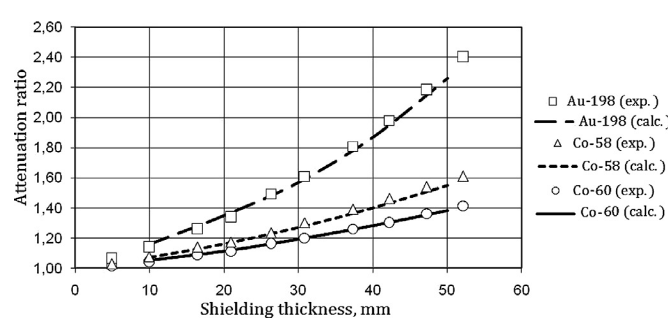

Fig. 2. Calculated and experimental dependencies of the gamma dose rate attenuation ratios (^{60}Co, ^{198}Au and ^{58}Co sources) on the thickness of the Abris RZnk-02 material with 20% of Pb as the filling agent.

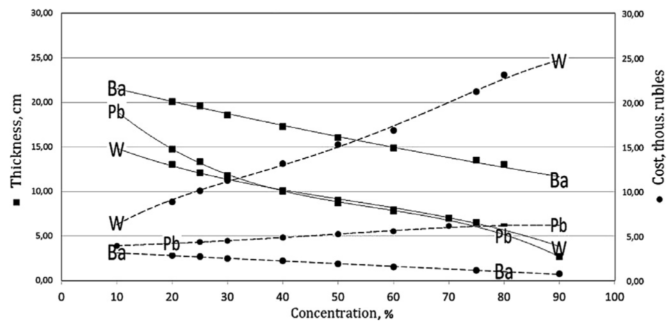

Fig. 3. RPM thickness and cost depending on the filling agent (barite, lead or tungsten) concentration required for attenuating the dose rate from ^{137}Cs by a factor of five.

material with barite (the barite content of 50%) or lead (the lead content of 20%) used as the filling agent.

The algorithm for determining the optimal composition of homogeneous RPMs with the given attenuating properties includes a study into the isotopic composition of radioactive contamination for the purpose of determining the radiation energy spectrum. The personnel exposure doses are scheduled with regard for data on the labor input for particular operations. Work areas requiring radiation shielding are identified. Requirements to the characteristics of protective materials (e.g., thickness limits), as well as radiation exposure limits for certain personnel (e.g., highly skilled welders, NDT inspectors) are introduced, and so the dose rates are reduced despite the cost of the protective measures [4].

The optimal concentration of potential filling agents and the thickness of the homogeneous protective material are found based on the ALARA (As Low As Reasonable Achievable) principle, using one of the ALARA procedure techniques (e.g., cost-benefit analysis). These techniques rely on the use of the monetary value of the unit of the collective dose (the so-called "alpha value" or "monetary value of the man-sievert"), which represents "how much money is it agreed to spend in order to avert one unit of the collective dose" [5].

In some cases, the maximum permissible dose (MPD) concept is used for planning. Based on the required gamma dose rate attenuation ratio at certain workroom points and the limits on the protective material thickness, the desired concentration of potential filling agents is determined, and the costs of protective materials are compared.

The presence of light chemical elements in the Abris RZ material, combined with a heavy filling agent, allows predicting the possibility for using this material in protection from mixed neutron and gamma radiation. At the present time, activities are under way to justify computationally the optimal composition for and to experimentally study the protective properties of homogeneous materials with respect to neutron radiation [6].

A series of studies has made it possible to obtain calculated dependencies of the attenuation factors for radiation from sources, typical of different situations, and for different RPM compositions and thicknesses. This data forms the input for the optimization of protection. As an example, Fig. 3 presents data on the thickness and cost of RPMs for attenuating the dose rate from cesium-137 by a factor five.

Conclusions

1. The design of the homogeneous RPM composition is highly promising in terms of radiation protection optimization.
2. As follows from a comparison of results from a study on the gamma radiation dose rate attenuation factors for the Abris homogeneous protective materials, depending on composition and thickness, the difference between the experimental data and the calculated values does not exceed 5%.
3. The Abris RPM manufacturing technology provides for the required protective properties for certain conditions of exposure (composition of radioactive contamination).

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