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ON THE PROSPECTS OF USING METAL HYDRIDES IN NUCLEAR ENERGY

The results of analytical and experimental studies of neutron-protective properties of a number of domestic materials and of the SWX-277 material (manufactured in the USA) are reported. SWX-277 is employed for protection against neutron irradiation in containers for dry storage of spent nuclear fuel in the Zaporizhzhya Nuclear Power Plant (NPP). The results of studies have confirmed the high protective properties of some domestic materials (in particular, titanium hydride), and the perspective of their wider use for protection against neutron irradiation.

Keywords: container, protection against neutrons, attenuation coefficient, titanium hydride.

1. Introduction

The interest in the application of hydrogen-containing materials for neutron shielding is explained by a large number of hydrogen atoms per 1 cm^3 of material. Because of the proximity of the mass of a neutron and that of a hydrogen nucleus, essentially whole neutron's energy can be dissipated in one collision. Since the probability of a frontal collision is small, about 15 ÷ 18 collisions with hydrogen are usually needed for the thermalization of neutrons with an initial energy of 1 MeV.

There are $4 \div 7 \cdot 10^{22}$ hydrogen atoms per 1 cm^3 in such widely used materials in the field of nuclear power as water, paraffin, and polyethylene [1]. Factors substantially constraining their use are the narrow temperature range and insufficient strength properties. Metal hydrides containing $4 \div 10 \cdot 10^{22}$ hydrogen atoms per 1 cm^3 are more promising materials because of sufficient mechanical strength and a wider range of working temperatures. It should be noted that the neutron-protective properties of hydrides may be further enhanced by including in their composition of boron-containing and hydrogen-containing materials, which will also expand the field of their application.

The applicability of metal hydrides in nuclear power technologies will increase also due to an alternative technology, which has been developed by the I. M. Frantsevich Institute for Problems of Materials Science (IPMS) of NAS of Ukraine, allowing for obtaining titanium hydride with the quality comparable with that of titanium hydride produced by Zaporizhzhya Titanium and Magnesium Combine (ZTMC) [2]. The radiation-protective properties are confirmed by the results of the estimation of the number of hydrogen atoms in titanium hydride produced by IPMS and by evaluation of their total neutron cross sections [3]. For this purpose, a special experimental set up was assembled in a horizontal channel of the reactor at the Institute for Nuclear Research (INR) of NAS of Ukraine, which allowed to determine the total neutron cross-section of the pressed powder of titanium hydride and to calculate the ratio between the hydrogen and titanium atoms. It was found that the six samples of the pressed titanium hydride powder produced by the I. M. Frantsevich IPMS have a ratio of 1.92, while the industrially produced (ZTMC) titanium hydride has the certified ratio of 2.0.

This is a continuation of previous studies [4] aiming to favor a wider application of titanium hydride in nuclear power plant technologies as a protective material against neutrons.

The lids of containers for dry storage of spent nuclear fuel (SNF) at the Zaporizhzhya NPP contain a proprietary SWX-277 (manufactured in the USA) material for neutron shielding. The thickness of a protective material layer is 50 mm. The experience of operation with the dry storage of SNF has shown the presence of certain problems related to the cost, delivery, and storage time of SWX-277 starting components, as well as with its rather limited neutron-shielding properties. In this regard, the development of a domestic alternative to SWX-277, which would have a lower cost and better neutron shielding properties is highly demanded.

2. Results of analytical assessment

The results of the analytical comparison of the neutron-protective properties of titanium and zirconium hydrides with those of SWX-277 and some other materials widely employed in nuclear power technologies were reported earlier by using the MCNP-4B program [4]. The cross-section values for the interaction of neutrons with matter were taken from the ENDF/B-VI library.

For the sake of comparison of protective properties, the coefficient of attenuation of the neutron flux density was used. It was estimated by the magnitude of the radiation dose rate in the center of the weather lid of the standard container for dry storage of SNF of ZNPP. This parameter allowed for comparison of the effectiveness of various protective materials as well as for comparison with the results of direct instrumental measurements of the radiation dose rate, which are carried out by the NPP personnel during routine maintenance in a dry SNF storage facility. The averaged result of measurements of the radiation dose rate on the lid of the container for dry storage of SNF is 40 ± 20 μSv/h. Note that the neutron component of the dose makes a predominant contribution to this value. The calculation results from [4] are reported in the Table.

Dose rate calculation results with alternative materials

Material	Chemical formula	The value of the dose rate, mSv/h
Boron carbide	B_4C	56
Graphite	C	216
Limonite	$2Fe2O_3$ H_2 O	128
Serpentinite	3MgO $2SiO_22H_2O$	127
ZhSTSBK	–	143
Zirconium hydride	ZrH_2	50
Titanium hydride	TiH_2	38
SWX-277	–	102 (measured 40 ± 20)

Since in this case, the task was to compare the neutron-protective properties of various materials, the resulting discrepancy between the calculated and measured dose rate values on the container lid is considered acceptable and the calculation model was not adjusted, and refinement of the accepted approximations was not made.

It can be seen from Table that in the case of using boron carbide, titanium hydride, and zirconium hydride to protect against neutrons, the dose rate is significantly lower than in the case of using SWX-277.

3. Results of experimental studies

This section presents the experimental studies of the neutron-protective properties of pressed titanium hydride powders manufactured by ZTMC and IPMS NAS of Ukraine in comparison to SWX-277.

The experiments were conducted via the narrow beam method by passing a neutron beam through the material under study in the reactor horizontal channel. The transmittance (attenuation) coefficient was determined by measuring the neutron flux density (dose rate) after and before the sample.

The measurements were carried out using a DKS-96 dosimeter-radiometer and a KURK radiation monitoring installation. The equipment allowed to individuate the contribution of the gamma and neutron components of the total dose, as well as evaluate the contribution of thermal, intermediate, and fast neutrons. The measurement error is estimated as not exceeding ± 10 % of the dose from the gamma component and ± 15 % for both the total dose and the dose from the neutron component. The error is mainly determined by the precision of the experimental set-up and a subtle inaccuracy of re-installing the sample at a given point of the channel

The plates of pressed titanium hydride powder with dimensions of 100 × 100 × 10 mm were used. Samples of SWX-277 were 100 × 100 × 23 mm, 100 × 100 × 25 mm, and 100 × 100 × 50 mm. All samples were irradiated at room temperature. The error in measuring the dose rate is estimated as not exceeding ± 10 %.

Fig. 1 shows the dependence of the neutron and gamma components of the total dose rate on the thickness of pressed titanium hydride powders manufactured by ZTMC and IPMS NAS of Ukraine in comparison to SWX-277.

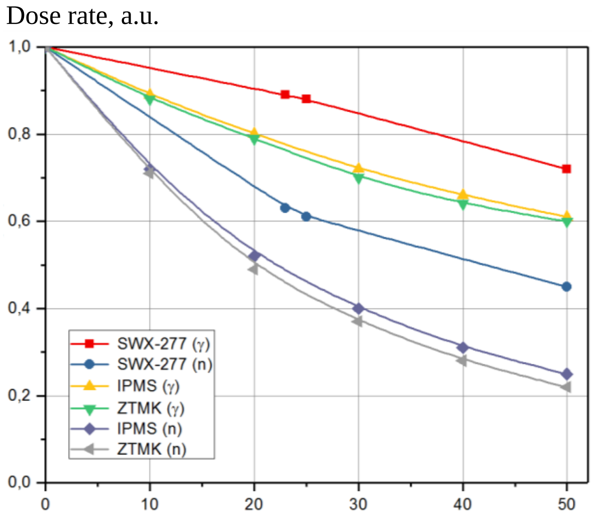

Fig. 1. The dependence of the neutron and the gamma dose rate versus the thickness of samples.

Fig. 1 shows that the neutron and gamma components of the attenuation coefficient for the pressed titanium hydride powders from both ZTMK and IPMS are greater than for SWX-277. As expected, the attenuation coefficient of the gamma-ray flux is much lower than that of the neutron flux. Moreover, the dose rate attenuation coefficients for samples with different manufacturers of TiH_2 powder (ZTMK and IPMS) practically coincide, which indicates the possibility of an alternative power supply.

Fig. 2 reports the dependencies of attenuation of the radiation dose rate due to the fast, intermediate, and thermal neutrons of the useSWX-277 and titanium hydride manufactured by IPMS. It can be seen that, in terms of the neutron components of the dose rate, the protective properties of SWX-277 material are noticeably inferior to the domestic materials from the pressed powder of titanium hydride.

To study the stability of the properties of SWX-277 and pressed titanium hydride powders from time, experiments with samples of ZTMC and IPMS were repeated 18 months after their initial irradiation in a horizontal channel of the reactor. The results are presented in Fig. 3.

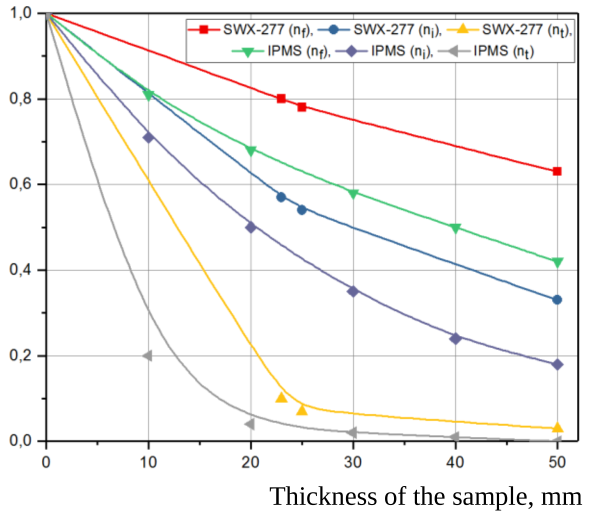

Fig. 2. The dependence of the dose rate of the neutron component on the thickness of the SWX-277 and titanium hydride produced by IPMS.

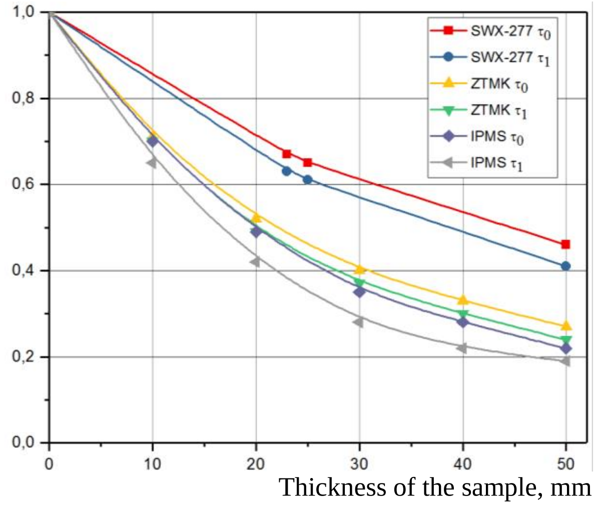

Fig. 3. The dependence of the dose rate on the thickness of SWX-277 and TiH_2 produced by ZTMC and IPMS, where the τ_0 – is initial irradiation, and τ_1 – is repeated irradiation after 18 months of storage, respectively.

The existing differences (10 - 15 %) in the results of the initial and repeated experiments, in our opinion, are explained by the measurement error bars and design imperfections of the experimental set-up for irradiation, which did not allow to restore the exact fixation of the samples upon irradiation. In general, the results obtained make it possible to consider the studied properties of pressed powders stable at least within the indicated time.

4. Conclusions

1. The study on the neutron-protective properties of the pressed titanium hydride powders produced by the ZTMC and IPMS, as well as of the SWX-277 material (manufactured in the USA), which are used as a shield against neutrons in containers for dry storage of SNF of Zaporizhzhya NPP was performed.

2. The absorbing properties of titanium hydride produced by IPMS NAS of Ukraine and ZTMC coincide within the experimental error bars and are stable over time. They exceed similar properties of SWX-277.

3. The prospects of using metal hydrides in nuclear energy is highlighted.

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ПРО ПЕРСПЕКТИВНІСТЬ ВИКОРИСТАННЯ В АТОМНІЙ ЕНЕРГЕТИЦІ ГІДРИДІВ МЕТАЛІВ

Наведено результати аналітичних та експериментальних досліджень нейтронно-захисних якостей ряду вітчизняних матеріалів та матеріалу SWX-277 (виробництва США). Матеріал SWX-277 використовується для захисту від нейтронного опромінення в контейнерах сухого зберігання відпрацьованого ядерного палива на Запорізькій АЕС. Результати досліджень підтвердили високі захисні властивості деяких вітчизняних матеріалів (зокрема, гідриду титану), а також перспективність більш широкого використання їх для захисту від нейтронного опромінення.

Ключові слова: контейнер, захист від нейтронів, коефіцієнт послаблення, гідрид титану.

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