Set of benchmark experiments on slit shielding compositions of thermonuclear reactors

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Abstract

The paper is based on the results of the ISTC project # 180 that has recently been completed. The aim of the project was the development of methodical, hardware and design basis to carry out computational and experimental research on non-uniform shieldings of thermonuclear reactors. As a result a set of benchmark experiments were created. On their basis verification of the domestic and foreign computational codes with the nuclear data estimated was realized. For these purposes the iron hollow slits shielding compositions irradiated with 14.8 MeV energy neutrons were studied. The experimental installations allowed research of the shielding compositions with the following characteristics: a solid structure, a structure with one slit of a central symmetry, and the structures with asymmetric slits and with two slits. The thickness of shielding compositions in this research was 500 mm. The results of experiments were compared to the results of calculations by means of the MCNP-4a and PRIZMA computing codes with use of the FENDL-1.1, FENDL-2, JENDL-3.2 and BAS-78 libraries of nuclear data. The results of comparison made it possible to obtain the recommendations for use of these nuclear data. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

The results of experiments on irradiation of mock-ups by neutron generators were adapted for verification of the computing codes using for cal-

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calculation of neutron and photon transport in units of construction for blanket and shielding of thermonuclear reactors (TNR). There is a good piece of research relating to the field, for example, the work on the ITER project on creation of the experimental TNR, see Refs. [1–3]. The shielding of TNR is a design having several hollow channels, slits and non-uniformities of various structure and configuration. This circumstance weakens its protective properties and makes the computational grounds of the design solutions uncertain. To remove this uncertainty, it is necessary to carry out the experimental and computational research on non-uniform shielding compositions possessing all basic features of the modern projects for TNR shielding. First of all, these are the compositions with hollow slits corresponding to the assembly gaps between the shielding blocks.

The aim of the ISTC project # 180 was development of methodical, hardware and design basis for experiments on irradiation of iron shielding compositions with slits by a neutron generator. In addition, it was aimed to realize experiments and to prepare using their results the database for verification of computational techniques as well as various domestic and foreign computing codes and libraries of the estimated nuclear data used during design and research of TNR.

Penetration of neutrons and photons from a source of neutrons with energy of 14.8 MeV in mock-ups of iron shieldings with hollow slits was researched. The cross size of slits in compositions was 20 mm. In experiments the spatial distributions of the following normalized functionals of neutron and photons were measured:

- rates of various nuclear reactions;
- heating rates in a matter of shielding;
- spectra of neutrons and photons.

All experiments have been carried out at Moscow State Engineering Physics Institute. The steel with 98.7% of iron was used as the matter for mock-ups of shieldings. The use of this matter increases a level of reliability in treatment of discrepancy in calculation and experiment because of its low quantity of impurities. To a great degree the statement of experiments and creation of a methodical basis for their realization were based on the results from Ref. [4].

2. Experimental equipment

The cross-section sizes of all mock-ups were 1000 × 1000 mm². Mock-ups of iron shielding compositions of the following types were analyzed:

- a bulk structure;
- a structure with a central symmetrical slit;
- a structure with asymmetric slits,
- a structure with two slits located randomly.

The distance between axes of the central symmetrical slit and the asymmetric ones was equaled to 32.5, 70 and 120 mm. The mutual location of two slits in shielding compositions corresponded to three cases as follows:

- neutrons of a source can cross both slits simultaneously;
- the closest location of two slits, when neutrons of a source can cross only one slit simultaneously;
- a distance between slits is comparable with a free path of neutrons of 14.8 MeV energy in iron.

The neutron generator with the yield around 10¹¹n/s was used in all experiments. For monitoring of a neutron yield a technique was applied for counting the corresponding alpha-particles in the reaction of neutron production. In this case the error of the absolute counting of neutrons was about 2.5%. The schematic drawing of shielding compositions is shown in Fig. 1. More detailed description of the neutron generator with a system of measurement of an absolute output of neutrons and sizes of the mock-ups examined are given in Ref. [5].

3. Peculiarities of a technique for measurement of spatial distributions of the absolute normalized rates of nuclear reactions in slit shielding compositions

The measurements of spatial distributions of the rates of nuclear reactions in shielding compositions with slits have features which should be taken into account during arrangement of experiments and designing of experimental installations. These features are connected to the existence of
big gradients of neutrons and photons in the area of slits in such systems. The presence of these gradients makes great demands either to sizes of detectors or to a design of the installation. For this reason the optimization research was conducted that led to production of the set of detectors for the threshold reactions with variable cross-section sizes. The following threshold nuclear reactions were chosen at issue: $^{115}\text{In}(n,n')$, $^{64}\text{Zn}(n,p)$, $^{56}\text{Fe}(n,p)$, and $^{19}\text{F}(n,2n)$. The set was added by the reaction $^{233}\text{U}(n,f)$. The following features of measurements in slit shielding compositions were taken into account in determination of weights and sizes of detectors:

- significant gradients of neutron fields next to the borders of slits in perpendicular directions to them;
- negligible gradients of a neutron field along a direction of slits,
- reduction on two-three orders of the values of reactions rates with a high-energy threshold under moving away from the edges of slits.

On the basis of the calculations conducted the weights of detectors necessary for measurements of reactions rates with a statistical error of 3–5% were determined. In addition, their shapes and sizes were obtained, necessary for determination of the required spatial resolution of the functionals under measurement. To reduce a number of detectors, the modules in the form of a parallelepiped with the edge sizes equal to $2 \times 5 \times 30 \text{ mm}^3$ were manufactured. The detectors of various widths with a required spatial resolution in the place of their location were made from them. In experiments the detectors were installed on a back surface of shielding with the help of the holder shown in Fig. 1. The accuracy of the co-ordinate during placement of the detector did not exceed 0.2 mm. The detectors of small width were placed in the co-ordinates with strong gradients of a neutron field. The length of detectors was 60 mm, and the height was 5 mm. The detectors were placed on the back surface of assembly in the way that the sides of $60 \times 5 \text{ mm}^2$ were parallel to a surface of the slit. The minimum width of a detector was equal to 2 mm.

All mock-ups of shielding compositions have been assembled on a platform, the position of which was regulated by jacks with an accuracy of fractions of a millimeter. The placement of a mock-up was considered completed when rates of nuclear reactions in co-ordinates symmetrical to a central axis did not differ from each other more than 5%.

The position of a neutron source relative to the axis of a central slit requires to take into account a mutual direction of two geometrical characteristics: the slit axis in the experimental installation.

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Fig. 1. Mock-up of the shielding with two slits (distance between axes of slits is 70 mm). 1 — ionconductor of the neutron generator, 2 — target, 3 — collimator, 4 — holder of detectors, 5 — slit.
and the drift of an ionic spot on the target because of possible change of an accelerating potential. If the drift of an ionic spot is perpendicular to a direction of the slit axis, one has to stabilize the accelerating neutrons generator potential equaled to 200 kV at the level of 0.5%. That is why a direction of the slit axis in the installation should coincide with a drift direction of an ionic spot on the target. In this case variation of a potential accelerating deutron is not of practical importance.

In all experiments the rates of nuclear reactions were normalized on one neutron of a source and one nucleus of a detector. For activation measurements the system of eight gamma-spectrometers was used of the NaJ(Tl) type described in Ref. [6]. All possible components of a source of errors in shielding compositions of a slit structure were analyzed. As a result it is possible to make a statement that the final root-mean-square error in measurements of a reactions rate in the installations of this structure is a little more than in solid mock-ups, and its value is about 10%.

4. Results of measurement of spatial distributions of the absolute normalized rates of nuclear reactions

As a result of the experiment the spatial distributions of the absolute normalized rates for various nuclear reactions on back surfaces of eight mock-ups of iron shielding compositions of solid and slit structures were obtained. The axial measurements were also conducted in the models of a solid structure. In addition, the rates of nuclear reactions in all applied activation detectors on the distance of 151 mm from a neutron-productive layer of the target in the case when the experimental installation was out were measured. These measurements were the initial test of a computational procedure, in which the various libraries of nuclear data were used, and they also determined deviation of experimental results from computational ones for an actual target unit of a neutron generator. The comparison of the results of these experiments with the calculations are shown in Table 1. Some typical results of the experiments are presented in Fig. 2.

5. Measurements of spatial distributions of heating rates in a matter of shielding compositions

The technique based on application of thermoluminescent detectors (TLD) was used for measurements of heating rates in a matter of iron compositions. TLD of a CaSO4(Dy) type and a SrSO4(Tb) type were applied. The detectors were made of a powder poured into the glass ampoules having internal and external diameters of 1 and 2 mm, respectively, and a height from 15 to 20 mm. The Harshaw-2080 type device was used for processing TLD. The heating device provided uniform heating of detectors in a volume with a constant linear velocity in an interval of temperatures from 50 to 400°C. The main characteristics of TLD are enumerated in Table 2.

The main requirements to a technique of absorbed dose measurements that corresponds to the conditions of realization of experiments are as follows:
- high sensitivity;
- small disturbance of neutron and gamma fields;
- high spatial resolution;
- wide linear range of measurements for absorbed dose;
- error in measurements of an absolute value of absorbed dose on the level of 10–15%.

TLD used in experiments allow receiving values of the absorbed dose from photons in a matter of shielding compositions by means of an interpolation procedure on the effective nuclear number. However, the light output of TLD measured in experiments after irradiation of detectors in shielding compositions will correspond to the absorbed dose not only from photons, but also from neutron radiation. Therefore, it is correct to consider that the dose absorbed in TLD will be determined by the sum of two components:

\[ D_T = D_n + D_g, \]

where \( D_n \) is a neutron component of the absorbed dose, and \( D_g \) is a component corresponding to a gamma constituent. The following possible cases of obtaining the contribution from a neutron component were examined with use of threshold reactions in detectors irradiated in mock-ups:
Table 1
Comparison of calculated and experimental reactions rates (1/source neutron/nucleus), obtained in a neutron spectrum of source on a distance of 151 mm under 0° from a direction of a deutron beam

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Calculation 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Library of sections</td>
<td>RSC 'INPE'</td>
</tr>
<tr>
<td>$^{93}$Nb($^{238}$n,$^{239}$n)$^{92m}$Nb</td>
<td>ADL-3 [4]</td>
<td>1.69 $\times$ 10$^{-28}$</td>
</tr>
<tr>
<td></td>
<td>IRDF-90 [5]</td>
<td>1.66 $\times$ 10$^{-28}$</td>
</tr>
<tr>
<td></td>
<td>FENDL 1.1 [6]</td>
<td></td>
</tr>
<tr>
<td>$^{19}$F($^{238}$n,$^{238}$n)$^{18}$F</td>
<td>ADL-3</td>
<td>2.21 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>BROND2 [7]</td>
<td>1.88 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>ENDF/B-VI [8]</td>
<td>1.90 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>IRDF-90</td>
<td>1.79 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>JEF2 [9]</td>
<td>2.27 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>JENDL3 [10]</td>
<td>1.94 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>FENDL 1.1</td>
<td></td>
</tr>
<tr>
<td>$^{56}$Fe($^{56}$p,$^{56}$Mn)</td>
<td>ADL-3</td>
<td>3.95 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>BROND2</td>
<td>3.90 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>ENDF/B-VI</td>
<td>3.86 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>IRDF-90</td>
<td>3.83 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>JENDL3</td>
<td>3.83 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>FENDL 1.1</td>
<td>3.74 $\times$ 10$^{-29}$</td>
</tr>
<tr>
<td></td>
<td>FENDL 2 [11]</td>
<td></td>
</tr>
</tbody>
</table>

1 The statistical error of calculation did not exceed 1%.
2 The error of experiment was $\sim$3%.
3 The calculation was carried out by the BRAND computing code.
4 The calculation was carried out by the MCNP-4a computing code.

- unfolding of a neutrons spectrum by the measured rates of reactions;
- decomposition of a function of a neutron response of TLD by cross-sections of nuclear reactions measured;
- use of a formalism of effective parameters of threshold reactions.

The analysis conducted has shown that all ways developed for taking into account a neutron component of the dose provide approximately the same values of an error during its determination. The modification of the technique for measurement of energy emission let us reject usage of computational neutrons spectra and to take into account for this purpose only experimental information. The technique of measurement of energy emission is published in detail in Ref. [7].

The measurements with the help of TLD were carried out in shielding compositions in the same co-ordinates where the measurements of the rates of nuclear reactions were conducted. A typical result of these experiments is illustrated in Fig. 3. Besides, the results of calculation of heating rates with use of the experimental spectra of photons in all axial co-ordinates of mock-up have been obtained.

6. Measurement of neutrons and photons spectra

The spectral measurements were carried out either inside a bulk iron composition in the points of measurement of nuclear reaction rates or on back surfaces of slit compositions. In addition, the spectral research of a neutrons source was made in the absence of models. It has enabled evaluation of a target unit on the characteristics of irradiation of detectors in mock-ups. For this purpose the spectrometers of neutrons and photons on the base of a styblene crystal were applied. A spectrometer allows the data in absolute units of density of neutrons and photons fluxes in co-ordinates of location of a styblene crystal to be obtained. The styblene crystal with the sizes of
30 × 30 mm² and the crystal of a cubic shape with the sizes of 20 × 20 × 20 mm³ were used for measurements of spatial distributions of spectra inside a bulk mock-up. A crystal of a cubic shape was employed for measurements of neutron spectra with various orientation of an optical axis of a crystal. The measurements with a cubic crystal were also used for development of a methodical basis of experiments. In addition, for measurements of spectra on a back surface of mock-ups there was used the styblene crystal with the sizes of 40 × 40 mm², and for measurement of neutrons spectra in slit compositions the slab-type crystals with the thickness of about 6 mm and various heights were applied. The application of ‘narrow’ crystals is explained by necessity of obtaining the high spatial resolution in measurements in slit shielding compositions. The characteristics of the spectrometer used in experiments are described in more detail in Refs. [8–11].

### Table 2
The characteristics of thermoluminiscent detectors

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Type of detector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CaSO₄(Dy)</td>
</tr>
<tr>
<td>Effective nuclear number</td>
<td>15.2</td>
</tr>
<tr>
<td>Weight of sample in measurements (mg)</td>
<td>3–6</td>
</tr>
<tr>
<td>Temperature of annealing of detectors (°C)</td>
<td>400</td>
</tr>
<tr>
<td>Time of annealing of detectors (min)</td>
<td>15</td>
</tr>
<tr>
<td>Limits of integration for a light-out curve (°C)</td>
<td>90–300</td>
</tr>
<tr>
<td>Density of substance (g/cm³)</td>
<td>2.96</td>
</tr>
<tr>
<td>Feding of irradiated detectors</td>
<td>&lt;3% for 72 h</td>
</tr>
</tbody>
</table>

7. Calculations

The calculational research was carried out in three basic directions:
- calculation of characteristics of radiation fields in shielding compositions of solid and slit structures;
- analysis of formation of fields of radiation in conditions of experiment;
- creation of the GERA-2 computing code for variant computation of radiations transport in 3D geometry.
The main part of calculation was made by means of the MCNP-4a computing code with use of various libraries of nuclear data. The nuclear data for iron were taken from the library EFF. The data of the EFF-2.4 library were used for the $^{54}$Fe, $^{57}$Fe, and $^{58}$Fe isotopes. For the $^{56}$Fe isotope the data of the EFF-3.0 library, recommended by IAEA for replacement of the data for iron ENDF/B-VI in the library FENDL-2, were adopted. For other elements of the model the nuclear data of FENDL-1.1 were applied. To calculate the rates of nuclear reactions the nuclear data from the IRDF-90 library were used. Besides, the calculations with use of the JENDL-3.2 library of nuclear data were also carried out. The statistical error in all calculations was at the level of 6%. Dr. D.V. Markovskij of the Russian Research Center ‘Kurchatov Institute’ has done the calculations by the MCNP-4a computing code with the nuclear data of FENDL-2.

The part of calculations was made with use of the PRIZMA computing code (see Ref. [12]) with the nuclear data of BAS-78 of Ref. [13]. In the calculations, by means of this code, each detector was simulated as a sphere of the 1 mm radius. These calculations were correlated with that obtained by the MCNP-4a computing code with the constants of the ENDF/B-V library. The PRIZMA computing code was also used for calculations of the background conditions in the experimental hall at MEPhI, where the experimental installation and the neutron generator were located.

To realize the variant calculations of experiments the GERA-2 computing code was developed, solving the transport equation in the XYZ geometry on a basis of the probabilistic technique of discrete ordinates, which is the updated version of the code originally published in Ref. [14].

8. Comparison of experimental and calculational results

The results of measurements for reactions rates, heating rates and spectra of neutrons in all mock-ups were compared to the calculational data. The ratio of Calculational values to appropriate Experimental ones, ie C/E, were used as the criterion of comparison for reactions rates and energy emission. The comparison of experimental spectra of neutrons and photons with calculational ones was carried out by plotting these values on the graphs for all axial co-ordinates of the bulk model. The most typical results of comparison of rates of reactions for the model with two slits are shown in Figs. 4 and 5. The experimental and calculational spectra of neutrons and photons in axial co-ordinates of the solid model are presented in Figs. 6 and 7. The results of comparison of various experimental data on heating rates with calculations are placed in Fig. 8.

9. Conclusions

As a result of realization of the part of the project presented in the paper the following set of research was completed:

- designed and mounted the mock-ups of the iron shielding compositions with hollow slits located variously in the structure of models;
- adapted the techniques of measurement of absolute and normalized rates of nuclear reactions, heating rates and spectra of neutrons, which can be used in the benchmark experiments on the non-uniform shielding compositions characterized by strong gradients of neutron and photon fields;
- created the mutually conformed database of experimental results, in which results of measurements of absolute and normalized on a nucleus of a detector and a neutron of a source of rates of various threshold reactions, the reaction of fission of $^{235}$U, heating rates in iron from photons as well as spectra of neutrons and photons are included;
- compared all experimental results with calculational ones that have allowed recommendations for use of various libraries of nuclear data to be supplied.

The results of the research are published in the reports submitted to the collaborators of the project (Refs. [15–17]), and presented at the conferences (Refs. [18,19]). All experimental results are systematized in the tables, so in this way it forms
the database, which can be used to verify any computing codes with various nuclear data. On the basis of the analysis of obtained experimental data the following basic conclusions can be made.

1. The features of a slit structure of mock-ups became apparent enough practically in all experiments. It results from the fact that not far from slits the neutrons of a source pass smaller distance in a matter of a model until the point of measurement on a back surface of mock-ups in comparison with the points of measurement away from slits.

2. The results of experiments have demonstrated that in the displaced slits there is a profile of distribution of rates of nuclear reactions.

3. The phenomenon of mutual influence of slits is observed (Ref. [5]).

4. The analysis of the measured spatial distributions of rates of nuclear reactions, spectra of neutrons and appropriate computational values has shown that unified effective parameters of all threshold reactions exist in all points of an axial measuring channel of a solid iron composition (Ref. [5]). This fact can be used to obtain the group flux of neutrons from activation measurements and in this way to raise the level of information in activation experiments.

In addition, comparison of the results of calculations with the experimental data allows the formation of the conclusions.

1. Calculation of various rates of reactions, measured on distance of 151 mm from the target unit in absence of mock-up has demonstrated that the greatest divergence between rates of one type reaction for various libraries of nuclear data can change from 4 to 26%, though on average they will be well correlated with experimental results.

2. For the mock-up of a bulk structure in all axial co-ordinates the following regularity of
behavior of the measured rates of nuclear reactions, heating rates and spectra of neutrons and photons are observed:

- in the first co-ordinates of mock-ups the ratio \( C/E \) for various rates of reactions (excepting calculated with use of JENDL-3.2) in the biggest part of the cases observed are within the limits of 10–15% of a corridors of errors;
- in accordance with increase of a co-ordinate the ratio \( C/E \) for all reactions (excepting two of them \(^{115}\text{In}(n,n')\) and \(^{233}\text{U}(n,f)\) calculated by means of JENDL-3.2) decreases that testifies on underestimation in calculations the results of experiment;
- the greatest divergence of the experimental and calculational values (to 60%) is observed for the calculational data obtained with use of JENDL-3.2, the least one corresponds to the constants of FENDL-2 and BAS-78;
- comparison of the experimental data for heating rates obtained from measurements with TLD and photon spectra shows that there is the distinction between them within the limits of 40–50%; however, all calculational results lay between them and describe the experimental results adequately;
- the neutron spectra calculated with use of the nuclear data of BAS-78, FENDL-1.1 and FENDL-2 correlate among themselves in all coordinates of a mock-up and with experimental ones in the limits of 20%, though on a back surface of a mock-up this deviation in the field of low energies for calculations with the nuclear constants of BAS-78 reaches 80%.

![Fig. 5. Comparison of calculational and experimental values of C/E gamma-ray heating rates on back surface of shielding models.](image-url)

- steel, □ air. -- ■ -- Fendl-2, -- ▲ -- Fendl-1.1.
Fig. 6. The neutrons spectrums in a central axis of uniform shielding models on different distances from front surface. BAS 78, PRIZMA, Fendl1.1, MCNP4a, Fendl2, MCNP4a, experiment.

- Photon spectra are described satisfactorily by calculation in all co-ordinates of a mock-up, though understating of their results is available in the field of low energies (up to 1 MeV) for calculations with the constants of BAS-78 and for all used nuclear constants in the whole area of energies of photons on a back surface of a mock-up.

3. On back surfaces of the mock-ups of slit structure the following behavior of the rates of
nuclear reactions, heating rates and spectra of neutrons and photons measured in experiments are observed:
- in all coordinates for rates of reactions with a high energy threshold, i.e. $^{64}$Zn(n,p), $^{56}$Fe(n,p), and $^{19}$F(n,2n), the values of the ratio C/E smaller than unit are typical; and for the JENDL-3.2 library this value is the least of all and lays within the limits of 0.6–0.8;
- an overestimation takes place from 10 to 40% during calculation by means of the JENDL-3.2 library for the results of experiments on rates of the reactions $^{115}$In(n,n') and $^{233}$U(n,f); at that time there is an underestimation to 30% of all experimental rates of reactions, calculated with the help of the FENDL-1.1 library;
- the values of the ratio C/E for the rate of the reaction $^{233}$U(n,f) for all kinds of nuclear data and for all mock-ups practically coincide among themselves within the limits of errors of experiments and calculations; they have the values on the level of 0.6–0.8;
- in the co-ordinates of back surfaces of mock-ups, which are next to slits, particularly to the central symmetric one, the values of C/E are always closer to unit; it can be explained by the smaller path of neutrons in a matter of mock-ups;
- in the co-ordinates of back surfaces of mock-ups, next to the displaced and double slits, the ratio C/E have the values exceeding considerably the statistical errors of experiment and calculation; it can be connected to not taking into account the presence of a profile of neutron fields in slits in combination with experimental errors on placing the detectors coordinate near to slit, where the gradients of neutron fields are particularly high;
- the values of C/E for heating rates in the mock-up of solid structure obtained with the help of TLD, are on the level of 1.0–1.2;
- for the slit compositions in the co-ordinates, close to slits the values of C/E in various models tend either to increase or to reduction; it demands some additional research for proper explanation.

Fig. 7. Gamma-ray spectra in a central axis of uniform shielding models on different distances from front surface. steel, □ air.
Fig. 8. Distribution of gamma-ray heating rates in central axis of uniform shielding model. – x - experiment, TLD, - ■ - experiment, stilbene, - ● - Fendl2, MCNP-4a, - ○ - Fendl1.1, MCNP-4a, - ▲ - BAS 78, PRIZMA.

4. Analysis of the results of experiments allows the libraries of nuclear data FENDL-2 and BAS-78 for calculation of slit iron compositions as the best ones among the sets of nuclear data reviewed during the present research to be recommended.

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