

## **STRIGA - A COMPUTER TOOL FOR MODELING TRIGA RESEARCH REACTOR**

**Dušan Čalić**

Institute Jožef Stefan  
Jamova 39  
1000 Ljubljana, Slovenia  
dusan.calic@ijs.si

**Žiga Štancar, Luka Snoj**

Institute Jožef Stefan  
Jamova 39  
1000 Ljubljana, Slovenia  
ziga.stancar@ijs.si, luka.snoj@ijs.si

### **ABSTRACT**

TRIGA Mark II research reactor at Jožef Stefan Institute has been operating for more than fifty years and has undergone more than 200 core configuration changes. Determining the current fuel composition is very important to calculate various parameters. Current reactor burnup calculations are performed using TRIGLAV code [1]. TRIGLAV code is based on diffusion model in two dimensions where the group constants are calculated using lattice cell code WIMSD [2].

New techniques, methods, software and increase of the processing capacity of the new computers motivates us to develop STRIGA package. Based on a loading scheme for TRIGLAV code we have developed a tool that can read old TRIGLAV inputs and make a 3D Monte Carlo Serpent input for TRIGA research reactor. This is a very detailed 3D model that has already been validated on core configurations 132 and 133 that were also considered in the criticality benchmark experiment in 1991.

With the use of STRIGA tool we can study the full burnup history of TRIGA research reactor without major effort, since the code only requires simple loading scheme and some information about previous burnup cycles. Also some utility codes which perform various functions; such as library generation and data management, are part of the STRIGA tool.

### **1 INTRODUCTION**

Our goal is to increase the accuracy of criticality calculations of burned systems in TRIGA research reactors. In the past several approaches have been tested [3], where usually one step was performed with the use of deterministic codes, like WIMSD, TRIGLAV or ORIGEN2.1 [4]. With the use of the STRIGA tool, those kind of criticality studies are performed only with the Monte Carlo method using Serpent code [5]. In this paper the STRIGA tool is presented.

## 2 TRIGA RESEARCH MODEL

The TRIGA reactor at Jožef Stefan Institute is a typical 250 kW TRIGA Mark II. It is a light water reactor cooled by natural convection. There are 91 locations in the core, which can be occupied by fuel rods, the neutron source, irradiation channels, etc. Elements in the core are arranged in six concentric rings: A, B, C, D, E and F with 1, 6, 12, 18, 24 and 30 available locations respectively. The core is surrounded by a graphite reflector enclosed in aluminium casing. An annular groove in the upper part of the reflector body is provided to contain the so-called carousel irradiation facility. The Serpent 3-D TRIGA model with radial and tangential beam ports is presented in Figures 1 and 2.

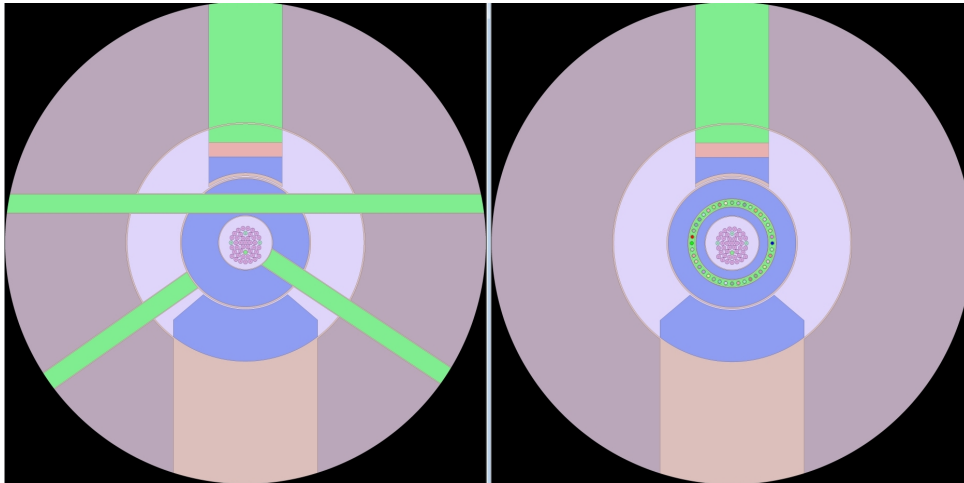


Figure 1: Geometrical model (xy view- top view) of the TRIGA research reactor presenting the rotary groove in the graphite reflector with 40 irradiation locations (right, green circle), and the radial and tangential beam ports (left).

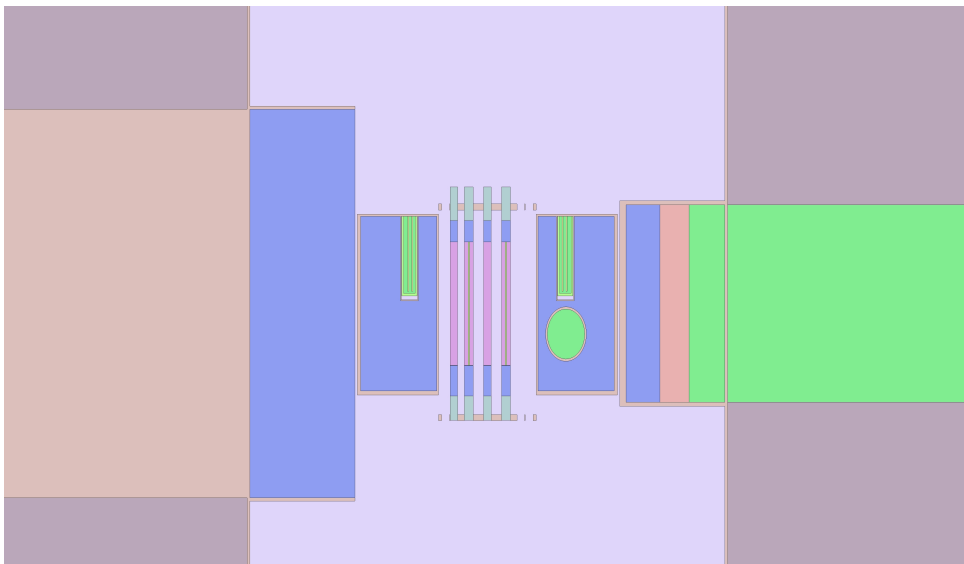


Figure 2: Geometrical model (xz view) of the TRIGA research reactor presenting graphite of the thermalizing and thermal column.

### 3 SERPENT CODE

Serpent is a Monte Carlo reactor physics code. Development started at VTT Technical Research Centre of Finland nine years ago, and since its public release in 2009, the code has gathered an active user community of more than 250 users in 100 organizations in 28 countries around the world. The Serpent code is used in different nuclear fields: group constant generation and fuel cycle studies, full Monte Carlo research reactor modeling and in coupled multi-physics calculations.

Serpent 2 is still in a beta-testing phase, and available to licensed users of Serpent 1. Development of Serpent 2 started due to the difficulties in memory handling in Serpent 1. In Serpent 2 the unionized energy grid approach in lattice physics calculations was made optional, and different optimization modes were introduced for large and small burnup calculation problems. Parallelization is based on the combination of MPI and OpenMP, which is a shared-memory parallelization technique that allows dividing the calculation into multiple threads within the same computational unit, without increasing the overall memory demand. Test calculations on a modern PC workstation with 96 GB of memory have shown that Serpent 2 can handle 200,000 depletion zones in burnup calculation, without limitations in parallelization [6].

A geometrically detailed 3-D Serpent model of the TRIGA Mark II research reactor core with its closest surrounding structures was already benchmarked against experimental measurements [7]. The results of criticality, reaction rate and neutron flux distribution calculations were compared to Monte Carlo code MCNP and experimental results. Multiplication factor results ( $k_{eff}$ ) are within the experimental uncertainties compared to benchmark model  $k_{eff}$ . The calculated results of reaction rates within the core are almost completely consistent with the MCNP results and in very good agreement with the experimental results. This means that for the specific core configuration the geometry and the material properties are modelled very well.

Due to the increased speed of computers, the use of Monte Carlo codes for burnup calculations is becoming more practical, even for research reactors. At Jožef Stefan Institute the TRIGLAV in-house developed fuel management tool is mainly used for fuel element burnup calculation. TRIGLAV is a computer program for reactor calculations of TRIGA Mark II research reactor cores, based on lattice code WIMSD. The code is simple. First the TRIGA geometry is adjusted to cylindrical core arrangement, where every fuel and non-fuel element position in the core is treated as a unit cell. For all unit cells group constants are calculated using WIMSD. These four group constants are used to solve the neutron diffusion equation in two dimensional cylindrical geometry. The idea was to develop a tool that can read input data files that are used in the TRIGLAV code and make an input for 3-D TRIGA using Monte Carlo code Serpent.

## 4 STRIGA TOOL

The fact that STRIGA can read input TRIGLAV files is an advantage, especially for inexperienced users because TRIGLAV only runs under Microsoft Windows operating system and has a friendly graphical user interface (GUI), called TriglavW. The GUI helps the user to prepare both input files. These two data files are commonly referred as "triglav.inp" and "elem.inp". Both files provide fuel and core description of the current fuel core configuration and are prepared and edited through the main TriglavW interface, presented in Figure 3.

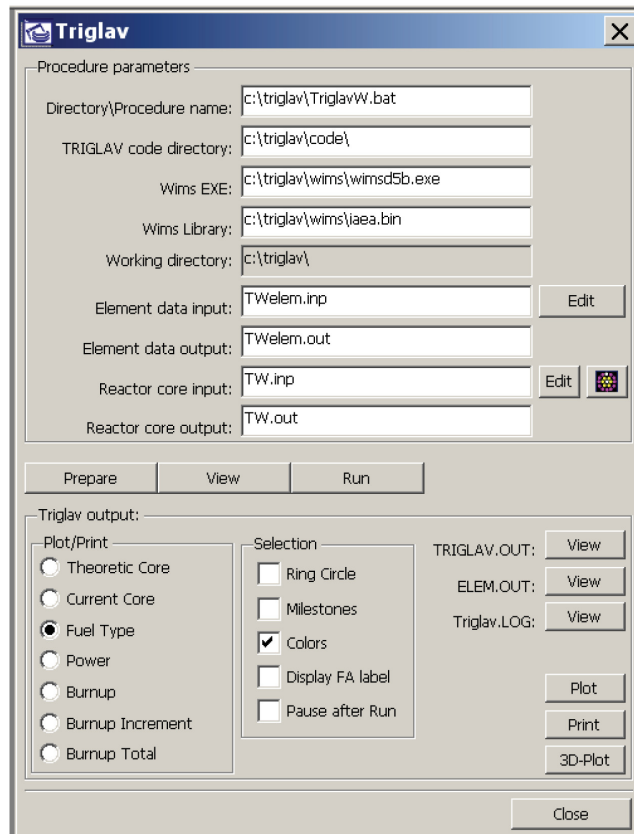


Figure 3: TriglavW window used to prepare and edit TRIGLAV input files.

After both input files are prepared with the TriglavW interface the STRIGA tool is used. STRIGA is a simple tool, written in standard FORTRAN-77 language. One important aspect for development of the STRIGA tool is fuel shuffling. 3D input for TRIGA research reactors using Monte Carlo code Serpent requires a lot of data, and every time you change the configuration of the core you have to rewrite the input. For inexperienced users this takes a lot of time. However, with the TRIGLAV code the procedure is simplified because the TriglavW also has a built-in core loading pattern editor presented in Figure 4. All fuel elements and non-fuel elements can be moved from one to another location (fuel shuffling) by a simple "click and point" procedure.

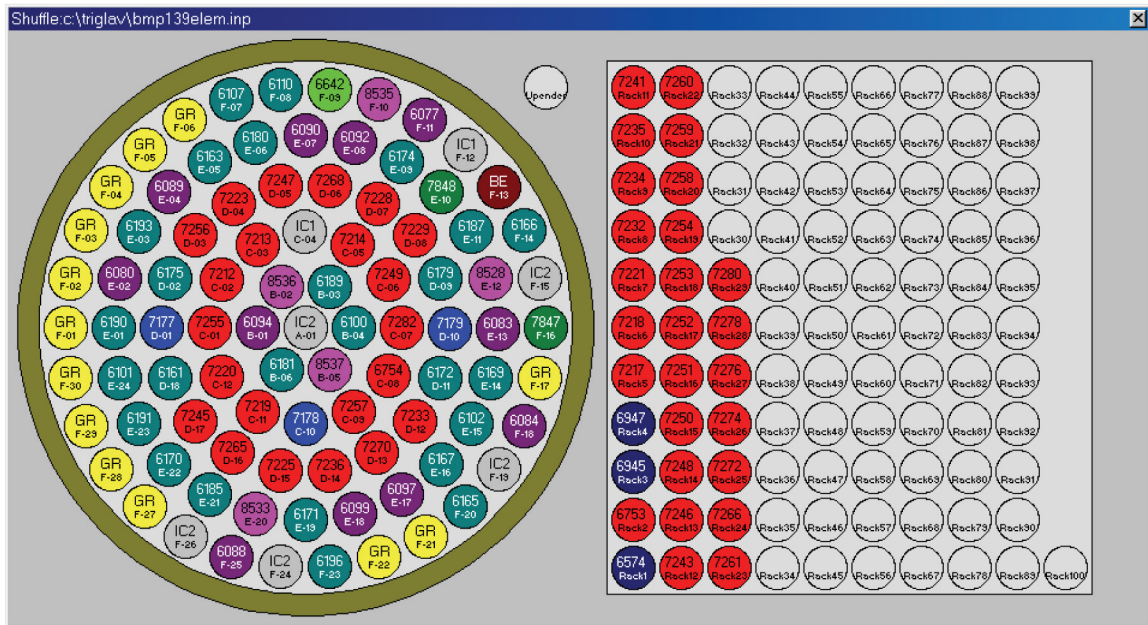


Figure 4: Triga core loading pattern editor.

Another important aspect of the STRIGA tool is the presence of set of data libraries that contains various classes of data, such as reactor core geometry, material composition etc. The list of libraries is the following:

- TRIGA.dim - dimensions and geometry description,
- TRIGA.lib - material description,
- TRIGA.iso - burnup isotopic description.

A block diagram representing the STRIGA system is shown in Figure 5.

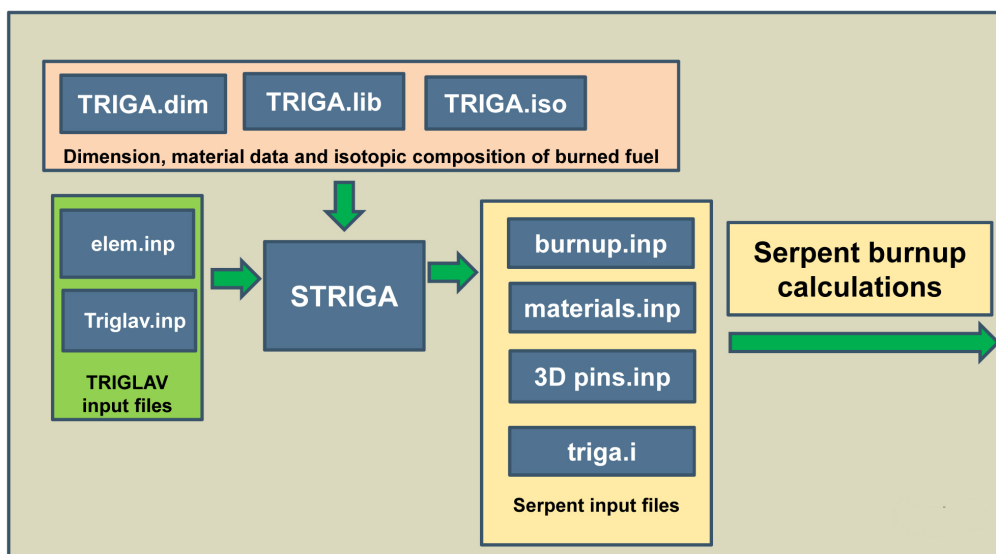


Figure 5: Block diagram representing the STRIGA tool.

#### 4.1 Dimensions and geometry description

The definition of geometry in Serpent is very similar to MCNP, with the use of universe based model. This means that the geometry is divided into separate levels, which are all constructed independently and nested one inside the other. This approach allows complicated systems, like the 3-D TRIGA model, to be divided into smaller parts.

For example, the 3-D geometry of the standard TRIGA fuel element is shown in Figure 6. This is the best illustration of a universe based geometry construction. The lowest level is the definition of the fuel pin. Each 3-D fuel element is divided into several different pins. Each pin is further divided into material regions and outer radii, and each pin is described independently in its own universe. The next level is the fuel element in which the pin universes are arranged in a 3-D geometry. In the next geometry level these fuel elements universes are arranged in another lattice to form the TRIGA core layout, which is then nested into the core surroundings.

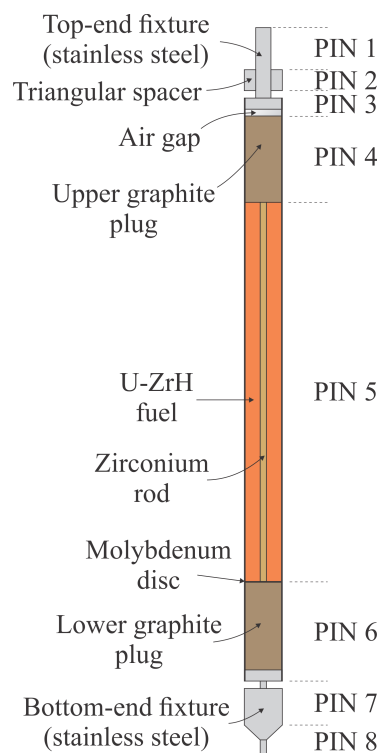


Figure 6: Example of 3-D modeling in Serpent code. Fuel elements are defined with unique pins, each representing materials and outer radii.

#### 4.2 Materials

In Serpent code each material consists of a list of nuclides and each nuclide is associated with its cross section library, as defined in the input file. Nuclide names follow a common convention, also used by MCNP. Also important is the definition of the nuclide temperature, which are fixed when the cross section data is generated and cannot be changed afterwards. The definition of correct temperature is important to correctly model the Doppler broadening of resonance peaks due to the heating of the fuel at high reactor power.

Each non-fuel material is defined in the TRIGA.lib data library and it starts with a \$ sign. After that the unique material name, total atomic density and number of nuclides in a

given material are defined. Then, the isotopic composition and the appropriate atomic fractions follow. An example is shown in Figure 7.

```

c -----
c MATERIALS IN TRIGA REACTOR
c -----
c
c GIVEN IN ATOMIC DENSITIES AND ATOMIC FRACTIONS
c -----
$*   Zr-rod 4.28430E-02   5
    40090 5.14499E-01
    40091 1.12201E-01
    40092 1.71501E-01
    40094 1.73800E-01
    40096 2.79995E-02
$*   Air 5.43466E-05   2
    8016 1.99974E-01
    7014 8.00026E-01
$*   Cladd 8.78646E-02  22
    6000 3.60134E-03
    14028 3.55115E-02
    14029 1.80318E-03
    14030 1.18861E-03
    15031 6.98247E-04
    16032 6.40296E-04
    16033 5.12614E-06
    16034 2.89357E-05
    24050 8.58454E-03
    24052 1.65545E-01
    24053 1.87715E-02
    24054 4.67262E-03
    25055 1.96831E-02
    26054 3.78253E-02
    26056 5.93782E-01
    26057 1.37127E-02
    26058 1.82491E-03
    28058 6.27128E-02
    28060 2.41569E-02
    28061 1.05008E-03
    28062 3.34812E-03
    28064 8.52673E-04

```

Figure 7: Example of material definitions in TRIGA.lib data library.

### 4.3 Fuel material burnup

The treatment of burnup in STRIGA differs from the approach adopted in TRIGLAV code. The burnup calculations in TRIGLAV code are performed with the WIMSD code. These calculations are made with the repetition of the transport calculations in prescribed burnup-up steps and at specific power of fuel element.

Monte Carlo burnup calculations are still a few order slower than the deterministic codes. Therefore, it was necessary to adopt a different approach, as used in the TRIGLAV code. In STRIGA code a library of isotopic composition, TRIGA.iso, is constructed for each fuel cycle. This data library is defined with the utility code, part of the STRIGA tool, after each burnup calculations of the given fuel configuration. In TRIGA.iso data library, the cycle number, number of fuel elements and number of nuclides for each fuel cycle are defined. After that, for each fuel element the total burnup in units of  $MWd/kgU$ , total atomic density and atomic fractions of given nuclides are given. An example is shown in Figure 8. This way, for a given core configuration with burned fuel, we can extract the isotopic composition for each fuel element and perform for example a criticality calculations. Then, the calculated  $k_{eff}$  values can be compared to experimental values.

```

* Comment: Isotopic Inventory Library for TRIGA research reactor
* Author: Dusan Calic

* Cycle number: 1
* Number of Isotopes in fuel: 66
* Number of different fuel elements in given cycle: 61

$* IDENT: FUEL-6574 Author/Date: DC/18-APR-17
$* CYCLE: 1
$* BURNUP: 1.66280E+00 [MWd/kgU]
$* ISOFU: 9.16166E-02 66
Kr83 1.73857E-08 Zr90 1.77658E-02 Zr91 3.87432E-03 Zr92 5.92221E-03 Zr94 6.00156E-03
Zr96 9.67038E-04 Mo95 5.70157E-08 Tc99 1.88883E-07 Ru101 1.65771E-07 Ru103 3.71635E-08
Ru106 1.17223E-08 Rh103 6.02036E-08 Rh105 4.97834E-10 Pd105 3.08152E-08 Pd107 4.97192E-09
Pd108 1.90641E-09 Ag109 1.09628E-09 Cd113 3.76555E-10 In115 4.02138E-10 Sb125 1.04358E-09
Te127m1.62577E-10 I127 4.71975E-09 Xe131 8.41063E-08 Xe134 2.51623E-07 Xe135 7.13245E-10
Xe136 2.36535E-07 Cs133 2.00033E-07 Cs134 1.22728E-10 Cs135 1.73649E-07 Cs137 1.97015E-07
Nd143 1.59442E-07 Nd145 1.25340E-07 Pm147 6.04536E-08 Pm148 0.00000E+00 Pm148m0.00000E+00
Pm149 8.23285E-10 Sm147 2.69516E-09 Sm148 1.37379E-10 Sm149 1.89267E-08 Sm150 1.48919E-08
Sm151 1.22006E-08 Sm152 9.61603E-09 Eu151 0.00000E+00 Eu152 0.00000E+00 Eu153 5.02424E-09
Eu154 0.00000E+00 Eu155 9.72084E-10 Gd154 0.00000E+00 Gd155 0.00000E+00 Gd156 4.47693E-10
Gd157 0.00000E+00 Gd158 2.41798E-10 Er166 0.00000E+00 Er167 0.00000E+00 U234 1.32673E-10
U235 3.64205E-04 U236 6.18167E-07 U237 0.00000E+00 U238 1.46215E-03 Np237 8.52776E-10
Np239 8.45342E-09 Pu238 0.00000E+00 Pu239 3.14895E-07 Pu240 1.23191E-09 Pu241 0.00000E+00
Pu242 0.00000E+00

```

Figure 8: Isotopic library for fuel elements in a given cycle.

## 5 CONCLUSION

STRIGA is a new tool for research reactor calculations of TRIGA reactor cores. In combination with the friendly graphical user interface developed for TRIGLAV code, the program is very easy to use. The user is now able to calculate important core parameters with great precision. STRIGA tool was developed to study burnup of different core configurations with the use of the Serpent code, which will be performed in the near future. It should be pointed out that the purpose of STRIGA tool is not to have another burnup fuel code, but to perform criticality burnup calculations since the TRIGLAV code was not designed for absolute criticality calculations.

## REFERENCES

- [1] Peršič A., Žagar T., Ravnik M., Slavič S., Žefran B., Čalić D., Trkov A., Žerovnik G., Jazbec A., Snoj L., TRIGLAV: A program package for TRIGA reactor calculations, Nucl.Eng. and Design, 318, pp. 24-34, 2017.
- [2] Askew J. R., Fayers F. J., Kemsshell P. B., A General Description of the Code WIMS, J. Br. Nucl. Energy Soc., 5, pp. 564., 1996.
- [3] Jeraj R., Žagar T., Ravnik M., Monte Carlo simulation of the TRIGA Mark II benchmark experiment with burned fuel, Nuclear technology 137(3), 2002.
- [4] Croff A., G., A user's manual for the ORIGEN2 computer code, ORNL/TM-7175, 1980.
- [5] Leppänen, J., et al., The Serpent Monte Carlo code: Status, development and applications in 2013, Ann. Nucl. Energy, 82, 142-150, 2015.
- [6] Leppänen, J., Isotalo, A., 2012. Burnup calculation methodology in the Serpent 2 Monte Carlo code. In: PHYSOR-2012. Knoxville, TN, Apr. 15-20, 2012.
- [7] Čalić D., Žerovnik G., Trkov A., Snoj L., Validation of the Serpent 2 code on TRIGA Mark II benchmark experiments, Appl. Radiat. Isot., 107, pp. 165-170, 2016.