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Томский
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УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий
Направление подготовки 14.04.02 Ядерные физика и технологии
Отделение ядерно-топливного цикла

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Обоснование возможности эксплуатации реактора ИРТ-Т на повышенном уровне мощности

УДК 621.039.55:621.039.516

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Томск – 2020 г.

School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Possibility justification of IRT-T reactor operating at an increased power level

UDC 621.039.55:621.039.516

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Group	Full name	Signature	Date
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Position	Full name	Academic degree, academic rank	Signature	Date
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Section "Financial Management, Resource Efficiency and Resource Saving"

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Ekaterina V. Menshikova	PhD		

Section "Social Responsibility"

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Dan A. Verigin	PhD		

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Programme Director	Full name	Academic degree, academic rank	Signature	Date
Nuclear Power Installation Operation	Vera V. Verkhoturova	PhD		

Tomsk – 2020

Learning outcome (LO) code	Learning outcome (a graduate should be ready)	Requirements of the FSES HE, criteria and / or interested parties
	Professional competencies	
LO1	To apply deep mathematical, scientific, socio-economic and professional knowledge for conducting theoretical and experimental research in the field of the use of nuclear science and technology.	FSES HE Requirements (PC-1,2, 3, 6, UC-1,3), Criterion 5 RAEE (p 1.1)
LO2	To demonstrate ability to define, formulate, and solve interdisciplinary engineering tasks in the nuclear field using professional knowledge and modern research methods.	FSES HE Requirements (PC-2,6,9,10,14, UC-2,3,4, BPC1,2), Criterion 5 RAEE (p 1.2)
LO3	To plan and conduct analytical, simulation and experimental studies in complex and uncertain conditions using modern technologies, and to evaluate critically research results.	FSES HE Requirements (PC-4,5,6,9,22, UC-1,2,5,6), Criterion 5 RAEE (p 1.3)
LO4	To use basic and special approaches, skills and methods for identification, analysis, and solution of technical problems in the field of nuclear science and technology.	FSES HE Requirements (PC-7,10,11,12,13, UC-1-3,BPC1,3), Criterion 5 RAEE (p 1.4)
LO5	To operate modern physical equipment and instruments, to master technological processes in the course of preparation for the production of new materials, instruments, installations, and systems.	FSES HE Requirements (PC-8,11,14,15, BPC-1), Criterion 5 RAEE (p 1.3)
LO6	To demonstrate ability to develop multioption schemes for achieving production goals with the effective use of available technical means and resources.	FSES HE Requirements (PC-12,13,14,16, BPC-2), Criterion 5 RAEE (p 1.3)
	Cultural competencies	
LO7	To demonstrate ability to use a creative approach to develop new ideas and methods for designing nuclear facilities, as well as to modernize and improve the applied technologies of nuclear production.	FSES HE Requirements (PC-2,6,9,10,14, UC-1,2,3), Criterion 5 RAEE (p 1.2,2.4,2.5)
	Basic professional competencies	
LO8	To demonstrate skills of independent learning and readiness for continuous self-development within the whole period of professional activity.	FSES HE Requirements (PC-16,17,21, UC-5,6, BPC-1), Criterion 5 RAEE (p 2.6) coordinated with the requirements of the international standard EURACE & FEANI

LO9	To use a foreign language at a level that enables a graduate to function successfully in the international environment, to develop documentation, and to introduce the results of their professional activity.	FSES HE Requirements (BPC-3, UC-2,4), Criterion 5 RAEE (p 2.2)
LO10	To demonstrate independent thinking, to function efficiently in command-oriented tasks and to have a high level of productivity in the professional (sectoral), ethical and social environments, to lead professional teams, to set tasks, to assign responsibilities and bear liability for the results of work.	FSES HE Requirements (PC-18,20,21,22,23, UC-1,4, BPC-2), Criterion 5 RAEE (p 1.6,2.3) coordinated with the requirements of the international standard EUR-ACE & FEANI

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School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
Nuclear Fuel Cycle Division

APPROVED BY:
Programme Director
_____ Verkhoturova V.V.
«____» _____ 2020

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	Full name
0AM8I	Shinkarenko Semyon Evgenievich

Topic of research work:

Possibility justification of IRT-T reactor operating at an increased power level.	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№129-4/c at 08.05.2020

Deadline for completion of Master Thesis:	01.06.2020

TERMS OF REFERENCE:

Initial date for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	– IRT-T core; – Power 6 MW; – Fuel UO_2; – Enrichment at U_5 90 [%]; – Calculations results of previously reactor cycles; – TVS-3M model

List of the issues to be investigated, designed and developed *(analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).*	– Detailed design of a TVS-3M model of reactor IRT-T; – Software development – Determine optimal initial conditions of fresh fuel assemble; – Determine maximum possible power of reactor; – Determine the refueling regime of fresh fuel assembly during operation of reactor at uprated power; – Define requirements to reactor core layout for placing fresh fuel assembly
List of graphic material *(with an exact indication of mandatory drawings)*	Presentation

Advisors to the sections of the Master Thesis
(with indication of sections)

Section	Advisor
	Ekaterina V. Menshikova
Social responsibility	Dan A. Verigin

Date of issuance of the assignment for Master Thesis completion according to the schedule	

Assignment issued by a scientific supervisor / advisor (if any):

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Artyom G. Naimushin	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM8I	Shinkarenko Semyon Evgenievich		

TASK FOR SECTION
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

To the student:

Group	Full name
0AM8I	Shinkarenko Semyon Evgenievich

School	Nuclear Science and Engineering	Division	Nuclear fuel cycle
Degree	Master	Educational Program	

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human	– Salary costs – 171487 rub – STR budget – 250103 rub
2. Expenditure rates and expenditure standards for resources	– Electricity costs – 5,8 rub per 1 kW
3. Current tax system, tax rates, charges rates, discounting rates and interest rates	– Labor tax – 27,1 %; – Overhead costs – 30%;
The list of subjects to study, design and develop:	
1. Assessment of commercial and innovative potential of STR	– comparative analysis with other researches in this field;
2. Development of charter for scientific-research project	– SWOT-analysis;
3. Scheduling of STR management process: structure and timeline, budget, risk management	– calculation of working hours for project; – creation of the time schedule of the project; – calculation of scientific and technical research budget;
4. Resource efficiency	– integral indicator of resource efficiency for the developed project.
A list of graphic material *(with list of mandatory blueprints):*	
1. Competitiveness analysis *2. SWOT- analysis* *3. Gantt chart and budget of scientific research* *4. Assessment of resource, financial and economic efficiency of STR* *5. Potential risks*	

Date of issue of the task for the section according to the schedule	

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	E.V. Menshikova	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM8I	Shinkarenko Semyon Evgenievich		

Task for section
«Social responsibility»

To student:

group	Full name
0AM8I	Shinkarenko Semyon Evgenievich

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	Specialization	14.04.02

Тема ВКР:

Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	The level of energy release in fresh fuel assemblies of IRT-T. Application area: safety of nuclear reactor
List of items to be investigated and to be developed:	
1. Legal and organizational issues to provide safety: − Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; − Organizational activities for layout of workplace.	− Labour code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT − Sanitary Rules 2.2.2/2.4.1340-03. Hygienic requirements for PC and work with it
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	− Enchanced electromagnetic radiation level − Insufficient illumination of workplace − Excessive noise − Deviation of microclimate indicators − Electric shock
3. Ecological safety:	− Indicate impact of nuclear power plant on hydrosphere, atmosphere and lithosphere
4. Safety in emergency situations:	− Fire safety;

Assignment date for section according to schedule	

The task was issued by consultant:

Position	Full name	Scientific degree, rank	Signature	date
assistant professor	Verigin D.A.	Cand.of Sc.		

The task was accepted by the student:

Group	Full name	Signature	date
0AM8I	Shinkarenko Semyon Evgenievich		

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School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
Level of education: Master degree programme
Nuclear Fuel Cycle Division
Period of completion: spring semester 2019/2020 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis:	01.06.2020

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
1.02.2020	*Task issuance*	
6.03.2020	*Determining optimal initial conditions of fresh fuel assembly*	
25.03.2020	*Determining maximum possible power of reactor*	
28.04.2020	*Defining requirements to reactor core layout for placing fresh fuel assembly.*	

COMPILED BY:
Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Artyom G. Naimushin	PhD		

AGREED BY:

Programme Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Installation Operation	Vera V. Verkhoturova	PhD		

Abstract

The final qualification work is set out in 73 pages, contains 16 figures, 23 tables, 10 sources, 1 appendix.

Key words: energy release, burnup depth, nuclear reactor, IRT-T, TVS-3M.

The object of study is the fuel assembly TVS-3M.

The purpose of the work is to develop an optimal scheme for the initial placement and further movement of fuel assemblies during the reactor campaign.

In the process of MT implementation, a detailed design model of the fuel assemblies of the IRT-T reactor was created, calculations in the MCU-PTR code were carried out, and an analysis of the results was performed.

As a result of the study, the energy releases for various configurations of the core were calculated, the dependences of the energy distribution in the fuel assemblies on their location relative to the core and close fuel assemblies were obtained, the optimal scheme of fuel reloading and fuel assembly displacement at the end of the cycle was developed.

Graduation work was done in a text editor Microsoft Word.

Content

<center>Definitions list</center>

A nuclear reactor is a device used to initiate and control a self-sustained nuclear chain reaction, accompanied by the energy release.

Burn up fraction is the fraction of the initial number of nuclei of a given type that have experienced nuclear conversion in a reactor when exposed to neutrons (expressed as a percentage).

A nuclear reactor cycle is the operating time of a reactor with the same load of nuclear fuel.

Nuclear fuel cycle - fuel operating time in terms of the full reactor power; time during which the fuel is in the reactor.

The energy resource of a reactor is the amount of energy that a reactor can produce during a campaign.

Effective days - reactor operating time for one day at rated power.

Abbreviations list

EP   —   emergency protection

AR   —   automatic regulation;

ER   —   energy release;

ULS   —   upper limit switch;

MT   —   master's thesis;

VEC   —   vertical experimental channel

HEC   —   horizontal experimental channel;

RR   —   research reactor;

CMD   —   control and measuring devices

PC   —   personal computer;

FA   —   fuel assembly;

FE   —   fuel element;

NCT   —   neutron capture therapy;

CPS   —   control and protection system.

Introduction

Research nuclear facilities (RNF) play an important role in the development of nuclear energy and the safety of nuclear facilities. Without a wide program of basic and applied research at the RNF, it is impossible to justify the safety of nuclear facilities.

Research reactors serve as a source of neutrons for experimental work in various fields of science and technology, as well as for the production of radioactive isotopes. With the development of information technology, in addition to direct measurements of physical characteristics, mathematic models are used that simulate various aspects of the operation of a nuclear installation. This approach allows us to evaluate the critical characteristics of reactors at the design stage.

The IRT-T reactor is a pool-type research reactor using demineralized water as a moderator, coolant and top protection and beryllium as a reflector. Highly enriched dispersed fuel in an aluminum matrix is used as fuel.

One of the areas in which the IRT-T reactor conducts research is the organization and implementation of neutron capture therapy, which is a cancer treatment method using reactions that arise between radiosensitive drugs and neutrons.

The research carried out in this thesis allowed us to find a way to increase the power of the reactor by creating the optimal scheme for reloading and moving fuel assemblies in the core. With an increase in reactor power, work with a large flux of thermal neutrons will be available, which will make it possible to conduct experiments and studies related to NCT for which a high neutron flux is required.

The goal of this work was to substantiate the possibility of operating the IRT-T reactor at an increased power level.

To achieve this goal, the following tasks were solved:

- selection of software and methodological support for the calculations;
- construction of a detailed model of fuel assemblies of the IRT-3M type;
- determine optimal initial conditions of fresh fuel assembly;

- determine maximum possible power of reactor;
- determine the refueling regime of fresh fuel assembly during operation of reactor at uprated power;
- define requirements to reactor core layout for placing fresh fuel assembly.

As input data, was use the results of modeling the reactor core in a precision three-dimensional neutron-physical calculation program MCU5.

1. Description of IRT-T reactor systems

1.1. General characteristics of the reactor

The research reactor IRT-T was built in 1959–1967 and commissioned in July 1967. After 10 years, in June 1977, the reactor was stopped for reconstruction due to progressive corrosion of the aluminum shell of the reactor tank and corrosion of aluminum heat exchangers. During the reconstruction, a new 12Kh18N10T steel reactor tank was mounted, the equipment of I and II reactor cooling circuits was completely replaced, the CPS was brought into line with the requirements of the rules in force during this period. The equipment of I and II circuits is mounted in the newly constructed premises of the RR. The reactor was commissioned after reconstruction in 1984. In 2000, measurement sensors were replaced in the channels for measuring flow, pressure, and coolant level in the reactor cooling circuits. In 2005, his control and protection system was modernized. During the period of operation of the IRT-T research reactor, there was not a single nuclear and radiation incident related to the release of radioactive substances into the environment.

The IRT-T reactor is a pool-type research reactor using distilled water as a moderator, coolant and overhead protection. The reactor is intended for carrying out scientific research on solid state physics, neutron activation analysis of the elemental composition of substances, production of radionuclides, silicon doping, neutron radiography. Students of the physical, technical and thermal power faculties of the National Research Tomsk Polytechnic University (NR TPU) undergo laboratory practice at the reactor.

A longitudinal section of the reactor is shown in Figure 1.
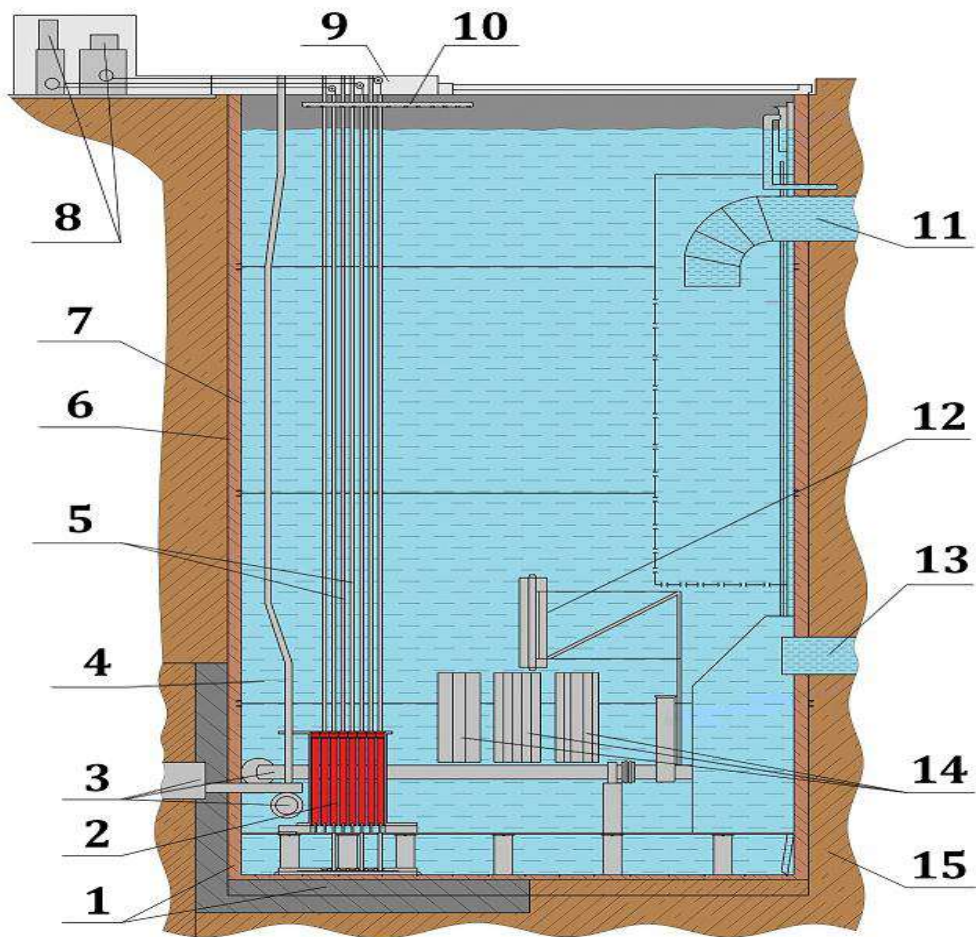
Figure 1 – A longitudinal section of the reactor

1 – heat shield; 2 – core; 3 – horizontal experimental channels; 4 – vertical experimental channels; 5 – CPS channels; 6 – aluminum tank; 7 – stainless steel tank; 8 – drive rods CPS; 9 – CPS site; 10 – choking device; 11 – pressure pipe; 12 – fuel assembly transportation device; 13 – suction pipe; 14 – temporary storage of fuel assemblies; 15 – heavy concrete.

1.2. Core

The core is located in a pool filled with demineralized water at a depth of 6.5 m (center of the core). The core body is made of aluminum alloy AD-1. The upper part of the core together with the supporting spacing grille are mounted on a steel flange 29 mm thick. The flange is welded to the sheets of the built-in retention tank and rests on six posts made of steel pipes Ø108 mm. Bottom racks are welded to a 30 mm thick steel base plate. The plate is attached to the bottom of the tank by welding. The bottom core lattice for CPS channels with a thickness of 30 mm is welded to the base plate from above. The base plate and the lower grille protect the concrete under the bottom of the tank from radiation heating. In places of contact parts of aluminum alloys with steel parts, gaskets made of titanium are installed to prevent corrosion of aluminum. The core body has 56 cells for the installation of fuel assemblies and beryllium blocks.

The fuel assembly, beryllium reflector blocks, neutron trap blocks, control rod follower are installed on the reference spacing grid. At the top of the fuel assembly, reflector blocks, propellants are spaced by special projections on their upper tips. At the bottom, they are fixed on the distance grid with the help of slots in the lower tips.

The core is assembled from an IRT-3M type fuel assembly with a short migration length and a high multiplication factor, which makes it possible to obtain geometrically small core sizes and large neutron leakage into the reflector. The maximum number of core cells in which fuel assemblies can be installed is 56 pieces. The nominal load consists of 12 standard fuel assemblies (eight pipe) and 8 fuel assemblies with control rods (six pipe).

The beryllium blocks adjacent to the core have external dimensions of 69x69x660 mm. On the right side in the corners there are two large beryllium blocks of 138.5x138.5x660 mm with stoppers with a diameter of 96 mm and 44 mm.

Through two rows of beryllium blocks surrounding the core on the right side, a large beryllium block is installed, surrounding one of the main horizontal channels, the HEC-4. This channel is mainly used for neutron transmutation doping of silicon.

The reflector uses both solid blocks and blocks with central holes with a diameter of 48 mm and beryllium plugs installed in them with a diameter of 44 mm. The weight of a solid block of beryllium is 5.7 kg.

All shim rods are made in the form of boron carbide rods (density of 1.813 g / cm^3) with a stainless-steel shell with a diameter of 23 mm and a thickness of 0.7 mm. The absorbing part has a diameter of 21.2 mm, a length of 600.0 ± 1.5 mm and contains 383.9 ± 2.0 g of boron carbide of natural enrichment. From the bottom, an end propellant made of SAV-1 alloy is attached to the absorbing rod. Fastening is carried out using parts made of stainless steel 12X18H9T with a length of 18 mm and a density of 7.9 g / cm^3. The length of the aluminum part of the end propellant is 457 mm, diameter is 23 mm.

The reactor operates, as a rule, five days a week with a stop over the weekend. Planned preventive maintenance of equipment is carried out quarterly. The effective operating time at a nominal power level of 6 MW per year of operation is ~ 3,500 hours.

1.3. Characteristics of fuel assemblies

In the core, fuel assemblies of the type IRT-3M are used - eight-tube, six-tube. These fuel assemblies use tubular fuel elements of square section with a wall thickness of 1.4 mm. The thickness of the SAV-1 aluminum alloy shells is 0.5 mm each.

The core is made of uranium dioxide in an aluminum matrix. Inside the eight-tube fuel assembly, a displacer is installed with an outer diameter of 14 mm. A channel with a control and protection rod (CPS) or an experimental channel with an outer diameter of 28 mm is installed inside a six-tube fuel assembly.
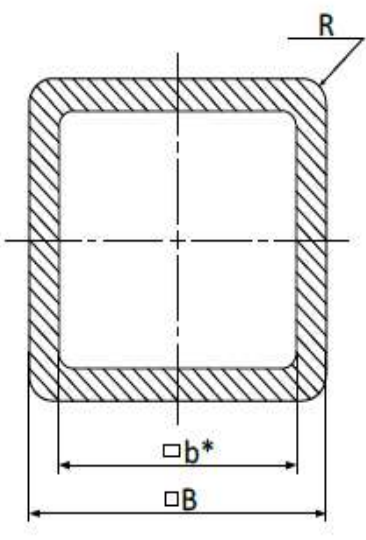
Table 1 shows the design parameters of the IRT-3M FA in Table 2 - geometric characteristics and mass of fuel rods of regular fuel assemblies.

Table 1 – Design parameters of the IRT-3M FA

Parameter name, units rev.	IRT-3M 8 pipes	IRT-3M 6 pipes
The thickness of the fuel core, mm	0,4	
Shell thickness, mm	0,5	
The length of the active layer, mm	580	
Fuel composition	UO_2+Al	
Shell material	CAB-1	
The concentration of uranium in the core, gm / cm3	1,07	
Uranium enrichment - 235%	90±1	
The content of uranium-235 in fuel assemblies, g	300,0	263,7
The gap between the fuel rods, mm	2,05	
Thermal conductivity of the fuel core, W / (m · K)	120	
Heat capacity of the fuel core, J / (kg · K)	900	
Thermal conductivity of the shell, W / (m · K)	175	
The heat capacity of the shell, j / (kg · K)	900	

Fuel element number 8 is not square, but round. The rounding radius of square fuel rods on the outer border is 4.4 mm. Technological tolerances in the manufacture of fuel rods according to parameter B have tolerances of +0.1 and –0.3 mm, and according to parameter b *: 0 and –0.05 mm.

Table 2 - Form, dimensions and masses of standard fuel assemblies

Number of FE	Length of FE, mm	B, mm	b*, mm	M_{235}, g	M, kg
1	721	69,4	66,5	59,4±3,5	0,75
2	650	62,5	59,6	53,2±3,2	0,60
3	650	55,6	52,7	47,0±2,8	0,53
4	650	48,7	45,8	40,9±2,5	0,46
5	650	41,8	38,9	34,7±2,1	0,39
6	650	34,9	32,0	29,5±1,7	0,32
7	650	28,0	25,1	22,5±1,3	0,26
8	650	21,2	18,3	13,8±0,8	0,15

The six-tube fuel assembly of the IRT-3M type differs from the 8-tube one in that it removed the aluminum propellant tube and two central fuel rods, and the CPS channel was installed in their place (Figure 2). The CPS channel is made of SAV-1 alloy.
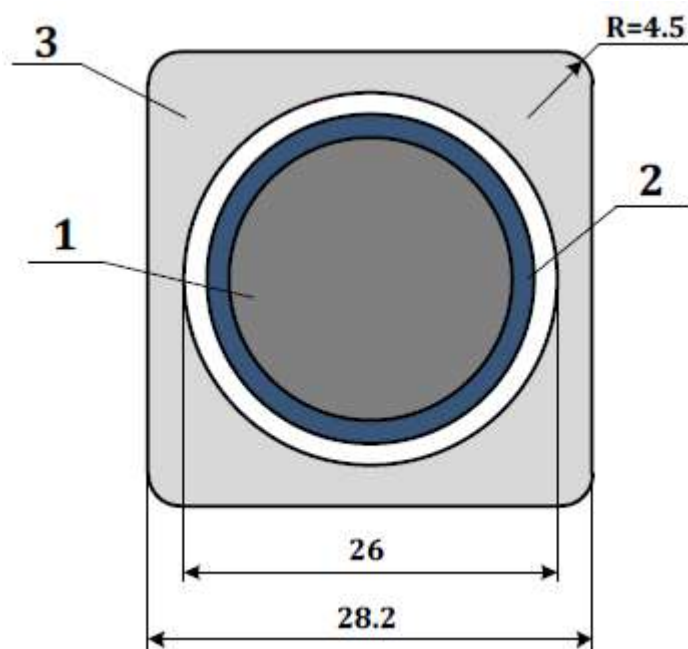
Figure 2 - CPS channel with an absorbing rod in the center of a six-tube fuel assembly: 1 - boron carbide; 2 - core sheath; 3 - rod channel.

A standard FA of the IRT-3M is depicted in Figure 1.5 [1]. Inside all fuel rods there is a cylindrical propellant made from SAV-1 alloy with a diameter of 14 mm and a thickness of 1 mm.

The main physical parameters of the reactor are shown in Table 3.

Table 3 - Neutronic Characteristics of the IRT-T Reactor

Parameter name	Value
Reactor power, MW	6
U-235 mass loaded with fresh FA, kg	5,47
Reactivity margin at the start of the cycle (after overload)	$\leq 11\ \beta_{eff}$
Reactivity margin at the end of the cycle (before overload)	$< 2,5\ \beta_{eff}$
The effectiveness of the RO CPS at the beginning of the cycle:	
- regulating rods (AR, KS-1,2,3)	$12,5\ \beta_{eff}$
- scram protection rods (AZ -1,2)	$6\ \beta_{eff}$

Nuclear safety regulations require that the subcriticality of a reactor with fully submerged control rods (AR, KS) and fully withdrawn AZ rods must be at least 2% Δk / k.

The direction of movement of the coolant from top to bottom. In normal operation, the pumping of the coolant through the core is performed by three pumps: two primary circuit pumps (300 m^3 / h) and emergency cooling pump (50 m^3 / h). The nominal water level in the reactor basin is 7.3 m.

1.4. Neutronic characteristics of the core

The neutronic characteristics of the reactor are determined by its physical scheme based on the use of fuel assemblies of the IRT-3M type with a short migration length of neutrons and a beryllium reflector.

In the core, in the reflector, in the working bodies of the CPS, as well as in other parts of the reactor, materials have been used that have been sufficiently tested in

research reactor engineering with well-studied properties, including when working in radiation conditions: metal-ceramics metal beryllium, stainless steel, aluminum alloys.

The core has sufficiently high neutron-multiplying properties ($K\infty \approx 1,75$), which determines the possibility of obtaining high neutron-physical parameters in experimental volumes.

The minimum critical mass is 3.01 kg; the reactivity margin is ~ 0.14% Δ k / k (experimental channels are installed in 4 central beryllium blocks).

The reactivity balance of the workload of 20 fuel assemblies with the periodic replacement in the core of one of the most burnt fuel assemblies with "fresh" (partial overload mode):

- the maximum reactivity margin at the beginning of the cycle after overload– 7.2% Δ k / k;

- equilibrium isotope poisoning of xenon-135 and samarium-149 4.8% Δ k /k;

- reactivity temperature effect–0.4% Δ k / k;

- operational stock –1.0% Δ k / k;

- burnup –1.0% Δ k / k.

2. Theoretical part
2.1. MCU-PTR

The MCU-PTR program is designed to simulate the processes of neutron and photon transfer by analog and non-analog Monte Carlo methods, based on estimated nuclear data in systems with three-dimensional geometry, taking into account changes in the isotopic composition of materials.

The program allows to simulate systems consisting of volumetric elements of almost arbitrary shape. The geometrical module of the program uses a combinatorial approach based on the description of complex spatial forms by combinations of simple bodies and surfaces using the operations of intersection, addition, and union. There is a certain set of types of body primitives. For each such type of body, parameters are set that completely describe the shape of a particular body and its position in space. In the geometric module, it is possible to specify lattices, which are obtained by multiplying some of the initial elements specified using combinatorics. Another tool that allows you to form the geometry of a system of repeating objects (elements) is the so-called network. The use of gratings and networks dramatically simplifies the task of geometry and saves the RAM of the computer.

The constant software support is the MDBTP50 library.

The program has a modular structure and is composed of the following modules:

– a control module that performs the functions of a monitor;

– a transport module simulating particle trajectories in the system;

– a composite physical module, designed to draw the interaction of particles with matter on the basis of the library MDBTP50;

– a geometric module simulating the straight sections of the trajectories between collisions;

– a registration module that allows you to calculate a wide range of neutron flux functionalities;

– a source module that simulates the phase coordinates of the source particles (or zero–generation neutrons when solving criticality problems);

– a hardware module that includes programs that may depend on the type of computer and operating system;

– burnup module, which allows calculating changes in the isotopic composition of reactor materials during the campaign.

The physical module of the program allows modeling collisions of particles with matter on the basis of the listed systems of constants, and it is possible to use various models of the interaction of neutrons and photons.

Thus, the MCU-PTR allows you to create and perform physical calculations for systems of any complexity, which is necessary for the simulation of reactors of all known types and classes.

3. Practical part

3.1. Detailed construction of the model of the core IRT-T

The construction of a more detailed TVS-3M model was carried out by dividing it in height into seven equal layers of 8.28 cm each. Given the geometry, each fuel assembly was divided into 16 elementary parts, in which sections with curves in the corners of the fuel assemblies and rectilinear sections are separately distinguished, which, in turn, were divided into three equal parts to take into account the central and peripheral zones of the rectilinear partition region. The choice of such a partition of fuel assemblies is due to the peculiarity of the assembly geometry and the convenience of partitioning, construction, and calculations.

The original TVS-3M model was built with a height division into six equal layers and with no radial division.

A visual representation of the partition is shown in Figures 3 and 4.
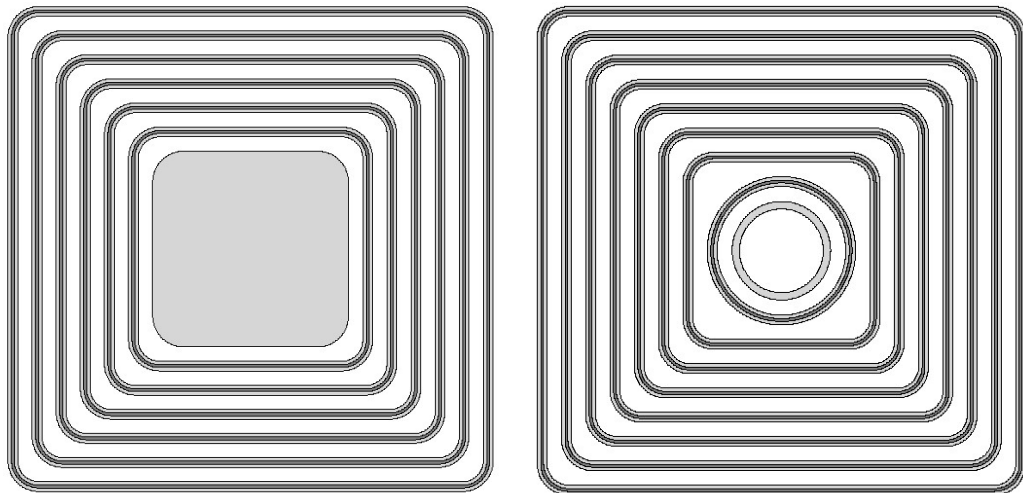
Figure 3 - Initial models of six and eight pipe fuel assemblies
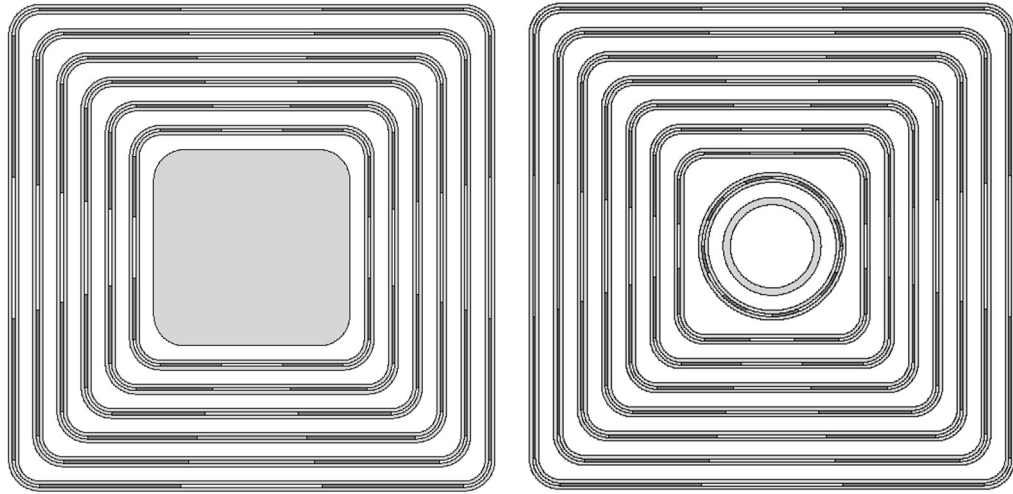
Figure 4 - Models of six and eight pipe fuel assemblies after dividing

To determine the energy release and fuel burnout in each cell and, accordingly, in a fuel assembly, it is necessary to know its elementary volume. The cell volumes are divided into three groups: main (rectangle), which in turn are divided into seven more (according to the number of fuel rods), rounding off at the corners of the fuel rods (for the first seven fuel rods they are the same) and circular (dividing the eighth fuel rod into sixteen equal sectors).

Table 4 presents the cell sizes obtained by dividing.

Table 4 - Dimensions of unit cells

Area	Rectangle							Rounding	Circle
TVEL	1	2	3	4	5	6	7	–	–
Thickness, cm	0.04								
Length, cm	2.02	1.79	1.56	1.33	1.10	0.87	0.64	–	–
Height, см	8.28								
Volume, cm^3	0.67	0.59	0.52	0.44	0.36	0.29	0.21	0.18	0.13

In the original model, a conditionally "separate" fuel material was assigned to each individual cell. The initial breakdown of fuel assemblies was carried out only in height of six layers; accordingly, there were 120 initial materials of assignment. After a detailed construction of the model as described above, 18200 assignment materials were obtained. Accordingly, each material was assigned to a separate unit cell of the

partition. Obtaining such an amount of materials was carried out as follows: the condition for the existence of six and eight pipe fuel assemblies was taken into account (the need to have more materials for six pipe fuel assemblies to replace them with eight pipe assemblies). From this assumption, it follows that the maximum number of fuel rods is accepted 8 (eight tube fuel assemblies) each of which is divided into sixteen parts, therefore, the maximum number of materials that fall on one layer is 128 (for the convenience of calculations and their subsequent analysis, it was accepted to round the number of materials in a layer up to 130). Having a fuel assembly with a conditional breakdown into 7 layers of 130 materials each, obtain 910 materials per fuel assembly. In the IRT-T reactor, 20 fuel assemblies are operated, from which a final number of fuel equivalent materials equal to 18200 was obtained.

Having a huge amount of materials in the calculations, it is necessary to be able to determine at any time the boundaries of the materials assigned to the fuel assembly, numbers: fuel assembly, layer, fuel rod and partition cell to which any necessary material belongs. This is necessary in cases of moving fuel assemblies, replacing them with "fresh" ones, determining the location of any material in the core, checking for errors that appear during calculations, increasing the speed of data analysis. For this, an algorithm was found in the Microsoft Excel software environment for finding all the query parameters listed above. Below are the algorithms for finding: the boundaries of materials assigned to fuel assemblies, numbers: fuel assemblies, layer, fuel rod and cell.

The initial boundary of the fuel assembly materials:

$$G_1 = M_{fa} \cdot (N_{fa} - 1) + 1$$

where, is M_{fa} the number of materials per 1 fuel assembly, N_{fa} is the fuel assembly number.

The final boundary of the fuel assembly materials:

$$G_2 = N_{ml} \cdot N_l$$

FA number:

$$N_{fa} = \frac{M}{M_{fa}} \text{ if } \frac{M}{M_{fa}} \text{was} \leq C_1, \text{ then } N_{fa} = C_1 + 1$$

where, M is the number of the material sought, C_1 is the whole relationship $\frac{M}{N_l}$.

Layer number (for convenience, all subsequent operations are carried out relative to the first 910 materials (M') assigned to the 1st fuel assembly):

$$M' = M - (N_{fa} - 1) \cdot N_l$$

$$N_l = \frac{M'}{M_l} \text{ if } \frac{M'}{M_l} \text{ was} \leq C_2, \text{ then } N_l = C_2 + 1$$

where, M_l– the amount of materials per layer, C_2- the whole relationship $\frac{M}{M_l}$.

FE number:

$$N_{fe} = \frac{M' - (N_l - 1) \cdot M_l}{M_{fe}} \text{ if } \frac{M' - (N_l - 1) \cdot M_l}{M_{fe}} \text{ was} \leq C_3, \text{ then } N_{fe} = C_3 + 1$$

where, M_{fe} is the amount of materials per 1 FE, C_3 is a whole relationship

$$\frac{M' - (N_l - 1) \cdot M_l}{M_{fe}}.$$

Cell number:

$$N_c = M' - (N_l - 1) \cdot M_l - (N_{fe} - 1) \cdot M_{fe}$$

In order to verify the correctness of the model's operability, the core was tentatively loaded with fresh fuel assemblies. After launching the experimental model, the functional values in each cell were obtained at the moments when the reactor was launched and the reactor reached power. Knowing the functional values in each cell, the energy release values in each unit cell were calculated. Figure 5 shows the energy release values (kW) in each fuel assembly obtained after separation of the experimental model. Gray color shows six pipe fuel assemblies. And white, respectively, eight pipe assemblies.

279,42	301,48	311,79	316,65
228,21	262,46	274,42	267,60
356,26			411,29
362,73			403,70
235,84	265,35	268,03	256,42
285,25	303,52	305,11	304,47

Figure 5 - Energy release values in each fuel assembly after separation of the experimental model

As can be seen from the figure, the ER values per one assembly correspond to the theoretical ones and do not exceed the maximum permissible values. For the point determination and visual representation of data in the radial and axial planes.

Using this model allows to conduct a visual analysis of the obtained values of ER and burnout in any plane of interest to us and for any material, regardless of layer number; Another advantage of the model is the ability to consider these parameters with respect to all assemblies of the core and a single fuel assembly. An example of a visual representation of ER relative to an individual assembly is presented 6.
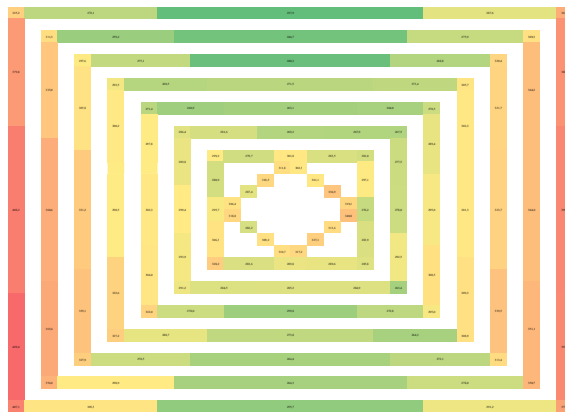
Figure 6 - Distribution of ER in 10th fuel assemblies

3.2. Software development for the research results analysis

As a result of the increase in the conventional fuel materials number (from 120 to 18200), it became necessary to create a program to simplify calculations and reduce the time for analyzing the results. It was decided to use the Python programming

language version 3.8 because of its ease of mastering the language, ease of writing codes and its readability. Created program SMAC (set of modules for analysis and calculation) includes a set of modules (Figure 7), each of which is responsible for performing a specific function.
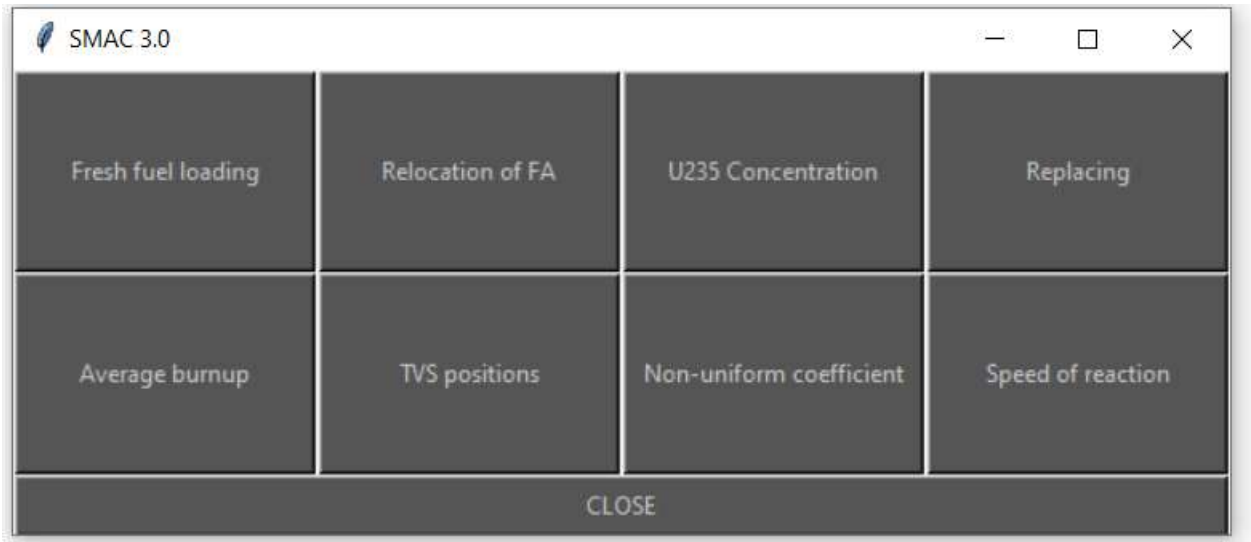
Figure 7 – SMAC main menu

The first module performs the function of replacing any assembly with a fresh one. Only one assembly can be freshened at a time (Figure 8).

Figure 8 – Fresh fuel loading module

The second module is designed to move fuel assemblies along the core. Movement is carried out by pair replacement of two assemblies. Only one assembly pair can be moved at a time (Figure 9).

Figure 9 – Relocation of fuel assembly

The third module calculates the percentage burnup of 235 uranium for each of the 18,200 elements.

The fourth module replaces the 6-pipe fuel assembly with an 8-pipe one and vice versa. Only one assembly can be changed at a time (Figure 10).

Figure 10 – TVS replacing

The fifth module allows to calculate the average burnup over the entire fuel assemblies and displays the data in the form of a core diagram in which all fuel assemblies are arranged in increasing order from 1 to 20 (Figure 11 a).

Module number six displays on the screen the layout of the core, that is, the actual position of the fuel assembly in the core (Figure 11 b). This both figures show core configuration K-01.1-F1804N04.

This configuration is the layout of the core in which the fresh fuel assemblies are numbers 4 and 18. Freshly assembled so that they occupy the most non-energy-intensive places and are surrounded by burned assemblies.

The seventh module displays the volumetric coefficient of unevenness of all fuel assemblies in the core. The module displays an image in the form of a block diagram. (Figure 11 c).

a) Average bur...

Open file		Save file	
56.93	20.38	49.55	0.0
36.59	32.15	23.43	32.41
51.98			42.19
4.99			54.66
35.84	18.85	29.58	33.0
57.89	0.0	20.11	60.04
CLOSE			

b) TVS position

Open file		Save file	
18	9	11	3
5	6	7	8
12			20
1			17
13	14	15	16
4	2	19	10
CLOSE			

c) Non-unifor...

Open file		Save file	
1.49	1.7	1.13	1.83
1.43	1.2	1.27	1.38
1.67			1.65
1.39			1.52
1.31	1.38	1.31	1.35
1.51	1.65	1.7	1.5
CLOSE			
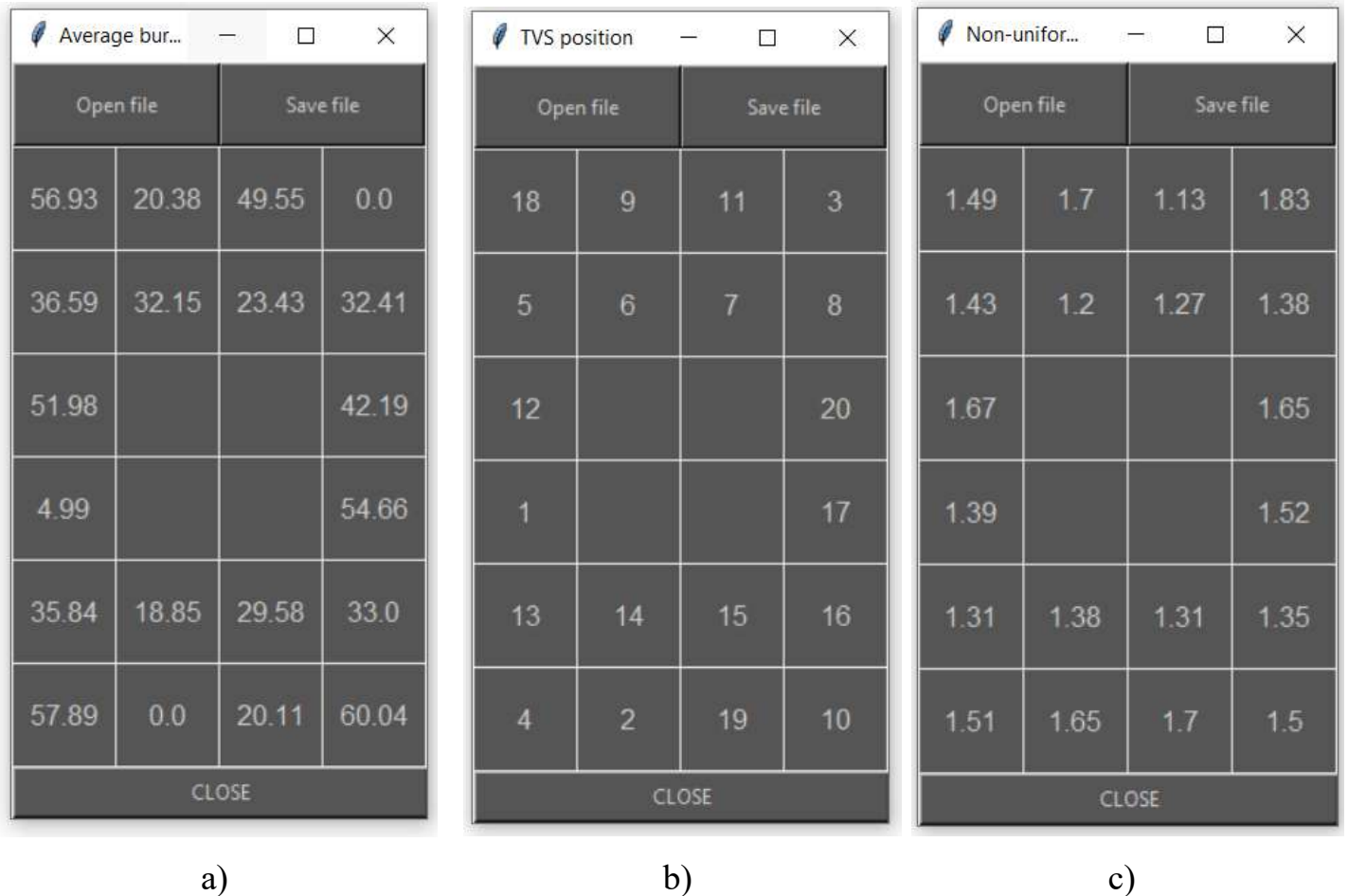
Figure 11 – Program module examples

a – Average burnout module, b – TVS positions module, c – Non-uniform coefficient module

The last module is responsible for calculating the rate of fission of uranium by 235 neutrons. The result of the module is a text file with the reaction rates of each elementary calculation block contained in it. After that, the data is used to calculate the energy release in each of the elements. Based on all this, a complete analysis of the data obtained takes place (Figure 12).
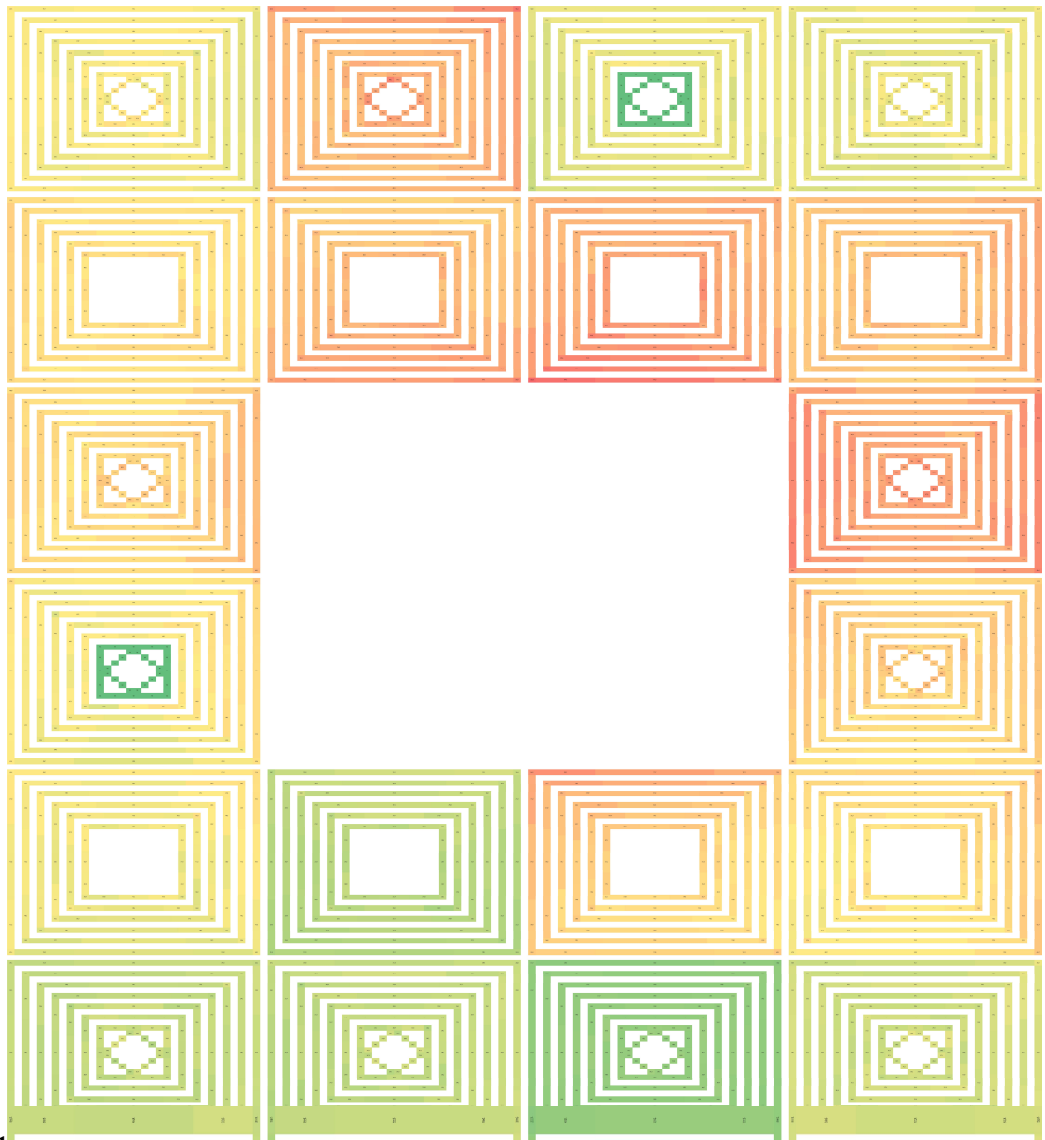
Figure 12 – The result of data after using the program to calculate the fission reaction rate

3.3. Calculation of the maximum increase in reactor power

According to the following task, for starters it is necessary to choose the optimal position of the fresh assembly in the core. The optimal position is one in which the assembly has the lowest energy release from the surface. For this, a fresh assembly was placed in turn in all positions of the core, with the exception of positions 5–8 and 13–16, since only six-tube assemblies can be in these positions. The data on the maximum energy release are presented in table 5. Figure 13 shows the numbering of fuel assembly positions in the core.
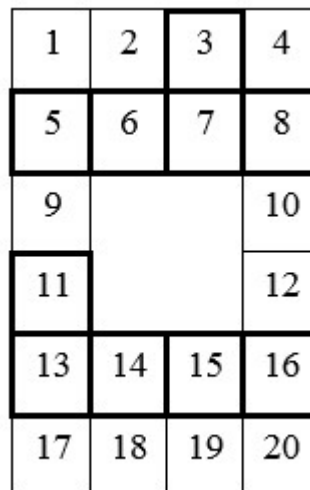
Figure 13 – Positions of fuel assemblies

Table 5– Maximum energy release of fresh fuel assembly

Position	Energy, kW/m^2	Position	Energy, kW/m^2
1	508.37	11	658.84
2	557.75	12	716.53
3	569.96	17	563.52
4	618.17	18	578.24
9	688.49	19	576.34
10	725.73	20	597.61

As can be seen from table 6, the position with the lowest energy release is the first (kW /m^2), but this value is not the maximum for a given core composition. As shown in Figure 14, fuel assemblies in position 9 (kW /m^2) have the maximum energy release. Also, a key factor affecting energy release is the burnout of assemblies. As shown in Figure 14, fuel assemblies in the 9th position have a low fuel burn-up value (4.99%). And in areas with increased energy release for fresh assembly, fuel assemblies that have a burn-out of more than 20% allocate the optimum value (about 500 kW /m^2), and assemblies with a burn-out of 50% or more, emit about 300 kW /m^2. From this it follows, the recommendation for the composition of the core: do not place assemblies with a burnout of 20% or lower at positions 9-12. High rates of energy release at these points are caused by their surroundings with a beryllium reflector.

kW/m2					Burn Up			
508,37	212,47	160,00	227,77		0,00	60,04	49,55	51,98
246,73	306,46	407,58	262,19		36,59	32,15	23,43	32,41
600,77			285,82		4,99			54,66
458,46			529,25		20,11			20,38
243,57	423,67	325,96	252,41		35,84	18,85	29,58	33,00
198,19	219,39	259,39	172,42		57,89	56,93	42,19	66,76

Figure 14 – Energy release and burn up of fuel assemblies

After determining the optimal parameters of the fresh assembly, it is necessary to determine the maximum possible power of the reactor with this core composition. The maximum possible (permissible) is the power at which the energy release of any assembly does not exceed 800 kW /m^2. The step of increasing power was taken equal to 0.5 MW. The results are presented in Figure 15.

kW/m2					kW/m2			
550,74	230,18	173,33	246,75		593,10	247,88	186,66	265,74
267,29	332,00	441,55	284,04		287,86	357,54	475,51	305,89
650,84			309,64		700,90			333,46
496,67			573,36		534,87			617,46
263,87	458,98	353,12	273,44		284,17	494,28	380,29	294,47
214,71	237,68	281,00	186,79		231,22	255,96	302,62	201,15

a)   b)

kW/m2			
635,46	265,59	200,00	284,72
308,42	383,08	509,48	327,74
750,97			357,28
573,08			661,57
304,47	529,59	407,45	315,51
247,74	274,24	324,23	215,52

c)

kW/m2			
677,83	283,30	213,33	303,70
328,98	408,62	543,44	349,59
801,03			381,10
611,29			705,67
324,76	564,89	434,61	336,54
264,25	292,52	345,85	229,89

d)

Figure 15 – Energy release of fuel assemblies at different power.

a – 6.5 MW, b – 7 MW, c – 7.5 MW, d – 8 MW.

As can be seen from Figure 15, the maximum reactor power for this composition is 7.5 MW, since at 8 MW fuel assemblies in the 9th position exceed the maximum allowable energy release value. At the same time, the fresh assembly does not exceed the mark of 700 kW /m^2.

Based on the above calculations, a list of recommendations for organizing the composition of the core was compiled:

1. To ensure safety and create conditions for increasing the power of the reactor in positions 9-12, it is necessary to place fuel assemblies with fuel burnup of at least 40%, which will ensure the optimal (safe) level of energy release at these points;

2. There are two possible ways of arranging the remaining fuel assemblies in the core. The first is a graduated arrangement from the left to the right periphery, starting with the least burned assembly. Such an arrangement should possibly have a mirror character. The second – if it is not possible to carry out graduation, position the least burnt assembly between two more burnt ones. This will prevent a large arrival of neutrons from low-burned assemblies and thereby compensate for their distribution in a more energy-stressed position.

3. The gradual (step-by-step) movement of fresh fuel assemblies from the extreme left to the extreme right position with their subsequent location in positions 9-12.

An example of the use of recommendations is presented in Figure 16. Data are given for a reactor power of 6 MW.

kW/m2					Burn Up			
467,99	239,00	377,57	149,54		0,00	51,98	4,99	49,55
216,73	278,18	339,97	242,26		36,59	32,15	23,43	32,41
281,00			245,43		54,66			60,04
281,01			244,91		56,93			57,89
271,46	454,76	334,15	270,68		35,84	18,85	29,58	33,00
539,08	439,07	406,68	267,21		0,00	20,38	20,11	42,19

Figure 16 – Energy release and burn up of fuel assemblies after recommendations

In this reactor composition (K-01.1-F1804N04), two fresh assemblies (18 and 4) were placed in the core in positions with minimal energy release and surrounded by fuel assemblies with burnup of at least 20%. Assemblies with burnout of at least 40% (54.66, 60.04, 56.93, 57.89 for this case) are placed at positions 9-12, which allows achieving energy release at these points no higher than 300 kW /m^2, which is almost two times less than the previous composition.

After constructing the core, taking into account the recommendations, it is necessary to determine the maximum possible level of reactor power. The calculation results are presented on figure 17.

kW/m2					kW/m2			
506,99	258,92	409,03	162,00		545,99	278,83	440,50	174,46
234,79	301,36	368,30	262,44		252,85	324,54	396,63	282,63
304,41			265,88		327,83			286,33
304,42			265,32		327,84			285,72
294,08	492,66	362,00	293,23		316,70	530,56	389,84	315,79
584,01	475,66	440,57	289,48		628,93	512,25	474,47	311,74

a)   b)

kW/m2			
584,98	298,75	471,96	186,92
270,91	347,72	424,96	302,82
351,25			306,78
351,26			306,13
339,33	568,46	417,69	338,34
673,85	548,84	508,36	334,01

c)

kW/m2			
623,98	318,67	503,43	199,39
288,97	370,91	453,29	323,01
374,66			327,23
374,67			326,54
361,95	606,35	445,54	360,90
718,78	585,43	542,25	356,28

d)

kW/m2			
662,98	338,58	534,89	211,85
307,03	394,09	481,62	343,19
398,08			347,69
398,09			346,95
384,57	644,25	473,38	383,46
763,70	622,01	576,14	378,55

e)

kW/m2			
701,98	358,50	566,36	224,31
325,09	417,27	509,95	363,38
421,50			368,14
421,51			367,36
407,19	682,15	501,23	406,01
808,62	658,60	610,03	400,81

f)

Figure 17 – Energy release of fuel asseblies at diffirent power after recommendetions a – 6.5 MW, b – 7 MW, c – 7.5 MW, d – 8 MW, e – 8.5 MW, f – 9 MW.

As can be seen from Figure 6, the maximum possible reactor power reached 8.5 MW, which is 1 MW or 13% more than the standard composition of the reactor (up to recommendations). Moreover, the assemblies located in position 9-12 do not exceed the energy release mark of 400 kW /m^2.

4. Financial management, resource efficiency and resource saving

The purpose of this section discusses the issues of competitiveness, resource efficiency and resource saving, as well as financial costs regarding the object of study of Master's thesis. Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants and the necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

4.1. Competitiveness analysis of technical solutions

In order to find sources of financing for the project, it is necessary, first, to determine the commercial value of the work. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. This analysis is advisable to carry out using an evaluation card.

First of all, it is necessary to analyze possible technical solutions and choose the best one based on the considered technical and economic criteria.

Evaluation map analysis presented in Table 6. The position of your research and competitors is evaluated for each indicator by you on a five-point scale, where 1 is the weakest position and 5 is the strongest. The weights of indicators determined by you in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i,$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

Five criteria for evaluating competitor models were selected. The most important of them were selected to analyze the results and the results in accuracy. The analysis of the results increases the number of directions studied, and the accuracy of the results reduces the likelihood of error.

In addition, detailing criteria were identified because it is important that the model is described in detail and recreated. Based on a more accurate model, the possibility of obtaining more accurate data increases.

Criteria for model size and calculation speed were identified as less important. The size criterion indicates the complexity of the user's model perception. The calculation speed shows the relative amount of time needed to get the results.

In this work, all calculations were performed using the new virtual model of the core of the IRT-T reactor. However, there is an old model that is currently in use. However, the new reactor model is much more accurate because of its granularity than the old model does not have.

Table 6 – Evaluation card for comparison of competitive technical solutions

Criteria	Criteria weight	Score		Competitiveness	
		Old model	New model	Old model	New model
Results accuracy	0.3	2	4	0.6	1.2
Detailing	0.2	3	5	0.6	1.0
Model size	0.1	4	3	0.4	0.3
Analysis of the results	0.3	3	4	0.9	1.2
Computation speed	0.1	4	2	0.4	0.2
	1	16	18	2.9	3.9

As can be seen from table 6, the competitiveness of the new model is much higher than that of the old. Moreover, the rating of the new is higher than the old. The main disadvantage of the new model is the speed of calculations due to the huge number of units being calculated.

4.2. SWOT analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several stages. The first stage consists of describing the strengths and weaknesses of the project, identifying opportunities and threats to the project that have emerged or may appear in its external environment. The second stage consists of identifying the compatibility of the strengths and weaknesses of the project with the external environmental conditions. This compatibility or incompatibility should help to identify what strategic changes are needed.

Table 7 – Interactive matrix of the project

	Strengths: S1. The relevance of the chosen theme. S2. Practical work on reactor installation. S3. Detailed study the model under study. S4. Model application on real installation. S5. Detailed analysis of energy release and burnout at changing reactor power.	**Weaknesses:** W1. The presence of the human factor. W2. The possibility of an error in the calculation. W3. Long time calculations. W4. High level of knowledge for performing calculations. W5. Limited number of calculated parameters.
Opportunities: O1. Publication in scientific journals. O2. The performance of the experiment on other reactors. O3. The application of the calculation in the new advanced reactor facilities. O4. Creation of a regulated scheme of loading and further reloading of fuel.	The results of the analysis of the interactive matrix of the project fields "Strengths and opportunities": 1. Conducting experiments on other reactors will practically confirm the reliability of the results. 2. Publication of the results and disseminate used calculation method for other nuclear power plants. 3. Economic benefits when purchasing fresh fuel caused by a more efficient way to use it.	The results of the analysis of the interactive matrix of the project fields "Weaknesses and opportunities": 1. The occurrence of errors due to lengthy calculations; This factor may be at work attentive eliminate. 2. The requirement for extensive knowledge of the subject reactor graphite; This is not big disadvantage, as receiving additional knowledge will not bring harm and broaden horizons.
Threats: T1. Radiophobia of the population. T2. Low demand for results in the absence of publications.	The results of the analysis of the interactive matrix of the project fields "Strengths and threats": 1. Fear of the population to radio emission can lead to a decrease in the demand and demand for technology in production.	The results of the analysis of the interactive matrix of the project fields "Weaknesses and threats": 1. The influence of the human factor can negatively affect the reliability of the results, which will lead to falling chance of publication.

| T3. Non-interest of third-party organizations in the application of the results of work. | 2. Lack of publications on this topic may lead to a decline in the level of dissemination of work results, which will affect the interest of third parties in this topic. | However, with complex operation, the occurrence of an error can be minimized. |

4.3. Project initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined and the initial financial resources are fixed. The internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined.

Table 8 – Stakeholders of the project

Project stakeholders	Stakeholder expectations
Division for Nuclear-Fuel Cycle of TPU	Relocation method and loading of fuel assemblies allowing safe raising of reactor power

Table 9 – Purpose and results of the project

Purpose of project:	Possibility justification of IRT-T reactor operating at an increased power level
Expected results of the project:	Reactor core overload regulation
Criteria for acceptance of the project result:	Absence of errors during the calculation
Requirements for the project result:	Calculation error less than 25%
	Adequate system performance in software conditions
	Availability of a workable model of the IRT-T reactor

At the current stage it is important to decide who will be in the workgroup of this project, to define roles for each participant and to assign the functions for each participant. Besides, there should be considered working hours. This information is represented in table 10.

Table 10 – Project workgroup

№	Participant	Role in the project	Functions	Labor time, hours.
1	A.G. Naimushin	Scientific advisor	Student control	480
2	S. E. Shinkarenko	Engineer	Doing scientific work	2016
Total				2496

4.4. Project limitations

Project constraints are the factors, which are limiting the degree of freedom for project team members and serving as boundaries of the project.

Table 11 – Project constraints

Factors	Constraints/Admissions
Project's budget	
Source of financing	National Research Tomsk Polytechnic University
Project timeline:	01.02.2020-10.05.2020
Date of approval of plan of project	01.02.2020
Completion date	25.05.2020

4.5. Timing schedule of the project

As part of the planning of a research project, it is necessary to build a timetable and a calendar schedule for the project. The timetable is shown in table 4.5.1. Scientific advisor and an engineer are the main contributors to the report.

Table 12 – Timetable of the project

№	Job title	Duration, working days	Start date	Date of completion	Participants
1	Development of research task	2	1.02.2020	3.02.2020	Scientific advisor Engineer
2	Drafting and approving the research task	4	4.02.2020	7.02.2020	Scientific advisor
3	The choice of research direction	6	8.02.2020	14.02.2020	Scientific advisor Engineer
4	Selection and study of materials on the topic	11	15.02.2020	29.02.2020	Engineer
5	Calendar planning of the work	4	1.03.2020	5.03.2020	Scientific advisor, Engineer
6	Performing calculations and analyzing the received data	43	6.03.2020	27.04.2020	Engineer
7	Summarizing and evaluating results	3	28.04.2020	1.05.2020	Scientific advisor, Engineer
8	Detailed report writing	3	2.05.2020	8.05.2020	Engineer
9	Checking the correctness of the report on the state standard	1	9.05.2020	12.05.2020	Scientific advisor Engineer
10	Preparations to the defense of the thesis	11	13.05.2020	25.05.2020	Engineer

A Gantt chart, or harmonogram, is a type of bar chart that illustrates a project schedule. This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis. The width of the horizontal bars in the graph shows the duration of each activity.

№	Activities	Participants	Tc,	Duration of the project															
				February				March				April				May			
				1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Development of research task	Supervisor	2	▮															
2	Drafting and approving the research task	Supervisor	4	▮															

№	Name of work	Performers	T_{ki}																											
3	The choice of research direction	Supervisor, student	6		▮																										
4	Selection and study of materials on the topic	Student	11			▬																									
5	Calendar planning of the work	Supervisor, student	4				▮																								
6	Performing calculations and analyzing the received data	Student	43					▬▬▬▬																						
7	Summarizing and evaluating results	Supervisor, student	3																			▮								
8	Detailed report writing	Student	3																				▮							
9	Checking the correctness of the report on the state standard	Supervisor, Engineer	1																						▮					
10	Preparations to the defense of the thesis	Engineer	11																							▮			

4.6. Material costs of scientific research

The amount of costs associated with the implementation of this work is the basis for the formation of the project budget. This budget will be presented as the lower limit of project costs when forming a contract with the customer.

For current work, MCU-5 PTR software was used, which is free. Besides, there was used a laptop with cost 39000 rubles, which is less than 40000 rubles, hence depreciation of hardware is not necessary

Material costs, required for this research are shown in table 13.

Table 13 – Material costs

Name	Amount (S_{mat}), rub.
Office supplies	1000
Access to the Internet	600
Total:	1600

4.7. Costs of special equipment

This point includes the costs associated with the acquirement of special equipment (instruments, stands, devices and mechanisms) necessary to carry out work on a specific topic.

Table 14 – Costs of special equipment

№	Equipment identification	Quantity of equipment	Price per unit, rub.	Total cost of equipment, rub.
1.	Personal computer (laptop)	1	39000	39000

4.8. Calculation of the base salary

This point includes the basic salary of participants directly involved in the implementation of work on this research. The value of salary costs is determined based on the labor intensity of the work performed and the current salary system

The basic salary (S_b) is calculated according to the following formula:

$$S_b = S_a \cdot T_w$$

where S_b – basic salary per participant;

T_w – the duration of the work performed by the scientific and technical worker, working days;

S_a - the average daily salary of a participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v}$$

где S_m – monthly salary of an participant, rub .;

M – the number of months of work without leave during the year:

at holiday in 48 days, M = 11.2 months, 6 day per week;

F_v – valid annual fund of working time of scientific and technical personnel (251 days).

Table 15 – Balance of working time

Criteria for working time	Scientific advisor	Engineer
Calendar amount of days	365	365
Amount of non-work days:	66	66
– weekend;	52	52
– holidays.	14	14
Loss of working days, days:	48	48
– vacation;	48	48
– sick absence.	0	0
Current annual working hours F_d, days	251	251

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg}$$ (x)

where S_{base} – base salary, rubles;

k_{reg} – regional rate.

Base salary calculation for the scientific advisor and for an engineer is in table 16.

Table 16 – Base salary calculation

Performers	S_{em}, rub	k_r	S_m, rub	S_d, rub.	T_w, w.days.	S_{base}, rub	S_{bon}, rub
Scientific advisor	35120	1.3	45656	2037	20	40746	4074
Engineer	17310	1.3	22503	1004	84	84336	8434

The base salary for a scientific advisor from TPU is calculated based on industrial remuneration. In TPU this remuneration considers next content for salary:

- – emolument, determined by the enterprise;
- – incentive payments, determined by the head of departments for efficient work, the accomplishment of job duties and etc.;
- – other payments;
- – regional salary coefficient.

Additional salary equals to 10 % from the base salary. According to calculations, the additional salary for an engineer is 8433 rubles and for scientific advisor, it is 4074 rubles.

4.9. Contributions in non-budget funds

This part of costs shows the necessary contribution according to laws of the Russian Federation about social assurance, pension fund and medical insurance from costs on salary.

Contributions are calculated as follows:

$$S_{soc} = k_{contr} \cdot \left(S_{base} + S_{bon} \right), \tag{4.9.1}$$

where k_{contr} – the coefficient for contributions in non-budget funds.

Besides, contributions in non-budget funds are not required for scholarships. At the moment of the 2020 year, the insurance fees are 30 %, however, for education enterprises, there is a reduced rate equal to 27.1 %.

Results of calculation for social funds are presented in table 17.

Table 17 – Contributions in non-budget funds

	Scientific advisor	Engineer
Base salary, rub.	40746	84336
Additional base salary, rub.	4074	8434
Coefficient for non-budget contributions, %	27.1	
Total, rub.	11042	22855

4.10. Overhead costs

Overhead costs account from 30 % to 90 % of the amount of base and additional salary of employees. In this case overhead rate is equal to 30 %.

$$S_{overh} = k_{overh} \cdot (S_{base} + S_{bon}). \qquad (4.10.1)$$

Table 18 – Overhead costs

	Scientific advisor	Engineer
Base salary, rub.	40746	84336
Additional base salary, rub.	4074	8434
Coefficient for non-budget contributions, %	30	
Total, rub.	12224	25301

4.11. Other direct costs

Main works for research project were made on a laptop for four months. The input voltage of laptop equals 20 V and input current is 3.25 A. Hence, the output power of the laptop is 65 W or 0.065 kW.

Costs on electric energy are calculated as follows:

$$S_e = C_{el} \cdot P \cdot F_{hw}, \qquad (4.11.1)$$

where C_{el} – energy rate (5.8 rub per 1 kW·h);

P – hardware power, kW;

F_{hw} – hardware time of use, h.

Therefore, costs for electric energy during the time of use of laptop:

$$S_e = 5.8 \cdot 0.065 \cdot 1302 = 491 \text{ rubles.}$$

4.12. Budgeting of project costs

Calculated costs for research work are a base for budgeting of project costs, which is a lower limit for scientific-technical production costs.

Table 19 – Budgeting of project costs

Cost item	Amount, rubles
Material costs	1600
Costs of special equipment	39000
Base salary	125082
Additional salary	12508
Contributions in non-budgetary funds	33897
Overhead costs	37525
Other direct costs	491
Total	250103

4.13. Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted average values: financial efficiency and resource efficiency.

The integral indicator of the financial efficiency of a scientific study is obtained in the course of estimating the budget for the costs of three (or more) variants of the execution of a scientific study. For this, the largest integral indicator of the implementation of the technical problem is taken as the calculation base (as the denominator), with which the financial values for all the options are correlated.

The integral financial measure of development is defined as:

$$I_{\phi}^{p} = \frac{\Phi_{pi}}{\Phi_{max}},$$
(4.13.1)

where I_{ϕ}^{p} – integral financial measure of development;

Φ_{pi} – the cost of the i-th version;

Φ_{max} – the maximum cost of execution of a research project (including analogues).

The obtained value of the integral financial measure of development reflects the corresponding numerical increase in the budget of development costs in times (the

value is greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero).

Since the development has one performance, then $I_{\phi}^{p} = 1.$

The integral indicator of the resource efficiency of the variants of the research object can be determined as follows:

$$I_{m}^{a} = \sum_{i=1}^{n} a_{i} b_{i}^{a} , \ I_{m}^{p} = \sum_{i=1}^{n} a_{i} b_{i}^{p} , \tag{4.13.2}$$

where I_{m} – integral indicator of resource efficiency for the i-th version of the development;

a_{i} – the weighting factor of the i-th version of the development;

b_{i}^{a}, b_{i}^{p} – score rating of the i-th version of the development, is established by an expert on the selected rating scale;

n – number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table 20.

Table 20 – Evaluation of the performance of the project

Criteria	Criteria weight	Points	
		Old model	New model
Results accuracy	0.3	2	4
Detailing	0.1	3	5
Model size	0.1	4	3
Analysis of the results	0.2	3	4
Computation speed	0.3	4	2
	1	16	18

The integral indicator of the development efficiency ($I_{\phi u н p}^{p}$) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I_{\phi u н p}^{p} = \frac{I_{m}^{p}}{I_{\phi}^{p}}, \ I_{\phi u н p}^{a} = \frac{I_{m}^{a}}{I_{\phi}^{a}} \ \text{and etc.} \tag{4.13.3}$$

Comparison of the integral indicator of the current project efficiency and analogues will determine the comparative efficiency. Comparative effectiveness of the project:

$$Э_{ср} = \frac{I_{финр}^{p}}{I_{финр}^{a}}.$$
(4.13.4)

Thus, the effectiveness of the development is presented in table 21.

Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem from the standpoint of financial and resource efficiency.

Table 21 – Efficiency of development

№	Indicators	Points	
		Comsol model	Ansys model
1	Integral financial measure of development	1	1
2	Integral indicator of resource efficiency of development	2.9	3.9
3	Integral indicator of the development efficiency	2.9	3.9

Comparative effectiveness of the project:

$$Э_{ср} = \frac{3.9}{2.9} = 1.34.$$

Comparing the values of integrated performance indicators allows us to understand and choose a more effective solution to a technical problem in terms of financial and resource efficiency. But since the problem has rather strict conditions, the solution has only one option.

4.14. Conclusions on financial management part

Thus, in this section was developed stages for design and create competitive development that meet the requirements in the field of resource efficiency and resource saving.

These stages includes:

-        development of a common economic project idea, formation of a project concept;

-        organization of work on a research project;

-        identification of possible research alternatives;

-        research planning;

-        assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;

-        determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

As a result, the current project is more competitive from the point of results accuracy, detailing and results analysis, because its competitiveness is higher than competitor's option. Besides, the budget of the project equals 250103 rubles and integrating efficiency indicator equals 3.9 which is in 1.34 times greater in comparison with the competitor.

5. Social responsibility

5.1. Introduction

In this research work, the features of energy distribution in the IRT-T reactor at elevated power levels were studied. During the study, acceptable levels of increase in reactor power were determined while maintaining safe operating conditions and the absence of increasing limit parameters. All work was carried out using a physical model without exposure to ionization radiation. The developed system will allow you to remotely determine the optimal position of the fuel assemblies to increase the power level.

5.2. Legal and organizational items in providing safety

Nowadays one of the main way to radical improvement of all prophylactic work referred to reduce Total Incidents Rate and occupational morbidity is the widespread implementation of an integrated Occupational Safety and Health management system. That means combining isolated activities into a single system of targeted actions at all levels and stages of the production process.

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process.

According to the Labor Code of the Russian Federation, every employee has the right:

- to have a workplace that meets Occupational safety requirements;

- to have a compulsory social insurance against accidents at manufacturing and occupational diseases;

- to receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace, about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors;

- to refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;

- be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;

- for training in safe work methods and techniques at the expense of the employer;

- for personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;

- for extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;

- for warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

The labor code of the Russian Federation states that normal working hours may not exceed 40 hours per week, The employer must keep track of the time worked by each employee.

Rules for labor protection and safety measures are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

5.3. Basic ergonomic requirements for the correct location and arrangement of researcher's workplace

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm, and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

The following requirements are also provided for the organization of the workplace of the PC user: The design of the working chair should ensure the maintenance of a rational working posture while working on the PC and allow the posture to be changed in order to reduce the static tension of the neck and shoulder muscles and back to prevent the development of fatigue.

The type of working chair should be selected taking into account the growth of the user, the nature and duration of work with the PC. The working chair should be lifting and swivel, adjustable in height and angle of inclination of the seat and back, as well as the distance of the back from the front edge of the seat, while the adjustment of each parameter should be independent, easy to carry out and have a secure fit.

5.4. Occupational safety

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker.

A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

5.4.1. Analysis of harmful and dangerous factors that can create object of investigation

The object of the study is "Investigation of the influence of the position of fresh fuel assemblies on the level of energy release in them and the possibility of increasing the reactor power through simulation on a PC." Therefore, the object of study itself cannot cause harmful and dangerous factors.

5.4.2. Analysis of harmful and dangerous factors that can arise at workplace during investigation

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 22.

Table 22 - Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	Work stages			Legal documents
	Development	Manufacture	Exploitation	
1. Deviation of microclimate indicators	+	+	+	Sanitary rules 2.2.2 / 2.4.1340–03. Sanitary and epidemiological rules and regulations "Hygienic requirements for personal electronic computers and work organization."
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings.

				Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises of residential, public buildings and in the construction area. Sanitary rules 2.2.4.548–96. Hygienic requirements for the microclimate of industrial premises.
5. Abnormally high voltage value in the circuit, the closure which may occur through the human body	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety. Maximum permissible levels of touch voltages and currents.
6. Increased levels of ionizing radiation				Sanitary Rules 2.6.1. 2523 -0 9. Radiation Safety Standards (NRB-99/2009).

The following factors effect on person working on a computer:

- physical:
  o temperature and humidity;
  o noise;
  o static electricity;
  o electromagnetic field of low purity;
  o illumination;
  o presence of radiation;
- psychophysiological:
  o psychophysiological dangerous and harmful factors are divided into:
    - physical overload (static, dynamic)
    - mental stress (mental overstrain, monotony of work, emotional overload).

Deviation of microclimate indicators

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible values of the microclimate characteristics are established in accordance with [2] and are given in Table 23.

Table 23 - Optimal and permissible parameters of the microclimate

Period of the year	Temperature, ^{C}	Relative humidity,%	Speed of air movement, m/s
Cold and changing of seasons	23-25	40-60	0.1
Warm	23-25	40	0.1

Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It result in weakened attention, deteriorated memory, decreased response, and increased number of errors in work. Noise can be generated by operating equipment, air conditioning units, daylight illuminating devices, as well as spread from

the outside. When working on a PC, the noise level in the workplace should not exceed 50 dB.

Increased level of electromagnetic radiation

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [2], the intensity of the electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

- in the frequency range 5 Hz - 2 kHz - 25 V / m;
- in the frequency range 2 kHz - 400 kHz - 2.5 V / m.

The magnetic flux density should be no more than:

- in the frequency range 5 Hz - 2 kHz - 250 nT;
- in the frequency range 2 kHz - 400 kHz - 25 nT.

Abnormally high voltage value in the circuit

Depending on the conditions in the room, the risk of electric shock to a person increases or decreases. Do not operate the electronic device in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with metal components connected to the ground and the metal casing of electrical equipment. The operator works with electrical devices: a computer (display, system unit, etc.) and peripheral devices. There is a risk of electric shock in the following cases:

- with direct contact with current-carrying parts during computer repair;
- when touched by non-live parts that are under voltage (in case of violation of insulation of current-carrying parts of the computer);
- when touched with the floor, walls that are under voltage;
- short-circuited in high-voltage units: power supply and display unit.

Upper limits for values of contact current and voltage

	Voltage, V	Current, mA
Alternate, 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

Insufficient illumination of the working area

Light sources can be both natural and artificial. The natural source of the light in the room is the sun, artificial light are lamps. With long work in low illumination conditions and in violation of other parameters of the illumination, visual perception decreases, myopia, eye disease develops, and headaches appear.

According to the standard, the illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

The brightness of the lamps of common light in the area with radiation angles from 50 to 90° should be no more than 200 cd/m, the protective angle of the lamps should be at least 40°. The safety factor for lamps of common light should be assumed to be 1.4. The ripple coefficient should not exceed 5%.

5.4.3. Justification of measures to reduce the levels of exposure to hazardous and harmful factors on the researcher
Deviation of microclimate indicators

The measures for improving the air environment in the production room include: the correct organization of ventilation and air conditioning, heating of room. Ventilation can be realized naturally and mechanically. In the room, the following volumes of outside air must be delivered:

- at least 30 m 3 per hour per person for the volume of the room up to 20 m 3 per person;

- natural ventilation is allowed for the volume of the room more than 40 m 3 per person and if there is no emission of harmful substances.

The heating system must provide sufficient, constant and uniform heating of the air. Water heating should be used in rooms with increased requirements for clean air.

The parameters of the microclimate in the laboratory regulated by the central heating system, have the following values: humidity 40%, air speed 0.1 m / s, summer temperature 20-25 ° C, in winter 13-15 ° C. Natural ventilation is provided in the laboratory. Air enters and leaves through the cracks, windows, doors. The main disadvantage of such ventilation is that the fresh air enters the room without preliminary cleaning and heating.

Excessive noise

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

Increased level of electromagnetic radiation

There are the following ways to protect against EMF:
- increase the distance from the source (the screen should be at least 50 cm from the user);

- the use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50 μrem / hr. According to the norms [2], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100 μR / h.

Fatigue of the organs of vision can be associated with both insufficient illumination and excessive illumination, as well as with the wrong direction of light.

Abnormally high voltage value in the circuit

Measures to ensure the electrical safety of electrical installations:

-        disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;

-        posting of posters indicating the place of work;

-        electrical grounding of the housings of all installations through a neutral wire;

-        coating of metal surfaces of tools with reliable insulation;

-        inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporating elements, the conclusion in the body of current-carrying parts) .

Insufficient illumination of the working area

Desktops should be placed in such a way that the monitors are oriented sideways to the light openings, so that natural light falls mainly on the left.

Also, as a means of protection to minimize the impact of the factor, local lighting should be installed due to insufficient lighting, window openings should be equipped with adjustable devices such as blinds, curtains, external visors, etc.

5.5. Ecological safety

5.5.1. Analysis of the impact of the research object on the environment

Most nuclear power plants release gaseous and liquid radiological effluents into the environment, which must be monitored. Civilians living within 80 km of a nuclear power plant typically receive about 0.1 µSv per year.

All reactors are required to have a containment building in according to international requirements. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment

Large volumes of water are used during the process of nuclear power generation,. The uranium fuel inside reactors undergoes induced nuclear fission which releases great amounts of energy that is used to heat water. The water turns into steam and rotates a turbine, creating electricity. Nuclear plants are built near bodies of water.

All possible impact of nuclear power plant on environment is greatly reduced in operating regime by many safety precautions means. The most danger of nuclear energy come because of different sorts of disaster

5.5.2. Analysis of the environmental impact of the research process

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent lamps is a hazardous substance and its improper disposal greatly poisons the environment.

Outdated devices goes to an enterprise that has the right to process wastes. It is possible to isolate precious metals with a purity in the range of 99.95–99.99% from

computer components. A closed production cycle consists of the following stages: primary sorting of equipment; the allocation of precious, ferrous and non-ferrous metals and other materials; melting; refining and processing of metals. Thus, there is an effective disposal of computer devices.

5.5.3. Justification of environmental protection measures

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity.

Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

5.6. Safety in emergency

5.6.1. Analysis of probable emergencies that may occur at the workplace during research

The fire is the most probable emergency in our life. Possible causes of fire:
- malfunction of current-carrying parts of installations;
- work with open electrical equipment;
- short circuits in the power supply;
- non-compliance with fire safety regulations;
- presence of combustible components: documents, doors, tables, cable insulation, etc.

Activities on fire prevention are divided into: organizational, technical, operational and regime.

5.6.2. Substantiation of measures for the prevention of emergencies and the development of procedures in case of emergencies

Organizational measures provide for correct operation of equipment, proper maintenance of buildings and territories, fire instruction for workers and employees, training of production personnel for fire safety rules, issuing instructions, posters, and the existence of an evacuation plan.

The technical measures include compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment.

The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

- elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);

- use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;

- the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);

- correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of fire works);

- training of production personnel in fire safety rules;

- the publication of instructions, posters, the existence of an evacuation plan;

- compliance with fire regulations, norms in the design of buildings, in the organization of electrical wires and equipment, heating, ventilation, lighting;

- the correct placement of equipment;

- well-time preventive inspection, repair and testing of equipment.

In the case of an emergency, it is necessary to:

- inform the management (duty officer);

- call the Emergency Service or the Ministry of Emergency Situations - tel. 112;

- take measures to eliminate the accident in accordance with the instructions.

5.7. Conclusions

In this section about social responsibility the hazardous and harmful factors were revealed. All necessary safety measures and precaution to minimize probability of accidents and traumas during investigation are given.

Possible negative effect on environment were given in compact form describing main ecological problem of using nuclear energy.

It could be stated that with respect to all regulations and standards, investigation itself and object of investigation do not pose special risks to personnel, other equipment and environment.

Conclusion

In the thesis, the research reactor of the Tomsk Polytechnic University IRT-T is considered, the main technical characteristics of the reactor, cooling system and fuel assemblies are given.

The design of the reactor core of the IRT-T reactor, operation parameters and conditions, reliability and safety requirements, requirements for core assembly are considered.

As a result of the WRC, a model was developed for carrying out calculations of the IRT-T reactor, which allows one to determine the detailed distribution of energy release and fuel burnup depth of any layout when using fuel assemblies of the IRT-3M type.

One of the results achieved is the developed software that includes a list of modules thanks to which it became possible to efficiently analyze the results. When using the program, the time for data analysis was reduced by 10 times.

Based on the above calculations, the optimal initial parameters for loading fresh fuel were obtained. This includes: the optimal assembly position, which is position 1 for one fresh assembly and position 1, 17 for two fresh assemblies, ways to place the remaining fuel assemblies in the core. Also in the course of the work, recommendations were made for loading fresh fuel and its further reloading, namely:

1. In positions 9-12 fuel burnup of fuel assemblies is not less than 40%;

2. Using one of the two ways to build the remaining fuel assemblies.;

3. Step-by-step movement of the assembly from the left to the right periphery.

The maximum possible power level was calculated before and after using the recommendations for the composition of the core (name of the new composition K-01.1-F1804N04), which showed a 13% increase in power relative to the old composition (with the old composition, the maximum possible power: 7.5 MW, with the new: 8.5 MW).

From the foregoing, can conclude that the maximum increase in reactor power after transforming the layout of the core without violating safety and operating rules is 8.5 MW, which is 41.6% more than the original power.

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Appendix A

```python
# encoding: utf-8
from tkinter.filedialog import *
from tkinter import *
import re


def destroy_r():
    root.destroy()


# ------------------------- Fresh fuel reloading module -------------------------


'''
This module performs the function of replacing any assembly with a fresh one.
Only one assembly can be freshened at a time. Use "PDC" file format.
'''


def window_1():
    def fresh_fuel():
        conc = '\nU235 2.4600E-03\nU238 2.18873E-04\nU234 2.47349E-05\nO16  4.92014E-03\nAL  5.39359E-02\nstop'
        f = 'MATR'
        b = ['    ', '   ', '  ', '  ', '  ']
        c = '     0  -10.0'
        material = entry_1.get()
        material_1 = 910 * (int(material) - 1) + 1
        n = material_1
        q = askopenfilename()
        work_file = open(q).read()
        while n < material_1 + 910:
            n += 1
            m = len(str(n))
            e = int(n) - 1
            a = re.sub(f + b[m - 1] + str(e) + c + '\n(.*?)\nstop', 'MATR' + b[m - 1] + str(e) + c + conc, work_file,
                flags=re.DOTALL)
            work_file = a
        else:
            print('completed')
            qe = asksaveasfilename()
            file_1 = open(qe, 'w')
            file_1.write(work_file)
            file_1.close()

    def destroy_w():

        wind.destroy()

    # ------------------------- Work window -------------------------
    wind = Toplevel(root)
    wind.title('Fresh fuel loading')
    wind.geometry('608x150+510+250')

    frame_1 = Frame(wind, bg='#6666ff', height=150, width=608)
    frame_1.place(x=0, y=0)

    label_1 = Label(frame_1, text='Fresh TVS', bg='#6666ff')
```

```python
    label_1.place(x=250, y=10, height=20, width=100)
    label_11 = Label(frame_1, text='TVS number', bg='#6666ff', anchor='w')
    label_11.place(x=20, y=60, height=20, width=100)

    entry_1 = Entry(frame_1)
    entry_1.place(x=140, y=60, height=20, width=320)

    btn_1 = Button(frame_1, text='Open/Load', background="#555", foreground="#ccc", command=fresh_fuel)
    btn_1.place(x=480, y=60, height=20, width=100)

    but_close = Button(frame_1, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
    but_close.place(x=1, y=119, height=30, width=606)


# ------------------------- Relocation of AF -------------------------

'''
The second module is designed to move fuel assemblies along the reactor core.
Movement is carried out by pair replacement of two assemblies.
Only one assembly pair can be moved at a time.
Use "geom" file name.
'''


def wind_2():
    def changepos():
        TVS_1 = entry_21.get()
        TVS_2 = entry_22.get()
        key = 'LCELL '
        end = 'ENDL'
        test_1 = ['tvs1', 'tvs2', 'tvs3', 'tvs4',
                  'kc11', 'kc31', 'az1', 'kc21',
                  'tvs9', 'tvs10', 'tvs11', 'tvs12',
                  'kc12', 'az2', 'kc32', 'kc22',
                  'tvs17', 'tvs18', 'tvs19', 'tvs20'
                  ]
        test_2 = ['tvs1', 'tvs2', 'tvs3', 'tvs4',
                  'kc11', 'kc31', 'az1', 'kc21',
                  'tvs9', 'tvs10', 'tvs11', 'tvs12',
                  'kc12', 'az2', 'kc32', 'kc22',
                  'tvs17', 'tvs18', 'tvs19', 'tvs20'
                  ]

        of = askopenfilename()
        s = open(of).read()
        box1 = re.findall(key + test_1[int(int(TVS_1) - 1)] + "\n(.*?)\n" + end,
                  s, flags=re.DOTALL)
        box2 = re.findall(key + test_1[int(int(TVS_2) - 1)] + "\n(.*?)\n" + end,
                  s, flags=re.DOTALL)

        zamena1 = re.sub(key + test_1[int(int(TVS_2) - 1)] + '\n(.*?)\n' + end,
                  key + test_1[int(int(TVS_2) - 1)] + '\n' + box1[0] + '\n' + end,
                  s, flags=re.DOTALL)
        zamena2 = re.sub(key + test_1[int(int(TVS_1) - 1)] + '\n(.*?)\n' + end,
                  key + test_1[int(int(TVS_1) - 1)] + '\n' + box2[0] + '\n' + end,
                  zamena1, flags=re.DOTALL)

        sf = asksaveasfilename()
        file_1 = open(sf, 'w')
        file_1.write(zamena2)
        print(zamena2)
```

```python
  def destroy_w():
    wind.destroy()

  # ------------------------- Work window -------------------------
  wind = Toplevel(root)
  wind.title('Relocation of FA')
  wind.geometry('608x150+510+250')

  frame_2 = Frame(wind, bg='#668cff', height=150, width=608)
  frame_2.place(x=0, y=0)

  label_2 = Label(frame_2, text='Changing TVS', bg='#668cff')
  label_2.place(x=250, y=10, height=20, width=100)
  label_21 = Label(frame_2, text='The first TVS', bg='#668cff', anchor='w')
  label_21.place(x=20, y=40, height=20, width=100)
  label_22 = Label(frame_2, text='The second TVS', bg='#668cff', anchor='w')
  label_22.place(x=20, y=80, height=20, width=100)

  entry_21 = Entry(frame_2)
  entry_21.place(x=140, y=40, height=20, width=320)
  entry_22 = Entry(frame_2)
  entry_22.place(x=140, y=80, height=20, width=320)

  btn_2 = Button(frame_2, text='Open/Load', background="#555", foreground="#ccc", command=changepos)
  btn_2.place(x=480, y=60, height=20, width=100)

  btn_close = Button(frame_2, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
  btn_close.place(x=1, y=119, height=30, width=606)

# ------------------------- 235 U concentration -------------------------
'''
The third module calculates the percentage burnout of 235 uranium for each of the 18,200 elements.
'''


def wind_3():
  keyword = "U235"
  sm = 2.21670E-03
  om = 2.4600E-03
  p = 0.09890243902439033
  p_1 = '0.09890'
  of = askopenfilename()
  of_1 = asksaveasfilename()
  of_2 = asksaveasfilename()
  work_file = open(of, 'r')
  sf_1 = open(of_1, 'w')
  sf_2 = open(of_2, 'w')
  # ------------------------- Concentration return block -------------------------
  for line in work_file:
    if keyword in line:
      a = (line.lstrip('U235'))
      b = (a.lstrip())
      sf_1.write(b)
  work_file.close()
  sf_1.close()
  # ------------------------- Burnout calculation block -------------------------
  sf_1 = open(of_1, 'r')

  # ------------------------- Burnout calculation -------------------------
  a = sf_1.readlines()
  for n in range(0, 18200):
```

```python
    c = str(round((1 - float(a[n]) / om), 8))
    m = str((1 - float(a[n]) / om))
    o = n / 130
    b = [' ', ' ', ' ', '  ', '   ']
    if '0.09890243902439033' in m:
      c = '0'
    if all([(n in range(910, 1819)), (n in range(11831, 12739))]):
      c = str(round((1 - float(a[n]) / om), 8))

      # ------------------------- Space alignment of results -------------------------
    if n in range(10000 - 1, 18201):
      x = b[0]
    elif n in range(1000 - 1, 10000):
      x = b[1]
    elif n in range(100 - 1, 1000):
      x = b[2]
    elif n in range(10 - 1, 100):
      x = b[3]
    else:
      x = b[4]

    # ------------------ Printing and Saving of result -----------------
    result = ('MATR:' + str(n + 1) + x + c + '0' + "\n")
    sf_2.write(result)
    print(result, end='')
  sf_1.close()
  sf_2.close()


def destroy_w():
  pass

  '''wind = Toplevel(root)
  wind.title('Concentration')
  wind.geometry('608x150+510+250')

  frame_4 = Frame(wind, bg='#66b3ff', height=150, width=608)
  frame_4.place(x=0, y=0)

  label_4 = Label(frame_4, text='Concetration', bg='#66b3ff')
  label_4.place(x=250, y=10, height=20, width=100)
  label_41 = Label(frame_4, text='Number of TVS', bg='#66b3ff', anchor='w')
  label_41.place(x=20, y=60, height=20, width=100)

  entry_44 = Entry(frame_4)
  entry_44.place(x=140, y=60, height=20, width=320)

  btn_4 = Button(frame_4, text='Open/Load', background="#555", foreground="#ccc", command=conc)
  btn_4.place(x=480, y=60, height=20, width=100)

  btn_close = Button(frame_4, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
  btn_close.place(x=1, y=119, height=30, width=606)'''


# ------------------------- Replacing -------------------------

def wind_4():
  def destroy_w():

    wind.destroy()

  def swap6():
```

```python
    file = open('ex_6.txt', 'r', encoding='utf-8')
    file_read = file.read()
    file.close()
    i = entry_41.get()
    t = (int(i) - 1) * 910 + 1
    for k in range(1821, 2700):

        b = re.sub('put' + str(k) + ' \n', str(t) + '\n', file_read)
        file_read = b
        k += 1
        t += 1
        if k % 130 == 0:
            k = k + 35
    key = 'LCELL '
    end = 'ENDL'
    test_1 = ['tvs1', 'tvs2', 'tvs3', 'tvs4',
            'kc11', 'kc31', 'az1', 'kc21',
            'tvs9', 'tvs10', 'tvs11', 'tvs12',
            'kc12', 'az2', 'kc32', 'kc22',
            'tvs17', 'tvs18', 'tvs19', 'tvs20'
            ]
    of = askopenfilename()
    s = open(of).read()
    c = re.sub(key + test_1[int(int(i) - 1)] + "\n(.*?)\n" + end, key + test_1[int(int(i) - 1)] + '\n' + file_read,
            s, flags=re.DOTALL)
    sf = asksaveasfilename()
    file_1 = open(sf, 'w')
    file_1.write(c)
    file_1.close()

def swap8():
    file = open('ex_8.txt', 'r', encoding='utf-8')
    file_read = file.read()
    file.close()
    i = entry_42.get()
    t = (int(i) - 1) * 910 + 1
    for k in range(1, 910):
        b = re.sub('put' + str(k) + ' \n', str(t) + '\n', file_read)
        file_read = b
        k += 1
        t += 1

    key = 'LCELL '
    end = 'ENDL'
    test_1 = ['tvs1', 'tvs2', 'tvs3', 'tvs4',
            'kc11', 'kc31', 'az1', 'kc21',
            'tvs9', 'tvs10', 'tvs11', 'tvs12',
            'kc12', 'az2', 'kc32', 'kc22',
            'tvs17', 'tvs18', 'tvs19', 'tvs20'
            ]
    of = askopenfilename()
    s = open(of).read()
    c = re.sub(key + test_1[int(int(i) - 1)] + "\n(.*?)\n" + end, key + test_1[int(int(i) - 1)] + '\n' + file_read,
            s, flags=re.DOTALL)
    sf = asksaveasfilename()
    file_1 = open(sf, 'w')
    file_1.write(c)
    file_1.close()

wind = Toplevel(root)
wind.title('Replacing')
wind.geometry('608x150+510+250')
```

```python
    frame_4 = Frame(wind, bg='#668cff', height=150, width=608)
    frame_4.place(x=0, y=0)

    label_4 = Label(frame_4, text='Changing TVS', bg='#668cff')
    label_4.place(x=250, y=10, height=20, width=100)
    label_41 = Label(frame_4, text='From 8 to 6', bg='#668cff', anchor='w')
    label_41.place(x=20, y=40, height=20, width=100)
    label_42 = Label(frame_4, text='From 6 to 8', bg='#668cff', anchor='w')
    label_42.place(x=20, y=80, height=20, width=100)

    entry_41 = Entry(frame_4)
    entry_41.place(x=140, y=40, height=20, width=320)
    entry_42 = Entry(frame_4)
    entry_42.place(x=140, y=80, height=20, width=320)

    btn_41 = Button(frame_4, text='start', background="#555", foreground="#ccc", command=swap6)
    btn_41.place(x=480, y=40, height=20, width=100)
    btn_42 = Button(frame_4, text='start', background="#555", foreground="#ccc", command=swap8)
    btn_42.place(x=480, y=80, height=20, width=100)

    btn_close = Button(frame_4, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
    btn_close.place(x=1, y=119, height=30, width=606)


# ------------------------- Average burnout -------------------------

def wind_5():
    wind = Toplevel(root)
    wind.title('Average burnout')
    wind.geometry('245x447+690+250')

    def destroy_w():

        wind.destroy()

    def average_burnout():
        of = askopenfilename()
        a = open(of).read()
        c = re.findall('U235 (.*?)\n', a)
        j = 0
        g = []
        om = 2.4600E-03
        while j < 18201:
            e = round((1 - float(c[j]) / om), 8)
            b = str(round((1 - float(c[j]) / om), 8)) + '\n'
            g.append(e)
            j += 1
        else:
            e = []
            n = 1
            k = 910
            f = [float(item) for item in g]
            while n < 21:
                o = str(round((sum(f[(n - 1) * 910:n * 909]) / k) * 100, 2)) + '\n'
                o_1 = str((round((sum(f[(n - 1) * 910:n * 909]) / k) * 100, 2))) + '\n'

                n += 1
                e.append(o_1)
            else:
                f = '0.012'
                label_l = Label(wind, text=e[0], background="#555", anchor='s', font='13', fg='#ccc')
```

```python
        label_l.place(x=1, y=51, height=60, width=60)
        label_2 = Label(wind, text=e[1], background="#555", anchor='s', font='13', fg='#ccc')
        label_2.place(x=62, y=51, height=60, width=60)
        label_3 = Label(wind, text=e[2], background="#555", anchor='s', font='13', fg='#ccc')
        label_3.place(x=123, y=51, height=60, width=60)
        label_4 = Label(wind, text=e[3], background="#555", anchor='s', font='13', fg='#ccc')
        label_4.place(x=184, y=51, height=60, width=60)

        label_5 = Label(wind, text=e[4], background="#555", anchor='s', font='13', fg='#ccc')
        label_5.place(x=1, y=112, height=60, width=60)
        label_6 = Label(wind, text=e[5], background="#555", anchor='s', font='13', fg='#ccc')
        label_6.place(x=62, y=112, height=60, width=60)
        label_7 = Label(wind, text=e[6], background="#555", anchor='s', font='13', fg='#ccc')
        label_7.place(x=123, y=112, height=60, width=60)
        label_8 = Label(wind, text=e[7], background="#555", anchor='s', font='13', fg='#ccc')
        label_8.place(x=184, y=112, height=60, width=60)

        label_9 = Label(wind, text=e[8], background="#555", anchor='s', font='13', fg='#ccc')
        label_9.place(x=1, y=173, height=60, width=60)
        label_01 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_01.place(x=62, y=173, height=60, width=60)
        label_02 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_02.place(x=123, y=173, height=60, width=60)
        label_10 = Label(wind, text=e[9], background="#555", anchor='s', font='13', fg='#ccc')
        label_10.place(x=184, y=173, height=60, width=60)

        label_l1 = Label(wind, text=e[10], background="#555", anchor='s', font='13', fg='#ccc')
        label_l1.place(x=1, y=234, height=60, width=60)
        label_03 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_03.place(x=62, y=234, height=60, width=60)
        label_04 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_04.place(x=123, y=234, height=60, width=60)
        label_12 = Label(wind, text=e[11], background="#555", anchor='s', font='13', fg='#ccc')
        label_12.place(x=184, y=234, height=60, width=60)

        label_13 = Label(wind, text=e[12], background="#555", anchor='s', font='13', fg='#ccc')
        label_13.place(x=1, y=295, height=60, width=60)
        label_14 = Label(wind, text=e[13], background="#555", anchor='s', font='13', fg='#ccc')
        label_14.place(x=62, y=295, height=60, width=60)
        label_15 = Label(wind, text=e[14], background="#555", anchor='s', font='13', fg='#ccc')
        label_15.place(x=123, y=295, height=60, width=60)
        label_16 = Label(wind, text=e[15], background="#555", anchor='s', font='13', fg='#ccc')
        label_16.place(x=184, y=295, height=60, width=60)

        label_17 = Label(wind, text=e[16], background="#555", anchor='s', font='13', fg='#ccc')
        label_17.place(x=1, y=356, height=60, width=60)
        label_18 = Label(wind, text=e[17], background="#555", anchor='s', font='13', fg='#ccc')
        label_18.place(x=62, y=356, height=60, width=60)
        label_19 = Label(wind, text=e[18], background="#555", anchor='s', font='13', fg='#ccc')
        label_19.place(x=123, y=356, height=60, width=60)
        label_20 = Label(wind, text=e[19], background="#555", anchor='s', font='13', fg='#ccc')
        label_20.place(x=184, y=356, height=60, width=60)

def save():
    k = 'TVS_1 = ' + e[0] + 'TVS_2 = ' + e[1] + 'TVS_3 = ' + e[2] + 'TVS_4 = ' + e[3] + 'TVS_5 = ' + e[
        4]
    k_1 = 'TVS_6 = ' + e[5] + 'TVS_7 = ' + e[6] + 'TVS_8 = ' + e[7] + 'TVS_9 = ' + e[8] + 'TVS_10 = ' + \
        e[9]
    k_2 = 'TVS_11 = ' + e[10] + 'TVS_12 = ' + e[11] + 'TVS_13 = ' + e[12] + 'TVS_14 = ' + e[
        13] + 'TVS_15 = ' + e[14]
    k_3 = 'TVS_16 = ' + e[15] + 'TVS_17 = ' + e[16] + 'TVS_18 = ' + e[17] + 'TVS_19 = ' + e[
        18] + 'TVS_20 = ' + e[19]
```

```python
        sf = asksaveasfilename()
        file_1 = open(sf, 'w')
        file_1.write(''.join(e))
        file_1.close()

    but_2 = Button(wind, text='Save file', background="#555", foreground="#ccc", command=save)
    but_2.place(x=123, y=1, height=49, width=121)

  but_1 = Button(wind, text='Open file', background="#555", foreground="#ccc", command=average_burnout)
  but_1.place(x=1, y=1, height=49, width=122)

  btn_close = Button(wind, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
  btn_close.place(x=1, y=417, height=30, width=245)


# ------------------------- TVS position -------------------------

def wind_7():
  def destroy_w():

    wind.destroy()

  wind = Toplevel(root)
  wind.title('TVS position')
  wind.geometry('245x447+690+250')

  def tvs_position():

    of = askopenfilename()
    a = open(of).read()
    text = 'top101 5 10 -11 z6        # m='
    c = re.findall(text + '(.*?)' + '\n', a, flags=re.DOTALL)
    e = []
    j = 0
    while j < 20:
      f = str((int(c[j]) - 1) // 910 + 1)
      e.append(f)
      j += 1
    else:

      label_l = Label(wind, text=e[0], background="#555", font='13', fg='#ccc')
      label_l.place(x=1, y=51, height=60, width=60)
      label_2 = Label(wind, text=e[1], background="#555", font='13', fg='#ccc')
      label_2.place(x=62, y=51, height=60, width=60)
      label_3 = Label(wind, text=e[2], background="#555", font='13', fg='#ccc')
      label_3.place(x=123, y=51, height=60, width=60)
      label_4 = Label(wind, text=e[3], background="#555", font='13', fg='#ccc')
      label_4.place(x=184, y=51, height=60, width=60)

      label_5 = Label(wind, text=e[4], background="#555", font='13', fg='#ccc')
      label_5.place(x=1, y=112, height=60, width=60)
      label_6 = Label(wind, text=e[8], background="#555", font='13', fg='#ccc')
      label_6.place(x=62, y=112, height=60, width=60)
      label_7 = Label(wind, text=e[10], background="#555", font='13', fg='#ccc')
      label_7.place(x=123, y=112, height=60, width=60)
      label_8 = Label(wind, text=e[6], background="#555", font='13', fg='#ccc')
      label_8.place(x=184, y=112, height=60, width=60)

      label_9 = Label(wind, text=e[12], background="#555", font='13', fg='#ccc')
      label_9.place(x=1, y=173, height=60, width=60)
      label_01 = Label(wind, text='', background="#555", font='13', fg='#ccc')
      label_01.place(x=62, y=173, height=60, width=60)
```

```python
        label_02 = Label(wind, text='', background="#555", font='13', fg='#ccc')
        label_02.place(x=123, y=173, height=60, width=60)
        label_10 = Label(wind, text=e[13], background="#555", font='13', fg='#ccc')
        label_10.place(x=184, y=173, height=60, width=60)

        label_l1 = Label(wind, text=e[14], background="#555", font='13', fg='#ccc')
        label_l1.place(x=1, y=234, height=60, width=60)
        label_03 = Label(wind, text='', background="#555", font='13', fg='#ccc')
        label_03.place(x=62, y=234, height=60, width=60)
        label_04 = Label(wind, text='', background="#555", font='13', fg='#ccc')
        label_04.place(x=123, y=234, height=60, width=60)
        label_12 = Label(wind, text=e[15], background="#555", font='13', fg='#ccc')
        label_12.place(x=184, y=234, height=60, width=60)

        label_13 = Label(wind, text=e[5], background="#555", font='13', fg='#ccc')
        label_13.place(x=1, y=295, height=60, width=60)
        label_14 = Label(wind, text=e[11], background="#555", font='13', fg='#ccc')
        label_14.place(x=62, y=295, height=60, width=60)
        label_15 = Label(wind, text=e[9], background="#555", font='13', fg='#ccc')
        label_15.place(x=123, y=295, height=60, width=60)
        label_16 = Label(wind, text=e[7], background="#555", font='13', fg='#ccc')
        label_16.place(x=184, y=295, height=60, width=60)

        label_17 = Label(wind, text=e[16], background="#555", font='13', fg='#ccc')
        label_17.place(x=1, y=356, height=60, width=60)
        label_18 = Label(wind, text=e[17], background="#555", font='13', fg='#ccc')
        label_18.place(x=62, y=356, height=60, width=60)
        label_19 = Label(wind, text=e[18], background="#555", font='13', fg='#ccc')
        label_19.place(x=123, y=356, height=60, width=60)
        label_20 = Label(wind, text=e[19], background="#555", font='13', fg='#ccc')
        label_20.place(x=184, y=356, height=60, width=60)

    def save():
        k = 'TVS_1 = ' + e[0] + '\n' + 'TVS_2 = ' + e[1] + '\n' + 'TVS_3 = ' + e[2] + '\n' + 'TVS_4 = ' + e[
            3] + '\n' + 'TVS_5 = ' + e[4] + '\n'
        k_1 = 'TVS_6 = ' + e[8] + '\n' + 'TVS_7 = ' + e[10] + '\n' + 'TVS_8 = ' + e[6] + '\n' + 'TVS_9 = ' + e[
            12] + '\n' + 'TVS_10 = ' + e[13] + '\n'
        k_2 = 'TVS_11 = ' + e[14] + '\n' + 'TVS_12 = ' + e[15] + '\n' + 'TVS_13 = ' + e[5] + '\n' + 'TVS_14 = ' + e[
            11] + '\n' + 'TVS_15 = ' + e[9] + '\n'
        k_3 = 'TVS_16 = ' + e[7] + '\n' + 'TVS_17 = ' + e[16] + '\n' + 'TVS_18 = ' + e[17] + '\n' + 'TVS_19 = ' + e[
            18] + '\n' + 'TVS_20 = ' + e[19] + '\n'
        sf = asksaveasfilename()
        file_1 = open(sf, 'w')
        file_1.write('\n'.join(e))
        file_1.close()

    but_2 = Button(wind, text='Save file', background="#555", foreground="#ccc", command=save)
    but_2.place(x=123, y=1, height=49, width=121)

    but_1 = Button(wind, text='Open file', background="#555", foreground="#ccc", command=tvs_position)
    but_1.place(x=1, y=1, height=49, width=122)

    btn_close = Button(wind, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
    btn_close.place(x=1, y=417, height=30, width=245)


# ------------------------- Non-uniform coefficient -------------------------

def wind_8():
    wind = Toplevel(root)
    wind.title('Non-uniform coefficient')
    wind.geometry('245x447+690+250')
```

```python
def destroy_w():

    wind.destroy()

def k_uniform():
    import re

    # Набор констант
    pw = 6000
    mm = 10000
    p = 6

    of = askopenfilename()
    file = open(of).read()

    b = '    Material       Mean       StdDev'

    box1 = re.findall(b, file, flags=re.DOTALL)
    box2 = re.findall(b + '\n(.*?)\n' + '\n', file, flags=re.DOTALL)  # Коробка с CP всех нуклидов и реакций
    box3 = re.findall('\w  ' + '(.*?)' + '  ', box2[6], flags=re.DOTALL)  # Коробка с CP N: U235 R: 18 E: 0.0
    box9 = re.findall('\w  ' + '(.*?)' + '  ', box2[7], flags=re.DOTALL)  # Коробка с CP N: U235 R: 18 E: 6.25

    box6 = [float(o) for o in box3]  # Перевод текста в дробное
    box10 = [float(o) for o in box9]  # Перевод текста в дробное

    text_file_2 = open("s.txt", "r")  # Открытие документа с площадьми ячеек
    box5 = text_file_2.readlines()  # Запись площадей построчно
    text_file_2.close()

    box7 = [float(u) for u in box5]

    sum_1 = [box10 + box6 for box10, box6 in zip(box10, box6)]  # Коробка суммы CP энергий 0 и 6.25
    density = sum(sum_1)  # Плотность CP
    q = [float(sum_1) / float(box7) for sum_1, box7 in zip(sum_1, box7)]  # RV/S
    q_1 = [round((i * pw / density * mm), 2) for i in q]  # RV*10000*P/(density*S); ЭВ с пов-ти kW/m^2;
Список ЭВ

    tvs = [i for i in range(1, 21)]
    tvs_8 = [1, 2, 4, 9, 10, 12, 17, 18, 19, 20]
    kv_ = []
    kr_ = []
    for e in tvs:
        if e in tvs_8:
            new_list = []

            m = (e - 1) * 7
            g = m + 7

            while m < g:
                part_max = max(q_1[130 * m:130 * (m + 1)])  # Максиамлное значение в слое
                part_avr = sum(q_1[130 * m:130 * (m + 1)]) / 128  # Среднее значение в слое
                m += 1
                new_list.append(part_max / part_avr)
            else:
                print(new_list)
                print(max(new_list))
                print(sum(new_list[0:7]) / 7)
                k = (max(new_list)) / (sum(new_list[0:7]) / 7)
                kv_.append(k)

        else:
```

```python
        new_list = []

        m = (e - 1) * 7
        g = m + 7

        while m < g:
            part_max = max(q_1[130 * m:130 * (m + 1)])  # Максиамлное значение в слое
            part_avr = sum(q_1[130 * m:130 * (m + 1)]) / 96  # Среднее значение в слое
            m += 1
            new_list.append(part_max / part_avr)
        else:
            print(list)
            print(max(new_list))
            print(sum(list[0:7]) / 7)
            k = (max(new_list)) / (sum(list[0:7]) / 7)
            kv_.append(k)

for x in tvs:
    if x in tvs_8:
        kk_ = []  # Бокс с неравномернотстью ( пустая)
        ttt = [u for u in range(0, 8)]
        nst = [910 * (x - 1) + 16 * y for y in ttt]  # Бокс с номерами начала твэл (ннт) в ТВС
        print('-------------------------- TVS: ' + str(x))
        # Расчет ведется аналогично как для твел, перебирается бокс ннт в ТВС
        for i in nst:
            end = i + 130 * 6 + 1
            rew = []
            lew = []

            while i < end:
                main_sum = sum(q_1[i:i + 16])
                le = max(q_1[i:i + 16])
                lew.append(le)
                rew.append(main_sum)
                i = i + 130
            else:
                print('\n' + '-------------------------- ' + str(i - 910) + '\n')
                print(lew)
                print(rew)
                print('max = ' + str(max(lew)))
                print('avr = ' + str(sum(rew) / 128))
                k = (max(lew)) / (sum(rew) / 128)
                kk_.append(k)
                print('k = ' + str((max(lew)) / (sum(rew) / 128)))
        avr_k = sum(kk_) / 8
        kr_.append(avr_k)
        print('----------------- неравномерности ТВС №: ' + str(x) + '\n' + str(kk_) + '\n' + 'avr K = ' + str(
            sum(kk_) / 8) + "\n")
    else:
        kk_ = []  # Бокс с неравномернотстью ( пустая)
        ttt = [u for u in range(0, 6)]
        nst = [910 * (x - 1) + 16 * y for y in ttt]  # Бокс с номерами начала твэл (ннт) в ТВС
        print('-------------------------- TVS: ' + str(x))
        # Расчет ведется аналогично как для твел, перебирается бокс ннт в ТВС
        for i in nst:
            end = i + 130 * 6 + 1
            rew = []
            lew = []

            while i < end:
                main_sum = sum(q_1[i:i + 16])
                le = max(q_1[i:i + 16])
```

```python
                lew.append(le)
                rew.append(main_sum)
                i = i + 130
            else:
                print('\n' + '-------------------------- ' + str(i - 910) + '\n')
                print(lew)
                print(rew)
                print('max = ' + str(max(lew)))
                print('avr = ' + str(sum(rew) / 96))
                k = (max(lew)) / (sum(rew) / 96)
                kk_.append(k)
                print('k = ' + str((max(lew)) / (sum(rew) / 96)))
        avr_k = sum(kk_) / 6
        kr_.append(avr_k)


kr_f = [float(i) for i in kr_]
kv_f = [float(i) for i in kv_]
kt_f = [round((kr_f * kv_f), 2) for kv_f, kr_f in zip(kr_f, kv_f)]
kts_f = [str(i) for i in kt_f]


label_l = Label(wind, text=kt_f[0], background="#555", font='13', fg='#ccc')
label_l.place(x=1, y=51, height=60, width=60)
label_2 = Label(wind, text=kt_f[1], background="#555", font='13', fg='#ccc')
label_2.place(x=62, y=51, height=60, width=60)
label_3 = Label(wind, text=kt_f[2], background="#555", font='13', fg='#ccc')
label_3.place(x=123, y=51, height=60, width=60)
label_4 = Label(wind, text=kt_f[3], background="#555", font='13', fg='#ccc')
label_4.place(x=184, y=51, height=60, width=60)

label_5 = Label(wind, text=kt_f[4], background="#555", font='13', fg='#ccc')
label_5.place(x=1, y=112, height=60, width=60)
label_6 = Label(wind, text=kt_f[5], background="#555", font='13', fg='#ccc')
label_6.place(x=62, y=112, height=60, width=60)
label_7 = Label(wind, text=kt_f[6], background="#555", font='13', fg='#ccc')
label_7.place(x=123, y=112, height=60, width=60)
label_8 = Label(wind, text=kt_f[7], background="#555", font='13', fg='#ccc')
label_8.place(x=184, y=112, height=60, width=60)

label_9 = Label(wind, text=kt_f[8], background="#555", font='13', fg='#ccc')
label_9.place(x=1, y=173, height=60, width=60)
label_01 = Label(wind, text='', background="#555", font='13', fg='#ccc')
label_01.place(x=62, y=173, height=60, width=60)
label_02 = Label(wind, text='', background="#555", font='13', fg='#ccc')
label_02.place(x=123, y=173, height=60, width=60)
label_10 = Label(wind, text=kt_f[9], background="#555", font='13', fg='#ccc')
label_10.place(x=184, y=173, height=60, width=60)

label_l1 = Label(wind, text=kt_f[10], background="#555", font='13', fg='#ccc')
label_l1.place(x=1, y=234, height=60, width=60)
label_03 = Label(wind, text='', background="#555", font='13', fg='#ccc')
label_03.place(x=62, y=234, height=60, width=60)
label_04 = Label(wind, text='', background="#555", font='13', fg='#ccc')
label_04.place(x=123, y=234, height=60, width=60)
label_12 = Label(wind, text=kt_f[11], background="#555", font='13', fg='#ccc')
label_12.place(x=184, y=234, height=60, width=60)

label_13 = Label(wind, text=kt_f[12], background="#555", font='13', fg='#ccc')
label_13.place(x=1, y=295, height=60, width=60)
label_14 = Label(wind, text=kt_f[13], background="#555", font='13', fg='#ccc')
label_14.place(x=62, y=295, height=60, width=60)
label_15 = Label(wind, text=kt_f[14], background="#555", font='13', fg='#ccc')
label_15.place(x=123, y=295, height=60, width=60)
```

```python
        label_16 = Label(wind, text=kt_f[15], background="#555", font='13', fg='#ccc')
        label_16.place(x=184, y=295, height=60, width=60)

        label_17 = Label(wind, text=kt_f[16], background="#555", font='13', fg='#ccc')
        label_17.place(x=1, y=356, height=60, width=60)
        label_18 = Label(wind, text=kt_f[17], background="#555", font='13', fg='#ccc')
        label_18.place(x=62, y=356, height=60, width=60)
        label_19 = Label(wind, text=kt_f[18], background="#555", font='13', fg='#ccc')
        label_19.place(x=123, y=356, height=60, width=60)
        label_20 = Label(wind, text=kt_f[19], background="#555", font='13', fg='#ccc')
        label_20.place(x=184, y=356, height=60, width=60)

        def save():
            k_0 = 'TVS_1 = ' + kts_f[0] + '\n' + 'TVS_2 = ' + kts_f[1] + '\n' + 'TVS_3 = ' + kts_f[
                2] + '\n' + 'TVS_4 = ' + kts_f[3] + '\n' + 'TVS_5 = ' + kts_f[4] + '\n'
            k_1 = 'TVS_6 = ' + kts_f[8] + '\n' + 'TVS_7 = ' + kts_f[10] + '\n' + 'TVS_8 = ' + kts_f[
                6] + '\n' + 'TVS_9 = ' + kts_f[12] + '\n' + 'TVS_10 = ' + kts_f[13] + '\n'
            k_2 = 'TVS_11 = ' + kts_f[14] + '\n' + 'TVS_12 = ' + kts_f[15] + '\n' + 'TVS_13 = ' + kts_f[
                5] + '\n' + 'TVS_14 = ' + kts_f[11] + '\n' + 'TVS_15 = ' + kts_f[9] + '\n'
            k_3 = 'TVS_16 = ' + kts_f[7] + '\n' + 'TVS_17 = ' + kts_f[16] + '\n' + 'TVS_18 = ' + kts_f[
                17] + '\n' + 'TVS_19 = ' + kts_f[18] + '\n' + 'TVS_20 = ' + kts_f[19] + '\n'
            sf = asksaveasfilename()
            file_1 = open(sf, 'w')
            file_1.write(k_0)
            file_1.write(k_1)
            file_1.write(k_2)
            file_1.write(k_3)
            file_1.close()

        but_two = Button(wind, text='Save file', background="#555", foreground="#ccc", command=save)
        but_two.place(x=123, y=1, height=49, width=121)

    but_one = Button(wind, text='Open file', background="#555", foreground="#ccc", command=k_uniform)
    but_one.place(x=1, y=1, height=49, width=122)

    but_close = Button(wind, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
    but_close.place(x=1, y=417, height=30, width=245)


# ------------------------- Speed of reaction -------------------------

def wind_9():
    wind = Toplevel(root)
    wind.title('Speed of reaction')
    wind.geometry('245x447+690+250')

    def destroy_w():

        wind.destroy()

    def sor():
        of = askopenfilename()
        file = open(of).read()
        a = '\n'
        b = '   Material      Mean      StdDev'
        box2 = re.findall(b + '\n(.*?)\n' + a, file, flags=re.DOTALL)  # Коробка с СР всех нуклидов и реакций
        box3 = re.findall('\w  ' + '(.*?)' + '  ', box2[6], flags=re.DOTALL)  # Коробка с СР N: U235 R: 18 E: 0.0
        box9 = re.findall('\w  ' + '(.*?)' + '  ', box2[7], flags=re.DOTALL)  # Коробка с СР N: U235 R: 18 E: 6.25

        # Коробка с СК

        box6 = [float(o) for o in box3]  # Перевод текста в дробное
```

```python
    box10 = [float(o) for o in box9]  # Перевод текста в дробное
    sum_1 = [box10 + box6 for box10, box6 in zip(box10, box6)]  # Коробка суммы СР энергий 0 и 6.25
    text_file_2 = open("s.txt", "r")  # Открытие документа с площадьми ячеек
    box5 = text_file_2.readlines()  # Запись площадей построчно
    text_file_2.close()
    mm = 10000
    pw = 6000
    p = 6

    box7 = [float(u) for u in box5]  # Коробка с площадьми в дробном виде

    density = sum(sum_1)  # Плотность СР
    q = [float(sum_1) / float(box7) for sum_1, box7 in zip(sum_1, box7)]  # RV/S
    q_1 = [round(i * pw / density * mm, 2) for i in q]  # RV*10000*P/(density*S); ЭВ с поверхности kW/m^2;
Список ЭВ
    data = [i for i in q_1]  # Data of EE
    n = 1
    e = []
    saving_list = []
    k = 910
    while n < 21:
        o = str(round((max(data[(n - 1) * 910:n * 909])), 2))
        o_1 = str(round(max(data[(n - 1) * 910:n * 909]), 0))

        n += 1
        e.append(o_1)
        saving_list.append(o)
    else:
        f = '0.012'
        label_l = Label(wind, text=e[0], background="#555", anchor='s', font='13', fg='#ccc')
        label_l.place(x=1, y=51, height=60, width=60)
        label_2 = Label(wind, text=e[1], background="#555", anchor='s', font='13', fg='#ccc')
        label_2.place(x=62, y=51, height=60, width=60)
        label_3 = Label(wind, text=e[2], background="#555", anchor='s', font='13', fg='#ccc')
        label_3.place(x=123, y=51, height=60, width=60)
        label_4 = Label(wind, text=e[3], background="#555", anchor='s', font='13', fg='#ccc')
        label_4.place(x=184, y=51, height=60, width=60)

        label_5 = Label(wind, text=e[4], background="#555", anchor='s', font='13', fg='#ccc')
        label_5.place(x=1, y=112, height=60, width=60)
        label_6 = Label(wind, text=e[5], background="#555", anchor='s', font='13', fg='#ccc')
        label_6.place(x=62, y=112, height=60, width=60)
        label_7 = Label(wind, text=e[6], background="#555", anchor='s', font='13', fg='#ccc')
        label_7.place(x=123, y=112, height=60, width=60)
        label_8 = Label(wind, text=e[7], background="#555", anchor='s', font='13', fg='#ccc')
        label_8.place(x=184, y=112, height=60, width=60)

        label_9 = Label(wind, text=e[8], background="#555", anchor='s', font='13', fg='#ccc')
        label_9.place(x=1, y=173, height=60, width=60)
        label_01 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_01.place(x=62, y=173, height=60, width=60)
        label_02 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_02.place(x=123, y=173, height=60, width=60)
        label_10 = Label(wind, text=e[9], background="#555", anchor='s', font='13', fg='#ccc')
        label_10.place(x=184, y=173, height=60, width=60)

        label_l1 = Label(wind, text=e[10], background="#555", anchor='s', font='13', fg='#ccc')
        label_l1.place(x=1, y=234, height=60, width=60)
        label_03 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_03.place(x=62, y=234, height=60, width=60)
        label_04 = Label(wind, text='', background="#555", anchor='s', font='13', fg='#ccc')
        label_04.place(x=123, y=234, height=60, width=60)
```

```python
        label_12 = Label(wind, text=e[11], background="#555", anchor='s', font='13', fg='#ccc')
        label_12.place(x=184, y=234, height=60, width=60)

        label_13 = Label(wind, text=e[12], background="#555", anchor='s', font='13', fg='#ccc')
        label_13.place(x=1, y=295, height=60, width=60)
        label_14 = Label(wind, text=e[13], background="#555", anchor='s', font='13', fg='#ccc')
        label_14.place(x=62, y=295, height=60, width=60)
        label_15 = Label(wind, text=e[14], background="#555", anchor='s', font='13', fg='#ccc')
        label_15.place(x=123, y=295, height=60, width=60)
        label_16 = Label(wind, text=e[15], background="#555", anchor='s', font='13', fg='#ccc')
        label_16.place(x=184, y=295, height=60, width=60)

        label_17 = Label(wind, text=e[16], background="#555", anchor='s', font='13', fg='#ccc')
        label_17.place(x=1, y=356, height=60, width=60)
        label_18 = Label(wind, text=e[17], background="#555", anchor='s', font='13', fg='#ccc')
        label_18.place(x=62, y=356, height=60, width=60)
        label_19 = Label(wind, text=e[18], background="#555", anchor='s', font='13', fg='#ccc')
        label_19.place(x=123, y=356, height=60, width=60)
        label_20 = Label(wind, text=e[19], background="#555", anchor='s', font='13', fg='#ccc')
        label_20.place(x=184, y=356, height=60, width=60)

    def save():
        """
        k = 'TVS_1 = ' + e[0] + 'TVS_2 = ' + e[1] + 'TVS_3 = ' + e[2] + 'TVS_4 = ' + e[3] + 'TVS_5 = ' + e[
          4]
        k_1 = 'TVS_6 = ' + e[5] + 'TVS_7 = ' + e[6] + 'TVS_8 = ' + e[7] + 'TVS_9 = ' + e[8] + 'TVS_10 = ' + \
          e[9]
        k_2 = 'TVS_11 = ' + e[10] + 'TVS_12 = ' + e[11] + 'TVS_13 = ' + e[12] + 'TVS_14 = ' + e[
          13] + 'TVS_15 = ' + e[14]
        k_3 = 'TVS_16 = ' + e[15] + 'TVS_17 = ' + e[16] + 'TVS_18 = ' + e[17] + 'TVS_19 = ' + e[
          18] + 'TVS_20 = ' + e[19]
        """
        sf = asksaveasfilename()
        file_1 = open(sf, 'w')
        file_1.write('\n'.join(saving_list))
        file_1.close()

    but_2 = Button(wind, text='Save file', background="#555", foreground="#ccc", command=save)
    but_2.place(x=123, y=1, height=49, width=121)

  but_1 = Button(wind, text='Open file', background="#555", foreground="#ccc", command=sor)
  but_1.place(x=1, y=1, height=49, width=122)

  btn_close = Button(wind, text='CLOSE', background="#555", foreground="#ccc", command=destroy_w)
  btn_close.place(x=1, y=417, height=30, width=245)

# ---------------------------------------------Main window---------------------------------------------


root = Tk()
root.title('SMAC 3.0')
root.geometry('608x232+510+250')

but_1 = Button(root, text='Fresh fuel loading', background="#555", foreground="#ccc", command=window_1)
but_1.place(x=1, y=1, height=100, width=150)

but_2 = Button(root, text='Relocation of FA', background="#555", foreground="#ccc", command=wind_2)
but_2.place(x=153, y=1, height=100, width=150)

but_3 = Button(root, text='U235 Concentration', background="#555", foreground="#ccc", command=wind_3)
but_3.place(x=305, y=1, height=100, width=150)
```

```python
but_4 = Button(root, text='Replacing', background="#555", foreground="#ccc", command=wind_4)
but_4.place(x=457, y=1, height=100, width=150)

but_5 = Button(root, text='Average burnout', background="#555", foreground="#ccc", command=wind_5)
but_5.place(x=1, y=102, height=100, width=150)

but_7 = Button(root, text='TVS positions', background="#555", foreground="#ccc", command=wind_7)
but_7.place(x=153, y=102, height=100, width=150)

but_8 = Button(root, text='Non-uniform coefficient', background="#555", foreground="#ccc",
command=wind_8)
but_8.place(x=305, y=102, height=100, width=150)

but_9 = Button(root, text='Speed of reaction', background="#555", foreground="#ccc", command=wind_9)
but_9.place(x=457, y=102, height=100, width=150)

btn_close = Button(root, text='CLOSE', background="#555", foreground="#ccc", command=destroy_r)
btn_close.place(x=1, y=203, height=30, width=606)

root.mainloop()
```