TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

The Ministry of Science and Higher Education of the Russian Federation
Federal state autonomous educational institution of higher education
"National Research Tomsk Polytechnic University"

School of Energy and Power Engineering
Major (MEP) 14.05.02 «Nuclear power plants: design, operation and engineering / Атомные станции: проектирование, эксплуатация и инжиниринг»
MEP/MPEP Design and operation of nuclear power plants
Department The Butakov Research Center

FINAL QUALIFICATION WORK OF A SPECIALIST

Topic
Design a nuclear power plant with a VVER-type reactor with an electrical power of 1000 MW

UDC _ 621.311.25:621.039.52.002.5____

Student

Group	Full name	Signature	Date
507I	Abdelal Mostafa Mohamed Mohamed Elwan		

FQW Supervisor

Position	Full name	Academic degree, title	Signature	Date
Associate Professor of The Butakov Research Center	V. E. Gubin	PhD		

CONSULTANTS ON THE SECTIONS:

On the section "Financial management, resource efficiency and resource conservation"

Position	Full name	Academic degree, title	Signature	Date
Associate Professor of DSSH SCEE	E.V. Menshikova	Cand. Philosoph. Sc.		

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Head of MEP, position	Full name	Academic degree, title	Signature	Date
Associate Professor of The Butakov Research Center	A.V. Zenkov	Cand. Tech. Sc.		

Tomsk – 2023

PLANNED RESULTS OF THE MASTERING OF MEP
Planned results of training on the educational program
Design and operation of nuclear power plants

Competence code	Competence name
General cultural competencies	
UK(U)-1	Able to carry out a critical analysis of problem situations based on a systematic approach, develop an action strategy
UK(U)-2	Able to manage a project at all stages of its life cycle
UK(U)-3	Able to organize and manage the work of the team, developing a team strategy to achieve the goal
UK(U)-4	Able to apply modern communication technologies, including in foreign language(s), for academic and professional interaction
UK(U)-5	Able to analyze and take into account the diversity of cultures in the process of intercultural interaction
UK(U)-6	Able to identify and implement the priorities of their own activities and ways to improve them based on self-assessment and lifelong learning
UK(U)-7	Able to maintain the proper level of physical fitness to ensure full-fledged social and professional activities
UK(U)-8	Able to create and maintain safe living conditions, including in case of emergencies
General professional competencies	
OPK(U)-1	The ability to solve the problems of professional activity on the basis of information and bibliographic culture using information and communication technologies and taking into account the basic requirements of information security
OPK(U)-2	Willingness to communicate in oral and written forms in Russian and foreign languages to solve the problems of professional activity
OPK(U)-3	Willingness to lead a team in the field of their professional activity, tolerantly perceiving social, ethnic, confessional and cultural differences
Professional competencies	
PK(U)-1	willingness to use scientific and technical information, domestic and foreign experience in the design and operation of nuclear power plants
PK(U)-2	the ability to carry out mathematical modeling of processes and objects based on standard packages of computer-aided design and research
PK(U)-3	readiness to conduct research and participate in testing of the main equipment of nuclear power plants and nuclear power plants in the process of development, creation, installation, commissioning and operation
PK(U)-4	willingness to use technical means to measure the main parameters of research objects, to prepare data for compiling reviews, reports and scientific publications
PK(U)-5	the ability to draw up a report on the completed task, readiness to participate in the implementation of the results of research and development in the field of design and operation of nuclear power plants
PK(U)-6	possession of the basics of calculating the strength of structural elements, mechanisms and machines, approaches to the reasonable choice of the method of processing and connecting elements of power equipment
PK(U)-7	the ability to reasonably choose the means of measuring thermophysical parameters, to evaluate the errors of measurement results

PK(U)-8	the ability to analyze and assess the degree of environmental hazard of human production activities at the stages of research, design, production and operation of technical facilities, to master the basic methods of protecting production personnel and the public from the possible consequences of accidents, catastrophes, natural disasters
PK(U)-9	the ability to formulate project goals, choose criteria and indicators, identify priorities for solving problems
PK(U)-10	readiness to develop designs for units and elements of apparatus and systems in accordance with the terms of reference using design automation tools, for use in the development of technical projects of new information technologies
PK(U)-11	readiness for the development of design and working technical documentation, for the execution of completed design work in the field of designing nuclear power plants
PK(U)-12	readiness to participate in the design of the main equipment, control and management systems of nuclear power plants, taking into account environmental requirements and safe operation
PK(U)-13	readiness to conduct a preliminary feasibility study of design calculations in the field of designing nuclear power plants
PK(U)-14	willingness to prepare initial data for the selection and justification of scientific, technical and organizational solutions based on an economic analysis of existing and projected
PK(U)-15	the ability to use information technology in the development of new installations, materials, devices and systems, the willingness to collect, analyze and prepare initial data for information systems of nuclear power plants and their components
PK(U)-16	the ability to analyze neutron-physical, technological processes and algorithms for control, management and protection of nuclear power plants in order to ensure their efficient and safe operation
PK(U)-17	the ability to carry out neutron-physical and thermal-hydraulic calculations of nuclear reactors in stationary and non-stationary modes of operation
PK(U)-18	the ability to assess nuclear and radiation safety in the operation of nuclear power plants, as well as in the management of nuclear fuel and other waste
PK(U)-19	readiness to use means of automated control, protection and control of technological processes
PK(U)-20	the ability to demonstrate the basics of ensuring optimal operating modes of a nuclear reactor, thermal mechanical equipment and the NPP power unit as a whole during start-up, shutdown, operation at power and transition from one power level to another in compliance with safety requirements
PK(U)-21	the ability to analyze the technologies of installation, repair and dismantling of NPP (and NPP) equipment in relation to the conditions of construction, operation and decommissioning of NPP power units
PK(U)-22	readiness to organize workplaces, their technical equipment, placement of technological equipment
PK(U)-23	readiness to control compliance with technological discipline and maintenance of technological equipment
PK(U)-24	the ability to draw up technical documentation (work schedules, instructions, plans, estimates, applications for materials, equipment), as well as established reporting in approved forms
PK(U)-25	readiness to perform work on standardization and preparation for certification of technical means, systems, processes, equipment and materials
PK(U)-26	readiness to organize the work of small teams of performers, planning the work of personnel and payroll funds
PK(U)-27	the ability to organize an examination of technical documentation, readiness to investigate the causes of equipment malfunctions, take measures to eliminate them
PK(U)-28	the ability to analyze production and non-production costs to ensure the required product quality
PK(U)-29	the ability to carry out and analyze research and technological activities as an object of management
Professionally specialized competencies	

PSK(U)-1.1	the ability to draw up thermal schemes and mathematical models of processes and apparatus for converting nuclear fuel energy into thermal and electrical energy
PSK(U)-1.2	readiness to conduct physical experiments at the stages of the physical and power start-up of the power unit in order to determine the neutron-physical parameters of the reactor plant and the plant as a whole
PSK(U)-1.3	the ability to use mathematical models and software systems for the numerical analysis of the entire set of processes in the nuclear power and thermal mechanical equipment of the NPP
PSK(U)-1.4	the ability to perform thermal -hydraulic , neutron-physical and strength calculations of units and elements of the designed equipment using modern tools
PSK(U)-1.5	readiness to develop designs for NPP and NPP elements and systems in order to modernize them and improve technical and economic indicators using modern design tools and new information technologies
PSK(U)-1.6	readiness to conduct a preliminary technical and economic analysis of the developments of current and prospective nuclear power plants and nuclear power plants
PSK(U)-1.7	the ability to prepare initial data for the calculation of thermal schemes of various types of nuclear power plants and nuclear power plants
PSK(U)-1.8	the ability to carry out draft and pre- draft design and construction of elements and systems of nuclear power plants, taking into account the principles and means of ensuring nuclear and radiation safety
PSK(U)-1.9	the ability to conduct an examination of the technical documentation of the main NPP equipment and study the causes of malfunctions of process equipment, to find ways to eliminate them
PSK(U)-1.10	the ability to formulate initial data, select and justify scientific, technical and organizational solutions in the field of designing elements and systems of nuclear power plants
PSK(U)-1.11	the ability to perform work on standardization and preparation for certification of technical means, systems and equipment of nuclear power plants
PSK(U)-1.12	the ability to put into practice the principles of organization of NPP operation, as well as to understand the fundamental features of stationary and transient modes of reactor plants and power units during normal operation, during its violations, during repairs and refueling
PSK(U)-1.13	the ability to understand the reasons for the restrictions imposed on the modes associated with safety requirements and design features of the main equipment and the capabilities of NPP process flow diagrams
PSK(U)-1.14	the ability to perform typical operations to control the reactor and power unit on the conceptual simulator
PSK(U)-1.15	willingness to apply the principles of ensuring optimal operating modes of a nuclear reactor, thermal mechanical equipment and the power unit as a whole under various NPP operating modes in compliance with safety requirements

TOMSK POLYTECHNIC UNIVERSITY — ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

School of Energy and Power Engineering
Major (MEP) 14.05.02 «Nuclear power plants: design, operation and engineering / Атомные станции: проектирование, эксплуатация и инжиниринг»
Department The Butakov Research Center

APPROVE:
Head of MEP
_____ _______ A.V. Zenkov
(Signature) (Date) (Full name)

ASSIGNMENT
for the final qualification work

Student:

Group	Full name
507I	Abdelal Mostafa Mohamed Mohamed Elwan

Topic of the work:

Design a nuclear power plant with a VVER-type reactor with an electrical power of 1000 MW	
Approved by the director's order (date, number)	

The deadline for the completion of the work by the student:	15.01.2023

TECHNICAL ASSIGNMENT:

Initial data *(the name of the object of research or design; performance or load; operating mode (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements for the operation (operation) of the object or product in terms of operational safety, environmental impact, energy consumption; economic analysis, etc.)*	Design a fully functional nuclear power plant with a VVER-type reactor with an electrical power of 1000 MW
List of sections of the explanatory note subject to research, design and development *(analytical review of literary sources in order to clarify the achievements of world science and technology in the field under consideration; statement of the task of research, design, construction; content of the procedure of research, design, construction; discussion of the results of the work performed; name of additional sections to be developed; conclusion on the work)*	1. Active safety system from modern VVER reactor 2. Design calculation of nuclear power reactor; 3. Design Calculation of a Saturated Steam Generator 4. Design NPP with WWER-1000 Type Reactor 5. Design calculation of the turbine condenser
List of graphic material *(with the exact indication of the required drawings)*	1. NPP Scheme 2. Horizinatl steam generator 3. PNR VVER- 1000

Consultants on the sections of the final qualifying work
(with the indication of sections)

Section	Consultant
Financial management, resource efficiency and resource conservation	Associate Professor of DSSH SCEE E.V. Menshikova
Social responsibility	Associate Professor of DGTS SCEE O.A. Antonevich

Date of issue of the assignment for the final qualification work in accordance with the calendar academic schedule	15.06.2022

The task was issued by the supervisor:

Position	Full name	Academic degree	Signature	Date
Associate Professor of The Butakov Research Center	V.E. Gubin	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
507I	Abdelal Mostafa Mohamed Mohamed Elwan		15.06.2022

TOMSK POLYTECHNIC UNIVERSITY / ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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Degree Specialist
Department The Butakov Research Center
Execution period (Fall Semester 2022/2023)

CALENDAR RATING-PLAN
of the final qualification work

Student:

Group	Full name
507I	Abdelal Mostafa Mohamed Mohamed Elwan

Topic of the work:

Design a NPP power unit with VVER-reactor and an electric power of 1000 MW

The deadline for the completion of the work by the student:	15.01.2023

Date of control	Title of the section (module) / type of work (research)	Maximum score of the section (module)
15.09.22 - 30.09 .22	Literature review	5
08.10.22 – 08.10.22	Designing NPP	55
23.10.22 – 01.11.22	Designing SG	25
02.10.22 – 05.11.22	Designing PNR	25
07.11.22 – 11.11.22	Designing part of the Condenser	20
12.11.22 – 29.11.22	Social responsibility	5
01.12.22 – 11.12.22	Financial management	5
12.12.22 – 15.12.22	Checking plagiarism	5
15.12.22 – 10.1.23	Drawings	15

FORMED BY:
FQW Supervisor

Position	Full name	Academic degree, title	Signature	Date
Associate Professor of The Butakov Research Center	V. E. Gubin	PhD		

APPROVED BY:
Head of MEP

Position	Full name	Academic degree, title	Signature	Date
Associate Professor of The Butakov Research Center	A.V. Zenkov	Cand. Tech. Sc.		

Student

Group	Full name	Signature	Date
507I	Abdelal Mostafa Mohamed Mohamed Elwan		

ABSTRACT

Final qualification work contains 118 p , 34 fig, 54 tab., 19 sources, 4 app

Keywords: NPP, SG, PNR, Low pressure regenerative heater, High pressure regenerative heater .

The object of research is Design an NPP power unit with VVER type reactor

Purpose of work is check the active safety the VVER reactor with electrical power 1000 MW.

Within the work : we studied the active safety system in the NPP, We also considered the calculations of NPR, SG, NPP and condenser.

As a result of the work we find out that there is more type of defenses applied in the NPP such as defense in depth which have five levels of defense

Main design, technological, technical and operational characteristics:

1. Design calculation of nuclear power reactor;
2. Design calculation of a saturated steam generator;
3. Design NPP with a VVER 1000 type reactor;
4. Design calculation of the turbine condenser.

Degree of implementation: Preliminary design

Application area: Country with hot weather and near the sea such as Egypt

Cost effectiveness/significance of work it's between the implementation of NPP unit and the developed algorithm for the rest of the designs.

It is planned to apply and enhance new safety systems to ensure high safety in the NPP units and to make people less afraid of nuclear energy in the future.

Table of Contents

Introduction

Nuclear power plants are modern energy facilities that are the optimal source of heat and electricity. On the one hand, nuclear power plants are efficient and have a large capacity, on the other hand, they do not harm the environment, and during their operation there are no emissions of sulfur dioxide, carbon dioxide, nitrogen oxides and other harmful impurities.

In a nuclear power plant, energy is generated through a controlled nuclear fission reaction in a nuclear reactor.

My research design consists of designing a fully functional nuclear power plant by designing all the main elements of the life cycle of the plant, turbine plant, nuclear reactor, horizontal steam generator and condenser.

As part of the work, the design of the NPP thermal scheme with high and low pressure turbines and a single-stage superheater and closed-type recuperative heaters.

A separate block of work is the development of the concept of defense in depth of a nuclear power plant, since safety issues are the main ones in the operation of any facility using atomic energy.

List of Abbreviations

No	Abbreviation	Definition
1	NPPs	Nuclear power plants
2	LWRs	Light water reactors
3	WWER	water water energetic reactor
4	FA	Fuel assembly
5	MCP	Main circulation pipeline
6	ECCS	emergency core cooling system
7	SG	Steam generator
8	PWR	Pressurized water reactor
9	pp	Perforated plate
10	LPH	Low-pressure reheaters
11	HPH	High -pressure reheaters
12	CP	Condensate pump
13	FWP	Feed water pump
14	HPC	High pressure cylinder
15	LPC	Low pressure cylinder
16	SH	Super heater
17	FSS	Federation to the state social insurance bodies
18	PF	the pension fund
19	FFOMS	Federal Foundation Compulsory Medical Insurance
20	CVCS	chemical and volume control system
21	NCRP	National Council on Radiation Protection
22	LCA	life cycle analysis
23	MPD	maximum permissible discharge
24	H.E.T	Heat exchanger tubes

Active safety system from modern VVER reactor

With the present day conditions, in order to successfully promote new NPP designs in the electric power markets, it is necessary to ensure enhanced technical/economic performances provided that international safety requirements are properly adhered to.

Active safety features are those that attempt to avoid collisions before it happens, unlike passive safety system which enhance VVER inherent safety features and try to find safety solutions for the accidents to limit the consequence.

Safety is the main argument in favor of choosing a Russian nuclear power plant with a VVER reactor. The recent VVER reactor designs incorporate the most modern approaches to safety that are based on the defense-in-depth principle.

1. Safety of Nuclear Power Plant Design

Safety systems of modern Russian nuclear power plants consist of four barriers. Each such barrier is designed to prevent the spread of ionizing radiation and radioactive substances into the environment.

Containment safety equipment includes preventive systems and beyond design basis accident (BDBA) management systems.

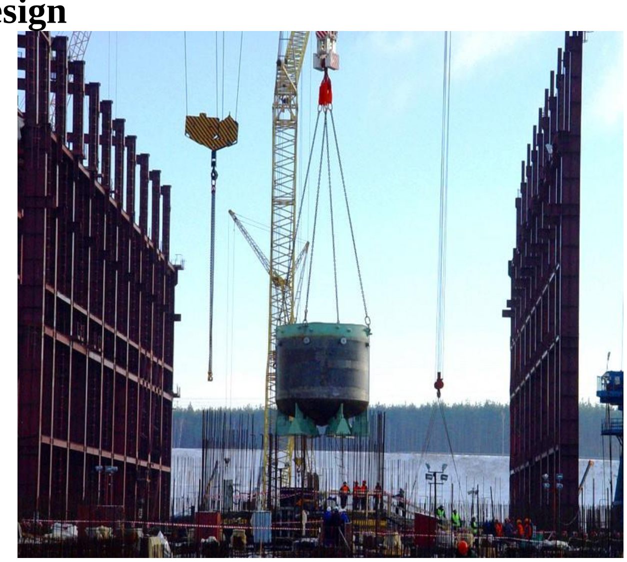


Figure 1. containment wall cooling systems

Preventive systems include spray systems; containment wall cooling systems; heat exchangers designed to reduce containment wall temperature; and recombiners designed to prevent hydrogen explosion.

These include several safety levels with an optimal combination of multi-channel passive and active systems. Russian nuclear power plants with pressurized water reactors (VVER) are equipped with several independent safety trains guaranteed to perform their functions in all modes.

2. Defense in depth principle

Defense-in-depth concept, applied in the design, is based on application of the system of physical barriers on the way of propagation of ionizing radiation and radioactive substances to the environment and the system of engineering and organizational measures oriented to protection of barriers and maintaining their effectiveness.

Table1. Defense in depth levels

Safety Targets	Way of Realization
Prevention of failures and anticipated operational occurrences (AOO)	Conservative design principles Quality assurance system for design and engineering works
AOO control and failure reveal	Safety culture Plant parameters Instrumentation&Control Systems (I&C) Normal operating systems
Accident management within design limits	Postulated scenarios Operation schedule Safety systems and localizing systems
Severe accident management, release localization	Extra design measures to prevent design basis accident development to sever accident and to mitigate accident consequences
Planning of protective measures	PSA-3. Decreasing of hazard to people and environment due to administrative measures

3. Containment Functions for Severe Accidents

- Localizing and cooling-down of core melt;
- Preventing core-concrete interaction;
- Limiting H2 combustion loads;

- Increase of time span available to operator;
- Limiting releases to environment.

The design of nuclear power plants and employed safety principles offer the highest degree of protection against both external and internal exposure

External exposures include the following:

- hurricane, tornado with a maximum wind speed and frequency of once every 10,000 years;
- shock wave with front pressure of 30 KPa (compare);
- seismic impacts up to 8 points on the MSK-64 scale;
- flooding with the maximum probability of once every 10,000 year

Table 2. Main characteristics of prototype

№	Feature name	unit	Prototype WWER
1	Type of FA		Triangular
2	The size of the key, m	h_{sk}	-
4	Lattice (grid) pitch (absolute), mm	s	12.75
5	Pitch-to-diameter ratio (relative pitch (spacing))	s/d_{clad}	1.4
6	Total number of rods, pc.	n_r	331
7	- number of fuel rods, pc.	n_{fuel}	-
8	- number of control rods, pc.	n_{cr}	12…18
9	- number of central tubes, pc.	$n_{c.tube}$	1
10	Outer diameter of the central tube, mm	$d_{c.tube}$	13.3
11	The outer diameter of the tube for the control rod, mm	$d_{cr.tube}$	12.6
12	Type of fuel element		rod
13	The outer diameter of the fuel cladding, mm	d_{clad}	9.1
14	The thickness of the cladding, mm	δ_{clad}	0.65
15	Thickness of the gas gap between the cladding and pellets of the fuel element, mm	δ_{gg}	0.1…0.15
16	Outer diameter of fuel pellets (tablets), mm	d_{fp}	7.5
17	Diameter of the hole in the fuel pellet, mm	d_0	1
18	Material of the fuel cladding		Zr+1% Nb
19	Material of the fuel pellets		UO_2
20	Gas inside the fuel rod		helium

1. Thermal Calculation

1.1. Geometric dimensions of the fuel assembly

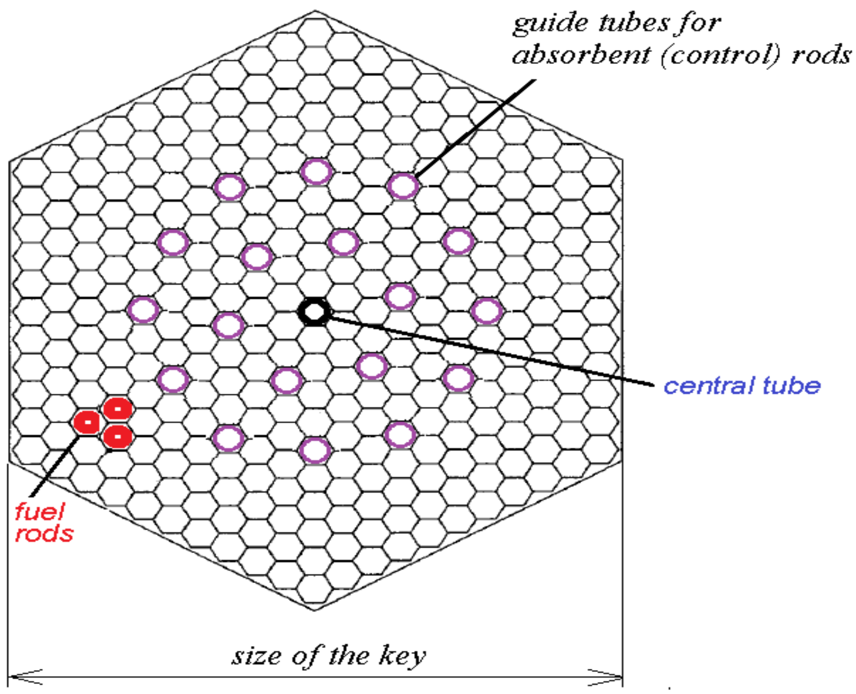


Fig. 2. Layout of rods in fuel assemblies of a WWER reactor

a) Triangular fuel assembly (FA)

number of rods on main diagonal FA n_{dig}

Total number of rods, pc.	n_{dig}, pc.
331	21

Length of the main diagonal FA, mm

$h_{dig} = n_{dig} \cdot s$;

$$h_{dig} = 21 \cdot 12.75 = 267.75\ mm.$$

The size of the key, mm

$h_{sk} = \frac{\sqrt{3}}{2} \cdot h_{dig} + s$;

$h_{sk} = \frac{\sqrt{3}}{2} \cdot 267.7 + 12.75 = 244.6$ mm .

a) Triangular fuel assembly

$f_{ca} = 6 \cdot \sqrt{\frac{1}{3}} \cdot \left(\frac{h_{sk}}{2}\right)^2$;

$$f_{ca} = 6 \cdot \sqrt{\frac{1}{3}} \cdot \left(\frac{0.2446}{2}\right)^2 = 0.0518\ m^2 \approx 0.052\ m^2.$$

At $n_{cr} = 15$;

$n_{fuel} = n_r - n_{cr} - n_{c.tube} = 331 - 15 - 1 = 315$ pc;

$$f_{col1} = 0.052 - \frac{\pi}{4} \cdot (315 \cdot (9.1 \cdot 10^{-3})^2 + 15 \cdot (12.6 \cdot 10^{-3})^2 + 1 \cdot (13.3 \cdot 10^{-3})^2$$
$$= 0.0293\ m^2.$$

1.2. Geometric dimensions of the core

$V_{core} = \frac{Q_r}{q_v}$;

$V_{core} = \frac{3099}{110} = 28.17\ m^3$.

1.3. Coolant flow through the reactor

$Q_r = G_1 \cdot (h_{out} - h_{in})$;

$$G_1 = \frac{Q_r}{(h_{out} - h_{in})} = \frac{(3099 \cdot 10^3)}{(1459 - 1289)} = 18290 \frac{kg}{s}.$$

$h_{in} = f(p_{col}, t_{in}) = f(15.64, 291.0) = 1299 \frac{kJ}{kg}$;

$h_{out} = f(p_{col}, t_{out}) = f(15.64, 321.0) = 1489 \frac{kJ}{kg}$.

1.4. Cross-sectional area of reactor core for coolant passage

$F_{csa} \cdot w_{col} = \frac{G_1}{\bar{\rho}_{col}}$

At $w_{col} = 6 \frac{m}{s}$;

$t_{s1} = f(p_{col}) = 345.5$ °C;

$t_{avg} = \frac{t_{in}+t_{out}}{2} = \frac{291+321}{2} = 306$ °C;

$$\bar{\rho}_{col} = f(p_{col}, t_{avg}) = 714;$$

$$F_{csa} = \frac{G_1}{\bar{\rho}_{col} \cdot w_{col}} = \frac{18290}{714 \cdot 4} = 4.269\ m^2.$$

1.5. The number of fuel assemblies

$$n_{fa} = \frac{4.269}{0.0293} = 145.5 \approx 146;$$

$F_{core} = 1{,}05 \cdot n_{fa} \cdot f_{ca};$

$F_{core} = 1.05 \cdot 146 \cdot 0.0518 = 7.945\ m^2.$

$S_{core} = \frac{\pi \cdot D_0^2}{4};$

$$D_0 = \sqrt{\frac{4 \cdot F_{core}}{\pi}} = \sqrt{\frac{4 \cdot 7.945}{\pi}} = 3.18m.$$

Height of cylindrical core, m

$$H_0 = 1.1 \cdot 3.18 = 3.5\ m.$$

Effective height of the core

$H_{eff} = H_0 + 2 \cdot \delta_{eff};$

$$H_{eff} = 3.5 + 2 \cdot 0.1 = 3.7\ m.$$

$V_{core}^{con} = \frac{\pi \cdot D_0^2}{4} \cdot H_0;$

$$V_{core}^{con} = \frac{\pi \cdot (3.18)^2}{4} \cdot 3.5 = 27.79\ m^3.$$

Check. Relative error should be less than 3%

$$\delta = \left| \frac{V_{core}^{con} - V_{core}}{V_{core}} \right| \le 0{,}03$$

$$\left|\frac{27.79 - 28.17}{28.17}\right| = 0.0134 \leq 0.03\,.$$

If FA is jacketless

$$g_{M} = \frac{G_1}{n_{af} \cdot n_{fuel}} = \frac{18290}{315 \cdot 146} = 0.398 \text{ kg/s}.$$

$$q_l(z) = q_{l0} \cdot \cos\left(\frac{\pi \cdot z}{H_{eff}}\right) = 19.26 \cdot \cos\left(\frac{\pi \cdot 0}{3.7}\right) = 34.46\,\frac{kW}{m};$$

Table3- Distribution of linear thermal flux

№	Z, m	$q_l(z)$, kW/m
1	-1.749	2.924
2	-1.166	18.89
3	-0.583	30.32
4	0	34.46
5	0.583	30.32
6	1.166	18.89
7	1.749	2.924

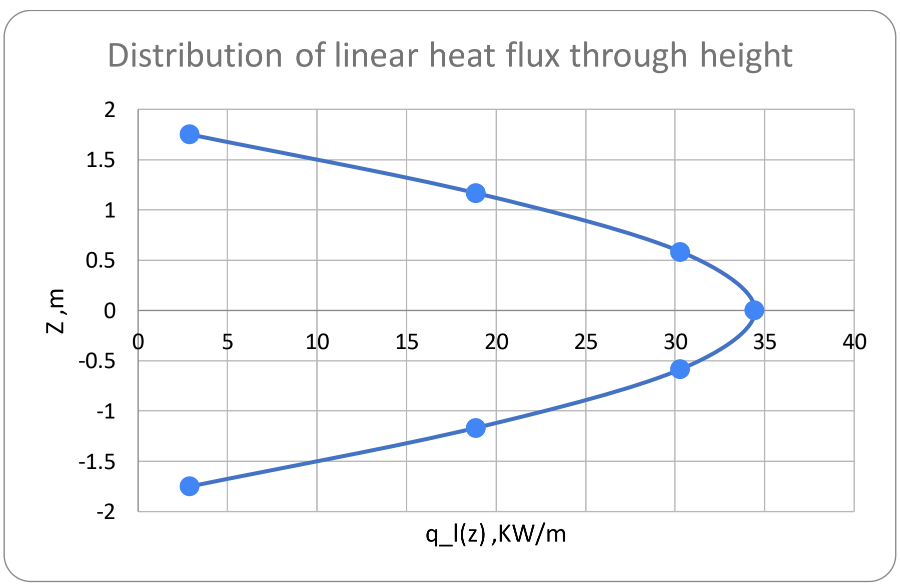


Fig.3 - Distribution of linear heat flux through height

Thermal power of the fuel element from the entrance to the reactor core to each coordinate value **z**

$$Q_{fuel}(z) = \int_{-\frac{H_0}{2}}^{z} q_l(z) \cdot dz = \frac{q_{l0} \cdot H_{eff}}{\pi} \cdot \left[\sin\left(\frac{\pi \cdot z}{H_{eff}}\right) + \sin\left(\frac{\pi \cdot H_0}{2 \cdot H_{eff}}\right)\right];$$

$$Q_{fuel}(z) = \frac{34.46 \cdot 3.7}{\pi} \cdot \left[\sin\left(\frac{\pi \cdot 0}{3.7}\right) + \sin\left(\frac{\pi \cdot 3.5}{2 \cdot 3.7}\right)\right] = 30.07 \text{ kW}.$$

Table 4- Distribution of thermal capacity

№	Z, m	$Q_f(z)\ kW$
1	-1.749	0
2	-1.166	6.494
3	-0.583	21.14
4	0	40.43
5	0.583	59.71
6	1.166	74.36
7	1.749	80.86

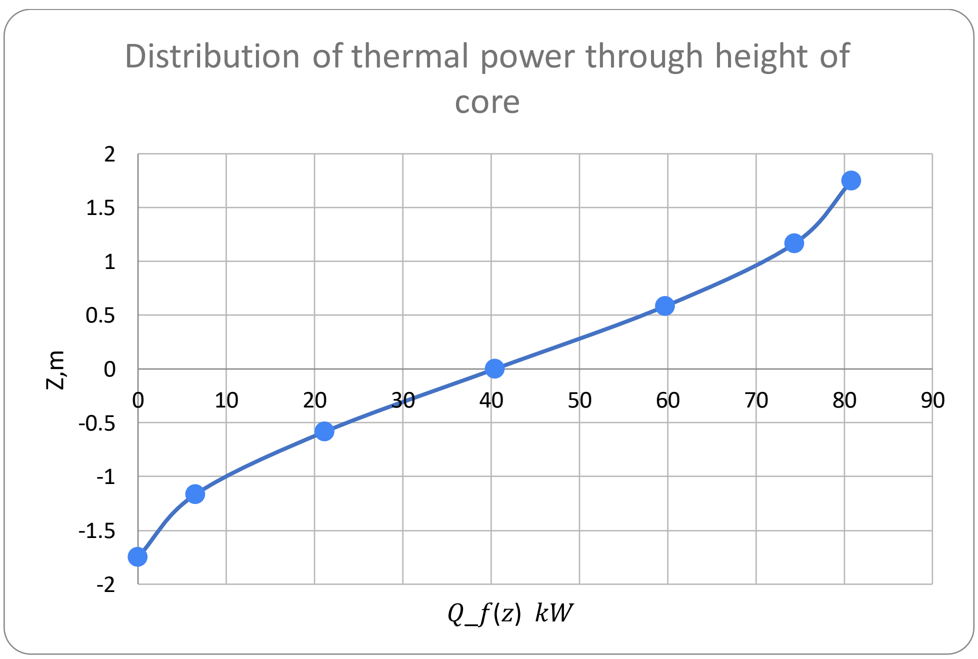


Fig. 4- Distribution of thermal power through height of core

Coolant enthalpy $\mathbf{h}(\mathbf{z})$ for each value of the coordinate $\mathbf{z}$ from the equation of heat balance

$$Q_{fuel}(z) = g_m \cdot [h(z) - h_{in}]\,;$$

$$h(z) = \left(\frac{Q_{fuel}(z)}{g_m}\right) + h_{in} = \left(\frac{40.43}{0.398}\right) + 1289 = 1391\,\frac{kJ}{kg}.$$

Table 5- Distribution of thermal capacity

№	Z, m	$Q_f(z)\ kW$	[h(z)], kJ/kg
1	-1.749	0	1289
2	-1.166	6.494	1306
3	-0.583	21.14	1342
4	0	40.43	1391
5	0.583	59.71	1439
6	1.166	74.36	1476
7	1.749	80.86	1493

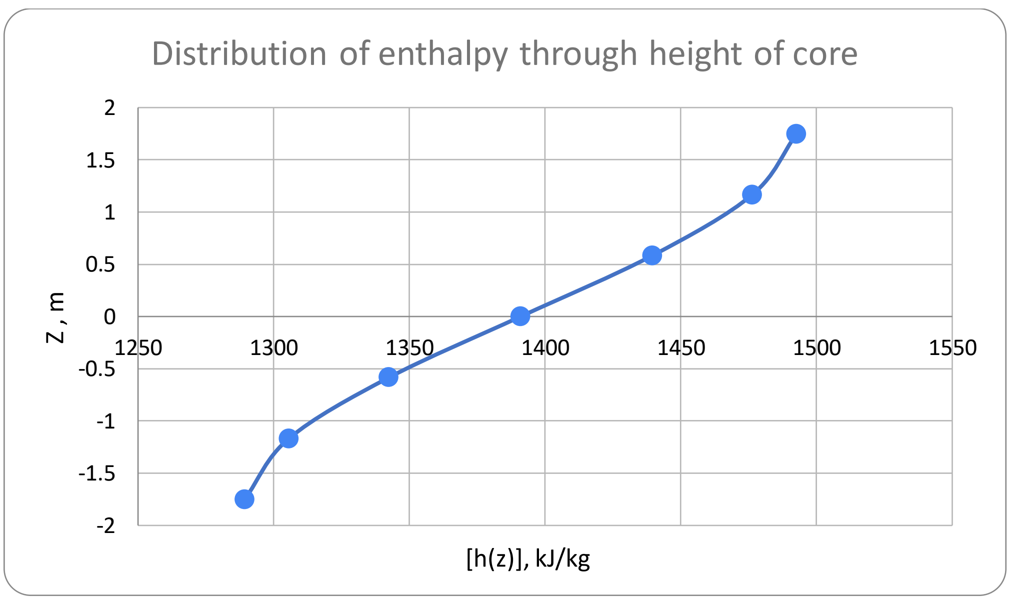


Fig. 5- Distribution of enthalpy through height of core

The relative enthalpy of the coolant for each value of the coordinate.

Table 6- Relative enthalpy of the coolant at each z

№	Z, m	[h(z)], kJ/kg	X(Z)
1	-1.749	1289	-0.362
2	-1.166	1306	-0.345
3	-0.583	1342	-0.306
4	0	1391	-0.255
5	0.583	1439	-0.205
6	1.166	1476	-0.166
7	1.749	1493	-0.149

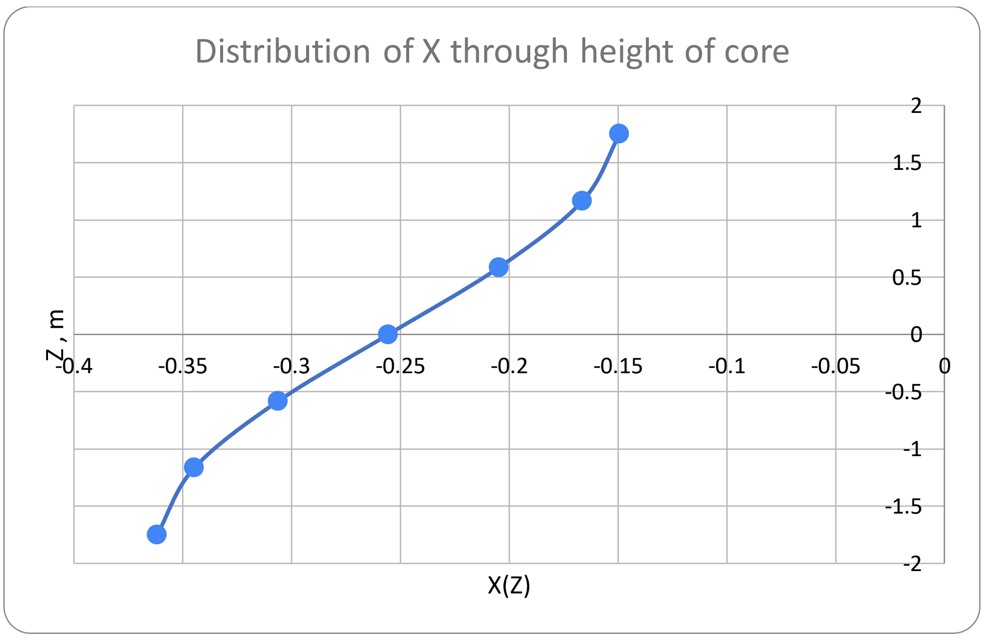


Fig.6- Distribution of X through height of core

Coolant temperature $\mathbf{t(z)}$ for each coordinate value $\mathbf{z}$ as a function of enthalpy $\mathbf{h(z)}$and pressure $\mathbf{p_{col}}$;

$$t(z) = f\left(P_{col}, h(z)\right);$$

Table 7- Coolant temperature at each z

№	Z, m	[h(z)], kJ/kg	$t(Z)$, ℃
1	-1.749	1289	291.0
2	-1.166	1306	294.09
3	-0.583	1342	300.9
4	0	1391	309.6
5	0.583	1439	317.8
6	1.166	1476	323.8
7	1.749	1493	326.3

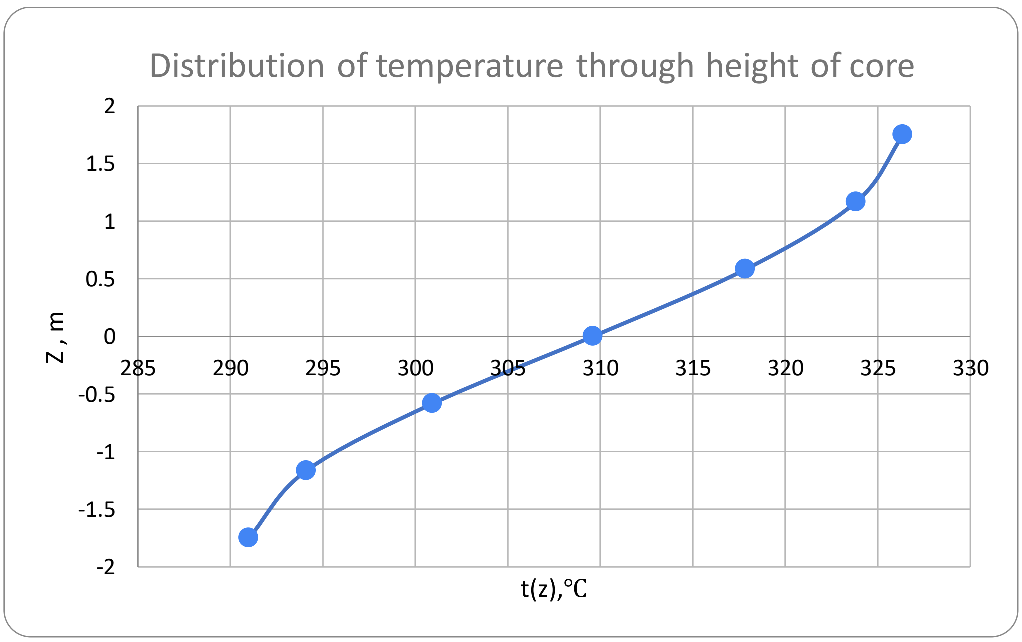


Fig.7- Distribution of temperature through height of core

The heat flux density $\mathbf{q_f(z)}$ for each value of the coordinates $\mathbf{z}$ of the equation

$$q_f(z) \cdot \pi \cdot d_{clad} \cdot H_0 = q_l(z) \cdot H_0 = \frac{47.74}{\pi \cdot (9.1 \cdot 10^{-3})} = 1.67 \frac{kW}{m^2}.$$

Table 8- Square heat flux q_f (z)

№	Z, m	[h(z)], kJ/kg	$q_f(z), kW/m^2$
1	-1.749	1289	102.3
2	-1.166	1306	660.9
3	-0.583	1342	1061
4	0	1391	1206
5	0.583	1439	1061
6	1.166	1476	660.9
7	1.749	1493	102.3

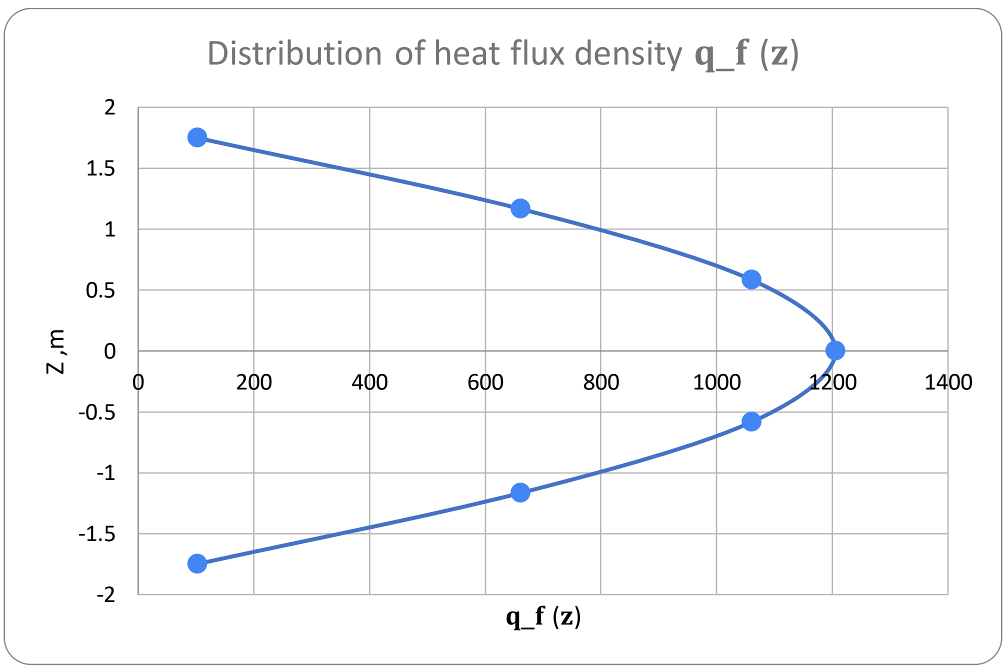


Fig.8- Distribution of heat flux density

Table 9- The results of calculations under paragraph

№	Z, m	$q_l(z)$, kW/m	$Q_{fuel}(z)$, kW	$h(z)$, kJ/kg	$x(z)$	$t(z)$,℃	$q_f(z), \frac{kW}{m^2}$
1	-1.749	2.924	0	1289	-0.362	291.0	102.3
2	-1.166	18.89	6.494	1306	-0.345	294.09	660.9
3	-0.583	30.32	21.14	1342	-0.306	300.9	1061
4	0	34.46	40.43	1391	-0.255	309.6	1206
5	0.583	30.32	59.71	1439	-0.205	317.8	1061
6	1.166	18.89	74.36	1476	-0.166	323.8	660.9
7	1.749	2.924	80.86	1493	-0.149	326.3	102.3

$$q_{cr} = 0.795 \cdot (1 - x)^n \cdot (\rho w)^m \cdot (1 - 0.0185 \cdot p) .$$

$(\rho w) = w_{in} \cdot \rho_{in} = 5251$

$$q_{cr} = 0.795 \cdot [1 - (-0.263)]^{1.142} \cdot (5251)^{0.263} \cdot (1 - 0.0185 \cdot 15.64) = 6.99 \frac{MW}{m^2}$$

Critical heat flux ratio

$$k_{chf}(z) = \frac{q_{cr}(z)}{q_s(z)} = \frac{6.99 \cdot 10^3}{1206} = 5.804 .$$

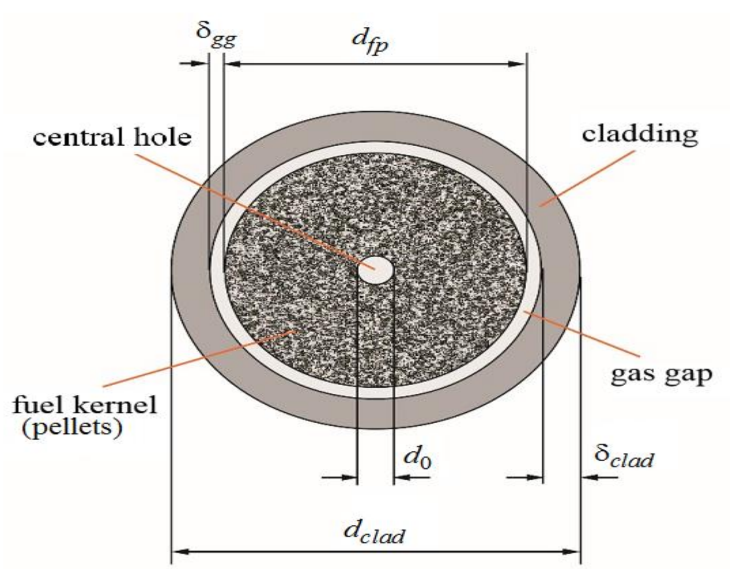


Fig. 9 Fuel rods cross section of convention and traditional design

Hydraulic diameter

$$d_h = d_{clad} \cdot \left(\frac{2\cdot\sqrt{3}\cdot x^2}{\pi} - 1\right) = 9.1 \cdot \left(\frac{2\cdot\sqrt{3}\cdot(1.4)^2}{\pi} - 1\right) = 10.6\, mm;$$

The Reynolds Criterion

$$Re = \frac{w_{col}^{max} \cdot d_h}{\nu} = \frac{6\cdot 10.6}{1.21\cdot 10^{-7}} = 525515\,.$$

The Nusselt criterion for a bundle of fuel rods washed by a water coolant For triangular fuel assembly

$$Nu(z) = A_1 \cdot Re(z)^{0,8} \cdot Pr(z)^{0,4} \;;$$

$$A_1 = 0.0165 + 0.02 \cdot \left(1 - \frac{0.91}{s_{rel}^2}\right) \cdot s_{rel}^{0.15}\;;$$

$$A_1 = 0.0165 + 0.02 \cdot \left(1 - \frac{0.91}{(1.40)^2}\right) \cdot (1.40)^{0.15} = 0.027\;;$$

$$Nu = 0.027 \cdot Re^{0.8} \cdot Pr^{0.4}\;;$$

$$Nu = 0.027 \cdot (525515)^{0.8} \cdot (0.882)^{0.4} = 996;$$

$$\alpha(z) = \frac{Nu(z) \cdot \lambda(z)}{d_h} = \frac{996.4 \cdot 0.5487}{10.6 \cdot 10^{-3}} = 51591\ \frac{W}{m^2 \cdot K}\,.$$

The temperature of the outer surface of the cladding of a fuel rod, ºC

$$t_{clad}^{out}(z) = t(z) + \frac{q_{l0}(z)}{\pi \cdot d_{clad} \cdot \alpha(z)} = 313.4 + \left(\frac{34.46\cdot 10^3}{\pi\cdot(9.1\cdot 10^{-3})\cdot 51591}\right) = 332.9\ ℃.$$

The temperature of the inner surface of the cladding of a fuel rod, ^{0}C

$$t_{clad}^{in}(z) = t_{clad}^{out}(z) + \frac{0.94 \cdot q_{l0}}{\pi \cdot \bar{d}_{clad}} \cdot \frac{\delta_{clad}}{\lambda_{clad}}\,.$$

$$t_{cl}^{in} = t_{cl}^{out} + \frac{0.94 \cdot q_l}{\pi \cdot d_{cl}^{med}} \cdot \frac{\delta_{cl}}{\lambda_{cl}} = 332.9 + \frac{0.94 \cdot 34.46 \cdot 10^3}{\pi \cdot 8.45 \cdot 10^{-3}} \cdot \frac{0.7 \cdot 10^{-3}}{19.13} = 374.2\ ℃\,.$$

$$\bar{d}_{clad} = d_{clad} - \delta_{clad}\;;$$

$$d_{cl}^{med} = 9.1 - 0.65 = 8.45\, mm = 0.0085\, m\,.$$

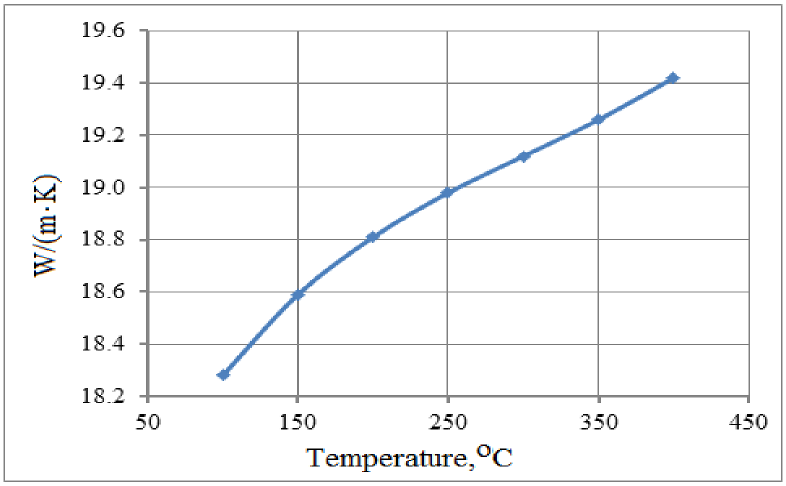


Fig 10. The dependence of thermal conductivity of zirconium alloy on temperature

Temperature of the outer surface of the fuel pellets, °C

$$t_{fp}^{out} = t_{clad}^{in}(z) + \frac{0,94 \cdot q_{l0}}{\pi \cdot \bar{d}_{gg} \cdot \alpha_{gg}} = 415.1 + \frac{0.94 \cdot 34.46 \cdot 10^3}{\pi \cdot (7.68 \cdot 10^{-3}) \cdot 4700} = 659.8 \text{ °C}.$$

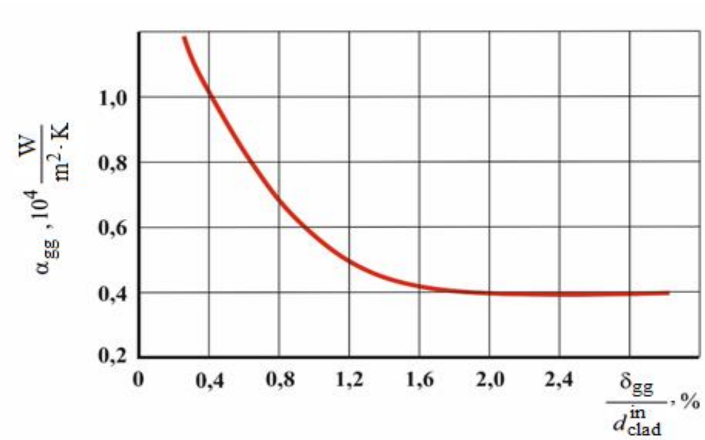


Fig. 11- The dependence of the conductivity of the contact layer of the cladding- fuel pellets on the ratio of the thickness of the gas gap to the internal diameter of the shell

$$t_0 = t_{fp}^{out} + \frac{0,94 \cdot q_{l0}}{4 \cdot \pi \cdot \lambda_{fp}} \cdot \left(1 - \frac{2 \cdot d_0^2}{d_{fp}^2 - d_0^2} \cdot \ln \frac{d_{fp}}{d_0}\right);$$

$$\lambda_{fp} = 0,942 \cdot 10^{-10} \cdot \bar{T}_{fp}^3 + 5500 / \left(500 + \bar{T}_{fr}\right);$$

$$\lambda_{fp} = 0.942 \cdot 10^{-10} \cdot (933.0)^3 + \frac{5500}{(500 + 933.0)} = 3.914 \frac{W}{m \cdot K}.$$

$$t_0 = (659.8) + \frac{0.94 \cdot 34.46 \cdot 10^3}{4 \cdot \pi \cdot 3.914} \cdot \left(1 - \frac{2 \cdot (1 \cdot 10^{-3})^2}{(7.5 \cdot 10^{-3})^2 - (1 \cdot 10^{-3})^2} \cdot \ln\left(\frac{7.5 \cdot 10^{-3}}{1 \cdot 10^{-3}}\right)\right) = 660.8 \text{ °C}$$

At Z= 1.166

$$t_{clad}^{out}(z) = t(z) + \frac{q_{l0}(z)}{\pi \cdot d_{clad} \cdot \alpha(z)} = 332.8 + \left(\frac{18.89 \cdot 10^3}{\pi \cdot (9.1 \cdot 10^{-3}) \cdot 54800}\right) = 335.9 \text{ °C}.$$

Table 10. The results of calculations through height of the reactor core

N_o	Z, m	$t_{clad}^{out}(z)$, ºC	$t_{clad}^{in}(z)$, ºC	$t_{fp}^{out}(z)$, ºC	$\lambda_{fp} \frac{W}{m \cdot K}$
1	-1.749	293.0	296.5	320.8	5.047
2	-1.166	307.2	330.1	486.7	4.407
3	-0.583	321.7	358.2	609.6	4.042
4	0	332.7	374.1	659.9	3.914
5	0.583	337.6	374.1	625.5	4.001
6	1.166	335.9	358.6	515.2	4.315
7	1.749	328.2	331.7	355.9	4.894

$$\bar{T}_{fp}^{new} = \frac{t_{fp}^{out} + t_0}{2} + 273{,}15 = \frac{(659.8 + 273.15) + 660.8}{2} = 796.9\ K;$$

$$\lambda_{fp}^{new} = 0.942 \cdot 10^{-10} \cdot (796.9)^3 + \frac{5500}{(500 + 796.6)} = 4.288\ \frac{W}{m \cdot K};$$

$$t_0^{new} = (659.9) + \frac{0.94 \cdot 34.46 \cdot 10^3}{4 \cdot \pi \cdot 4.288} \cdot \left(1 - \frac{2 \cdot (1 \cdot 10^{-3})^2}{(7.5 \cdot 10^{-3})^2 - (1 \cdot 10^{-3})^2} \cdot \ln\left(\frac{7.5 \cdot 10^{-3}}{1 \cdot 10^{-3}}\right)\right) = 660.7 \text{ °C};$$

First iteration

$$\left|\frac{t_0^{new} - t_0^{old}}{t_0^{old}}\right| = \left|\frac{660.7 - 660.8}{660.8}\right| \cdot 100 = 0.0123\ \% \le 3\ \%$$

Table 21. The results of calculations through height

N_o	Z, m	$q_f(z), \frac{kW}{m^2}$	$q_{cr}(z), \frac{MW}{m^2}$	$t_0(z)$, K	$k_{chf}\ (z)$
1	-1.749	102.3	7.6789	321.5	75.077
2	-1.166	660.9	7.5691	487.4	11.452
3	-0.583	1061	7.322	610.5	6.9028
4	0	1206	6.9983	660.7	5.8049
5	0.583	1061	6.6765	626.3	6.2943
6	1.166	660.9	6.4333	515.9	9.7338
7	1.749	102.3	6.3259	356.6	61.848

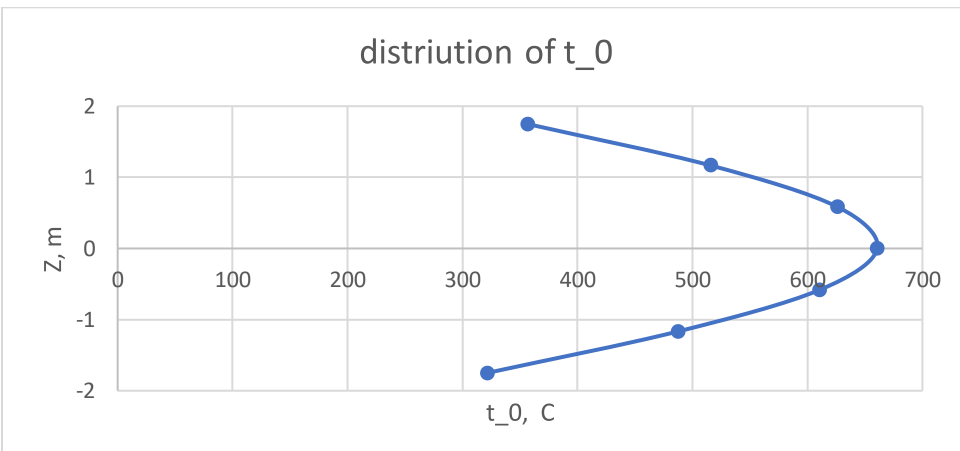


Fig. 12- distribution of temperature t_0

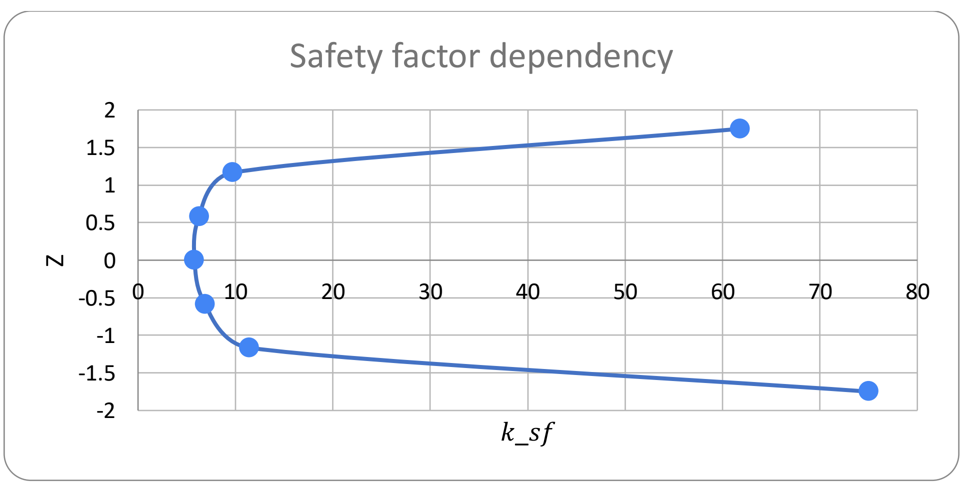


Fig. 13- The dependency of safety factor

2. Neutron-physical calculation

2.1. Dependence of effective multiplying factor

$$k_{eff} = \frac{k_{\infty} e^{-\alpha_0^2 \tau_{th}}}{1+\alpha_0^2 L^2}, \qquad (2.1)$$

2.2. The bulking or geometrical parameter

$$\alpha_0^2 = \left(\frac{2{,}405}{R+\delta}\right)^2 + \left(\frac{\pi}{H+2\delta}\right)^2; \qquad (2.2)$$

$$R = \frac{D_0}{2} = \frac{3{,}18}{2} = 1.59\ m \ \approx 159.03\ cm;$$

$$\alpha_0^2 = \left(\frac{2{,}405}{159.03+10}\right)^2 + \left(\frac{\pi}{349.9+2\cdot 10}\right)^2 = 0.00027\ cm;$$

2.3. Number of secondary neutrons

$$\nu = 2{,}47 \frac{\Sigma_{f5}}{\Sigma_{a5}+\Sigma_{a8}}; \qquad (2.4)$$

2.4. Macroscopic cross-section of absorption for moderator

$$\Sigma_{am} = \frac{1}{V_0}\left(V_{H_2O} N_{H_2O} \sigma_a^{H_2O} + V_{Zr} N_{Zr} \sigma_a^{Zr}\right); \qquad (2.5)$$

$$V_0 = \frac{\sqrt{3}}{2} \cdot s_{Waf}^2;$$

2.5. Core for triangular fuel lattice

$$N_{row} = \frac{21-1}{2} = 10;$$

$$s_{waf} = \frac{2}{\sqrt{3}} \cdot s \cdot \left(1 + \frac{3}{2} \cdot N_{row}\right) + \delta_{wg};$$

$$s_{waf} = \frac{2}{\sqrt{3}} \cdot 1.275 \cdot \left(1 + \frac{3}{2} \cdot 10\right) + 0.2 = 23.75;$$

$$V_0 = \frac{\sqrt{3}}{2} \cdot (23.75)^2 = \ 488.7\ cm^2.$$

2.6. Cladding for triangular fuel lattice

$$V_{cl} = n_{fr}\frac{\pi\left[d_{fr}^2 - \left(d_{fr} - 2\delta_{cl}\right)^2\right]}{4}; \quad (2.6)$$

$$V_{cl} = 331 \cdot \frac{\pi \cdot [(9.1 \cdot 10^{-3})^2 - (9.1 \cdot 10^{-3} - 2 \cdot 0.065)^2]}{4} = 57.11\, cm^2;$$

$$V_f = n_{fr}\frac{\pi d_{fp}^2}{4} = 331 \cdot \frac{\pi(0{,}0075)^2}{4} = 148.6\, cm^2;$$

2.7. Moderator for triangular fuel lattice

$$V_{H_2O} = V_0 - V_{Zr} - V_f; \quad (2.7)$$

$$V_{H_2O} = 488.7 - 57.11 - 148.6 = 283\, cm^2;$$

2.8. Molecular concentrations $N_i \frac{1}{cm^3}$ for water

$$N_{H_2O} = N_a \frac{\gamma_{H_2O}}{M_{H_2O}};$$

where $N_a = 6{,}022 \cdot 10^{23} \frac{1}{mol}$ is Avogadro constant;

$$\gamma_{H_2O} = f(P_o, \bar{t}_{cool}) = f\left(15.64\,, \frac{321 + 291}{2}\right) = 0.714 \frac{g}{cm^3};$$

$$M_f = A_u + 2A_O;$$

A_5, A_8 and A_O are atomic mass of U-235, U-238 and oxygen, $\frac{g}{mol}$;

$$A_5 = 235 \frac{g}{mol};$$

$$A_8 = 238 \frac{g}{mol};$$

$$A_O = 15.99 \frac{g}{mol};$$

$$A_u = c_5 A_5 + (1 - c_5)A_8 = 0.041 \cdot 235 + (1 - 0.041) \cdot 238 = 237.87 \frac{g}{mol};$$

$$M_f = A_u + 2A_O = 237.87 + 2(16) = 269.87 \frac{g}{mol};$$

$$N_{H_2O} = 6.022 \cdot 10^{23} \cdot \frac{0.714}{18} = 2.39 \cdot 10^{22} \approx 0.029 \cdot 10^{24} \frac{1}{cm^3};$$

$$N_{Zr} = N_a \frac{\gamma_{Zr}}{A_{Zr}};$$

where $N_a = 6{,}022 \cdot 10^{23} \frac{1}{mol}$ is Avogadro constant;

$$N_{Zr} = 6.022 \cdot 10^{23} \frac{6.51}{91.224} = 4.298 \cdot 10^{22} \approx 0.043 \cdot 10^{24} \frac{1}{cm^3};$$

$$N_f = N_a \frac{\gamma_f}{M_f};$$

$$N_f = 6{,}022 \cdot 10^{23} \frac{10.49}{269.87} = 2.341 \cdot 10^{22} \approx 0.0234 \cdot 10^{24} \frac{1}{cm^3};$$

$$N_5 = c_5 N_f = 0.041 \cdot 2.341 \cdot 10^{22} = 9.598 \cdot 10^{20} \approx 0.0096 \cdot 10^{24} \frac{1}{cm^3};$$

$$N_8 = (1 - c5)N_f = (1 - 0.041) \cdot 2.341 \cdot 10^{22} = 2.245 \cdot 10^{22}$$
$$\approx 0.0224 \cdot 10^{24} \frac{1}{cm^3};$$

Table 12. Some microscopic cross-sections

Element	σ_a, b	σ_a, cm^2	σ_f, b	σ_f, cm^2
$^{235}_{92}U$	694	$6{,}94 \cdot 10^{-22}$	582	$5{,}82 \cdot 10^{-22}$
$^{238}_{92}U$	2,71	$2{,}71 \cdot 10^{-24}$		
$^{16}_{8}O$	$0{,}27 \cdot 10^{-3}$	$2{,}7 \cdot 10^{-28}$		
H_2O	0,66	$6{,}6 \cdot 10^{-25}$		
$^{65}_{30}Zr$	0,18	$1{,}8 \cdot 10^{-25}$		

Absorption for moderator if water and cladding of a fuel rod are considered as moderator:

$$\Sigma_{am} = \frac{1}{V_0}\left(V_{H_2O} N_{H_2O} \sigma_a^{H_2O} + V_{Zr} N_{Zr} \sigma_a^{Zr}\right);$$

$$= \frac{1}{488.7}(283 \cdot\ 2.39 \cdot 10^{22} \cdot 6.6 \cdot 10^{-25} + 57.11 \cdot 4.298 \cdot 10^{22} \cdot 1.8 \cdot 10^{-25})$$

$$= 0.01 cm^{-1};$$

Absorption for fuel

$\Sigma_{af} = \Sigma_{a5} + \Sigma_{a8} = \frac{V_f}{V_0} N_5 \sigma_a^5 + \frac{V_f}{V_0} N_8 \sigma_a^8,$ (2.8)

$$\Sigma_{af} = \frac{148.5}{488.7} \cdot 9.598 \cdot 10^{20} \cdot 6{,}94 \cdot 10^{-22} + \frac{148.5}{488.7} \cdot 2.245 \cdot 10^{22} \cdot 2{,}71 \cdot 10^{-24}$$

$$= 0.221\ cm^{-1};$$

Nuclear concentration of ${}^{235}_{92}U$ and ${}^{238}_{92}U$ can found through concentration of fuel molecules:

$$\Sigma_{f5} = \frac{V_f}{V_0} N_5 \sigma_f^5;$$

$$\Sigma_{f5} = \frac{148.5}{488.7} \cdot 9.598 \cdot 10^{20} \cdot 5{,}82 \cdot 10^{-22} = 0.169\ cm^{-1};$$

Thermal neutron utilization factor

$$\theta = \frac{\Sigma_{af}}{\Sigma_{af} + \Sigma_{am}} = \frac{0.221}{0.221 + 0.01} = 0.956;$$

$$\nu = 2{,}47 \frac{\Sigma_{f5}}{\Sigma_{a5} + \Sigma_{a8}} = 2{,}47 \cdot \frac{0.169}{0.221} = 1.898;$$

k_∞ multiplying factor can be found with formula

$$k_\infty = \nu\mu\varphi\theta = 1.898 \cdot 1 \cdot 0.94 \cdot 0.956 = 1.706;$$

Diffusional length can be defined with diffusional length of moderator:

$L^2 = L_m^2(1 - \theta).$ (2.11)

$$L^2 = (2.88)^2 \cdot (1 - 0.56) = 0.36.$$

Effective multiplying factor

$$k_{eff} = \frac{k_\infty e^{\left(-\alpha_0^2 \tau_{th}\right)}}{1+\alpha_0^2 L^2} = \frac{1.706 \cdot e^{[-(0.00078)^2 \cdot 26.9]}}{1+0.00027 \cdot 0.36} = 1.694.$$

Table 13. Dependency between k_{eff} & $C, \%$

C, %	k_{eff}
0.5	0.873
1	1.199
2	1.474
3	1.596
4,1	1.67

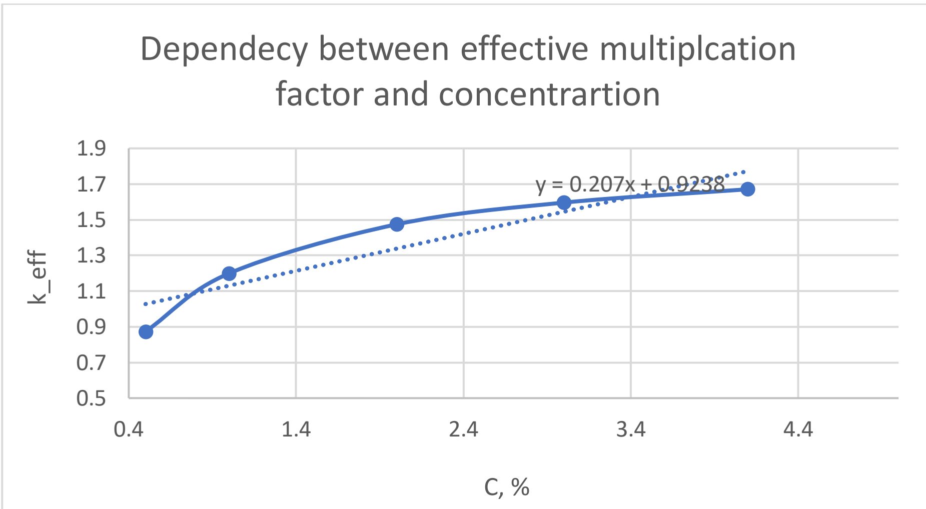


Fig. 14-The dependency of k_{eff} on fuel enrichmenst

3. Strength calculation of a reactor

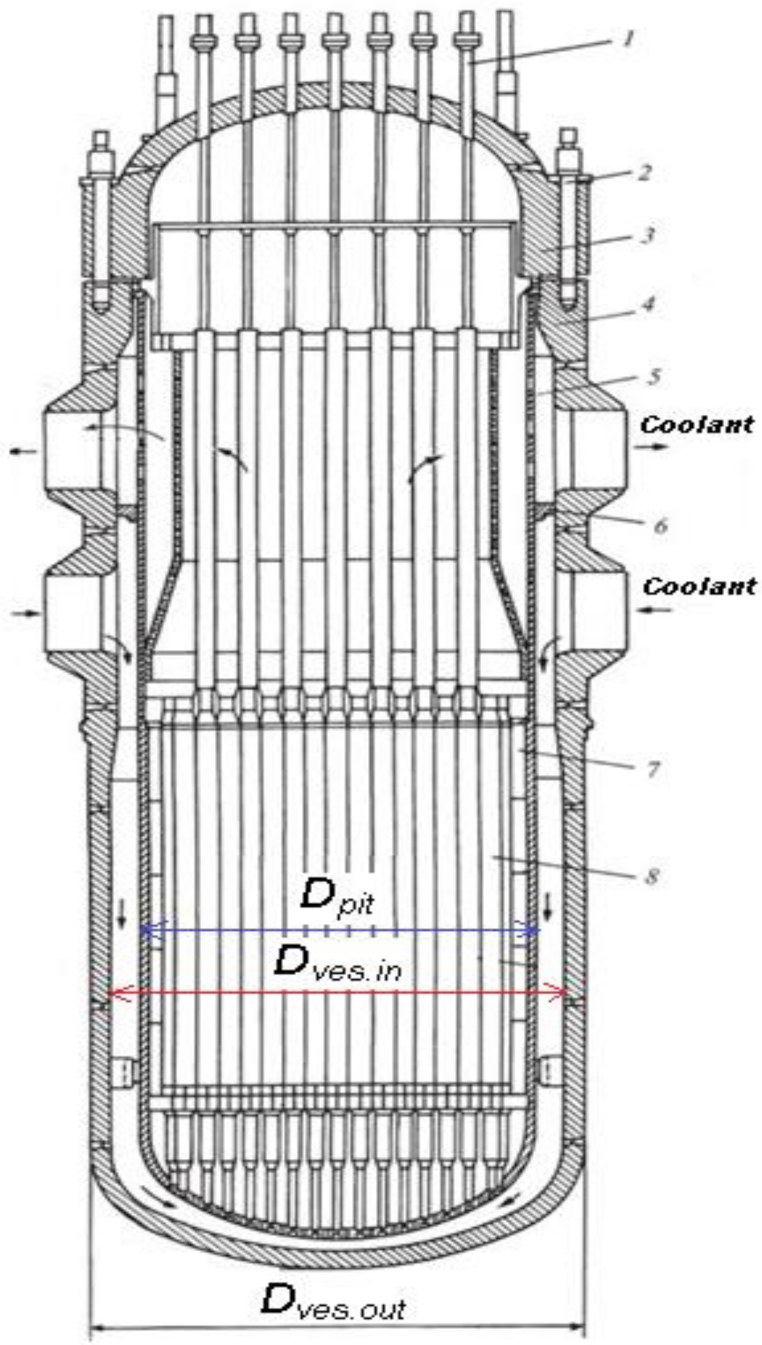


Figure 15- Longitudinal section of a WWER reactor

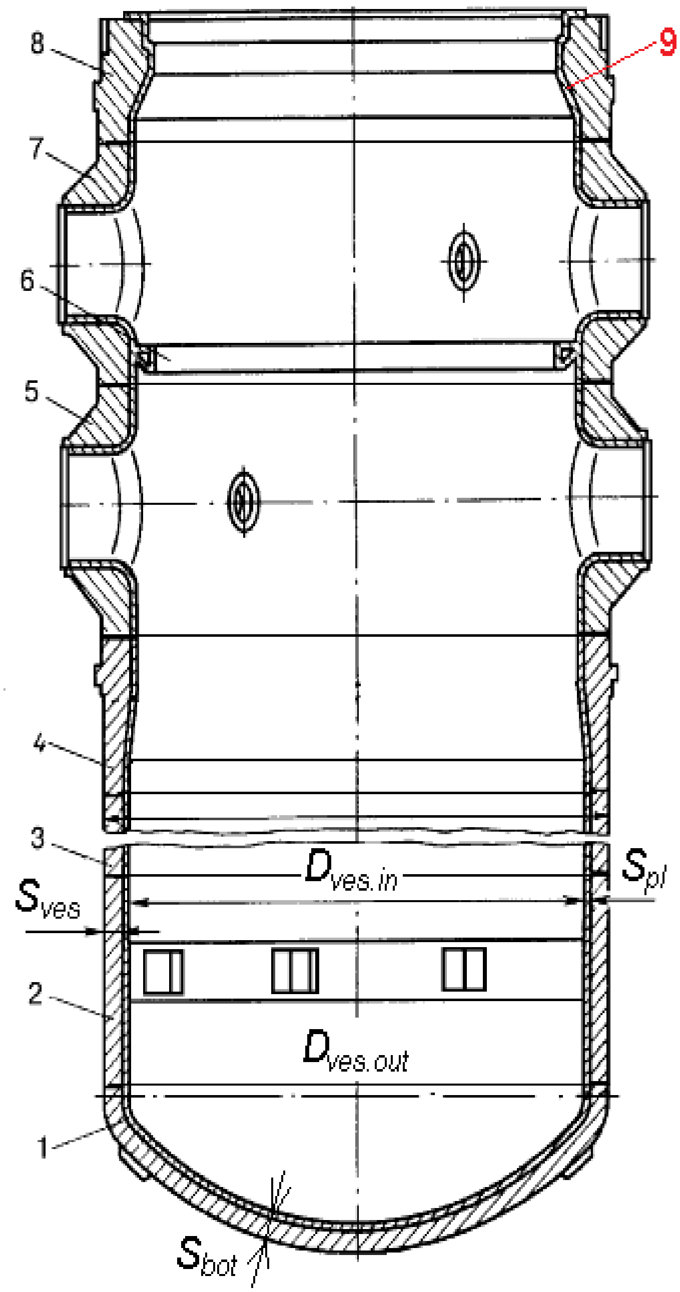


Figure 16 - WWER reactor vessel:

3.1. The thickness of the reactor vessel

$$s_{ves} = \frac{p_{des} \cdot D_{ves.in}}{2 \cdot \varphi \cdot [\sigma] - p_{des}} \qquad (2)$$

Here $p_{des} = 1{,}25 \cdot 0{,}9 \cdot p_{cool}$

3.2. Calculate nominal stress design

$$[\sigma] = \min\left\{\frac{\sigma_{sl}}{n_{sl}}; \frac{\sigma_{0,2}}{n_{0,2}}\right\}; \qquad (3)$$

$\sigma_{sl} = R_m^T = 500;$

$\sigma_{0,2} = R_{p0.2}^T = 402;$

$[\sigma] = min\left\{\frac{500}{2.6}; \frac{402}{1.5}\right\} = \{192.31; 268\};$

$[\sigma]_{min} = 192.31;$

$$s_{ves} = \frac{17.6 \cdot 4.258}{2 \cdot 1 \cdot 192.31 - 17.6} = 0.204;$$

Reactor vessel outer diameter

$$D_{ves.out} = D_{ves.in} + 2 \cdot s_{ves} + 2 \cdot s_{pl}; \qquad (4)$$

$D_{ves.out} = 4.258 + 2 \cdot 0.204 + 2 \cdot 0.008 = 4.682\ m.$

The thickness of the vessel bottom

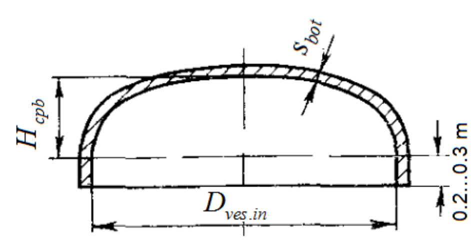


Figure 17- To the calculation of the elliptical bottom

$H_{cpb} = 0.2 \cdot 4.258 = 0.852\ m;$

$$s_{bot} = \frac{17.6 \cdot 4.258}{4 \cdot 1 \cdot 192.31 - 17.6} \cdot \frac{4.258}{2 \cdot 0.852} = 0.249.$$

4. Hydraulic calculation of the reactor

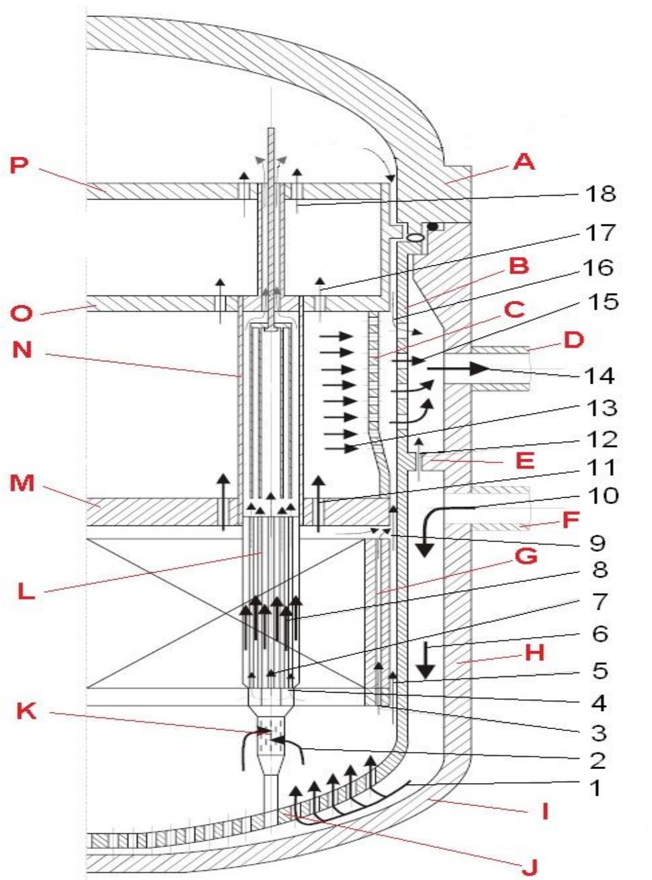


Figure 18 - Coolant circulation diagram in a VVER reactor:

4.1. The diameter of the pipes for inlet and outlet of the coolant

$$\frac{\pi \cdot d^2_{pip.in}}{4} \cdot w_{pip} \cdot 2 \cdot n_{loop} = \frac{G_1}{\rho_{avr}}. \qquad (1)$$

$$\rho_{avr} = f(\,15.64, 306) = 714\ \frac{kg}{m^3};$$

$$d_{pip.in} = \sqrt{\frac{4 \cdot G_1}{\pi \cdot w_{pip} \cdot n_{loop} \cdot \rho_{avr}}} = \sqrt{\frac{4 \cdot 18290}{\pi \cdot 12 \cdot 4 \cdot 714}} = 0.583\ m.$$

4.2. The inner diameter of the reactor vessel

$$\frac{\pi \cdot \left(D_{ves.in}^2 - D_{pit}^2\right)}{4} \cdot w_{gap} = \frac{G_1}{\rho_{in}}. \qquad (2)$$

$$\rho_{in} = f(\,15.64, 291) = 744.5\,\frac{kg}{m^3}.$$

$$D_{ves.in} = \sqrt{\frac{4 \cdot G_1}{\pi \cdot w_{gap} \cdot \rho_{in}} - D_{pit}^2} = \sqrt{\frac{4 \cdot 18290}{\pi \cdot 6 \cdot 744.5} - (3.594)^2} = 4.258\,m;$$

$$D_{ves.in} = 1.137 \cdot 3.594 = 4.086\,m.$$

4.3. Inner diameter of protective tube block shell

$$D_{ptb.in} = 1.05 \cdot 3.18 = 3.339\,m.$$

4.4. The speed of the coolant in the protective tube block

$$\left(\frac{\pi \cdot D_{ptb.in}^2}{4} - n_{pt} \cdot \frac{\pi \cdot d_{pt.out}^2}{4}\right) \cdot w_{ptb} = \frac{G_1}{\rho_{out}}. \qquad (3)$$

$n_{fa.cr} = 0.5 \cdot 146 = 73;$

$n_{pt} = 1.3 \cdot 73 = 94.9 \approx 95.$

$$w_{ptb} = \frac{G_1}{\rho_{out} \cdot \left(\frac{\pi \cdot D_{ptb \cdot in}^2}{4} - n_{pt} \cdot \frac{\pi \cdot d_{pt \cdot out}}{4}\right)};$$

$$w_{ptb} = \frac{18290}{664.2 \cdot \left(\frac{\pi \cdot (3.339)^2}{4} - 95 \cdot \frac{\pi \cdot (0.115)^2}{4}\right)} = 3.471\,\frac{m}{s}.$$

$$\xi_{fr} = 0{,}11 \cdot \left(\left(\frac{\Delta}{d_h}\right) + \left(\frac{68}{Re}\right)^{0{,}25}\right) \text{ where } \Delta \text{ is } 0.00002;$$

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho \cdot w^2}{2}\;.$$

$$d_h^{gap} = D_{ves.in} - D_{pit};$$

$$d_h^{gap} = 4.086 - 3.594 = 0.492 \text{ m};$$

$$H_{gap} \approx H_0 = 3.498 \text{ m};$$

$v_{in} = f(p_{col}, t_{in}) = f(15.64, 291) = 1.233 \cdot 10^{-7};$

$$Re_{gap} = \frac{w_{gap} \cdot d_h^{gap}}{v_{in}};$$

$$Re_{gap} = \frac{6 \cdot 0.492}{1.233 \cdot 10^{-7}} = 2396570.$$

For fuel assembly

$$d_h^{fa} = d_{clad} \cdot \left(\frac{2 \cdot \sqrt{3} \cdot s_{rel}^2}{\pi} - 1\right);$$

$$d_h^{fa} = 0.0106\text{m};$$

$$H_{fa} \approx 1.1 \cdot H_0 = 1.1 \cdot 3.498 = 3.848 \text{ m};$$

$\nu_{avr} = f(p_{col}, t_{avr}) = 1.204 \cdot 10^{-7} \frac{m^2}{s};$

$$Re_{FA} = \frac{w_{cool} \cdot d_h^{fa}}{v_{avg}} = \frac{4 \cdot 0.0106}{1.204 \cdot 10^{-7}} = 528090.$$

For the protective tube block;

$$d_h^{PTb} = \frac{\left(\frac{\pi}{4}\right) \cdot \left(\left(D_{ves.in}{}^2\right) - \left(n_{pt} \cdot d_{pt.out}{}^2\right)\right)}{\pi \cdot \left(D_{ves.in} + \left(n_{pt} \cdot d_{pt.out}\right)\right)};$$

$$d_h^{PTb} = \frac{\left(\frac{\pi}{4}\right) \cdot \left((4.258)^2 - (95 \cdot 0.115^2)\right)}{\pi \cdot \left(4.258 + (95 \cdot 0.115)\right)};$$

$$d_h^{PTb} = 0.278 \text{ m};$$

$$H_{PTB} \approx 1{,}5 \cdot H_0 = 5.248\, m$$

$$\nu_{out} = f(p_{col}, t_{out}) = 1.18 \cdot 10^{-7} \frac{m^2}{s};$$

$$Re_{PTB} = \frac{w_{PTB} \cdot d_h^{PTb}}{v_{out}} \quad Re_{PTB} = \frac{3.471 \cdot 0.278}{1{,}18 \cdot 10^{-7}} = 817619.$$

Table 14-Equations for hydraulic (friction)

Movement of coolant (friction)	d_h, m	H, m	$v, \frac{m^2}{s}$	Re
gap between the core	$d_h^{gap} = D_{ves.in} - D_{pit}$	$H_{gap} \approx H_0$	v_{in}	$Re_{gap} = \frac{w_{gap} \cdot d_h^{gap}}{v_{in}}$
in fuel assembly	$d_h^{fa} = d_{clad} \cdot \left(\frac{2 \cdot \sqrt{3} \cdot s_{rel}^2}{\pi} - 1\right)$	$H_{fa} \approx 1.1$	v_{avg}	$Re_{FA} = \frac{w_{cool} \cdot d_h^{fa}}{v_{avg}}$
in the protective tube block	$d_h^{PTb} = \frac{\left(\frac{\pi}{4}\right) \cdot \left(\left(D_{ves.in}{}^2\right) - \left(n_{pt} \cdot d_{pt.out}{}^2\right)\right)}{\pi \cdot \left(D_{ves.in} + \left(n_{pt} \cdot d_{pt.out}\right)\right)}$	$H_{PTB} \approx 1.5 \cdot H_0$	v_{out}	$Re_{PTB} = \frac{w_{PTB} \cdot d_h^{PTb}}{v_{out}}$

Table 15-Calculation of hydraulic pressure

	Movement of	d_h, m	H, m	$v, \frac{m^2}{}$	Re	$w, \frac{m}{s}$	ξ_{fr}	$\Delta P_{fr}, Pa$
1	gap between the core	0.492	3.49	1.233	2396575	w_{gap}	0.008	850,48
2	in fuel assembly	0.010	3.84	1.204	528090	w_{cool}	0.023	108360
3	in the protective tube	0.278	5.24	1.18	8176191	w_{PTB}	0.010	803,27
							ξ_{loc}	Δ
4	through inlet pipes					w_{pip}	0.75	38407
5	through the					w_{gap}	0.5	6401.2
6	inlet to fuel					w_{gap}	1.5	19204
7	outlet of fuel					w_{cool}	0.4	5121
8	through the					w_{PTB}	0.5	2142.3
9	through the					w_{PTB}	0.5	2142.3
1	through outlet pipes					w_{pip}	1	51210
$\sum P$							23464	0.2346 MPa

Design calculation of a saturated steam generator

1. Thermal calculation

Table 16. Initial data

Parameter	Denomination, units	Value
Coolant		water
Thermal power of SG	Q_{sg}, MW	754.9
Mass flow of steam	D_{st} *or* D_2, kg/s	413
Coolant flow	G_1, kg/s	4455
Coolant pressure at the inlet to the SG	p_1, MPa	15.64
Coolant temperature at the inlet to the SG	t_1', °C	321.0
Coolant temperature at the outlet of the SG	t_1'', °C	291.0
Steam pressure at the SG	p_{st} *or* p_2, MPa	6.58
Steam temperature at the outlet of the SG	t_{st} *or* t_s, °C	281.7
Feed water temperature	t_{fw}, °C	210
Blowdown flow rate, % (as a percentage of mass flow of steam)	α_{bd}, %	0.4

$$Q_{sg} = G_1(h_{in} - h_{out})$$

$$G_1 = \frac{Q_{sg}}{h_{in} - h_{out}} = (\frac{754.9 \cdot 10^3}{(1459 - 1289)} = 4455.4 \frac{kg}{s}.$$

$$D_{fw} = D_2 + D_{bd} = 413 + \left(\frac{0.4}{100} \cdot 413\right) = 827.7 \ \frac{kg}{s}$$

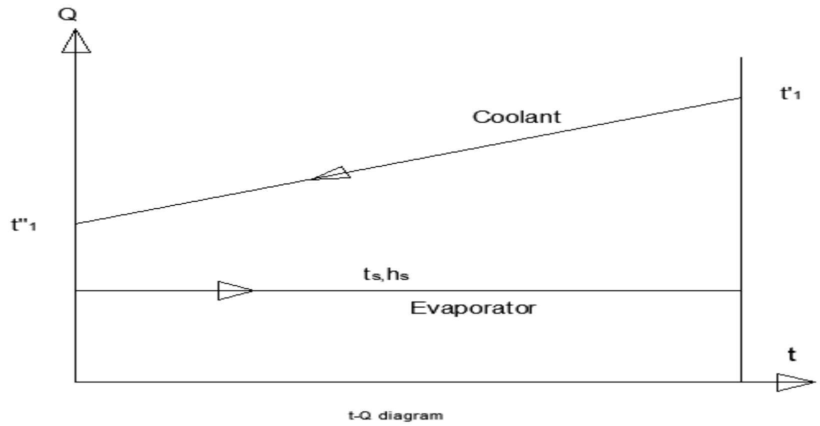


Figure 19. tQ diagram

1.1. Calculation of the wall thickness of the tubes of the heat transfer surface

$$\delta_{tube} = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C.; \qquad (1)$$

$p_{calc} = 0{,}9.1{,}25.P_1 = 17.6\ MPa.$

Table 17. Mechanical properties of steel 08X18H10T

t_{calc}, °C	100	150	200	250	300	350
σ_{sl}, MPa	412	392	392	373	363	353
$\sigma_{0,2}$, MPa	177	167	157	147	137	132

Table 18. Permissible deviations of tube sizes along wall thickness [3]

Wall thickness, mm	The deviation value with precision manufacturing		
	conventional accuracy	high accuracy	very high accuracy
0.5…0.6	± 0.1 mm	± 0.07 mm	
0.7… 1.0	± 0.15 mm	± 0.1 mm	
1.0… 3.0	± 15 %	± 12.5 %	± 12.5 %
> 3.0			- 10 %

$$C_4 = (\delta_{tube} - C) \cdot \left[1 - 2 \cdot \left(1 - \frac{b}{100}\right) \cdot \frac{2 \cdot \left(\frac{R_b}{d_{out}}\right) + 1}{4 \cdot \left(\frac{R_b}{d_{out}}\right) + 1}\right].$$

Table 19. Parameters of corrosion-resistant steel tubes

Outer diameter, mm	12, 13, 14, 15, 16, 17
tube wall thickness, mm	0.8, 1.0, 1.2, 1.4, 1.5, 1.8

$t_{calc} = 301.3°\text{C};$

$$\sigma_{sl} = 363\ MPa\ ; n_{sl} = 2.6;$$

$$\sigma_{0,2} = 137\ MPa\ ; n_{0,2} = 1.5;$$

$$\sigma_{min} = 91.33\ Mpa;$$

$\delta_{tube} = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} + C;$

$$\delta_{tube} - C = \frac{17.6 \cdot 16}{2 \cdot 1 \cdot 91.33 + 17.6} = 1.406\ mm$$

$\delta_{tube} - C = 1.406\ mm;$

$C_1 = \frac{12,5}{100} \cdot 1.406 = 0.176\ ;$

$b = 10;$

$$R_b = 3 \cdot d_{out};$$

$$R_b = 3 \cdot 16 = 48\ mm;$$

$\delta_{tube} - C = 1.406\ mm;$

$0,75.10^{-2}.\ a;$

$$1.406 > 0,075;$$

$$C_4 = (\delta_{tube} - C) \cdot \left[1 - 2 \cdot \left(1 - \frac{b}{100}\right) \cdot \frac{2 \cdot \left(\frac{R_b}{d_{out}}\right) + 1}{4 \cdot \left(\frac{R_b}{d_{out}}\right) + 1}\right]$$

$$C_4 = (1.4759) \cdot \left[1 - 2 \cdot \left(1 - \frac{10}{100}\right) \cdot \frac{2 \cdot \left(\frac{48}{16}\right) + 1}{4 \cdot \left(\frac{48}{16}\right) + 1}\right]$$

$C_4 = 0.04325;$

$C = C_1 + C_2 + C_3 + C_4;$

$C = 0.176 + 0.04325 = 0.219;$

Then the internal diameter of the heat exchange tube will be equal:

$$d_{in} = d_{out} - 2 \cdot \delta_{tube}$$

$$= 17 + 2 \cdot 1.7 = 13.6\ mm$$

$$f_{1tube} = \frac{\pi \cdot d_{in}^2}{4} = \frac{\pi \cdot (13.4 \cdot 10^{-3})^2}{4} = 0.000145\ m^2$$

$$\rho_{avr} = f(p_1,\ t_{1avr}) = 714\frac{kg}{m^3}$$

$$w = 5\ \frac{m}{s}$$

$$N_{tube} = \frac{4455.4}{714 \cdot 5 \cdot 0.000145} = 8595\ tube.$$

1.2. Determination of average temperature head in a steam generator

$\Delta t_{hig} = 321 - 281.7 = 39.3$ °C;

$\Delta t_{low} = 291 - 281.7 = 9.3$ °C;

$\Delta t_{avr} = \frac{39.3-9.3}{ln\left(\frac{39.3}{9.3}\right)} = 20.8$ °C.

1.3. Determination of the heat transfer coefficient from the coolant to the tube walls

$$\alpha_{1avr} = 0{,}021 \cdot \left(\frac{\lambda_{1avr}}{d_{in}}\right) \cdot (Re_{avr})^{0,8} \cdot (Pr_{avr})^{0,43}$$

$$\nu_{1avr} = f(p_1,\ t_{1avr}) = 1.21 \cdot 10^{-7} m^2/s$$

$$\lambda_{1avr} = f(p_1,\ t_{1avr}) = 0.5487\ \frac{W}{m \cdot °C}$$

$$Pr_{avr} = 0.8819$$

$$Re_{avr} = 561983\ ;$$

$\alpha_{1avr} = 0{,}021 \cdot \left(\frac{0{,}5487}{13.4 \cdot 10^{-3}}\right) \cdot (561983)^{0,8} \cdot (0.8819)^{0,43};$

$\alpha_{1avr} = 31939.4\ W/m^2K.$

1.4. Determination of the heat transfer coefficient from the walls of the tubes to the working fluid

we accept the initial value of the heat flux $q_{in} = 3 \cdot 10^5$W/m² (for the output section it is recommended to take $q_{out} = 6 \cdot 10^4$W / m²);

First iteration:

$$\alpha_{2in} = \frac{10.45}{3.3 - 0.0113 \cdot (t_s - 100)};$$

$$\alpha_{2in} = \frac{10.45}{3.3 - 0.0113 \cdot (281.7 - 100)} \cdot (3 \cdot 10^5)^{0.7} = 57182.9\ \mathbf{W/(m^2 \cdot {}^{o}C)};$$

$t_{tube.in} = t_s + 0.3 \cdot (t_1' - t_s)$

$$t_{tube,in} = 281.7 + 0.3(321 - 281.7) = 293.5\ ℃;$$

$$\lambda_{wal.in} = 14.48 + 0.0156 \cdot t_{tube.in};$$

$$\lambda_{Wall,in} = 14.48 + 0.0156 \cdot 293.5 = 19.06\ \mathbf{W/(m \cdot {}^{o}C)};$$

$$k_{in} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{tube}}{\lambda_{tube.in}} + 2 \cdot R_{ox} + \frac{1}{\alpha_2}\right]^{-1};$$

$$K_{in} = \left[\frac{1}{31939.4} + \frac{1.8 \cdot 10^{-3}}{19.06} + 2 \cdot 10^{-5} + \frac{1}{57182.9}\right]^{-1} = 6329.2;$$

$q_{in}' = k_{in} \cdot (t_1' - t_s)$

$$q_{in}' = 6329.2 \cdot (321 - 281.7) = 248806$$

$$0.95 \le \frac{q_{in}'}{q_{in}} \le 1.05;$$

$$\frac{q_{in}'}{q_{in}} = \frac{248806}{3 \cdot 10^5} = 0.829;$$

$$\mathbf{0.95 \le 0.829 \le 1.05};$$

$$\alpha_{2in} = \frac{10.45}{3.3 - 0.0113 \cdot (281.7 - 100)} \cdot (248806)^{0.7} = 50163\ \mathbf{W/(m^2 \cdot {}^{o}C)};$$

$t_{tube.in} = t_s + 0.3 \cdot (t_1' - t_s)$

$$K_{in} = \left[\frac{1}{31939.4} + \frac{1.8 \cdot 10^{-3}}{19.06} + 2 \cdot 10^{-5} + \frac{1}{50163}\right]^{-1} = 6232.7;$$

$$q'_{in} = 6232.7 \cdot (321 - 281.7) = 245011;$$

$$\frac{q'_{in}}{q_{in}} = \frac{245011}{248806} = 0.9847;$$

$$\mathbf{0.95 \leq 0.9847 \leq 1.05};$$

$$\alpha_{2out} = \frac{10.45}{3.3 - 0.0113 \cdot (281.7 - 100)} \cdot (6 \cdot 10^4)^{0.7} = 18534.8 \frac{\mathbf{W}}{\mathbf{m^2 \cdot ºC}};$$

$$t_{tube,in} = t_s + 0.3 \cdot (t''_1 - t_s);$$

$$t_{tube,in} = 281.7 + 0.3(291 - 281.7) = 284.5 \text{ ℃};$$

$$\lambda_{Wall,out} = 14.48 + 0.0156 \cdot 284.5 = 18.92 \ \mathbf{W/(m \cdot ºC)};$$

$$K_{out} = \left[\frac{1}{31939.4} + \frac{1.8 \cdot 10^{-3}}{18.92} + 2 \cdot 10^{-5} + \frac{1}{18534.8}\right]^{-1} = 5124.95$$

$$\boldsymbol{q'_{out} = k_{out}} \cdot (\boldsymbol{t''_1 - t_s});$$

$$\boldsymbol{q'_{out}} = 5124.95 \cdot (291 - 281.7) = 477162.2;$$

$$\frac{q'_{out}}{q_{out}} = \frac{477162.2}{6 \cdot 10^4} = 0.795 \quad \rightarrow\rightarrow \ \boldsymbol{We\ use\ q'_{out}\ as\ the\ new\ q} \quad (\mathbf{1});$$

$$\alpha_{2out} = \frac{10.45}{3.3 - 0.0113 \cdot (286.8 - 100)} \cdot (477162.2)^{0.7} = 15788.7 \frac{\mathbf{W}}{\mathbf{m^2 \cdot ºC}};$$

$$K_{out} = \left[\frac{1}{31939.4} + \frac{1.8 \cdot 10^{-3}}{18.92} + 2 \cdot 10^{-5} + \frac{1}{15788.7}\right]^{-1} = 4889.8;$$

$$\boldsymbol{q'_{out}} = 4889.8 \cdot (291 - 281.7) = 45526.7;$$

$$\frac{q'_{out}}{q_{out}} = \frac{45526.7}{47716.2} = 0.954;$$

$$\mathbf{0.95 \leq 0.954 \leq 1.05}.$$

1.5. Calculation of the average overall heat transfer coefficient

$$\left|\frac{k_{in} - k_{out}}{k_{out}}\right| = \left|\frac{6232.7 - 4889.8}{4889.8}\right| = 0.274 > 0.25;$$

$$k_{avr} = 0.333 \cdot (6232.7 + 4889.8 + 5540.0) = 5548.9.$$

1.6. Determine the area of the heat exchange surface

$$F = \frac{k_{sf} \cdot Q_{sg}}{k_{avr} \cdot \Delta t_{avr}} = \frac{1.05 \cdot 754.9 \cdot 10^3}{5548.9 \cdot 27.1} = 6834\ m^2.$$

1.7. Calculate the average length of one tube of the steam generator.

$l_{avr} = \frac{F}{\pi \cdot d_{avr} \cdot N_{tube}}$, m,

$$d_{avr} = 0.5 \cdot (d_{out} + d_{in}) = \frac{17 + 13.6}{2} = 15.3\ mm$$

$$l_{avr} = \frac{6834}{3.14 \cdot 0.0153 \cdot 8595} = 16.5\ m.$$

2. Design calculation

2.1. Calculation of the wall thickness of the collector, m

$$\delta_{coll} = \frac{p_{1calk} \cdot D_{col}^{in}}{2 \cdot \varphi_{\min} \cdot \sigma_{nom} - p_{1calk}}$$

$$\varphi_1 = \frac{0.025 - (17 \cdot 10^{-3})}{0.025} = 0.32m;$$

$$\varphi_2 = \frac{2 \cdot \left(0.025 - (17 \cdot 10^{-3})\right)}{0.025} = 0.64m;$$

$$\varphi_1 = \varphi_{min} = 0.32;$$

$$\delta_{coll} = \frac{p_{1calk} \cdot D_{col}^{in}}{2 \cdot \varphi_{\min} \cdot \sigma_{nom} - p_{1calk}} = \frac{(17.6) \cdot 0.8}{2 \cdot 0.32 \cdot 215 - (17.6)} = 0.1173\ m.$$

$$D_{col}^{out} = D_{col}^{in} + 2 \cdot \delta_{coll} = 0.8 + 2 \cdot 0.1173 = 1.0346\ m.$$

$$s_{2out} = s_2 \cdot \frac{D_{col}^{out}}{D_{col}^{in}} = 0.025 \cdot \frac{1..0346}{0.8} = 0.0323\ m\ .$$

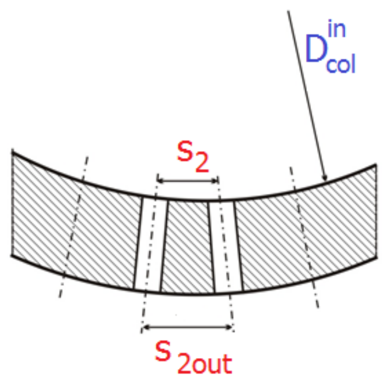


Fig. 20. Fragment of the wall of the collector

2.2. The length of the arc along the circumference of the collector occupied by tubes of the upper row

$$L_{c1} = \pi \cdot D_{col}^{out} .= \pi \cdot 1.03459 = 3.249\ m.$$

$$N_{tube1} = \frac{L_{c1}}{s_{2out}} .= \frac{3.249}{0.03233} = 101\ \ pcs.$$

2.3. The maximum width of the tube bundle at the level of the upper row of tubes

$$B_{bund}^{\max} = N_{tube1} \cdot s_{2out} + 3 \cdot B_{cor};$$

$$= 101 \cdot 0.03233 + 3 \cdot 0.2 = 3.848\ m$$

$$B_{pack} = \frac{B_{bund}^{\max} - 3 \cdot B_{cor}}{2}. = \frac{3.848 - 3 \cdot 0.2}{2} = 1.624 \text{ m.}$$

2.4. The distance between the axes of the collectors,

$$B_{dac} = 2 \cdot B_{pack} + 2 \cdot B_{cor}.$$

$$= 2 \cdot 1.624 + 2 \cdot 0.2 = 3.648\ m$$

2.5. Width of submerged perforated plate

$$B_{pp} = (1{,}05...1{,}1) \cdot B_{bund}^{\max}.$$

$$= 1.01 \cdot 3.848 = 4.233\ m$$

2.6. SG vessel width at level perforated plate

$$B_{ves.pp} = B_{pp} + 2 \cdot B_{gap},$$

$$= 4.233 + 2 \cdot 0.25 = 4.733\ m$$

2.7. Height of the location of the submerged perforated plate relative to the horizontal axis of the PG vessel

$$h_{pp} = h_0 + h_1 - h_{wl},$$

$$= 0.3 + 0.35 - 0.1 = 0.55\ m$$

$$h_{dr} = 0.1\ m$$

2.8. Internal diameter of the steam generator housing, m

$$D_{ves.in} = \sqrt{4 \cdot h_{pp}^2 + B_{ves.pp}^2}.$$

$$= \sqrt{4 \cdot (0.55)^2 + (4.733)^2} = 4.859\ m.$$

$$F_{es} = B_{ves.pp} \cdot l_{tube} = 4.733 \cdot 16.5 = 78.34\ m^2$$

2.9. Superficial steam velocity, m/s

$$w''_o = \frac{D_2}{F_{es} \cdot \rho''_2},$$

Here ρ''_2 is density of saturated vapor at the pressure p_2 of the working fluid

ρ''_2=34.12 kg/m³

$$w''_o = \frac{413}{78.34 \cdot 34.12} = 0.1545 \ \frac{m}{s};$$

The true volumetric vapor content in the water layer above the submerged perforated plate, m

$$\varphi_{bub} = \frac{w''_0}{w''_0 + (0,65 - 0,039 \cdot p_2)}.$$

$$\varphi_{bub} = \frac{0.1545}{0.1545 + (0.65 - 0.039 \cdot 17.6)} = 0.282 \ m.$$

Actual (real) water level above above the submerged perforated plate, m

$$h_{real} = \frac{h_{wl}}{(1 - \varphi_{bub})}$$

$$h_{real} = \frac{0.1}{1 - 0.282} = 0.139 \ m;$$

$$h_{sv} = \frac{D_{ves.in}}{2} - (h_{pp} + h_{real}).$$

$$= \frac{4.859}{2} - (0.55 + 0.139) = 1.34 \ m;$$

The minimum permissible height of the vapor volume must correspond to the following condition

$$h_{sv} \geq 0.4 \ m$$

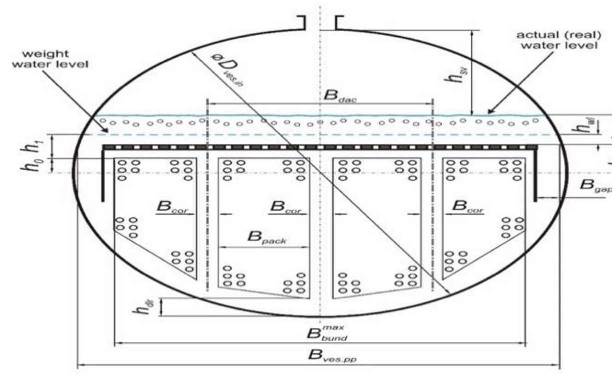
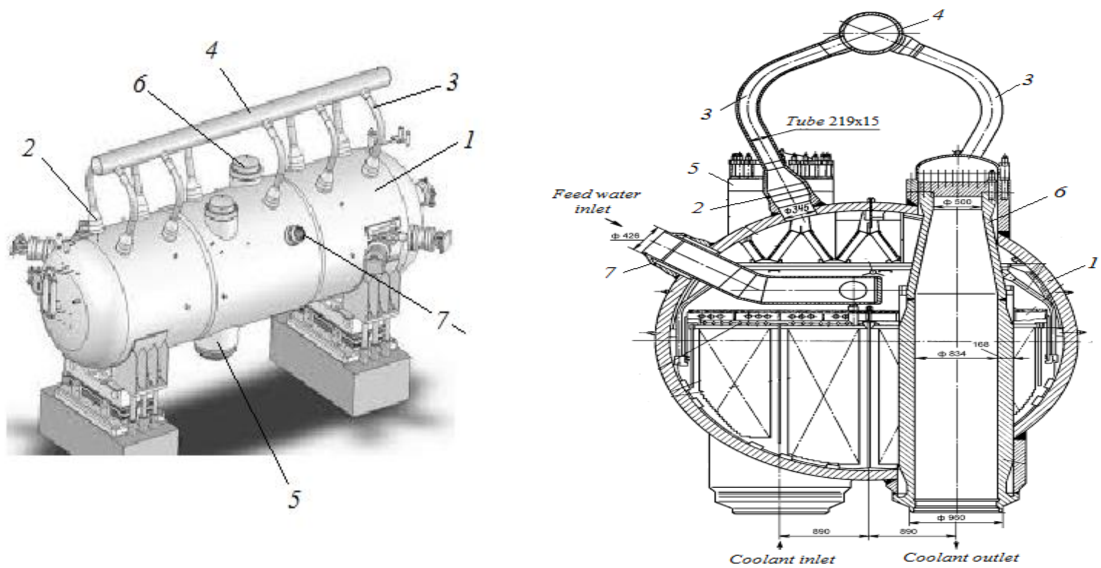


Figure 21. To determine the main layout dimensions

Characteristics of steam outlet nozzles.



a) b)

Figure 22. Exterior (a) and cross section (b) of a horizontal steam generator:

$$d_{noz,in} = \sqrt{\frac{4 \cdot 413}{\pi \cdot 9 \cdot 36 \cdot 34.12}} = 0.218\ m$$

Characteristics of the feed pipe

$$\frac{\pi \cdot d_{fw.in}^2}{4} \cdot w_{fw} = \frac{D_{fw}}{\rho_{fw}},$$

$$d_{fw,in} = \sqrt{\frac{4 \cdot 827.7}{\pi \cdot 4 \cdot 843.9}} = 0.559\ m.$$

3. Mechanical calculation

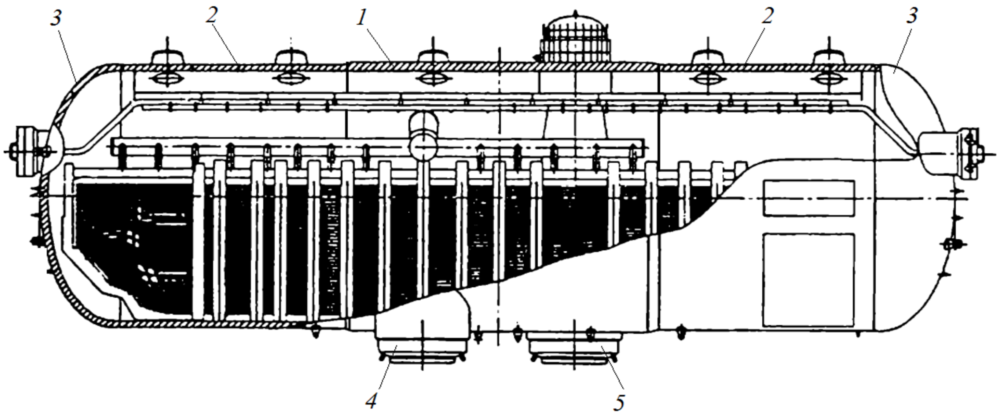


Figure 23. Longitudinal section of a horizontal steam generator

1.1. Calculation of the wall thickness of the side shell

$$\delta_{vss} = \frac{7.406 \cdot 4.859}{2 \cdot 1 \cdot 181.15 - 7.406} = 0.102\ m.$$

$$[\sigma] = \min\left\{\frac{\sigma_{sl}}{n_{sl}}; \frac{\sigma_{0,2}}{n_{0,2}}\right\} = min\left\{\frac{471}{2.6}; \frac{304}{1.5}\right\} = 181.15$$

$$\delta_{vss} = \frac{p_{calc} \cdot D_{ves.in}}{2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C$$

$$C = 0$$

$$\delta_{vss} = 0.102 + 0.001 = 0.103\ m.$$

1.2. Calculation of the wall thickness of the central shell

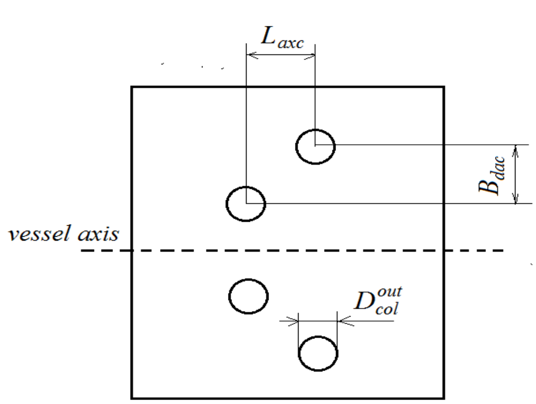


Fig. 24. To the calculation of the strength coefficient

$$\varphi_1 = \frac{2 \cdot L_{axc} - D_{col}^{out}}{2 \cdot L_{axc}} \;;$$

$$L_{axc} = 2 \cdot D_{col}^{out} = 2 \cdot 1.0346 = 2.069\ m$$

$$\varphi_1 = \frac{2 \cdot 2.069 - 1.0346}{2 \cdot 2.069} = 0.75$$

$$\varphi_2 = \frac{2 \cdot \left(2 \cdot B_{dac} - D_{col}^{out}\right)}{2 \cdot B_{dac}};$$

$$\varphi_2 = \frac{2 \cdot (2 \cdot 3.649 - 1.0346)}{2 \cdot 3.649} = 1.716$$

$$\varphi_3 = \frac{1 - \frac{D_{col}^{out}}{L_{axc}} \cdot \frac{1}{\sqrt{1+m^2}}}{\sqrt{1 - 0.75 \cdot \left(\frac{m^2}{1+m^2}\right)^2}},$$

$$m = B_{dac} / L_{axc} \;;$$

$$m = \frac{3.649}{2.069} = 1.763$$

$$\varphi_3 = \frac{1 - \frac{1.0346}{2.069} \cdot \frac{1}{\sqrt{1 + 1.763}}}{\sqrt{1 - 0.75 \cdot \left(\frac{(1.763)^2}{1 + (1.763)^2}\right)^2}} = 0.997$$

$$\varphi_{min} = \varphi_1 = 0.75$$

$$\delta_{vss} = \frac{7.406 \cdot 4.859}{2 \cdot 0.75 \cdot 181.15 - 7.406} = 0.1362\ m$$

1.3. Calculation of the thickness of bottom

$$\delta_{bot} = \frac{p_{calk} \cdot D_{ves.in}}{4 \cdot \varphi \cdot [\sigma]} \cdot \frac{D_{ves.in}}{2 \cdot h}, \qquad (3.4)$$

$$h = 0.2 \cdot 4.859 = 0.972\ m$$

$$\delta_{bot} = \frac{7.406 \cdot 4.859}{4 \cdot 1 \cdot 181.15} \cdot \frac{4.859}{2 \cdot 0.972} = 0.124\ m.$$

2. Hydraulic calculation of the steam generator

For the calculate the friction pressure losses it is necessary to use the Altshul formula

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2}, \qquad (4.1)$$

$\rho_{avr} = f\left(p_1, t_{1avr}\right)$ is the average density of the coolant in the SG, kg/m³;

$\xi_{fr} = 0{,}11 \cdot \left[\left(\Delta / d_h\right) + \left(68/\mathrm{Re}\right)\right]^{0{,}25}$ is coefficient of friction;

$\mathrm{Re} = w \cdot d_h / \nu_{avr}$ is Reynolds number;

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_{avr} \cdot w^2}{2}, \qquad (4.2)$$

Table 20. The values of the coefficient of local resistance

Type of local resistance	Coefficient value ξ_{loc}
Inlet of the coolant to the tubes from the collector	0.5
Output of the coolant from the tubes to the collector	1.0
Rotation of the coolant in U-shaped tubes	0.5

Table 21. To the hydraulic calculation of the horizontal ste)am generator

№	Plot name	Type of hydraulic resistance	Characteristic coolant velocity, m/s	Characteristic dimensions, m	Pressure losses, Па
1	Lifting movement of the coolant in the inlet collector (from section A-A to point 1)	Pressure drops due to friction. Friction factor $\xi_{fr.col}$ (Altshul formula)	$w_{col} = 4.7$ (the continuity equation for the collector)	$d_h = D_{col}^{in} =$ $L \approx D_{ves.in}/2 =$ (section 2 " Design calculation")	$\Delta P_{fr} = 0.01168 \cdot \frac{2.429}{0.8} \cdot \frac{714.04 \cdot (4.7)^2}{2} = 279.8\ pa.$
2	Inlet of the coolant to the tubes from the collector (point 1)	Local pressure drops Local resistance coefficient $\xi_{loc.in}$	$w_{tube} = 5$ (section 1.4. «Thermal calculation»)	$d_h = d_{in} =$ (section 1.3. «Thermal calculation»)	$\Delta P_{loc} = 0.5 \cdot \frac{714.04 \cdot (5)^2}{2} = 4462.8\ pa.$
3	Movement of the coolant in heat exchange tubes (from point 1 to point 3)	Pressure drops due to friction. Friction factor $\xi_{fr.tube}$ (Altshul formula)	$w_{tube} = 5$ (section 1.4. «Thermal calculation»)	$d_h = d_{in} =$ $L = l_{avr} =$ (section1.3. «Thermal calculation»)	$\Delta P_{fr} = 0.0273 \cdot \frac{16.55}{0.0136} \cdot \frac{714.04 \cdot (5)^2}{2} = 296600\ Pa.$
4	Output of the coolant from the tubes to the collector (point 3)	Local pressure drops , Local resistance coefficient $\xi_{loc.out}$	$w_{tube} = 5$ «Thermal calculation»)	$d_h = d_{in} =$ «Thermal calculation»)	$\Delta P_{loc} = 1 \cdot \frac{714.04 \cdot (5)^2}{2} = 8925.5\ Pa.$
5	Downward movement of the coolant in the output collector (from point 3 to section B-B)	Pressure drops due to friction. Friction factor $\xi_{fr.col}$	$w_{col} = 4$ (f	$d_h = D_{col}^{in} =$ $L \approx D_{ves.in}/2 =$ (	$\Delta P_{fr} = 0.01168 \cdot \frac{2.429}{0.8} \cdot \frac{714.04(4.7)^2}{2} = 279.8\ pa.$
Total					$= 310.5\ KPa.$ $= 0.3105\ MPa.$

2.1. Calculation of separation in a horizontal saturated steam generator

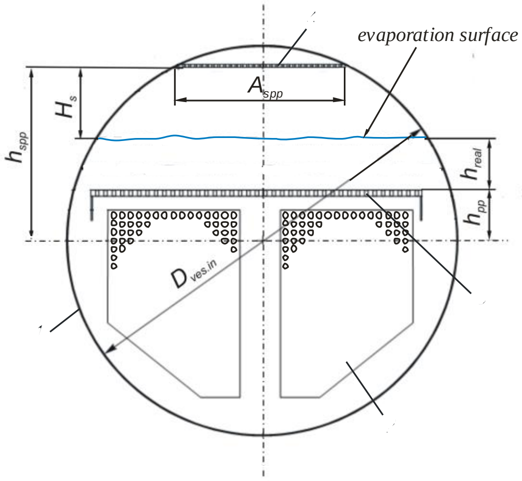


Figure 25. To the calculation of separation

$$F_{spp} = A_{spp} \cdot l_{avr}$$

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{D_{ves.in}}{2}\right)^2 - \left(h_{spp}\right)^2}$$

$$h_{spp} = \left(0{,}8...0{,}85\right) \cdot \frac{D_{ves.in}}{2}$$

$$h_{spp} = 0.82 \cdot \frac{4.859}{2} = 1.992\ m\ ;$$

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{4.859}{2}\right)^2 - (1.992\ )^2} = 2.781\ m^2;$$

$$F_{spp} = 2.781 \cdot 16.5 = 46.034\ m^2.$$

Distance (height) from the evaporation surface to steam-receiving perforated plate

$$H_s = 1.992 - 0.55 - 0.1393 = 1.303\ m.$$

Steam velocity before steam-receiving perforated plate

$$w''_{spp} = \frac{D_2}{\rho'' \cdot F_{spp}} = \frac{413}{34.1 \cdot 46.034} = 0.263\,\frac{m}{s}.$$

2.2. Determining the critical height of the steam volume

$$F(p) = 3.45 \cdot 10^3 \cdot \left[\frac{34.1 \cdot (747.2)^2}{(747.2 - 34.1)^6}\right]^{0.25} = 11.97\ ;$$

$$H_{sv}^{cr} = 0.087 \cdot [0.1545 \cdot 11.97]^{1.3} = 0.194\ .$$

2.3. Steam moisture at the top of the steam volume

$$M = 2.05 - 3.049 \cdot 6.583 + 0.9614 \cdot (6.583)^2 = 23.6\ ;$$

$$Y = 23.6 \cdot 10^{-4} \cdot \frac{(0.1545)^{2.76}}{(1.303)^{2.3}} = 0.0007\ \%\ .$$

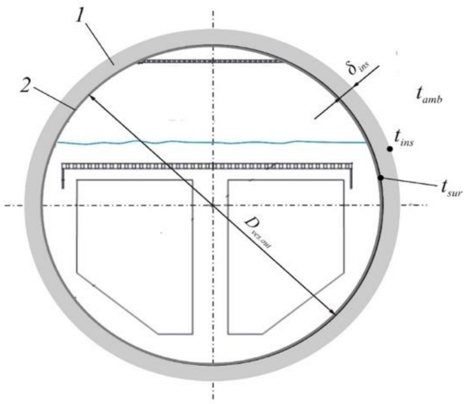


Fig 26. Design scheme of single-layer thermal insulation with a coating layer:

$$\delta_{ins} = \frac{\lambda_{ins} \cdot (t_{sur} - t_{ins})}{\alpha_{out} \cdot (t_{ins} - t_{amb})}; \qquad (1)$$

$t_{ins}^{avr} = 0{,}5 \cdot (t_{sur} + t_{ins})$ is average temperature of the insulation layer, °C.

$$t_{ins}^{avr} = \frac{281.7 + 45}{2} = 163.3\ ℃\ ;$$

$$\lambda_{ins} = 0.0002 \cdot (163.3. + 273) + 0.036 = 0.1233 \frac{W}{m \cdot K}\ ;$$

$$\delta_{ins} = \frac{0.1233 \cdot (281.7 - 45)}{8 \cdot (45 - 20)} = 0.1459\ m;$$

$$d_{out} = D_{ves.in} + 2 \cdot \delta_{vss} = 4.859 + 2 \cdot 0.1024 = 5.064\ m\ ;$$

$$\frac{d_{ins}}{5.064} \cdot \ln \frac{d_{ins}}{5.064} = \frac{2 \cdot 0.1233 \cdot (281.7 - 45)}{8 \cdot (45 - 20)}\ ;$$

$$d_{ins} = 5.86\ m\ .$$

Design NPP with WWER-1000 Type Reactor

1. Calculation of the basic thermal diagram

Table 22. Initial Data

Name	Symbol	Value
Electrical power	N_e MW	1000
Initial pressure	p_0, MPa	6.27
Initial temperature	t_0, °C	t_{sat0}
Final pressure	p_c, kPa	3.5
Number stages of Superheater	____	1
Feed water temperature	t_{fw}, ℃	220
Deaerator pressure	p_d , MPa	0.62

Table 23. Initial parameters

t_0	278.5℃
$h_0 = f(p_0, t_0)$	2782 kJ/kg
$s_0 = f(p_0, t_0)$	5.86 kJ/(kg℃)
$x = f(p_0, h_0)$	1

2. Calculation of main condensate

Main condensate temperature at the inlet to the deaerator $\mathbf{t_{mc}}$

$$t_{mc} = t_d - \Delta t_d$$

$$\Delta t_d = 12 \div 15 \text{ ℃}$$

we take it $\Delta t_d = 12$ ℃

$$t_d = f(p_d) = 160.1 \text{ ℃}$$

$$t_{mc} = 160.1 - 12 = 148.1 \text{ ℃.}$$

Find Cooler seals and ejector temperature $\mathbf{t_{cse}}$

$$t_{cs} = t_c + \Delta t_{cse}$$

$$\Delta t_{cse} = 3 \div 5\text{℃}$$

we take it $\Delta t_{cse} = 4$ ℃

$$t_c = f(p_c) = 26.7℃$$

$$t_{cse} = 26.7 + 3 = 30.7\ ℃$$

$$h_{cse} = f(t_{cse}) = f(30.7) = 129$$

$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}},$$

Δt_{LPH} it between 25÷35 ℃

We assume first $\Delta t_{LPH} = 30$ ℃

$$n_{LPH} = \frac{148.1 - 30.7}{30} = 3.91 \approx 4$$

$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}},$$

$$\Delta t_{LPH} = \frac{148.1 - 30.7}{4} = 29.4\ ℃$$

3. Calculation of low pressure heater

$$\Delta t_{LPH} = 29.4℃$$

$$t_{Hi} = t_{Hi-1} + \Delta t_{LPH}$$

$\theta_{LPH} = 1 \div 2$ we take it 2℃

$p_{exj} = (1.02 \div 1.05)p_{Hj}$ we take it $1.04p_{Hj}$

First RHFW is closed

$$t_{H6} = t_{cse} + \Delta t_{LPH} = 30.7 + 29.4 = 60.0\ ℃$$

$$t_{s6} = t_{H6} + \theta_{LPH} = 60.0 + 2 = 62.0\ ℃ \rightarrow p_{H6} = f(t_{s6}) = 0.0219\ \text{MPa}$$

$$p_{ex6} = (1.04)p_{H6} = 1.04 \cdot 0.0219 = 0.0228\ \text{MPa}$$

Second RHFW is closed

$$t_{H5} = t_{H6} + \Delta t_{LPH} = 60.0 + 29.4 = 89.4℃$$

$$t_{s5} = t_{H5} + \theta_{LPH} = 89.4 + 2 = 91.4\ ℃ \rightarrow p_{H5} = f(t_{s5}) = 0.074\ \text{MPa}$$

$$p_{ex5} = (1.04)p_{H5} = 1.04 \cdot 0.074 = 0.077\ \text{MPa}.$$

Third RHFW is Closed

$$t_{H4} = t_{H5} + \Delta t_{LPH} = 89.4 + 29.4 = 118.8\ ℃$$

$$t_{s4} = t_{H4} + \theta_{LPH} = 118.8 + 2 = 120.8℃ \rightarrow p_{H4} = f(t_{s4}) = 0.203\ \text{MPa}$$

$p_{ex4} = (1.04)p_{H4} = 1.04 \cdot 0.203 = 0.211$ MPa.

Fourth RHFW is Closed

$$t_{H3=mc} = t_{H4} + \Delta t_{LPH} = 118.8 + 29.4 = 148.1℃$$

$$t_{s3} = t_{H3} + \theta_{LPH} = 148.1 + 2 = 150.1℃ \rightarrow p_{H3} = f(t_{s3}) = 0.477 \text{ MPa}$$

$$p_{ex3} = (1.04)p_{H3} = 1.04 \cdot 0.477 = 0.497 \text{ MPa}$$

Table 24. Low pressure heater properties

Type	NO	t_H,℃	p_H, kPa	t_s,℃	p_{exj}, MPa
CL	3=mc	148.1	0.477	150.1	0.497
CL	4	118.8	0.203	120.8	0.211
CL	5	89.4	0.074	91.4	0.077
CL	6	60.0	0.0219	62.0	0.0228
	t_{cse}	30.7	-	-	-

Condensate pumps pressure $\mathbf{p_{cp}}$

$p_{cp1} = 4 \div 5$ bar , assume 5 bars = 0.5 MPa

$p_{cp2} = (1.1 \div 1.4)p_{MLPH2}$, assume 1.4· p_{MLPH2}

$$p_{cp2} = 1.4 \cdot (p_d) = 1.4 \cdot (0.62) = 0.868 \text{ MPa.}$$

$$h'_d = f(p_d) = f(0.627) = 676 \text{ kJ/kg}$$

- $\Delta h_{fwp} = v(p_{fwp} - p_d)$, where v is specific volume

$v = f(p_d) = f(0.627) = 0.0011 \text{ m}^3/\text{kg}$

$\Delta h_{fwp} = v\left(p_{fwp} - p_d\right) = 0.0011\ (8.15 - 0.627) \cdot 10^3 = 8.29 \text{ kJ/kg}$

$$h_{fwp} = h'_d + \Delta h_{fwp} = 676 + 8.29 = 684 \text{ kJ/kg}$$

$$t_{fwp} = f\left(p_{fwp}, h_{fwp}\right) = f(8.15, 684) = 161 \text{ ℃}$$

$$\Delta t_{HPH} = \frac{t_{fw} - t_{fwp}}{z_{HPH}};$$

$$z_{HPH} = \frac{t_{fw} - t_{fwp}}{\Delta t_{HPH}};$$

$z_{HPH} = \frac{220-161}{30} = 1.965 \approx 2;$

$\Delta t_{HPH} = \frac{220-161}{2} = 29.5.$

Real temperature rise after each heater

$$t_{fw} = (z_{HPH} \cdot \Delta t_{HPH}) + t_{fwp} = (29.5 \cdot 1) + 161 = 190.5\ ℃$$

$$t_{fw} = (z_{HPH} \cdot \Delta t_{HPH}) + t_{fwp} = (29.5 \cdot 2) + 161 = 220\ ℃$$

4. Calculation of high pressure heater

$$t_{H2} = t_{fwp} + \Delta t_{HPH} = 161 + 29.5 = 190.5\ ℃$$

$$t_{s2} = t_{H2} + \theta_{HPH} = 190.5 + 4 = 194.5℃ \rightarrow p_{H3} = f(t_{s2}) = f(194.5)$$

$$= 1.384\ \text{MPa}$$

$$p_{ex3} = (1.03)p_{H3} = 1.03 \cdot 1.384 = 1.426\ \text{MPa}$$

closed

$$t_{H1} = t_{H2} + \Delta t_{HPH} = 190.5 + 29.5 = 220℃$$

$$t_{s1} = t_{H1} + \theta_{HPH} = 220 + 4 = 224\ ℃ \rightarrow p_{H2} = f(t_{s1}) = f(224) = 2.502\ \text{MPa}$$

$$p_{ex2} = (1.02)p_{H2} = 1.03 \cdot 2.502 = 2.577\ \text{MPa}$$

Table 25. High *pressure heater parameters*

Type	NO	t_{Hj},℃	t_{sj},℃	p_{Hj}, MPa	p_{exj}, MPa
CL	1~fw	220	224	2.502	2.577
CL	2	190.5	194.5	1.348	1.426
fwp	t_{fwp}	161.0	-	-	

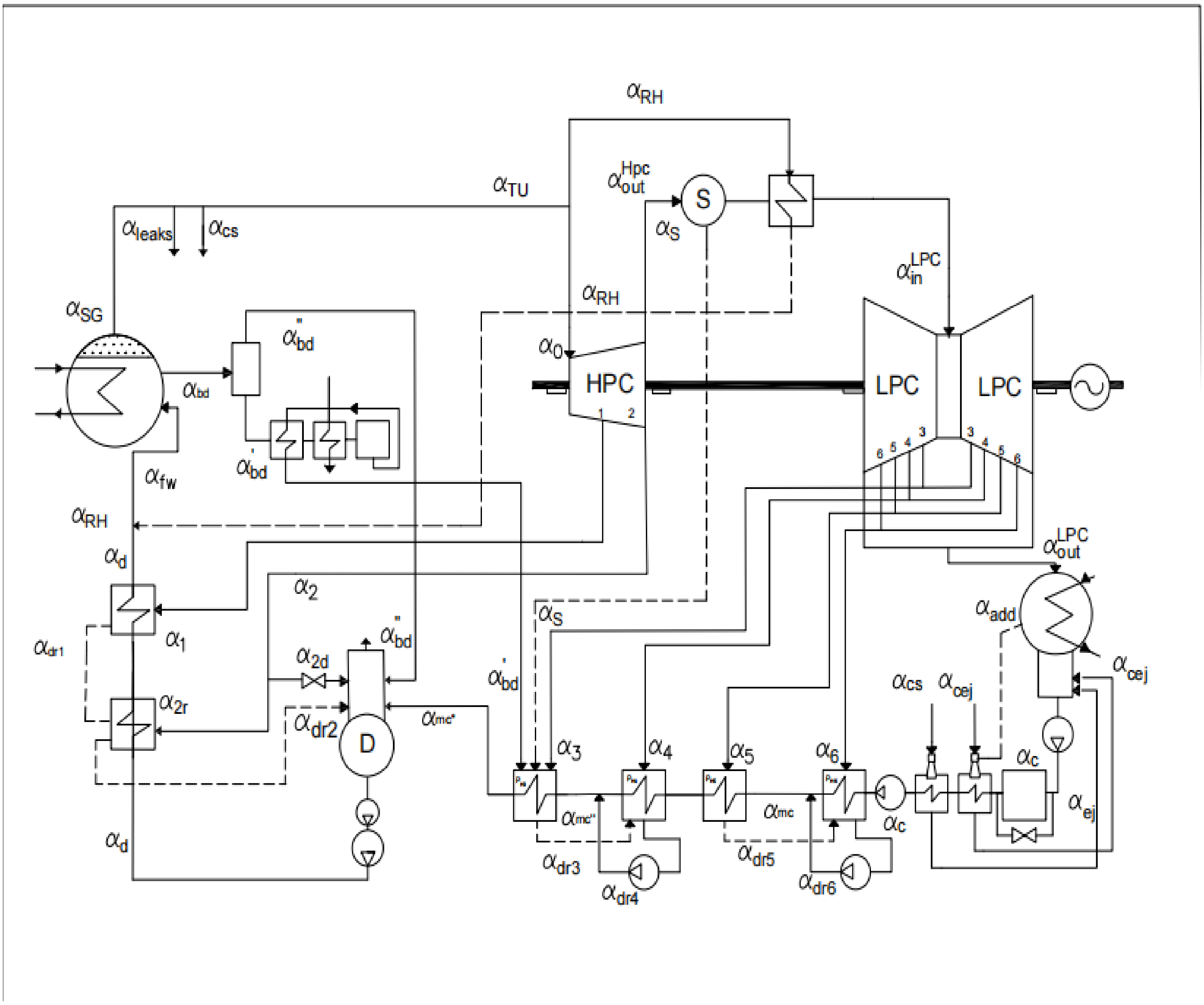


Figure 27. Sachem of NPP

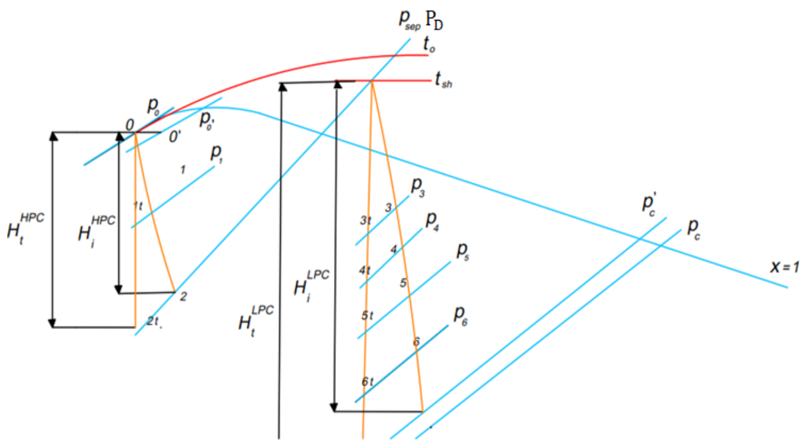


Figure 28. h-s diagram

5. Calculation of the process in the turbine

$$p_{0'} = p_0(0{,}95 \div 0{,}97) = p_0(0.95) = 6 \cdot (0.95) = 5.96\text{MPa}$$

Steam parameters at **0′**

Table 26. Steam parameters (0')

$p_{0'}$, MPa	5.96
$h_{0''} = h_0$ kJ/kg	2782
$t_{0'} = f(p_{0'}, h_{0'})$, ℃	275,1
$s_{0'}f(p_{0'}, h_{0'}) =$, kJ/(kg℃)	5.89

$$s_{0'} = s_{1t} = 5.89 \text{ kJ/(kg℃)}$$

$$h_{1t} = f(p_1, s_{1t}) = f(2.58, 5.89) = 2627 \text{ kJ/kg}$$

$$H_0^{HPC} = h_0 - h_{1t} = 2782 - 2627 = 154 \text{ kJ/kg}$$

$$H_i^{HPC} = H_0^{HPC} \cdot \eta_{0i}^{HPC} = 154 \cdot 0.83 = 128 \text{ kJ/kg}$$

$$h_1 = h_0 - H_i^{HPC} = 2781 - 128 = 2654 \text{ kJ/kg}$$

$$s_1 = f(p_1, h_1) = f(2.58, 2654) = 5.946 \text{ kJ/(kg℃)}$$

$$t_1 = f(p_1, s_1) = f(2.58, 5.946) = 225.6 \text{ ℃}$$

Isentropic process 2nd extraction where $p_2 = p_{ex2} = 2.085$ MPa, from Table 10

$$s_{0'} = s_{2t} = 5.89 \text{ kJ/(kg℃)}$$

$$h_{2t} = f(p_2, s_{0'}) = f(1.426\ ,5.89) = 2523 \text{ kJ/kg}$$

$$H_0^{HPC} = h_0 - h_{2t} = 2782 - 2523 = 258 \text{ kJ/kg}$$

$$H_i^{HPC} = H_0^{HPC} \cdot \eta_{0i}^{HPC} = 258 \cdot 0.83 = 214 \text{ kJ/kg}$$

$$h_2 = h_0 - H_i^{HPC} = 2782 - 214 = 2567 \text{ kJ/kg}$$

$$s_2 = f(p_2, h_2) = f(1.426\ ,2567) = 5{,}99 \text{ kJ/(kg℃)}$$

$$t_2 = f(p_2, s_2) = f(2.085, 5.974) = 195.9 \text{ ℃}$$

$$p_s = p_2 = 1.426 \text{ MPa}$$

Pressure losses in separator is about 5 %

$$p_{s'} = (1 - 0.05)p_s = (1 - 0.05) \cdot 1.426 = 1.354 \text{ MPa}$$

Enthalpy after separation $h_{s'}$

$$h_{s'} = f(p_{s'}, x = 1) = f(1.354, x = 1) = 2788 \text{ kJ/kg}$$

Superheating parameters

Pressure losses in superheater p_{SH} is about 95% of $p_{s'}$

$$p_{SH} = (0.95) \cdot p_{s'} = (0.95) \cdot 1.354 = 1.287 \text{ MPa}$$

• $\Delta t_R = 15 \div 20°C$ for the first stage, assume 20 °C

$$t_{SH1} = t_0 - \Delta t_R = 278.5 - 20 = 258.5 \text{ °C};$$

Enthalpy of steam after first superheater h_{SH1}

$$h_{SH1} = f(p_{SH}, t_{SH1}) = f(1.287, 258.5) = 2952 \text{ kJ/kg}$$

Enthalpy at the drain first superheater h'_{SH1}

$$h'_{SH1} = f(t_1) = f(260.6) = 1127 \text{ kJ/kg}$$

$$p_{SH'} = p_{SH}(0{,}95 \div 0{,}97) = p_{SH} \cdot (0.95) = 1.287 \cdot (0.95) = 1.22 \text{ MPa}$$

Table 27. Superheater parameters

$p_{SH'}$, MPa	1.22
$h_{SH'} = h_{Sh1}$, kJ/kg	1127
$t_{SH'} = f(p_{SH'}, h_{SH'})$, °C	188.8
$s_{SH'} f(p_{SH'}, h_{SH'}) =$, kJ/(kg°C)	6.854

with absolute internal efficiency $\eta_{0i}^{LPC} = 0.82$

Isentropic process 3th extraction where $p_3 = p_{ex3} = 0.497$ MPa, from *Table 2*

$$s_{SH'} = s_{3t} = 6.854 \text{ kJ/(kg°C)}$$

$$h_{3t} = f(p_3, s_{SH'}) = f(0.497, 6.854) = 2757 \text{ kJ/kg}$$

$$H_0^{LPC} = h_{SH'} - h_{3t} = 2952 - 2757 = 195 \text{ kJ/kg}$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 195 \cdot 0.82 = 160 \text{ kJ/kg}$$

$$h_3 = h_{SH'} - H_i^{LPC} = 2952 - 160 = 2792 \text{ kJ/kg}$$

$$s_3 = f(p_3, h_3) = f(0.497, 2792) = 6.925 \text{ kJ/(kg°C)}$$

$$t_3 = f(p_3, s_3) = f(0.47, 7) = 170.7 \text{ °C}$$

$$s_{SH'} = s_{3t} = 6.854 \text{ kJ/(kg°C)}$$

$$h_{4t} = f(p_5, s_{SH'}) = f(0.212, 6.854) = 2605 \text{ kJ/kg}$$

$$H_0^{LPC} = h_{SH'} - h_{4t} = 2952 - 2605 = 347 \text{ kJ/kg}$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 347 \cdot 0.82 = 285 \text{ kJ/kg}$$

$$h_4 = h_{SH'} - H_i^{LPC} = 2952 - 285 = 2667 \text{ kJ/kg}$$

$$s_4 = f(p_4, h_4) = f(0.212, 2667) = 7.0 \text{ kJ/(kg°C)}$$

$$t_4 = f(p_4, s_4) = f(0.212, 7.0) = 122.0 \text{ °C}$$

Isentropic process 5th extraction where $p_5 = p_{ex5} = 0.077$ MPa, from *Table 2*

$$s_{SH'} = s_{5t} = 6.854 \text{ kJ/(kg°C)}$$

$$h_{5t} = f(p_5, s_{SH'}) = f(0.077, 6.854) = 2443 \text{ kJ/kg}$$

$$H_0^{LPC} = h_{SH'} - h_{5t} = 2952 - 2443 = 508 \text{ kJ/kg}$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 508 \cdot 0.82 = 417 \text{ kJ/kg}$$

$$h_5 = h_{SH'} - H_i^{LPC} = 2952 - 417 = 2535 \text{ kJ/kg}$$

$$s_5 = f(p_5, h_5) = f(0.063, 2538) = 7.095 \text{ kJ/(kg°C)}$$

$$t_5 = f(p_5, s_5) = f(0.063, 7.187) = 92.4 \text{ °C}$$

Isentropic process 6th extraction where $p_7 = p_{ex7} = 0.023$ MPa, from *Table 2*

$$s_{SH'} = s_{6t} = 6.854 \text{ kJ/(kg°C)}$$

$$h_{6t} = f(p_6, s_{SH'}) = f(0.023, 6.854) = 2272 \text{ kJ/kg}$$

$$H_0^{LPC} = h_{SH'} - h_{6t} = 2962 - 2272 = 680 \text{ kJ/kg}$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 680 \cdot 0.82 = 555 \text{ kJ/kg}$$

$$h_6 = h_{SH'} - H_i^{LPC} = 2952 - 555 = 2394 \text{ kJ/kg}$$

$$s_6 = f(p_6, h_6) = f(0.023, 2394) = 7.208 \text{ kJ/(kg°C)}$$

$$t_6 = f(p_6, s_6) = f(0.023, 7.208) = 62.9 \text{ °C}$$

Isentropic process C' point

$$p_{c'} = (1.03 \div 1.05)p_c = 1.04p_c = 1.04 \cdot 0.0035 = 0.00364 \text{ MPa}$$

$$s_{SH'} = s_{c't} = 6.854 \text{ kJ/(kg°C)}$$

$$h_{c't} = f(p_{c'}, s_{SH'}) = f(0.0035, 6.854) = 2051 \text{ kJ/kg}$$

$$H_0^{LPC} = h_{SH'} - h_{c't} = 2952 - 2051 = 901 \text{ kJ/kg}$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 901 \cdot 0.82 = 738 \text{ kJ/kg}$$

$$h_{c'} = h_{SH'} - H_i^{LPC} = 2952 - 738 = 2213 \text{ kJ/kg}$$

$$s_{c'} = f(p_{c'}, h_{c'}) = f(0.0035, 2213) = 7.384 \text{ kJ/(kg°C)}$$

$$t_{c'} = f(p_{c'}, s_{c'}) = f(0.0035, 7.478) = 27.3 \text{ °C}$$

Exhaust steam quality from LPC,$x^{LPC} = f(t_{c'}, h_{c'}) = f(27.3, 2213) = 0.861$

Underproduction factor

$$y_i = \frac{H_i - H_j}{H_i}$$

For turbine with steam separating and superheating system

$H_i = (h_0 - h_c) + (h_{SH1} - h_s) = (2782 - 2213) + (2952 - 2788) = 953 kJ/kg$

where h_s, Enthalpy before separation. $\Delta h_{SSH} = h_{SH2} - h_s = 2952 - 2788 = 214$

For extraction before separating and superheating $H_j = h_0 - h_j$

$$H_0 = h_0 - h_{0'} = 2782 - 2782 = 0 \text{ kJ/kg}$$

$$H_1 = h_0 - h_1 = 2782 - 2654 = 128 \text{ kJ/kg}$$

$$H_2 = h_0 - h_2 = 2782 - 2567 = 214 \text{ kJ/kg}$$

For extraction after separating and superheating $H_j = \left(h_0 - h_j\right) + \Delta h_{SSH}$

$$H_3 = (h_0 - h_3) + \Delta h_{SSH} = (2782 - 2792) + 214 = 374 \text{ kJ/kg}$$

$$H_4 = (h_0 - h_4) + \Delta h_{SSH} = (2782 - 2667) + 214 = 499 \text{ kJ/kg}$$

$$H_5 = (h_0 - h_5) + \Delta h_{SSH} = (2782 - 2535) + 214 = 631 \text{ kJ/kg}$$

$$H_6 = (h_0 - h_6) + \Delta h_{SSH} = (2782 - 2394) + 214 = 772 \text{ kJ/kg}$$

$$H_{c'} = (h_0 - h_{c'}) + \Delta h_{SSH} = (2785 - 2213) + 214 = 953 \text{ kJ/kg}$$

$$y_0 = \frac{H_i - H_0}{H_i} = \frac{953 - 0}{953} = 1;$$

$$y_1 = \frac{H_i - H_1}{H_i} = \frac{953 - 128}{953} = 0.866;$$

$$y_2 = \frac{H_i - H_2}{H_i} = \frac{953 - 214}{972} = 0.775;$$

$$y_3 = \frac{H_i - H_3}{H_i} = \frac{953 - 374}{953} = 0.607;$$

$$y_4 = \frac{H_i - H_4}{H_i} = \frac{953 - 499}{953} = 0.476;$$

No.	Extracted steam			Steam in heaters (drain)			Heater's outlet water			Extracted steam work in cylinder	Underproduction factor
	p_j	t_j	h_j	P_{Hj}	T_{sj}	h'_j	p_{wj}	t_{wj}	h_{wj}	H_i	y_i
	MPa	°C	kJ/kg	MPa	°C	kJ/kg	MPa	°C	kJ/kg	kJ/kg	
0	6270	2781,534	278,4744	-	-	-	-	-	-	-	-
0'	5956,5	2781,534	275,112	-	-	-	-	-	-	-	1
1	2577,107	2653,566	225,5777	2502,046	224	962,1855	220	8151	945,3072	127,9682	0,8657
2	1425,67	2567,15	195,898	1384,146	194,5159	827,7505	190,5159	8151	813,0575	214,3838	0,775008
D	1425,67	2567,15	195,898	620	160,1182	676,0886	-	620	676,0886	-	-
Sep	1354,387	2787,836	193,502	1354,387	193,5054	823,2256	-	-	-	-	0,775008
SH1	1.13	260.6	2962	6.0	260.6	1137	–	–	–	0	1
4	496,7164	2792,106	170,7516	477,612	150,1182	632,7621	148,1182	868	624,3894	373,9917	0,607502
5	211,6137	2667,157	122,0054	203,4748	120,757	507,0028	118,757	868	498,9801	498,9415	0,47637
6	76,94518	2534,738	92,44095	73,98575	91,39571	382,8415	89,39571	868	375,046	631,3599	0,337399
7	22,77686	2394,22	62,8963	21,90082	62,03445	259,6669	60,03445	868	252,0106	771,8782	0,189928
C'	3,64	2213,247	27,34122	-	-	-	-	-	-	952,851	0
C	3,5	2046,837	26,67319	3,5	26,67319	111,8357	-	-	-	-	-

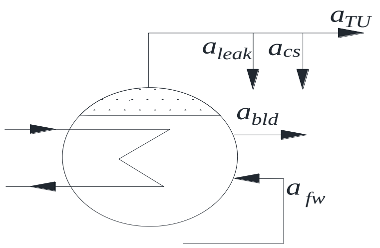
$$y_5 = \frac{H_i - H_5}{H_i} = \frac{953 - 631}{953} = 0.337;$$

$$y_6 = \frac{H_i - H_6}{H_i} = \frac{953 - 772}{953} = 0.189;$$

$$y_{c\prime} = \frac{H_i - H_{c\prime}}{H_i} = \frac{953 - 953}{953} = 0;$$

Power calculations

Feedwater



$$\alpha_{fw} = \alpha_{TU} + \alpha_{leak} + \alpha_{cs} + \alpha_{bld};$$

$$\alpha_{TU} = \alpha_0 + \alpha_{SH};$$

$$\alpha_{fw} = \alpha_0 + \alpha_{SH} + \alpha_{leak} + \alpha_{cs} + \alpha_{bld};$$

$\alpha_{fw} = 1 + \alpha_{SH} + 0.01 + 0.005 + 0.005$ (1)

Relative feed water flowrate

$\alpha_{fw} = 1.02 + \alpha_{SH}$; (2)

$\alpha_{fw} = \alpha_d + \alpha_{SH}$;

$$\alpha_{bd} = \alpha'_{bd} + \alpha''_{bd}$$

$$\alpha_{bd} \cdot h'_0 = h'_{bd} \cdot \alpha'_{bd} + h''_{bd} \cdot \alpha''_{bd};$$

$$h''_{bd} = f(P_{tank});$$

$$P_{tank} = (1.02 \div 1.08) \cdot P_d = 1.06 \cdot 0.62 = 0.657 \text{ MPa};$$

$$h''_{bd} = f(P_{tank} \rightarrow \text{saturation vapour}) = 2760 \ {}^{kJ}/_{kg};$$

$$h'_{bd} = f(P_{tank} \rightarrow \text{saturation water}) = 686 \ {}^{kJ}/_{kg};$$

$$h'_0 = f(P_0 \rightarrow \text{saturation water}) = 1229 \ {}^{kJ}/_{kg};$$

α_1	0.081

- **Separator**

$$\alpha_{out}^{HPC} = \alpha_0 - \alpha_1 - \alpha_2\ ;$$

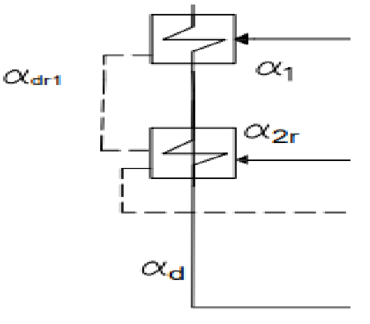
$$\alpha_{out}^{HPC} = \alpha_s + \alpha_{in}^{LPC}\ ;$$

$$\alpha_{out}^{HPC} \cdot h_2 = \alpha_s \cdot h'_s + \alpha_{in}^{LPC} \cdot h_{asp}\ ;$$

$$\alpha_{out}^{HPC} \cdot (2567) = \alpha_s \cdot (823) + \alpha_{in}^{LPC} \cdot (2788)\ .$$

$$\alpha_{in}^{LPC} \cdot (h_R - h_{asp}) = \frac{(\alpha_{SH} \cdot (h_o - h'_0))}{0.98}$$

$$\alpha_{in}^{LPC} \cdot (2952 - 2788) = \frac{(\alpha_{SH} \cdot (2781 - 1229))}{0.98}$$



$$\alpha_{SH} = 0.0977 \cdot \alpha_{in}^{IPC}$$

$$\alpha_{in}^{IPC} = 1 - \alpha_1 - \alpha_2 - \alpha_s\ ;$$

$$\alpha_{in}^{IPC} = 0.081 - \alpha_2 - \alpha_s\ ;$$

$$\alpha_s = \frac{x_{out} - x_{in}}{x_{out}} \cdot \alpha_{out}^{HPC} = \frac{1 - 0.8863}{1} \cdot \alpha_{out}^{HPC} = 0.1131\ \alpha_{out}^{HPC}$$

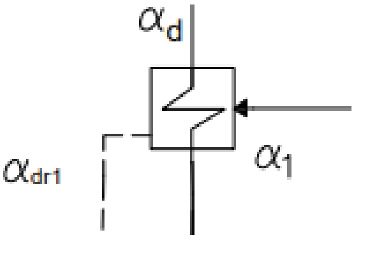
$$\alpha'_{bd} = 0.00367\ \ ;$$

$$\alpha''_{bd} = 0.00133\ \ ;$$

$$\alpha''_{bd} = 0.00133\ \ ;$$

RFWH 1

$$\frac{\alpha_d \cdot (h_{w1} - h_{w2})}{\eta_h} = \alpha_1 \cdot (h_1 - h_{dr1});$$



$\alpha_{dr1} = \alpha_1\ ;\ \ \alpha_d = 1.02$

$$\frac{1.02 \cdot (962 - 828)}{0.98} = \ \alpha_1 \cdot (2654 - 945);$$

$$\alpha_1 = \alpha_{dr1} = 0.081.$$

RFWH 2

Thermal balance:

$$\frac{\alpha_d \cdot \left(h_{w2} - h_{fwp}\right)}{\eta_h} = \alpha_{2r}(h_2 - h_{dr2}) + \alpha_{dr1} \cdot (h_{dr1} - h_{dr2});$$

$$\alpha_{dr2} = \alpha_{2r} + \alpha_{dr1} = \alpha_{2r}+\alpha_1 ;$$

$$\alpha_2 = \alpha_{2d} + \alpha_{2r} ;$$

$$\frac{1.02 \cdot (813 - 684)}{0.98} = \alpha_{2r}(2654 - 813) + 0.081 \cdot (962 - 813).$$

$$\alpha_{2r} = 0.071;$$

$$\alpha_{dr2} = 0.152;$$

Relative heating steam flowrate out of the fresh steam line which goes to the reheater (RH)

α_{dr1}	0.081
α_2	0.087

RFWH 3

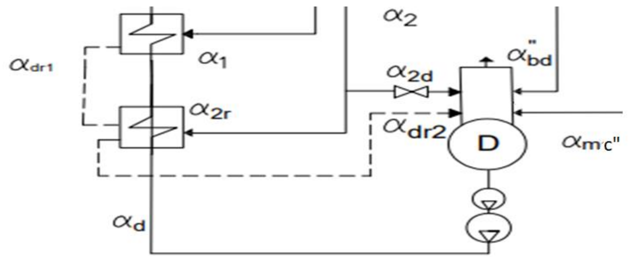
$$\frac{\alpha_d \cdot (h_{w3} - h_{fwp})}{\eta_h} = \alpha_{3r}(h_3 - h_{dr3}) + (\alpha_{dr2}) \cdot (h_{dr2} - h_{dr3})$$

$$\alpha_{dr2} = \alpha_2 + \alpha_{dr1} = \alpha_{dr2} = 0.087 + 0.081 = 0.152$$

$$\frac{1.02 \cdot (781 - 678)}{0.98} = \alpha_{3r}(2556 - 804) + (0.1325) \cdot (914 - 804) \qquad (13)$$

α_{2r}	0.071
α_{dr2}	0.152

Deaerator



$$\frac{\alpha_d \cdot h'_d + \alpha_{cej} \cdot h''_d}{\eta_{oph}} = \alpha_{2d} \cdot h_2 + \alpha''_{bd} \cdot h''_{bd} + \alpha_{mc"} \cdot h_{mc} + \alpha_{dr2} \cdot h_{dr2} ;$$

$$\alpha_{dr2} + \alpha_{mc"} + \alpha''_{bd} + \alpha_{2d} = \alpha_d + \alpha_{cej} ;$$

$$\frac{1.02 \cdot 676 + 0.002 \cdot 2756}{0.99} = 0.016 \cdot 2567 + 0.00133 \cdot 2758 + \alpha_{mc1} \cdot 625 + 0.152 \cdot 828 \;;$$

$$\alpha_{mc1} = 0.662$$

Low pressure cylinder extraction outlet.

$$\alpha_{out}^{LPC} = \alpha_{in}^{LPC} - \alpha_3 - \alpha_4 - \alpha_5 - \alpha_6 \,.$$

$$\alpha_{out}^{LPC} = 0.739 - \alpha_3 - \alpha_4 - \alpha_5 - \alpha_6 \,.$$

RFWH 3

$$\frac{\alpha_{mc} \cdot (h_{w3} - h_{w4})}{\eta_h} = \alpha_3 \cdot (h_3 - h_{dr3}) + \alpha'_{bd} \cdot (h'_{bd} - h_{dr3}) + \alpha_s \cdot (h'_s - h_{dr3}) \;;$$

$$\frac{0.853 \cdot (624 - 499)}{0.98} = \alpha_3 \cdot (2792 - 632) + 0.00367 \cdot (686 - 632) + 0.094 \cdot (823 - 632).$$

$$\alpha_3 = 0.064.$$

$$\alpha_{dr3} = \alpha'_{bd} + \alpha_3 + \alpha_s = 0.00367 + 0.064 + 0.094 = 0.162.$$

RFWH 4

$$\frac{\alpha_{mc} \cdot (h_{w4} - h_{w5})}{\eta_h} = \alpha_4 \cdot (h_4 - h_{dr4}) + \alpha_{dr3} \cdot (h_{dr3} - h_{dr4}) \;;$$

$$\frac{0.662 \cdot (499 - 375)}{0.98} = \alpha_4 \cdot (22667 - 507) + 0.162 \cdot (632 - 507) \;;$$

$$\alpha_4 = 0.029.$$

RFWH 5

$$\frac{\alpha_{mc''} \cdot (h_{w5} - h'_{w6})}{\eta_h} = \alpha_5 (h_5 - h_{dr5}) + \alpha_{dr4} \cdot (h_{dr4} - h_{dr5}) \;;$$

$$\frac{0.662 \cdot (375 - h'_{w6})}{0.98} = \alpha_5 (2535 - 375) + \alpha_{dr4} \cdot (507 - 383).$$

$$\alpha_{dr4} = \alpha_4 + \alpha_{dr3} = 0.029 + 0.162 = 0.191 \;;$$

RFWH 6

$$\frac{\alpha_c \cdot (h_{w6} - h_{cse})}{\eta_h} = \alpha_6(h_6 - h_{dr6}) + \alpha_{dr5} \cdot (h_{dr5} - h_{dr6}) \;;$$

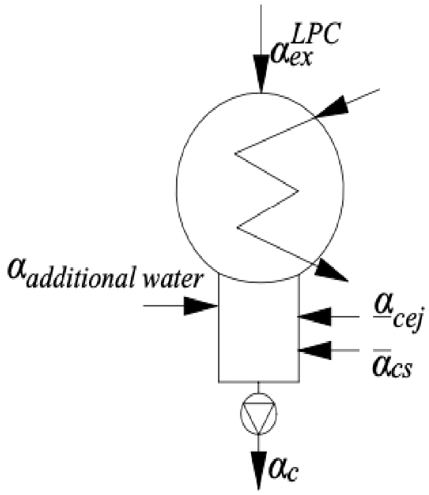
$$\frac{\alpha_c \cdot (252 - 129)}{0.98} = \alpha_6(2394 - 260) + \alpha_{dr5} \cdot (0.039 - 0.072)\;.$$

$$\alpha_{dr5} = \alpha_5\;;$$

$$\frac{\alpha_{mc} \cdot (h'_{w6})}{0.98} = \alpha_{dr6} \cdot h_{dr6} + \alpha_c \cdot h_{w6}\;;$$

$$\alpha_{dr6} = \alpha_6 + \alpha_{dr5}$$

Checking the system using condenser equations



$$\alpha_c = \alpha_{ex}^{LPC} + \alpha_{cs} + \alpha_{cej} + \alpha_{\text{addtional water}};$$

$$\alpha_c = 0.573 + 0.005 + 0.002 + 0.01 = 0.59$$

Table28. Relative flowrate

α_1	0.081
α_2	0.087
α_3	0.064
α_4	0.029
α_5	0.039
α_6	0.032
α_s	0.094
α_c	0.59

α_d	1.02
α_{dr1}	0.081
α_{dr2}	0.152
α_{dr3}	0.162
α_{dr4}	0.191
α_{dr5}	0.039
α_{dr6}	0.072
α_{2r}	0.071
α_{mc}	0.853
α_{mc1}	0.662
α_{exH}	0.832
α_{inL}	0.739
h'_{w4}	496
α_{exL}	0.573
α_{TU}	1.076
α_{SH1}	0.076
α_{fw}	1.096
h_{fw}	955

6. Determining steam flow to a turbine

Steam flow rate for a turbine is determined by the formula

$$G_0 = \frac{N_e \cdot 10^3}{H_i \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j))} \;;$$

Where:

η_M is mechanical efficiency of a steam turbine installation; $= 0.98$;

η_g is efficiency of the generator $= 0.985 \div 0.99$ assume it 0.99 ;

α_j is relative steam consumption in the j^{th} selection;

y_j is reproduction factor in each extraction;

N_e is electric power of NPP;

H_i is total internal heat drops in turbine, kJ/kg;

Table25. Flowrate and y factor

NO j	α_j	y_j	$(\alpha_j \cdot y_j)$
1	0.081	0.8657	0.0701
2	0.087	0.775	0.0674
3	0.064	0.607	0.0388
4	0.029	0.476	0.0138
5	0.039	0.337	0.0131
6	0.032	0.189	0.00607
Separator (s)	0.094	0.775	0.0728
$\sum(\alpha_j \cdot y_j)$	-	-	0.2094

$$G_0 = \frac{N_e \cdot 10^3}{H_i \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j))} = \frac{1000 \cdot 10^3}{953 \cdot 0.98 \cdot 0.99 \cdot (1 - 0.2094)}$$
$$= 1507\ \frac{kg}{s}.$$

CALCULATION OF INDICATORS OF THERMAL EFFICIENCY

Thermal loading of a steam generating unit, $\mathbf{Q_{SG}}$,kW

$$Q_{SG} = G_0 \cdot [(\alpha_{TU} + \alpha_{leak} + \alpha_{CS}) \cdot (h_0 - h_{fw}) + \alpha_{bld} \cdot (h_{bld} - h_{fw})]\ ;$$

$$Q_{SG} = 1507 \cdot [(1.076 + 0.01 + 0.005) \cdot (2782 - 955) + 0.005 \cdot (1229 - 955]$$
$$= 3006\ MW\,.$$

Values of flow rate at the part of NPP.

$$G_i = G_0 \cdot \alpha_i\,, \frac{kg}{s}\ ;$$

Table29. Values of flow rate at all the part of NPP

G_1	122.1	G_{fw}	1652
G_2	131.1	G_{SG}	1644
G_3	96.46	G_d	1537
G_4	43.71	G_c	889
G_5	58.78	G_{out}^{Hpc}	1254
G_6	48.23	G_{TU}	1622
G_{dr1}	122.0	G_{out}^{lpc}	864
G_{dr2}	229.1	G_{mc}	1286
G''_{bd}	2.004		
G_{leak}	15.07		
G_{cej}	3.014		
G_{cs}	7.536		
G_{leak}	15.07		
G_{dr3}	244.1		
G_{dr4}	287.8		
G_{dr5}	58.78		
G_{dr6}	108.52		
G_{SH1}	114.5		
$\boldsymbol{G_s}$	141.7		
G_{3d}	6,04		

Power Check

$N_e{}'=G_0 \cdot \left[H_i \cdot \alpha_{exL} + \sum(\alpha_j \cdot H_j)\right] \cdot \eta_M \cdot \eta_g;$

Table 30. Flowrate and H_j Extracted steam work in cylinder

Flow rate		H_j,kJ/kg		$(\alpha_j \cdot H_j)$
α_1	0,0704	H_1	86.80	6,1
α_2	0,0621	H_2	156.0	9,7
α_3	0,0602	H_3	229.1	13,8
α_4	0,0452	H_4	375.6	17,0
α_5	0,0355	H_5	508.6	18,1
α_6	0,0375	H_6	652.7	24,5
α_7	0,0353	H_7	798.8	28,2
α_s	0,0704	H_s	229.1	21,2
$\sum(\alpha_j \cdot H_j)$	———	———	————	138,5

$N_e{}'$=1507 · [953 · 0.573 + 136.9] · 0.98 · 0.99=998.6 MW;

$\delta N_e = 100 \cdot |N_e - N_e{}'|/N_e \leq 0.5\%$;

$\delta N_e = 100 \cdot \frac{|1000-998.6|}{998.6} = 0.139\ \% \leq 0.5\ \%$.

Thermal loading of turbine $\mathbf{Q_{TS}}$

$$Q_{TS} = G_0((\alpha_{TU} + \alpha_{cs}) \cdot (h_0 - h_{fw}) + \alpha''_{bd} \cdot (h''_{bd} - h_{fw}) + \alpha'_{bd} \cdot (h'_{bd} - h_{fw}) + \alpha_{add} \cdot (h_{add} - h_{fw}))\ ;$$

$$Q_{TS} = 1507 \cdot \big((1.076 + 0.005) \cdot (2782 - 955) + 0.00133 \cdot (2760 - 955) + 0.00367 \cdot (686 - 955) + 0.01 \cdot (209 - 955)\big) = 2974\ \text{MW}\ .$$

Electrical Efficiency

$$\eta_e = \frac{N_e}{Q_{TS}} = \frac{1000}{2974} = 0.336 = 33.6\%\ .$$

Steam turbine plant (STP) heat rate, for generating electricity;

$$q_{ts} = \frac{3600}{\eta_e} = \frac{3600}{0.336} = 10707\,\frac{kJ}{kW \cdot h}$$

Efficiency of heat transport

$$\eta_{pipe}^{II} = \frac{Q_{TS}}{Q_{SG}} = \frac{2974}{3006} = 989 = 98.9\%\,.$$

NPP Efficiency:

$$\eta_{NPP} = \eta_{rs} \cdot \eta_{pipe}^{II} \cdot \eta_{pipe}^{I} \cdot \eta_{SG} \cdot \eta_e;$$

$$\eta_{NPP} = 0.99 \cdot 0.989 \cdot 0.99 \cdot 0.99 \cdot 0.336 = 0.3228 = 32.28\%.$$

Overall reactor heat flow, MW

$$Q_{rs'} = \frac{Q_{SG}}{\eta_{SG}} = \frac{3006}{0.99} = 3036\ \text{MW};$$

$$Q_{rs} = \frac{Q_{rs'}}{\eta_{pipes}} = \frac{3036}{0.99 \cdot 0.989} = 3099\ \text{MW}$$

Total power, MW

$$Q_{total} = \frac{Q_{rs}}{\eta_{rs}} = \frac{3099}{0.99} = 3130\ \text{MW}$$

Specific flow rate of nuclear fuel (natural uranium) at nuclear power plants

$$b_{nf} = \frac{1000}{24 \cdot \bar{B} \cdot \eta_{Nb}} \cdot \frac{x_n - x_o}{x_e - x_o}\ ;$$

$$b_{nf} = \frac{1000}{24 \cdot 40 \cdot 10^3 \cdot 0.3228} \cdot \frac{0.04 - 0.0025}{0.0071 - 0.0025} = 26.3 \cdot 10^{-3}\,\frac{g}{MW \cdot h}.$$

Specific flow rate of degraded fuel for the electrical supply at nuclear power plants (block)

$$b_{Ndf} = \frac{0.0537}{\eta_{Nb}} = \frac{0.0537 \cdot 10^{-6}}{0.3228} = 16.6 \cdot 10^{-6}\ \frac{kg}{kW \cdot h}.$$

$$V_{FW} = 1.05 \cdot \frac{3600 \cdot G_d}{\rho}.$$

$$\rho = 910.3\ \ {}^{kg}/_{m^3};$$

$$V_{FW} = 1.05 \cdot \frac{3600 \cdot (1537)}{910.3} = 6348\,{}^{m^3}\!/_{h}\,.$$

$$H = \frac{\Delta p}{\rho g}.$$

$$\Delta p = p_{fwp} - (p_d + \rho g \Delta h).$$

$$\Delta h \ = \text{the hight of deaerator} \approx 14 \div 24\ \text{m}.$$

So, we take it 20 m

$$\Delta p = 8151 - [(620) + (910.3 \cdot 9.8 \cdot 20 \cdot 10^{-3})] = 7353\text{kPa};$$

$$H = \frac{7353 \cdot 10^3}{910.3 \cdot 9.8} = 824.2\ \text{m}.$$

First condensate pump $\mathbf{CP_1}$

$$V_{CP1} = \frac{3600 \cdot G_c}{\rho}.$$

$$\rho = 997.3\,{}^{kg}\!/_{m^3}\ ;$$

$$V_{CP1} = \frac{3600 \cdot (889.2)}{997.3} = 3210\ {}^{m^3}\!/_{h}\,.$$

$$H = \frac{\Delta p}{\rho g}.$$

$$\Delta p = p_{cp1} - p_c = 500 - 3.5 = 496.5\ \text{kPa}\ ;$$

$$H = \frac{496.5 \cdot 10^3}{997.3 \cdot 9.8} = 50.8\ \text{m}\,.$$

Second condensate pump $\mathbf{CP_2}$

$$V_{CP2} = \frac{3600 \cdot G_{mc}}{\rho}\ ;$$

$$\rho = 961.3\,{}^{kg}\!/_{m^3}\ ;$$

$$V_{CP2} = \frac{3600 \cdot (1285.7)}{961.3} = 4815\ {}^{m^3}\!/_{h}\,.$$

$$H = \frac{\Delta p}{\rho g}.$$

$$\Delta p = p_{cp2} - p_{cp1} = 868 - 500 = 368\ \text{kPa}\ ;$$

$$H = \frac{368\ \cdot 10^3}{961.3 \cdot 9.8} = 39.1\ \text{m}.$$

First drainage pump DP_1

$$V_{DP1} = \frac{3600(G_{dr6})}{\rho} = \frac{3600 \cdot 108}{961.3} = 404.4 \frac{m^3}{h} \; ;$$

$$\Delta p = p_{cp2} - p_{H6} = 868 - 21.9 = 846.1 \text{ kPa};$$

$$H = \frac{\Delta p}{\rho g} = \frac{846.1 \cdot 10^3}{961.3 \cdot 9.8} = 89.8 \text{ m};$$

Second drainage pump DP_2:

$$V_{DP2} = \frac{3600(G_{dr4})}{\rho} = \frac{3600 \cdot 287.8}{953} = 1087 \text{ m}^3/\text{h};$$

$$\Delta p = p_{cp2} - p_{H4} = 868 - 203.4 = 664.6 \text{ kPa};$$

$$H = \frac{\Delta p}{\rho g} = \frac{664.6 \cdot 10^3}{953 \cdot 9.8} = 71.1 \text{ m};$$

Table 31. Characteristic of pumps for NPP

<table>
<tr><td>PUMPS</td><td>Head H, m</td><td>Volumetric flow rate V, m^3/h</td><td rowspan="4">Chaise pump</td><td>Type</td><td>V, m^3/h</td><td>no</td><td>Operating</td><td>Reserve</td></tr>
<tr><td>Feed water</td><td>824</td><td>6348</td><td>ПЭА-1650-80</td><td>1650</td><td>4</td><td>3</td><td>-</td></tr>
<tr><td>First main condensate</td><td>51</td><td>3210</td><td>КсВ1 1600-90</td><td>1600</td><td>2</td><td>2</td><td rowspan="2">1</td></tr>
<tr><td>Second main condensate</td><td>39.1</td><td>4815</td><td>КСВ-1600-90</td><td>1600</td><td>3</td><td>2</td></tr>
<tr><td>Drain</td><td>89.8</td><td>404.4</td><td></td><td>КсВ 500-150</td><td>500</td><td>2</td><td>1</td><td></td></tr>
<tr><td>Drain 2</td><td>71.1</td><td>1087</td><td></td><td>КсВ 500-85</td><td>500</td><td>4</td><td>3</td><td>Drain</td></tr>
</table>

7. The regenerative heaters

Evaluate heat transfer Area F, m^2

$$F = \frac{Q}{k\overline{\Delta t}}.$$

$$Q = G\Delta h.$$

$$\Delta h = h_{w6} - h_{cse} = 252 - 129 = 123 \text{ kJ/kg};$$

$$Q = (G_c) \cdot \Delta h = (889.3) \cdot 123 = 109.4 \text{ MW}.$$

For RGFW 5 ‘’closed’’

$$\Delta h = h_{w5} - h_{mc'} = 375 - 250 = 125 \text{ kJ/kg};$$

$$Q = G'_{mc} \cdot \Delta h = 1286 \cdot 125 = 161 \text{ M}.$$

7.6.2. For RGFW 4 ‘’closed ‘’

$$\Delta h = h_{w4} - h_{w5} = 499 - 375 = 124 \text{ kJ/kg};$$

$$Q = G'_{mc} \cdot \Delta h = 1286 \cdot 124 = 159.5 \text{ MW}.$$

7.6.3. For RGFW 3 ‘’closed’’

$$\Delta h = h_{w3} - h_{mc''} = 624 - 496 = 128 \text{ kJ/kg};$$

$$Q = G_{mc''} \cdot \Delta h = 998 \cdot 128 = 128 \text{ MW}.$$

7.6.4. For RGFW 2 ‘’closed ‘’

$$\Delta h = h_{w2} - h_{fwp} = 813 - 684 = 129 \text{ kJ/kg};$$

$$Q = G_d \cdot \Delta h = 1537 \cdot 129 = 198 \text{ MW}.$$

7.6.5. For RGFW 1 ‘’closed’’

$$\Delta h = h_{w1} - h_{w2} = 945 - 813 = 132 \text{ kJ/kg};$$

$$Q = G_d \cdot \Delta h = 1537 \cdot 132 = 203 \text{ MW}.$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln(\frac{\Delta t_{big}}{\Delta t_{small}})}.$$

$$\Delta t_{big} = t_s - t_w^{in};$$

$$\Delta t_{small} = t_s - t_w^{out};$$

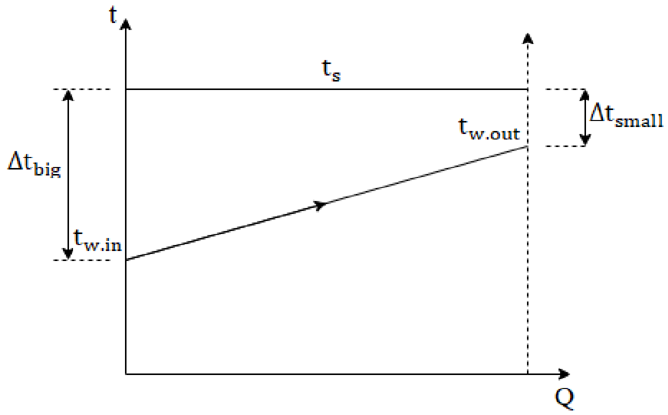


Figure 32-tQ diagram

For RGFW 6

$$\Delta t_{big} = t_{s6} - t_{cse} = 62.9 - 30.7 = 32.2℃\ ;$$

$$\Delta t_{small} = t_{s6} - t_{w6} = 62.9 - 60 = 2.9℃\ ;$$

$$\overline{\Delta t} = \frac{32.2 - 2.9}{\ln(\frac{32.2}{2.9})} = 12.2.$$

For RGFW 5

$$\Delta t_{big} = t_{s5} - t_{w6} = 92.4 - 60 = 32.4\ ℃\ ;$$

$$\Delta t_{small} = t_{s5} - t_{w5} = 92.4 - 89.4 = 3℃\ ;$$

$$\overline{\Delta t} = \frac{32.4 - 3}{\ln(\frac{32.4}{3})} = 12.3\ ℃.$$

For RGFW 4

$$\Delta t_{big} = t_{s4} - t_{w5} = 122 - 89.4 = 32.6℃;$$

$$\Delta t_{small} = t_{s4} - t_{w4} = 122 - 118.8 = 3.2\ ℃;$$

$$\overline{\Delta t} = \frac{32.6 - 3.2}{\ln(\frac{32.6}{3.2})} = 12.7\ ℃.$$

For RGFW 3

$$\Delta t_{big} = t_{s3} - t_{w4} = 170.7 - 118.8 = 51.9\ ℃\ ;$$

$$\Delta t_{small} = t_{s3} - t_{w3} = 170.7 - 148. = 22.7℃;$$

$$\overline{\Delta t} = \frac{51.9 - 22.7}{\ln(\frac{51.9}{22.7})} = 35.3\ ℃.$$

For RGFW 2

$$\Delta t_{big} = t_{s2} - t_{fwp} = 195.9 - 161 = 34.9\ ℃;$$

$$\Delta t_{small} = t_{s2} - t_{w2} = 195.9 - 190.5 = 5.4℃;$$

$$\overline{\Delta t} = \frac{34.9 - 5.4}{\ln(\frac{34.9}{5.4})} = 15.8\ ℃.$$

For RGFW 1

$$\Delta t_{big} = t_{s1} - t_{w2} = 225.6 - 190.5 = 34.5\ ℃;$$

$$\Delta t_{small} = t_{s1} - t_{w1} = 225.6 - 220 = 5.6℃;$$

$$\overline{\Delta t} = \frac{34.5 - 5.6}{\ln(\frac{34.5}{5.6})} = 15.9\ ℃.$$

Heat transfer Area F m^2

$$F = \frac{Q}{k\overline{\Delta t}}.$$

For RGFW 6

$$F = \frac{109.4 \cdot 10^6}{4000 \cdot 12.2} = 2242\ m^2.$$

For RGFW 5

$$F = \frac{161 \cdot 10^6}{4000 \cdot 12.3} = 3272 m^2.$$

For RGFW 5

$$F = \frac{159.5 \cdot 10^6}{4000 \cdot 12.7} = 3140 m^2.$$

For RGFW 3

$$F = \frac{128 \cdot 10^6}{4000 \cdot 35.3} = 906.5 m^2.$$

For RGFW 2

$$F = \frac{198 \cdot 10^6}{4000 \cdot 15.8} = 3133\ m^2.$$

For RGFW 1

$$F = \frac{203 \cdot 10^6}{4000 \cdot 15.9} = 3192\ m^2.$$

Table 32. Regenerative heaters parameters

RGFW NO	Δh, kJ/kg	G kg/s	Q, MW	k w/m^{2}K	$\overline{\Delta t}$ °C	F,m2
6(closed)	123	889.3	109.4	4000	12.2	2242
5 (closed)	125	1286	161	4000	12.3	3272
4 (closed)	124	1286	159.5	4000	12.7	3140
3 (Closed)	128	998	128	4000	35.3	906.5
2 (Closed)	129	1537	198	4000	15.8	3133
1 (Closed)	132	1537	203	4000	15.9	3192

Table 33. Characteristic of High-pressure heater

No of Heater	Type	No.
HPH-1	ПВ-2500-97-10А	1
HPH-2	ПВ-2500-97-10А	1

Table 34. Characteristic of low -pressure heater

No of Heater	Type	No.
LPH-3-closed	ПН-950-42-8А	1
LPH-4-closed	ПН-3200-30-16-IA	1
LPH-5-closed	ПН-3200-30-16-IA	1
LPH-6-closed	ПНС-2000-IA	1

8. Deaerator

$$V_D = \frac{3600 \cdot (G_d)}{\rho};$$

$$\rho = 910 \ {}^{kg}/_{m^3};$$

$$V_D = \frac{3600 \cdot 1537}{910} = 6080 \ m^3/h.$$

$$v = \frac{G_d \cdot \tau \cdot k}{\rho}.$$

$$v = \frac{1537 \cdot (5 \cdot 60) \cdot 1.15}{910} = 583 \ m^3.$$

Table 35. Characteristic of deaerator.

Deaerator size	Nominal productivity, kg / s	Working pressure, MPa	Deaerator column size	Number of columns	Geometric volume (capacity) of the storage tank, m³	Useful volume (capacity) of the storage tank, m³	Deaerator length, m	Deaerator height, m
ДП-6000/250-А-1	1666,6	0,97	КДП-6000-А-1; horizontal	1	400	250	36.0	7.9

8.Technical calculation of the selected steam pipeline in accordance with the task

$$d_{in} = \sqrt{\frac{4}{\pi \cdot w_{steam} \cdot \rho_{extraction}} \cdot \frac{G_{extraction}}{n_{flows}}};$$

$$d_{in} = \sqrt{\frac{4}{\pi \cdot 50 \cdot 14} \cdot \frac{122}{2}} = 0.233\ m \quad ;$$

$$D_{out} = 273\ mm = 0.273\ m\ ;$$

$$\text{Thickness of wall } (\delta) = 8\ mm = 0.008\ m\ ;$$

8.2. Mechanical calculation of steam pipe

$$\delta_{wall} = \frac{p_{calculated} \cdot d_{in}}{2\varphi[\sigma_{\text{H}}] - p_{calculated}} + C;$$

$$p_{calculated} = 1.25 \cdot 0.9 \cdot 2.577 = 2.9\ MPa\ ;$$

[σ] = 132.9 MPa

$$\delta'_{wall} = \frac{p_{calculated} \cdot d_{in}}{2\varphi[\sigma_{\text{H}}] - p_{calculated}} = \frac{2.9 \cdot 0.233}{2 \cdot 1 \cdot 132.9\ - 2.93} = 2.85\ mm \quad ;$$

The addition to the wall thickness is calculated by the formula:

$$C = C_1 + C_2 = C_{11} + C_{12} + C_2.$$

$$C_{11} = 0.15 \cdot \delta_{wall}{}' = 0.15 \cdot 2.85\ = 0.388\ mm\ \ ;$$

$C_{12} = 0$ – technological addition; mm

$C_2 = 1\ mm$ – an increase to compensate for the decrease in strength on the steam-water side.

$$C = C_1 + C_2 = C_{11} + C_{12} + C_2 = -0.611 + 1 + 0 = 0.612\ mm\ \ ;$$

$$\delta_{wall} = \frac{p_{calculated} \cdot d_{in}}{2\varphi[\sigma_{\text{H}}] - p_{calculated}} + C = 2.85 + 0.611 = 3.2\ mm$$

The pipe wall thickness

$$\delta_{wall}{}' = \frac{p_{calculated} d_{inlet}}{2\varphi[\sigma_{\text{H}}] - p_{calculated}}$$

After you have chosen the tube

$$w_{steam} = \frac{4 \cdot G_{extraction}}{\pi \cdot d_{inlet}{}^2 \cdot \rho_{extraction} \cdot n_{lines} \cdot n_{flows}} \quad ;$$

d_{inlet} – nominal inlet diameter of chosen tube = 257 mm.

$$w_{steam} = \frac{4 \cdot 122}{\pi \cdot (233 \cdot 10^{-3})^2 \cdot 14 \cdot 1 \cdot 2} = 102\ {}^{m}/_{s} \quad ;$$

Thermal insulation calculation

$$t_{insulation} = 45\ ℃\ \ ;$$

$$t_{wall} = 225.6\ ℃\ ;$$

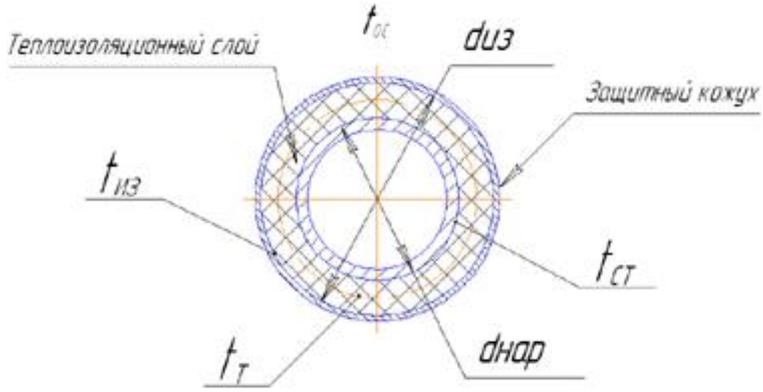


Figure 33. Design diagram of thermal insulation.

$$\alpha = \alpha_{convection} + \alpha_{radiation}.$$

$$\alpha_{convection} = 1.43 \cdot \sqrt[3]{\Delta t} = 1.43 \cdot \sqrt[3]{t_{insulation} - t_{ambient}}\ ;$$

$$\alpha_{convection} = 1.43 \cdot \sqrt[3]{\left((45 + 273) - (25 + 273)\right)} = 3.88\ {}^{W}/_{m^2 \cdot K}..$$

Radiation heat transfer coefficient:

$$\alpha_{radiation} = \frac{C \cdot \left(\left(\frac{T_{insulation}}{100}\right)^4 - \left(\frac{T_{ambient}}{100}\right)^4\right)}{t_{insulation} - t_{ambient}}\ ;$$

$$\alpha_{radiation} = \frac{5.67 \cdot \left(\left(\frac{45 + 273}{100}\right)^4 - \left(\frac{25 + 273}{100}\right)^4\right)}{45 - 25} = 6.63\ {}^{W}/_{m^2 \cdot K}.$$

$$\alpha = \alpha_{convection} + \alpha_{radiation} = 3.88 + 6.63 = 10.51\ {}^{W}/_{m^2 \cdot K}\ .$$

$$\lambda_{insulation} = 0.047 + 0.000185 \cdot \overline{t_{insulation}},\ \frac{W}{m \cdot K}\ ;$$

The average temperature of the insulation layer is:

$$\overline{t_{insulation}} = \frac{t_{wall} + t_{insulation}}{2} = \frac{(225.6 + 273) + (45 + 273)}{2} = 408.2\ K\ ;$$

$$\lambda_{insulation} = 0.047 + 0.000185 \cdot \overline{t_{insulation}} = 0.047 + 0.000185 \cdot 408.2$$
$$= 0.122\ {}^{W}/_{m \cdot K}\ .$$

$$\delta_{insulation} = \frac{\lambda_{insulation} \cdot (t_{wall} - t_{insulation})}{\alpha \cdot (t_{insulation} - t_{ambient})}\ ;$$

$$\delta_{insulation} = \frac{0.122 \cdot (225.6 - 45)}{10.51 \cdot (45 - 25)} = 0.106m\ .$$

The equation of condenser heat balance:

$$G_c \cdot (h_c - h'_c) = W \cdot c_p \cdot \Delta t \ .$$

Where:

$c_p = 4200 \ \frac{J}{kg\cdot℃}$ - specific heat capacity of service water;

$\Delta t = 3 \div 6$ ℃ - the heat of service water in condenser

The flow of service water to condenser will be calculated according to this equation:

$$W = \frac{G_c \cdot (h_c - h'_c)}{c_p \cdot \Delta t} = \frac{889.2 \cdot (2213 - 111.8)}{4200 \cdot 3 \cdot 10^{-3}} = 148.3 \ {m^3}/{s} \ .$$

Then we need calculate the power consumption of circulation service pump. The equation:

$$N = \frac{\rho \cdot g \cdot W \cdot H}{1000 \cdot \eta_{pump} \cdot \eta_{electic\ drive}} = \frac{1000 \cdot 9.8 \cdot 148 \cdot 20}{1000 \cdot 0.87 \cdot 0.98} = 31699 \text{ kW} \ .$$

Design calculation of the turbine condenser

$$i = \frac{N_e}{\eta_m \cdot \eta_g \cdot N_i^{max}} \quad ;$$

$$i = \frac{1000}{0.98 \cdot 0.99 \cdot 266.7} = 3.86 \approx 4\,;$$

The resulting number of flows i must be rounded up to the nearest even integer.

$$n_{con} = \frac{i}{2} = \frac{4}{2} = 2$$

$$N_i^{max} = \frac{m_1}{2 \cdot 10^{-3} \cdot \pi} \cdot k_{unl} \cdot H_i \cdot \frac{[\sigma] \cdot c_2}{\rho_{mat} \cdot n^2 \cdot v_2} \quad ;$$

$$N_i^{max} = \frac{1.3}{2 \cdot 10^{-3} \cdot \pi} \cdot 2.4 \cdot 953 \cdot \frac{[450] \cdot 200}{7800 \cdot (25)^2 \cdot 32.76} = 266.7\text{ MW.}$$

$$c_2^2 = \Delta h_{os} \cdot 2000 = 20 \cdot 2000 = 40000\,;$$

$$c_2 = 200\text{ m/s} \;;$$

1. Exhaust steam flow per condenser

$$G_{c1} = \frac{2 \cdot G_c}{i} = \frac{2 \cdot 889.1}{4} = 444.5\text{ kg/s} \quad ;$$

Table 36. Initial data

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	G_{c1}, kg/s	444.5
Condenser pressure	p_c, MPa	0.0036
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1}, ℃	15
Speed of the cooling water in the tubes of the condenser	w_w, m/s	2
Condenser tube sizes	$d_{out} \times \delta_{wall}$, mm	28×1
Tube material	-	stainless steel;

Flow rate of cooling water per condenser

$$W_1 = m \cdot G_{c1} \;;$$

$$W_1 = 50 \cdot 444.5 = 26670 \; {}^{kg}/_{s} \;;$$

$$n_{tube} = \frac{4 \cdot W_1 \cdot z}{\pi \cdot d_{inn}^2 \cdot \rho_w \cdot w_w} \;;$$

$$n_{tube} = \frac{4 \cdot 26670 \cdot 2}{\pi \cdot (26 \cdot 10^{-3})^2 \cdot 1000 \cdot 2} = 51 \cdot 10^3 \text{ pcs};$$

$$\Delta t_w = \frac{r}{c_w \cdot m} \;;$$

$$\Delta t_w = \frac{1935}{4.19 \cdot 60} = 7.69 \text{ ℃};$$

$r = h'' - h' = 2047 - 112 = 1935$ kJ/kg;

$$h'' = f(p_c) = 2047 \text{ kJ/kg};$$

$$h' = f(p_c) = 112 \text{ kJ/kg};$$

$$t_{w2} = t_{w1} + \Delta t_w \;;$$

$$t_{w2} = 15 + 7.69 = 22.7 \text{ ℃} \;;$$

The Heat power that is transferred to the cooling water in the condenser, kW

$$Q_{w1} = W_1 \cdot c_w \cdot \Delta t_w \;;$$

$$Q_{w1} = 26670 \cdot 4.19 \cdot 7.69 = 859337 \text{ kW}.$$

The average temperature difference, ºC

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)} \;;$$

$$\Delta t_{avr} = \frac{7.69}{\ln\left(\frac{26.7 - 15}{26.7 - 22.7}\right)} = 7.16\text{℃} \;;$$

$$d_c = 45 \text{ kg}/(m^2 \cdot h) \;;$$

$$k = 4070 \cdot a \cdot \left(\frac{1.1 \cdot w_w}{d_{inn}^{0.25}}\right)^x \cdot \left[1 - \frac{0.52 - 0.002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2\right] \cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{35}\right)\right] \cdot \Phi_d \;;$$

$$k = 4070 \cdot 0.595 \cdot \left(\frac{1.1 \cdot 2}{(0.026)^{0.25}}\right)^{0.232}$$

$$\cdot \left[1 - \frac{0.52 - 0.002 \cdot 55 \cdot \sqrt{0.595}}{1000} \cdot (35 - 15)^2\right]$$

$$\cdot \left[1 - \frac{2-2}{10} \cdot \left(1 - \frac{15}{35}\right)\right] \cdot 1 = 2968 \ \frac{W}{m^2 \cdot °C} \ .$$

2. Heat transfer surface area

$$F = \frac{Q_w}{k \cdot \Delta t_{avr}} = \frac{859337 \cdot 10^3}{2968 \cdot 7.16} = 40438 \ m^2.$$

The length of the heat transfer tubes

$$L = \frac{F}{n \cdot \pi \cdot d_{out}} = \frac{40438}{51 \cdot 10^3 \cdot \pi \cdot 0.028} = 9.01 \ m \ < 16 \ m \ .$$

$$d_c^{calk} = \frac{3600 \cdot G_{c1}}{F} = \frac{3600 \cdot 444.5}{40438} = 39.66 \ kg \ / \ (m^2 \cdot h);$$

The obtained value $\mathbf{d_c^{calk}}$ must be compared with the specified in paragraph ;

$$error = \left|\frac{d_c^{calk} - d_c}{d_c^{calk}}\right| \cdot \ 100 = \left|\frac{39.66 - 55}{39.66}\right| \ \cdot \ 100 = 38.8 \ \% > 3\% \ \ ;$$

Table 37. Recalculations:

d_c , $kg \ / \ (m^2 \cdot h)$	55	39.66
k , $\frac{W}{m^2 \cdot °C}$	2968	2934
F , m^2	40438	40909
L , m	9.01	9.12
d_c^{calk}, $kg \ / \ (m^2 \cdot h)$	39.66	39.2
error	38.8	1.17

Mass of condenser tubes

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot \left(d_{out}^2 - d_{inn}^2\right)}{4} \cdot \rho_{mat} \, , kg \ \ ;$$

$$M_{tube} = 51 \cdot 10^3 \cdot 9.12 \cdot \frac{\pi \cdot ((0.028)^2 - (0.026)^2)}{4} \cdot 7800 = 307732 \ kg \ \ ;$$

Cost of tubes

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}, \text{million rubles} ;$$

$$C_{tube} = \frac{307732 \cdot 350}{10^6} = 107.7 \text{ million rubles} ;$$

Cost of the condenser

$$C_{cond} = K_c \cdot C_{tube}, \text{million rubles};$$

$$C_{cond} = K_c \cdot C_{tube} = 1.75 \cdot 107.7 = 188.5 \text{ million rubles.}$$

3. Hydraulic calculation of the condenser

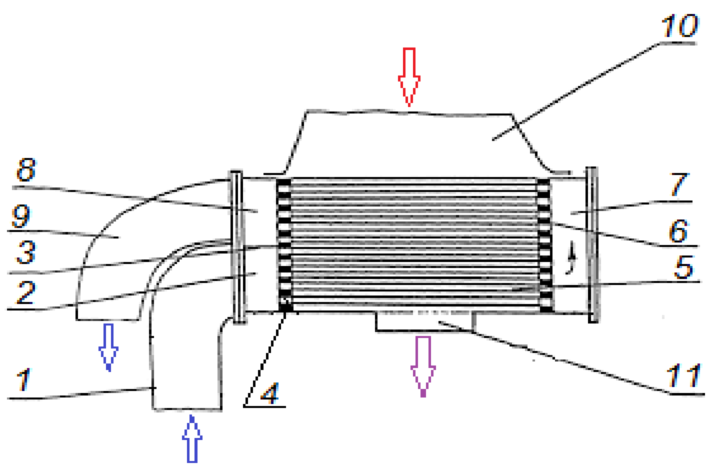


Figure 34. To the hydraulic calculation of the condenser.

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr};$$

For the calculate of local pressure losses it is necessary to use the following formula:

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2}, \text{Pa};$$

Type of local resistance	Coefficient value ξ_{loc}
Inlet to the tubes from the water chamber	0.5
Outlet from the pipes to the water chamber	1
Turning the water in the water chamber	0.5

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn} =$$

$$= (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2} =$$

$$= (2 \cdot 0.5 + 2 \cdot 1 + 0.5) \cdot \frac{1000 \cdot (2)^2}{2} = 7000 \text{ Pa.}$$

For the calculate the friction pressure losses it is necessary to use the Altshul formula

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2}, \text{Pa} \;;$$

$$\Delta p_{fr} = 0.037 \cdot \frac{2 \cdot 9.12}{0.026} \cdot \frac{1000 \cdot (2)^2}{2} = 51914 \text{ Pa}\,.$$

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr} = 7000 + 51914 = 58914$$

Power of the pump for pumping water through the condenser

$$N_p = \Delta p_{\Sigma} \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000}\;, \text{kW}\;;$$

$$N_p = 58914 \cdot \frac{26670}{1000 \cdot 0.88 \cdot 1000} = 1785 \text{ kW.}$$

Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp}\,, \text{kW} \cdot \text{h;}$$

$$E_p = 6500 \cdot 1785 = 11.6 \cdot 10^6 \;\text{kW} \cdot \text{h;}$$

The cost of electricity for pumping water through the condenser

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}\;, \text{million rubles}\;;$$

$$C_{el} = \frac{11.6 \cdot 10^6 \cdot 14}{10^6} = 162.4 \text{ million rubles.}$$

Table 38. Comparison of results:

Parameter	$\delta_{wall} = 1$ mm	$\delta_{wall} = 2$ mm
G_c, kg/s	444.5	444.5
W_1, kg/s	26670	26670
p_c, kPa	3.6	3.6
d_{out}, mm	28	28
Tube material	Stainless steel	Stainless steel
n_{tube}, pcs	$51 \cdot 10^3$	$59 \cdot 10^3$
F, m^2	40909	40712
l_{tube}, m	9.12	7.84
Mass of tubes, kg	307732	589408
Cost of tubes, Million rubles	107.7	206.2
Cost of condenser, Million rubles	188.5	360.8
Electric power consumption for the circulation pump drive, kW · h	$11.6 \cdot 10^6$	$10.9 \cdot 10^6$
The cost of electricity for pumping water through the condenser, Million rubles	162.4	152.6

FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING

To the student:

Group	Full name
507I	Abdelal Mostafa Mohamed Mohamed Elwan

School	Energy &Power Engineering	Division	The Butakov Research Center
Degree	Specialist	Educational Program	14.05.02 Nuclear power plants: design, operation and engineering

Input data to the section «Financial management, resource efficiency and resource saving»:	
3. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	• Salary costs – 164795.5 • STR budget – 35052
4. *Expenditure rates and expenditure standards for resources*	• Electricity costs – 5,8 rub per 1 kW
5. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	• Labor tax – 27,1 %; • Overhead costs – 66%;
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
507I	Abdelal Mostafa Mohamed Mohamed Elwan		

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.

The condenser is designed for circulating water supply systems for steam turbines. The steam turbine condenser consists of a body with a steam intake unit, condenser tubes fixed in tube sheets and adjacent to the body, front and rear water chambers with an additional unit for introducing a cooling medium.

An additional input unit is connected to the inlet part of the front water chamber, and the upper part of the rear water chamber is equipped with a unit for connection to the ejection system. This technical solution allows for reliable filling of the upper tubes of the condenser with a cooling medium with minimal energy and labor costs. A decrease in the thermal power of the turbine leads to a decrease in the electrical power generation and an increase in the cost of electricity Using this analysis, the scientific project was modified to improve the designs and make it withstand successfully.

in order to study this modification, the strengths and weaknesses of the comparative structures needed to be evaluated. All available information on competitive developments is used (Table 1). My calculation based on the condenser name 1000-КЦС -1.

Table 39. Results of Calculations of Competitive Structures of the condenser

Type of Cost		Design Options	
		1000-КЦС -1 with $d_{out} = 28\ mm; \delta_{wall} = 1\ mm$	1000-КЦС -1 with $d_{out} = 28\ mm; \delta_{wall} = 2\ mm$
C_{cond}	Million Rubles	188.5	360.8
C_{el}	Million Rubles	11.6	10.9

Table 40. Evaluation card for comparison of competitive technical solutions

Evaluation criteria *Example*	Criterion Weight *Wi*	Points		Competitiveness Taking into account weight	
		P_f	P_{i1}	C_f	C_{i1}
1	2	3	4	6	7
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0.2	3	4	0.6	0.8
2. Data accuracy	0.1	4	2	0.4	0.2
3.Efficiency of material	0.05	3	3	0.15	0.15
4. Environmental safety	0.07	2	4	0.14	0.28
5. Mass and volume	0.05	2	4	0.1	0.2
6. Reliability	0.02	3	2	0.06	0.04
Economic criteria for performance evaluation					
1. Development cost	0.08	4	2	0.32	0.16
2. Maintenance	0.03	4	3	0.12	0.09
3. Lifetime of material	0.2	3	2	0.6	0.4
4. Efficiency of product	0.2	2	3	0.4	0.6
Total	1			2.89	2.92

The analysis of competitive technical solutions is defined as follows:

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

Indices for indicators

First type 1000-КЦС -1 with $d_{out} = 28\, mm$; $\delta_{wall} = 1\, mm$;

2. Second type1000-КЦС -1 with $d_{out} = 28\, mm$; $\delta_{wall} = 2\, mm$

Example:

$$C = \sum W_i \cdot P_i = 0.24 \cdot 3 + 0.12 \cdot 4 + \cdots + 0.04 \cdot 4 = 3.09$$

The results show that the competitiveness of option 1 was 3.09, while that of option 2 was 3.38.

Thus, the investigated scientific development (condenser design), which uses tubes with $d_{out} = 28\,mm$; $\delta_{wall} = 2\,mm$, is competitive and has a number of advantages in terms of technical and economic indicators of resource efficiency.

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.

Table 41. SWOT analysis

	Strengths: 1. High overall efficiency 2. Almost perfect calculations 3. knowing all the material in the equipment	Weaknesses: 1. Probably some mistakes in calculations 2. If error occurred it will be hard to find
Opportunities: 1. Get to design all equipment 2. Learn more about the functionality of all nuclear power plant equipment	Because I designed a full functional nuclear power plant so now know every part and how to make it more efficient and how to get higher efficiency,	After designing a full functional nuclear power plant it comes with the difficulty like some calculations might become wrong and a lot to check so mistakes might happens.
Threats: 1. Low efficiency in some equipment to reduce cost 2. High cost project	Sacrifice more money for a obtaining a higher efficiency	Error may occur and its hard to detect where it happened so some fixation will be needed

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 42. Stakeholders of the project

Project stakeholders	Stakeholder expectations
TPU, design operation and engineering of nuclear power plant	High efficiency of a fully functional nuclear power plant

Table 43. Purpose and results of the project

<table>
<tr><td>Purpose of project:</td><td>Designing a fully functional nuclear power plant by designing all the main element of the life cycle of the plant.</td></tr>
<tr><td>Expected results of the project:</td><td>Based on the research and the analysis, find the defect and the complex and try to outcome them and solve these problems.</td></tr>
<tr><td>Criteria for acceptance of the project result:</td><td>Get all calculation to the right range to get a fully functional NPP</td></tr>
<tr><td rowspan="4">Requirements for the project result:</td><td>Maintain the efficiency of the equipment</td></tr>
<tr><td>Get the right usage of the material</td></tr>
<tr><td>Insure stability of the equipment</td></tr>
<tr><td>Complete the project on time</td></tr>
</table>

Table 44. Structure of the project

№	Participant	Role in the project	Functions	Labor time, hours (days without holidays x 5 hours per day)
1	Abdelal M. M	Executor	Design and work on the project	200
2	V.E. Gubin	Manger	Coordinates and assist the executor on the project	80
	Total			280

Table 45. Project limitations

Factors	Limitations / Assumptions
3.1. Project's budget	320 000 RUB
3.1.1. Source of financing	Own funds / Scholarship
3.2. Project timeline:	20 September 2022 – 10 January 2023
3.2.1. Date of approval of plan of project	15 July 2022
3.2.2. Completion date	19 December 2022

Project Schedule

Table 46. Project Schedule

Job title	Duration, working days (without holidays and weekends)	Start date	Date of completion	Participants
Literature review	8	15 September	30 September	Engineer
Calendar planning	5	1 October	7 October	Supervisor
Designing NPP	10	8 October	22 October	Engineer
Designing SG	7	23 October	1 November	Engineer
Designing PNR	3	2 November	5 November	Engineer
Designing part of the Condenser	4	7 November	11November	Engineer& Supervisor
Social responsibility	11	12 November	29 November	Engineer& Supervisor
Financial management	8	1 December	11 December	Engineer& Supervisor

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.

Table 47. A Gantt chart

№	Activities	Participants	T_c, days	Duration of the project											
				September			October			November			December		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Literature review	Engineer	7.5												
2	Calendar planning	Professor	4.6												
3	Designing NPP	Engineer	9.3												
4	Designing SG	Engineer	7												
5	Designing PNR	Engineer	3.2												
6	Designing part of the Condenser	Engineer & Supervisor	4.4												
7	Social responsibility	Engineering & Supervisor	10												
8	Financial management	Engineering & Supervisor	9												
Engineer				Supervisor											

Scientific and technical research budget

The following grouping of costs by items is used:

Material costs of scientific and technical research;

costs of special equipment for scientific work (Depreciation of equipment used for design);

basic salary;

additional salary;

labor tax;

overhead.

Calculation of material costs

These costs include office supplies, printing costs, and various equipment required for paperwork.

Table 48. Material costs

Name	Unit	Amount	Price per unit, rub.	Material costs, rub.
Paper	Pack	1	230	230
Pens	Unit	2	60	120
Pencil	Unit	3	60	180
Printing	Page	180	1.9	342
Staples	Pack	1	50	50
Stapler	Unit	1	130	130
Calculator	Unit	1	1500	1500
Total				2552

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 .

Table 49. Costs of special equipment (+software)

№	equipment identification	Quantity of equipment	Price per unit, rub.	Total cost of equipment, rub.
1.	Laptop	1	30 000	30 000
3.	Microsoft office	1	2500	2500
Total				32500

Basic 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 formula:

$$S_b = S_d \cdot T_w \qquad (3.3)$$

where S_b – basic salary per participant;

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

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

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v} \qquad (3.4)$$

где S_m – monthly salary of a 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).

Monthly salary is calculated by formula:

where: S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg} \qquad (3.5)$$

Table 50. The valid annual fund of working time

Working time indicators	
Calendar number of days	365
The number of non-working days - weekend - holidays	 52 14
Loss of working time	48

- vacation - isolation period - sick absence	
The valid annual fund of working time	251

Monthly salary is calculated by formula:

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

where S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 51. Calculation of the base salaries

Performers	S_{base}, rubles	$k_{premium}$	k_{bonus}	k_{reg}	S_{month}, rub.	W_d, rub.	T_p, work days from table 7	W_{base}, rub.
Engineer	19200	0	1.4	1.3	34944	1559.3	51	79524.3
Supervisor	37500				68250	3045.4	28	85271.2

Additional salary

This point includes the amount of payments stipulated by the legislation on labor, for example, payment of regular and additional holidays; payment of time associated with state and public duties; payment for work experience, etc.

Additional salaries are calculated on the basis of 10-15% of the base salary of workers:

$$W_{add} = k_{extra} \cdot W_{base},$$

$$W_{add} = k_{\text{extra}} \cdot W_{base}, \qquad (3.6)$$

Where: W_{add} – additional salary, rubles;

k_{extra} – additional salary coefficient (10%); (x)

W_{base} – base salary, rubles.

$W_{add.Sup} = 0.15 \cdot 85271.2 = 12790.7\ RUB$

$$W_{add.Eng} = 0.15 \cdot 79524.3 = 11928.6\ RUB$$

where W_{add} – additional salary, rubles;

k_{extra} – additional salary coefficient (10%);

W_{base} – base salary, rubles.

Labor tax

Tax to extra-budgetary funds are compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers.

Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \qquad (x)$$

where k_b – coefficient of deductions for labor tax.

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

Table 52. Labor tax

	Supervisor	**Engineer**
Coefficient of deductions	27.1%	
Salary (basic and additional), rubles	98061.9	91452.9
Labor tax, rubles	26574.7	24783.7

Overhead costs

Overhead costs include other management and maintenance costs that can be allocated directly to the project. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc.

Overhead costs account from 30% to 90% of the amount of base and additional salary of employees.

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add})$$

where k_{ov} – overhead rate.

Table 53. Overhead

	Supervisor	**Engineer**
Overhead rate	66 %	
Salary, rubles	98061.9	91452.9
Overhead, rubles	64720.8	60358.9

Other direct costs

Energy costs for equipment are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq},$$

where P_{el} – power rates (5.8 rubles per 1 kWh);

P – power of equipment, O= 0.3 kW;

F_{eq} – equipment usage time, hours.

$$C = 0.3 \cdot 5.8 \cdot 255 = 443.7\ rubles$$

Formation of budget costs

The calculated cost of research is the basis for budgeting project costs.

Determining the budget for the scientific research

Table 54. Items expenses grouping

Material costs	2552
Equipment costs	32500
Basic salary	164795.5
Additional salary (It is 15% from Basic salary)	24719.3
Labor tax	51358.4
Overhead	125079.7
Other direct costs	443.7
Total	401448.6
Material costs	2552

SOCIAL RESPONSIBILITY

Student:

Group	**Name**		
507I	Abdelal Mostafa Mohamed Mohamed Elwan		
School	**Energy and power engineering**	**Division**	**The Butakov Research center**
Educational level	**Specialist**	**Course/Specialty**	**14.05.02 Design, Operation Engineering of nuclear power plants**

Topic of FQW:

Design of an NPP power unit with a VVER-type reactor with an electric power 1000 MW	
Initial data for the chapter «social responsibility»:	
1. Characteristics of the researched object (substance, material, device, algorithm, technique, working area)	1. Active safety system from modern VVER reactor; 2. Design calculation of nuclear power reactor; 3. Design calculation of a saturated steam generator; 4. Design NPP with a VVER 1000 type reactor; 5. Design calculation of the turbine condenser.
List of questions to be researched, designed and developed:	
1. Legal and organizational issues of occupational safety consider special law norms of labor legislation. indicate the features of the labor legislation in relation to the specific conditions of the project.	GOST 12.2.061-81 Industrial equipment. General safety requirements to working places GOST 9241-4-2009 Ergonomic requirements for office work with visual display terminals (VDTs).
2. Occupational safety: 2.1. Analysis of the identified harmful and dangerous factors: the source of factor, the impact on human's body 2.2 Ssuggest measures to reduce the impact of identified harmful and dangerous factors	Harmful factors • Increased dust and gas content in the air in the working area; • Increase level of noise • emotional overload; • mental overstrain; • Ionizing radiation. Dangerous factors • Increased voltage in an electrical circuit, the closure of which can pass through the human body; • Increased or decreased temperature of surfaces of equipment materials.
3. Environmental Safety: Iinfluence on the atmosphere, hydrosphere, lithosphere	• **Atmosphere.** Nuclear reactors do not produce air pollution or carbon dioxide while operating but, they emit harmful pollutants, including mercury, non-mercury metallic toxics, acid gases, and organic air toxics such as dioxin. • **Hydrosphere pollution** Nuclear power releases a higher percentage of its waste water as liquid effluent streams instead of vapor.
4. Emergency Safety: describe the most likely emergency situation	• Radiation emergency A radiation emergency can result from an accidental such as: thermal explosion, release of radioactive material.
Date issue of the task for the chapter	

Consultant:

Post	**Name**	**Academic degree**	**Date**	**Signature**
Associate professor	**O.A. ANTONEVICH**	**PhD**		

Student:

Group	**Name**	**Date**	**Signature**
507I	Abdelal Mostafa Mohamed Mohamed Elwan		

Introduction

Managing safety and health is an integral part of managing a business. Businesses need to do a risk assessment to find out about the hazards and risks in their workplace and put measures in place to effectively control them to ensure these hazards and risks cannot cause harm to workers.

Legal and organizational issues of occupational safety

GOST 12.2.061-81 Industrial equipment. General safety requirements to working places

This standard establishes general safety requirements for the design, equipment and organization of workplaces in the design and manufacture of production equipment, design and organization of production processes. This standard fully complies with ST SEV 2695-80.

The design of the workplace should provide a comfortable working posture for a person, which is achieved by adjusting the position of the chair.

When it is impossible to adjust the height and angle of the footrest, the height and dimensions of the working surface, it is allowed to design and manufacture equipment with non-adjustable parameters. In this case, the height of the working surface is set based on the nature of the work, the requirements for sensory control and the required accuracy of actions, the average height of the workers (men - if only men work, women - if only women work, men and women - if both men and women work).

The mutual arrangement and layout of workplaces should provide safe access to the workplace and the possibility of quick evacuation in an emergency. Escape routes and passages must be marked and have adequate lighting.

The organization and condition of workplaces, as well as the distances between workplaces, must ensure the safe movement of workers and vehicles, convenient and safe handling of materials, workpieces, semi-finished products, as well as maintenance and repair of production equipment.

GOST 9241-4-2009 Ergonomic requirements for office work with visual display terminals (VDTs)

This International Standard establishes guidelines for use in the development of user requirements and in the design and installation of workstation equipment for VDT office work. The general principles and requirements set out in this standard should be taken into account when developing standards that establish requirements for the design of office furniture and equipment for the operator's workplace.

The design of the workplace should be preceded by an analysis of the production tasks for which it is intended. As a result of this analysis, information is obtained about the tasks and subtasks performed and the use of the necessary equipment. Priority should be given to the sources of information used in the execution of production tasks regarding the placement of displays, the location of equipment and auxiliary working aids

Workstations should enable intended users to perform their tasks efficiently and comfortably.

Occupational safety

Occupational safety and health, including compliance with the OSH requirements pursuant to national laws and regulations, are the responsibility and duty of the employer.

The employer should show strong leadership and commitment to OSH activities in the organization.

Workplace safety refers to the limitation of elements that can cause harm, accidents, and other negative outcomes in the workplace.It represents a culmination of policies, behaviors, and precautions that work to limit hazards, accidents, and other kinds of harm in a work environment.

Occupational hygiene is the discipline of protecting worker health by controlling workplace hazards that can cause harm .

Hazards and risks to workers' safety and health should be identified and assessed on an ongoing basis. Preventive and protective measures should be implemented in the following order of priority:

(a) eliminate the hazard/risk;

(b) control the hazard/risk at source, through the use of engineering controls or organizational measures;

(c) minimize the hazard/risk by the design of safe work systems, which include administrative control measures;

(d) where residual hazards/risks cannot be controlled by collective measures, the employer should provide for appropriate personal protective equipment, including clothing, at no cost, and should implement measures to ensure its use and maintenance.

Hazard prevention and control procedures or arrangements should be established and should:

(c) comply with national laws and regulations, and reflect good practice;

(d) consider the current state of knowledge, including information or reports from organizations, such as labour inspectorates, occupational safety and health services.

Factors (GOST 12.0.003-2015)	Stages of work			Legislation documents
	Developing	Manufacturing	Operation	
Increased dust and gas content in the air in the working area	+			GOST 12.2.061-81 Industrial equipment. General safety requirements to working places
Ionizing radiation		+	+	SanPiN 2.2.4.1329-03 Requirements for protection of personnel from the impact of impulse electromagnetic fields
Increased or decreased temperature of surfaces of equipment materials	+	+	+	*GOST 12.4.011-89* Means of protection. General requirements and classification;
Increased level of noise	+	+	+	GOST 12.1.003-2014 Occupational safety standards system. Noise. General safety requirements
Mental overstrain	+	+	+	GOST 9241-4-2009 Ergonomic requirements for office work with visual display terminals (VDTs). Part 5. Requirements for the location of the workstation and posture of the operator

Emotional overload	+	+	+	GOST 9241-4-2009 Ergonomic requirements for office work with visual display terminals (VDTs). Part 5. Requirements for the location of the workstation and posture of the operator
Increased voltage in an electrical circuit, the closure of which can pass through the human body	+	+	+	*GOST 12.1.019-2017* Electrical safety. General requirements and nomenclature of types of protection;

Harmful factors:

Increased dust and gas content in the air in the working area

While nuclear reactors do not emit carbon dioxide at the point of power generation, the nuclear fuel chain is responsible for carbon emissions during mining, milling, enriching, construction, transportation, and decommissioning .

Workplace dust is unavoidable in many occupations, but in high concentrations it can go from being an irritant to a real health risk.

While larger dust particles may seem like a health risk, it's actually finer dust that's the most dangerous.

To protect workers from radioactive air the US. atomic energy commission recognized that it could be filtered using mechanical filtration and developed HEPA filtration to protect scientists from exposure to radioactive particles.

Increase level of noise

Noise is random fluctuations of various physical nature, one of the most common adverse physical environmental factors that acquire important social and hygienic significance in connection with urbanization, as well as mechanization and automation of technological processes. Prolonged exposure to noise can lead to hearing loss or even deafness.

Noise also has an effect on the nervous system, causing an increase in pulse and breathing, an increase in energy consumption, which leads to earlier fatigue and exhaustion. Inattentiveness, depressed state, inhibition of intellectual processes is the result of the impact of noise on the human psyche. All this together entails a decrease in labour productivity and efficiency.

The noise sources in the designed laboratory installation are water and vacuum pumps, the maximum permissible noise level in laboratory rooms is 75 (13)

	Sound pressure levels, dBA, in octave bands with average geometric frequencies, Hz									Sound level, dBA
	32	63	125	250	500	1000	2000	4000	8000	
Laboratory Room	103	91	83	77	73	70	68	66	64	75

When developing an installation, it is necessary to take all measures to reduce noise at the design, assembly, installation and workplace organization stages.

This is achieved by:

1. Application of noise-safe equipment;
2. The use of means and methods of collective protection;
3. The use of personal protective equipment;

Personal protective equipment includes headphones, earbuds, helmets and plugs.

Collective protection is carried out at the expense of:

1. Sound insulation applications;
2. Improving noise reduction equipment;
3. Changes in the direction of noise;
4. Layout of premises and buildings.

Emotional overload

The emotional consequences of nuclear power plant disasters include depression, anxiety, post-traumatic stress disorder, and medically unexplained somatic symptoms. These effects are often long term and associated with fears about developing cancer.

Research on disasters involving radiation, particularly evidence from Chernobyl, indicates that mothers of young children and cleanup workers are the highest risk groups. The emotional consequences occur independently of the actual exposure received.

In contrast, studies of children raised in the shadows of the Three Mile Island (TMI) and Chernobyl accidents suggest that although their self-rated health is less satisfactory than that of their peers, their emotional, academic, and psychosocial development is comparable.

Ionizing radiation

Electric and magnetic fields are invisible areas of energy (also called radiation) that are produced by electricity, which is the movement of electrons, or current, through a wire

Nuclear reactor is the main source of radiation in the nuclear power plant.The reactor is a key component of a power plant, as it contains the fuel and its nuclear chain reaction, along with all of the nuclear waste products. The reactor is the heat source for the power plant, just like the boiler is for a coal plant.

Workers protect themselves from radiation by using protective equipment and to wear protective clothing as well as dosimeters to ensure they do not exceed dose limits.

Dangerous factors:

Increased voltage in an electrical circuit, the closure of which can pass through the human body

Any production is characterized by the use of a large number of electrical devices. In this regard, there is a possibility of injury from the effects of electric current on the human body. Therefore, measures to ensure electrical safety are of great importance.

To ensure the safety of work on electrical installations, the following organizational measures are carried out;

appointment of persons responsible for the organization and safety of work;

execution of an order or order for the production of works;

implementation of admission to work;

organization of supervision of the work;

registration of work termination, work breaks, transfers to other workplaces;

establishment of rational work and rest regimes.

The technical methods of ensuring electrical safety include

protective shells;

protective fences (temporary or stationary);

safe location of live parts;

insulation of live parts (working, additional, reinforced, double);

workplace isolation;

low voltage;

Increased or decreased temperature of surfaces of equipment materials

If the reaction temperature is too low, the reaction will be slower, and unreacted material may accumulate in the reactor.

If the reaction temperature then increases, the unreacted material will be available to react. If there is enough unreacted material, the energy released may exceed the reactor cooling capacity.Workers job is try to cool the equipment material if the temperature increases to maintain the equipment in safety working conditions.

Workers can wear heat protective suit to protect themselves from high temperature,Ways to protect equipment from increasing temperature

Allow for Airflow. Give your equipment a little breathing room

Use outsider coolant like water

Keep It Clean.

In Case of Emergency, Shut Down.

Environmental Safety

The environmental impact of nuclear power remains a contentious issue among scientists, activists, and policymakers. On the one hand, it can provide energy at scale without burning fossil fuels. On the other hand, system failures have tragic consequences and there is as yet no good solution for dealing with nuclear waste. This article presents some of the critical benefits and detriments of today's nuclear power.

Nuclear power plant emissions compared to fossil fuels

One way to compare the environmental impact of various electrical generation technologies is to analyze their life-cycle greenhouse gas emissions, which is the total amount of greenhouse gas output (measured in grams carbon dioxide equivalent, or gCO2eq) that can be expected from deploying a generator. Life-cycle analyses take into account the full life of the system, from obtaining materials through the construction process, to operation, to end of life waste management.

Nuclear energy produces radioactive wasteA major environmental concern related to nuclear power is the creation of radioactive wastes such as uranium mill tailings, spent (used) reactor fuel, and other radioactive wastes. These materials can remain radioactive and dangerous to human health for thousands of years.

Environmental consequences of nuclear energy: radioactive nuclear waste

The most pressing environmental issue when it comes to nuclear power is the waste it produces. There are a few types of radioactive material produced throughout the lifecycle of a nuclear power plant, most notably uranium mill tailings and used reactor fuel.

If these aren't handled and disposed of carefully, they pose many human and environmental health consequences. The U.S. has an entire regulatory commission set up to regulate and oversee the safe operation of nuclear power plants. The U.S. Nuclear Regulatory Commission (NRC) design regulations governing the handling, transportation, storage, and disposal of nuclear materials.

Nuclear emissions compared to other clean sources

Technology	Lifecycle emissions (gCO_2eq/kWh)
Wind	11
Hydropower	24*
Concentrated solar	27
Nuclear	**12**
Geothermal	38
Solar PV	48

Water consumption and risks:

During the process of nuclear power generation, large volumes of water are used. 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.

Greenhouse gas emissions:

Many stages of the nuclear fuel chain — mining, milling, transport, fuel fabrication, enrichment, reactor construction, decommissioning and waste management — use fossil fuels, or involve changes to land use, and hence emit carbon dioxide and conventional pollutants.

Nuclear energy contributes a very small number of emissions into the atmosphere which can cause many environmental problems such as global warming. Uranium is not burned in a nuclear power plant as coal is so there are no emissions from it. All of the waste that comes from the fission of uranium stays in the plant and is therefore able to be disposed of in a safe way in which the uranium is kept out of the environment. (7)

Emergency Safety

An emergency is an unexpected situation that endangers the safety of one or more individuals

The main objective of emergency planning is to reduce injuries, protect the community and maintain business continuity . An emergency plan usually includes necessary procedures during a crisis, a clear set of roles and responsibilities and established instructions for local emergency response and recovery bodies.

This is some of the emergencies that may happen:

Radiation emergency

Hurricanes

Chemical spills

Earthquake

For example, the laboratory room belongs to the category of fire hazard B3. In fire-hazardous premises, the scope and nature of organizational and technical measures depends on the category of fire hazard of the premises and should include

organization of fire protection;

certification of substances, materials, products, technological processes in terms of fire safety;

public involvement in fire safety issues;

development and implementation of fire safety norms and rules, instructions on the procedure for handling fire-hazardous substances and materials, on compliance with the fire safety regime and actions of people in the event of a fire;

production and application of visual agitation tools to ensure fire safety. (11)

Conclusion

I designed a nuclear power reactor and did all the calculations on 4 parts

1.Thermal calculations

2.Neturon physics calculations

3. Strength calculations

4.Hydraulic calculations

And i found out that:

- t_{clad}^{out} = 335.9°C ;
- $t_0(z) =$ 660.7 °C;
- $V_0 = 488.7 cm^2$;
- $V_f = 148.6\ cm^2$;
- $V_{Zr} = 57.11\ cm^2$;
- $V_{H_2O} = 283.0\ cm^2$;
- $L^2 = 0.36$;
- $D_{ves.in} 4.258\ m$;
- $D_{ves.out} = 4.682\ m$;
- $s_{bot} = 0.249$ m.

As a result of the calculations, a horizontal saturated steam generator with natural circulation of the working medium and with U-shaped tubes of the heat exchange surface:

- Q = 754.9 MW;
- l = 16.5 m;
- S_{2out} = 0.0323 mm;

For the calculation of the NPP with power 1000 MW.

First Calculation of the basic thermal diagram for the design mode of operation, which include calculating intial data like temperature and pressure and enthalpy.

Then we moved to the calculation of the main condensate which include calculation of the condensate temperature and LPH and HPH.

Then after calculation of High-pressure heaters, with my calculation the number of its 3 RFWH. And calculation of process in LPC and HPC with separator and superheater.

Then calculation of reduced power generation by the j-th extraction. Calculation of relative steam flow rate and study material and heat balance at each part of block.

With this calculation I calculate the thermal loading of steam generating unit $Q_{SG} = 3006$ MW, Steam flow rate in turbine $G_0 = 1507\ \frac{kg}{s}$, also, also, calculate the overall efficiency of NPP is 32.28 % .

And lastly, choose suitable material for each equipment according to my calculation, my choice should include technical and economic properties.For the condenser part i made a comparison between two condenser and i chose the best one based on the cost :

$C_{cond} = 401.1$ million rubles;

$C_{el} = 161.9$ million rubles.

For the financial management part, 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.

And for the last part of my project social responsibility part i examined every equipment, location, site, material and environment to be ready for any harmful or dangerous consequences that might happen in the site of the NPP

And the i prepared various solutions for these problems and calculate the maximum radioactive release allowed in the NPP site then made a couple of safety preparations of any kind of emergency such as fire or tornados or radioactive releases.

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