TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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

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 of a power unit with VVER for a NPP with electric capacity of 870 MW

UDC: 621.311.25:621.039.52

Student

Group	Full name	Signature	Date
507И	Shahin Yousef Reda Abdelhamid Elsayed		

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.		

On the section "Social responsibility"

Position	Full name	Academic degree, title	Signature	Date
Associate Professor of DGTS SCEE	O.A. Antonevich	Cand. Biolog. Sc.		

ДОПУСТИТЬ К ЗАЩИТЕ:

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

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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
507И	Shahin Yousef Reda Abdelhamid Elsayed

Topic of the work:

Design of a power unit with VVER for a NPP with electric capacity of 870 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.)*	The aim of the work is to design a nuclear power plant with a VVER-type reactor with an electrical power of 870 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. Description of Power Unit 2. Passive safety systems from modern VVER reactors 3. Design Calculation of a Saturated Steam Generator 4. Design NPP with VVER-870 Type Reactor 5. Design calculation of the turbine condenser 6. Financial management, resource efficiency and resource saving 7. Social responsibility

List of graphic material *(with the exact indication of the required drawings)*	1. Reactor installation. 2. Turbine installation. 3. Nuclear reactor. 4. Steam generator.

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, title	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
507И	Shahin Yousef Reda Abdelhamid Elsayed		15.06.2022

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Major (MEP) 14.05.02 «Nuclear power plants: design, operation and engineering / Атомные станции: проектирование, эксплуатация и инжиниринг»
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
507И	Shahin Yousef Reda Abdelhamid Elsayed

Topic of the work:

Design of a power unit with VVER for a NPP with electric capacity of 870 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)
…	…	…

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
507И	Shahin Yousef Reda Abdelhamid Elsayed		

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

To the student:

Group	Full name
507И	Shahin Yousef Reda Abdelhamid Elsayed

School	ИШЭ	Division	The Butakov Research Center
Degree	Specialist	Educational Program	14.05.02 Design, Operation and Engineering of Nuclear Power Plants.

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	– Salary costs – 56 700 rub; – STR budget – 310 675 rub;
2. *Expenditure rates and expenditure standards for resources*	– Electricity costs – 5,8 rub per 1 kW
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	– Labor tax – 27,1 %; – Overhead costs – 55%;
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
507И	Shahin Yousef Reda Abdelhamid Elsayed		

TASK FOR CHAPTER
«SOCIAL RESPONSIBILITY»

Student:

Group	**Name**
507I	Shahin Yousef Reda Abdelhamid Elsayed

School		**Division**	**The Butakov Research Center**
Educational level	Specialist	**Course/Specialty**	14.05.02 Design, Operation and Engineering of Nuclear Power Plants

Topic of FQW:

Design of a power unit with VVER for a NPP with electric capacity of 870 MW	
Initial data for the chapter «social responsibility»:	
1. Characteristics of the researched object (substance, material, device, algorithm, technique, working area)	Object - Design a nuclear power plant with a VVER-type reactor with an electrical power of 870 MW ▪ Passive safety systems from modern VVER reactors ▪ Design Calculation of a Saturated Steam Generator ▪ Design NPP with VVER-870 Type Reactor ▪ Design calculation of the turbine condenser
List of questions to be researched, designed and developed:	
1. Legal and organizational issues of occupational safety 1.1 consider special (specific to the projected work area) law norms of labor legislation. 1.2 indicate the features of the labor legislation in relation to the specific conditions of the project.	▪ GOST 12.2.003-91 Occupational safety standards system. Industrial equipment. General safety requirements; ▪ Federal Law of November 21, 1995 N 170-FZ "On the Use of Atomic Energy" ▪ Russian Federation. Labor Code of The Russian Federation of 31 December 2001
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 Suggest measures to reduce the impact of identified harmful and dangerous factors	**Harmful factors** ▪ Increased pressure of vapors or gases in vessels; ▪ Increased level of noise; ▪ Increased level of vibration; **Dangerous factors** ▪ Sharp edges, burrs on equipment, tools. ▪ Increased levels of electromagnetic radiation. ▪ Increased voltage in an electrical circuit, the closure of which can pass through the human body;
3. Environmental Safety: influence on the atmosphere, hydrosphere, lithosphere	▪ **Atmosphere affect** Emissions from ventilation systems and the radioactive wastes, spent (used) reactor fuel. ▪ **Hydrosphere affect** During the cooling process, the water becomes contaminated with radionuclides and must be filtered to remove as many radionuclides as possible. ▪ **Lithosphere affect** nuclear waste can cause changes in the availability of elements such as nitrogen, carbon and sulfur.
4. Emergency Safety: describe the most likely emergency situation	▪ Most typical emergency- fire breakout
Date issue of the task for the chapter	

Consultant:

Post	**Name**	Academic degree	**Date**	**Signature**
Associate professor	Антоневич О. А.	PhD		

Student:

Group	**Name**	**Date**	**Signature**
507I	Shahin Yousef Reda Abdelhamid Elsayed		

ABSTRACT

Final qualification work contains 141 p., 59 fig., 65 tab., 26 sources, 1 app.

Keywords: NPP, Nuclear reactor, VVER-870, steam generator, turbine, condenser, design, efficiency.

The object of research is design power unit with a VVER reactor with an electric power of 870 MW

Purpose of work is to design a nuclear power plant with a VVER-type reactor with an electrical power of 870 MW

Within the work (research, calculations, etc.) Design Calculation of a Saturated Steam Generator, Design NPP with VVER-870 Type Reactor, Design calculation of the turbine condenser.

As a result (research, calculations, etc.) Improving the efficiency and safety of NPP.

Main design, technological, technical and operational characteristics: horizontal steam generator: thermal power 655.5 MW; coolant mass flow 2703 kg/s; steam mass flow 351.4 kg/s; number of tubes 8813 pcs.; average tubes length 11.8 m.

Degree of implementation: Results proposed to be used in the developed and reference power units of nuclear power plants, [preliminary design]

Application area: nuclear energy.

Cost effectiveness/significance of work the developed algorithm for the design calculation of the thermal diagram of NPP and steam generator was used in the corresponding computer program to simulate the characteristics and results in a wide range of defining parameters.

It is planned to continue the development and research on the NPP efficiency of VVER type and improving its safety and improve horizontal steam generators efficiency in the future.

Contents

Introduction

In the upcoming years, cheap and plentiful power will be key to the modern world. In countries where alternative energy sources are insufficient, the use of nuclear energy for power generation is essential. Pressure is placed on traditional sources of electricity, such as coal, oil, and gas, as a result of the population's rising quality of living and continuous increases in industry.

The world's growing need will soon exceed the capacity of these sources. The most remarkable facts of nuclear power are the maximum amount of energy that a small quantity of active materials is able to produce. The total energy released after the fission of 1 kilogram of uranium is comparable to 3100 tons of coal or 1700 tons of oil. around four hundred of nuclear power plants is operated around the worldwide. The use of nuclear power is not just backed up by proof but it is also less expensive than power produced by traditional sources.

A simple Definition for the facility is plant that transforms atomic energy into useful power is a nuclear power plant. Reactor heat is typically applied to operate a turbine, which then drive an electric generator. an overview about Nuclear Plant, it is one of types of facilities which produce electricity as thermal plants but the difference is the way of generate the heat to generate steam in nuclear plants in uses nuclear reactions and this occur in nuclear reactor, and the fuel of this reactor is uranium dioxide, these atoms split when it is hit by a thermal neutron then large amount of heat is released as a result of fission reactions. nuclear facilities shut down their reactors. During the process of replacing the spent fuel with a fresh. Some of the main equipments of the facility is nuclear reactor, main circulating pump, Heat Exchanger, Feed pump, Condenser, Turbine and Generator. Nuclear plants have several advantages compared to the other power plants so it needs less area and more Suitable for high needs and good performance, Severe weather has no impact on power plants, and the need of water is not high and the most important that it is a Source of energy without carbon releases. The VVER series of reactors has developed to be the nuclear power industry's centerpiece in Russia and one of the greatest examples of a popular high-tech product globally. VVER is still developing working toward achieve so many main goals. This means more effective use of fuel, improved economic parameters and, of course, improve safety. The VVER use light water as a moderator and coolant.

The VVER and other PWR sorts vary from each other in a few critical ways both in terms of the materials included and the design. the taking after are a few characteristics of the VVER like Use of horizontal steam generators, Use of hexagonal fuel assemblies and Use of high-capacity pressurizer.

Section 1: Description of the primary components

Reactor and internals

Reactors are vertical, pressurized vessels that contain in-core instrumentation detectors, a core barrel with a baffle, protective tube units, fuel assemblies. VVER reactor vessel design is based on the following principles:

- verified manufacturing techniques and structural components;
- full in-shop production of the vessel including testing;
- the ability to carry ships by rail and water;
- the ability of periodic in-service verification of vessel.

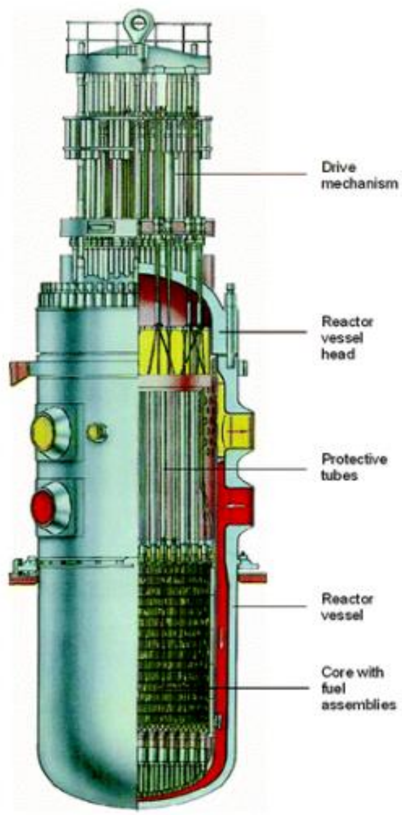

Figure 1.1-Reactor

The reactor vessel is made up of several forged shells that have been welded together, an elliptical bottom head, and solid ring sealing gaskets to keep out water.

Each of the vessel's two nozzle shells has four nozzles that are attached to the reactor coolant system's main coolant pipeline.

Heat-resistant alloy steel is used to construct the reactor vessel, grade 15Х2НМФА. The selection of welding materials and reactor vessel steel was made after a mechanical properties analysis.

The core barrel is a cylindrical, weld-together shell with a supporting bottom and a flange that rests on the vessel shoulder.

A displacer and a protective screen are provided by the core baffle, which is positioned in the core barrel at the core level and situated at a structural gap from the FA periphery row.

The force of the elastic element inserted between the PTU shoulder presses the PTU against the core barrel flange once it has been put on top. To space the FAs and prevent them from rising, a solid support system is created by the perforated PTU shell, plates, and protective tubes. The internals are made of corrosion-resistant steels of austenitic grade.

Main coolant pipeline (MCP)

The main coolant pipeline connects the reactor, steam generators and main coolant pump sets between themselves forming a circulation system.

MCP consists of four circulation loops, each loop has two sections of tubes. A section between a reactor outlet nozzle and steam generator inlet collector is a ^{2}hot^{2} leg. A section between steam generator outlet collector and RCP set inlet (suction) nozzle and between RCP set outlet (discharge) nozzle and reactor inlet nozzle is a ^{2}cold^{2} leg.

Reactor coolant pump

vertical centrifugal one-stage pump set that contains a hydraulic casing, internals, electric motor, top and bottom spacers. supports and auxiliary systems. The electric motor is of vertical asynchronous double-speed type. To prevent the reverse rotation of the rotor.

Basic characteristics of the reactor coolant system

The reactor coolant system involves: water-cooled water-moderated power reactor and four circulation loops consisting of steam generators, reactor coolant pumps and pipelines as well as the pressuring system connected to one of circulation loops.

The reactor coolant system is a barrier to the release of radioactive substances from the core into the secondary circuit system and the containment volume

Steam generator

The "Horizontal steam generator" concept, which related to heat exchange technology, can be applied to nuclear power plant steam producing facilities.

A horizontal steam generator's vessel is a massive, thick-walled vessel. It has a bottom, two side shells, and a middle shell. Welding is used to join every component to the other components.

Horizontal steam generators are preferred in the Russian nuclear sector. In Russia, steam generator tubes are constructed of steel of such 08H18N10T type.

Heat-exchanger of horizontal type with submerged heat exchanging surface.

The steam generator vessel is designed to house the internals. The steam generator vessel consists of forged shells, stamped elliptic bottoms and forged nozzles connected by welding. Vessel design provides easy access to examine the internals on the secondary side.

The design of VVER-870 uses Ordinary water under pressure serves as both the coolant and the moderator in a four-circuit nuclear steam producing vessel arrangement with a thermal neutron reactor. There are four cooling loops in the design.

Figure 1.2-steam generator

Section 2: Passive safety systems in modern nuclear reactors

Passive nuclear safety is a design approach for safety features, implemented in a nuclear reactor, that does not require any active intervention on the part of the operator or electrical/electronic feedback in order to bring the reactor to a safe shutdown state, in the event of a particular type of emergency (usually overheating resulting from a loss of coolant or loss of coolant flow). Such design features tend to rely on the engineering of components such that their predicted behavior would slow down, rather than accelerate the deterioration of the reactor state.

They typically take advantage of natural forces or phenomena such as gravity, buoyancy, pressure differences, conduction or natural heat convection to accomplish safety functions without requiring an active power source. Many older common reactor designs use passive safety systems to a limited extent, rather, relying on active safety systems such as diesel-powered motors. Some newer reactor designs feature more passive systems.

The motivation being that they are highly reliable and reduce the cost associated with the installation and maintenance of systems that would otherwise require multiple trains of equipment and redundant safety class power supplies in order to achieve the same level of reliability. However, weak driving forces that power many passive safety features can pose significant challenges to effectiveness of a passive system, particularly in the short-term following an accident.

Definition of passive safety system according to IAEA as (the system which is composed entirely of passive components and structures another definition as a system which uses active components in a very limited way to initiate subsequent passive operation) Due to the wide range of systems which may meet this definition.

Passivity

Passive means are used to deal with “design extension conditions” and “beyond design basis accidents” (passive SG cooling system, passive containment cooling system) and provide back up for active safety systems.

Passive safety systems in VVERs

The overall safety systems of the VVER-reactors include the emergency core cooling systems, reactor shutdown systems and the decay heat removal systems from the core and the containment to assure the heat removal and hence assure the core coolability. In the next sections these systems are described and discussed.

The VVER was designed to meet Russian safety requirements with consideration of both IAEA recommendations and European utility requirements. The strategy for management of design basis accidents utilizes both active and passive safety systems, while the strategy for beyond design basis accidents is mainly based on the use of passive safety systems. The following paragraphs describe some of the included passive safety systems.

Quick boron injection system

The fast boron infusion framework is extraordinarily saved for utilize in past pl an premise mischance administration where a scram did not, or fizzled to happen. The main idea of this system is to put the reactor core in a subcritical state by the injection of high concentration boric acid solution into the primary coolant loop. The fast boron injection system consists of 4 independent channels, each include of a tank filled with boric acid and connect to the primary-coolant loop and isolated from the system with valves. The flow of boric acid through these valves is initiated by a pressure-differential across the valves.

Core flooding system

The core flooding system is planning to provide a passive supply of boron solution into the reactor core to simultaneously remove decay heat and maintain the core at a subcritical state. It is planned to operate within the occasion a primary system leak during a station blackout (including the loss of diesel generators) and function for as long as possible, (at least 24 hours).

Passive heat removal system

The VVER-1000 system is planned to preserve heat evacuation from the reactor core during accidents with total loss of AC sources of electric power when either the primary loop is sealed or while leaks occur in the primary or secondary loops. The decay heat removal system content of 4 independent natural circulation loops, one for each coolant loop. Each steam generator has piping to the carry and distribute steam into the two heat exchangers. The steam is condensed in the heat exchangers and is back the SG.

The new Russian reactor design, which is currently unique among PWRs, employs both conventional active systems and cutting-edge passive technologies that do not require external power to conduct safety system operations. The passive filter system and the passive heat removal system are examined in particular.

- First stage of hydro-accumulators (HA-1).

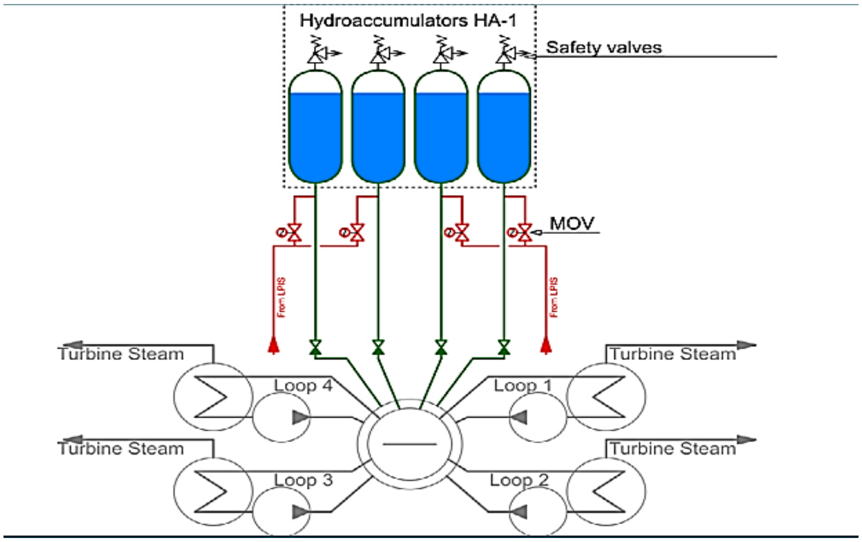

Figure 2.1-First stage of hydro-accumulators (HA-1)

- Second stage of Hydro-accumulators (HA-2).

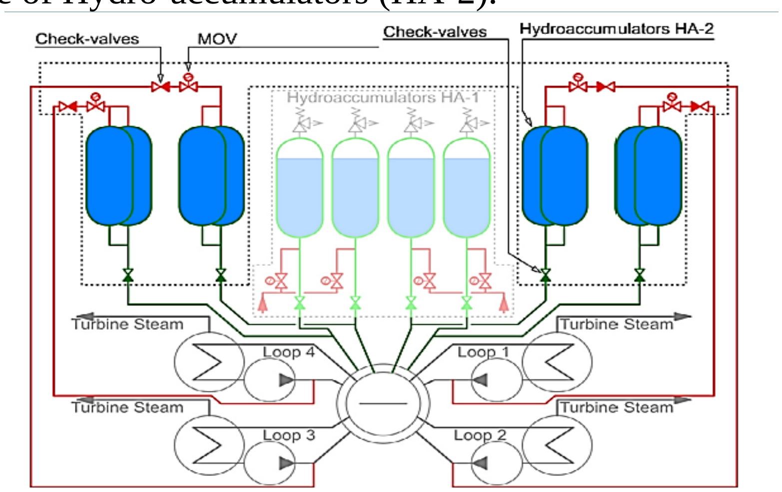

Figure 2.2-Second stage of Hydro-accumulators (HA-2)

- Third stage of Hydro-accumulators (HA-3)

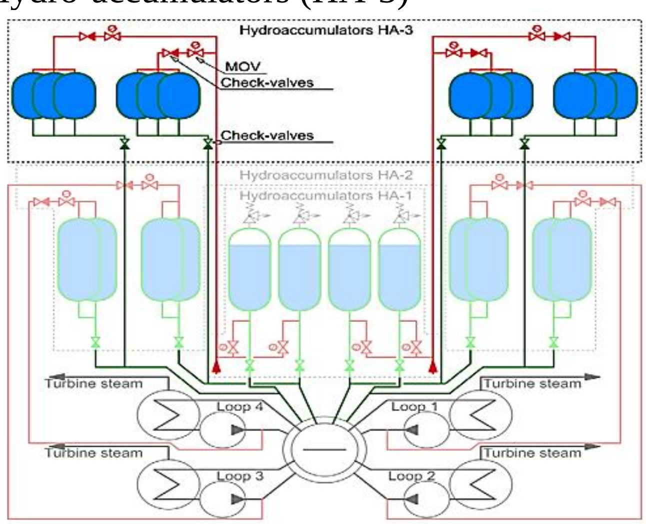

Figure 2.3- Third stage of Hydro-accumulators (HA-3)

Safety systems related with the Secondary system

- Passive Heat Removal System through Steam Generators (PHRS-SG).

Containment Safety Systems:

- Passive Containment Heat Removal System
- passive Autocatalytic Recombiners (PAR).

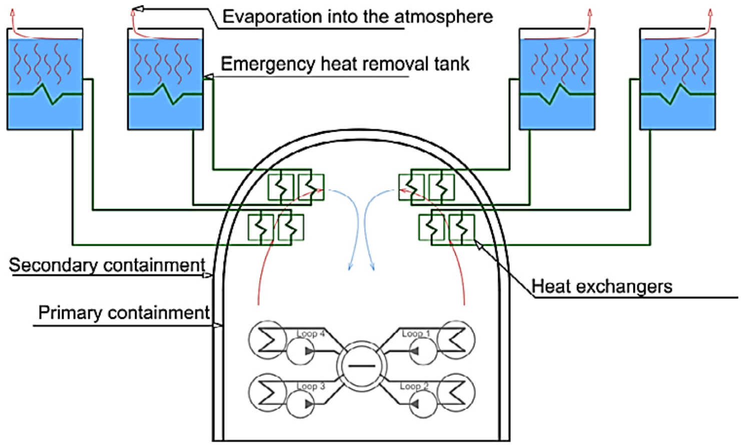

Figure 2.4-Passive Containment Heat Removal System

The plant is equipped with a passive heat removal system (PHRS) and a system of water tanks (hydraulic accumulators) in a first and second stage to ensure emergency heat removal from the core by passive safety measures. (HA-1 and HA-2).

The functioning of the passive heat removal system alone will be adequate to cool the reactor if a loss of all AC power sources at the site results in an active safety system failure. If this failure is unaccompanied by a loss of coolant from the reactor circulation circuit. The PHRS can operate in these circumstances for an infinite amount of time due to the usage of air as the ultimate heat sink.

The first stage's operational water tanks will supply enough reactor cooling to fill the reactor vessel in the event of a primary coolant leak and the failure of active safety devices. Long-term heat removal from the core requires the use of the second-stage tanks and the PHRS. In this instance, the primary circuit steam from the reactor is condensed by the PHRS using steam generators (SG). As a result, the condensate from the steam generator is added to the water in the second-stage tanks and returned to the primary circuit.

Passive system design

The following is a description of the major design elements of the passive safety systems. The image below shows a basic schematic and the layout of a VVER plant's passive safety measures.

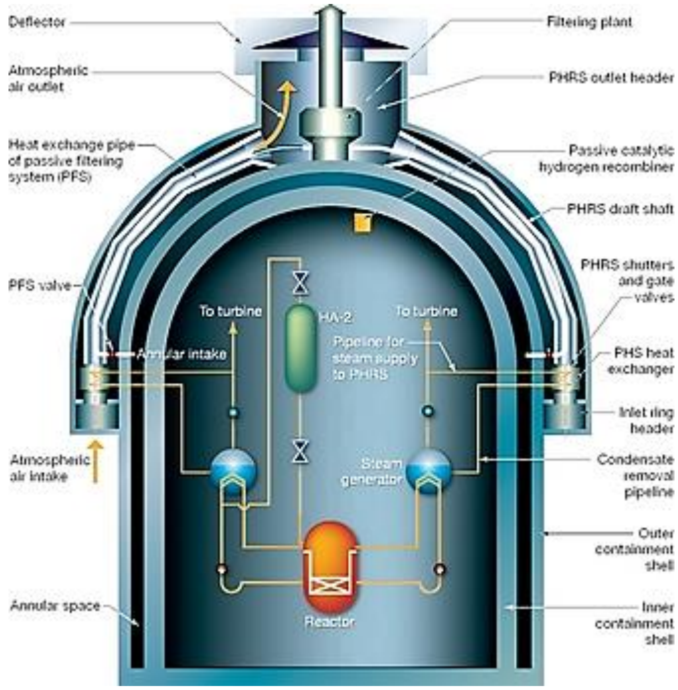

Figure 2.5-A basic diagram of passive safety systems in a VVER plant

In the event of a maximum two-side coolant loss in the primary circuit, the second stage water tanks (hydraulic accumulators) are designed to inject boric acid into the core for at least 24 hours (stored concentration: 16g/kg). When the primary circuit loses coolant and the reactor's pressure drops to 1.5 MPa, the system is activated.

Together with the water tanks from the first stage and PHRS, the second stage water tanks are utilized to cool the core in the event that the primary circuit's leak tightness is lost.

For this, the second stage water tank system features the following:

- progressive profiling of the water flow that is injected into the core as the amount of water in the tanks gets lower. According to flow profiling, residual heat is reduced.
- 960 m3 of coolant are stored in water tanks overall.
- In the event of the greatest coolant loss in the main circulation pipeline, the coolant inventory was chosen to ensure reactor make-up with coolant for 24 hours.

Four water tank sets make up the system. Two tanks are included in each set, and the drain lines allow for coolant flow profiling. The hydrostatic pressure causes coolant from HA-2 to flow into the reactor. The second stage tanks (HA-2) are connected to the pipes that link the first stage tanks (HA-1) to the reactor on the side of the drain line. In close proximity to the SG headers, the cold legs of the main circulation pipes are linked to the top portion of the HA-2 tanks through specific check valves. If the circuit pressure drops to 1.5 MPa, special check valves are programmed to open.

First water tanks of the first stage start up in abnormal circumstances involving coolant loss from the primary circuit (at around 5.9 MPa), and second-stage tanks subsequently enter the picture. (at < 1.5 MPa).

PHRS (passive heat removal system)

In the event of an accident that goes beyond the scope of the design and results in the loss of all AC power sources, the passive heat removal system is intended to provide for the long-term removal of residual heat from the reactor. When the primary circuit's coolant is lost, the system uses the second-stage water tanks to remove any remaining heat.

Four separate trains make up the system, one for each steam generator. Two heat exchangers/condensers, steam condensate pipelines with valves, air ducts with air shutters, and a controller are all included in each train.

Each SG's pipeline feeds steam to the heat exchanger in the PHRS. The ambient air in the heat exchangers causes steam to condense. The containment building's atmosphere is used to supply the air. The air enters a ring header that circles the confinement building due to natural draft. After that, individual air ducts deliver air to heat exchanger modules. In the heat exchanger modules, steam condenses into air, which then enters the draft shafts and exits through a shared header with a deflector.

The system's heat exchangers are warmed to the secondary circuit temperature while it is in standby, preventing thermal cycling upon PHRS initiation and supplying the best dynamics for PHRS to begin operating at its rated capacity. Each PHRS heat exchanger module has closed gate valves that open in response to a loss-of-power signal upstream and downstream. The valves prevent heat loss at the unit while the system is in standby and safeguard the equipment from an air shock wave.

A controller with two drives—one active and one passive—is located between the heat exchanger module and the gate valve.

According to changes in steam pressure in the steam generator, the passive drive, which consists of a bellows spring unit, activates the opening or closing of shutters. When the controller is operating on-load, the shutters are typically open. In order to keep steam pressure close to nominal levels, the shutters begin to close if the SG steam pressure drops below 5.8 MPa.

In beyond-design-basis catastrophes where there is a loss of all AC sources at the site but no primary circuit coolant leakage, the passive PHRS shutter controller drive regulates the process of heat removal from the reactor.

(PFS) Passive filtering system

The VVER design has a cross-connected passive system architecture. The employment of a passive filtering system (PFS) to filter leakages from the inner containment shell into the inter-containment cavity is a logical progression from including the PHRS system in NPP design. The thermal energy of air traveling through PHRS heat exchangers and condensers is used by PFS to operate.

The PFS system exploits the area between the containment's outer and inner shells to collect leaks from the inner shell. The system includes vent pipes for the filtering facility and heat-exchanging tubes for heat exchange. The heat-exchanging channels have intake valves and are connected to the filter at their outlet and the inter-containment cavity at their inlet. The PHRS system's hot air ducts contain the heat-exchanging channels, which warm and dry the steam-gas leakages that are directed into the filter.

The passive filtering mechanism functions in the manner described below. The valves linking the inter-containment cavity to the heat exchanger channels and the gate valves are closed during normal operation, allowing a regular ventilation system to cool the cavity. Due to leaks in the air line caused by the insufficient leak tightness of the PHRS gate valves, there is a modest flow of warm air in the draft shafts. Air heats up PFS components as it passes through the PHRS heat exchangers, keeping the system constantly operational when the PFS valve opens.

In the event of emergency reactor leaks, the inner containment shell's pressure rises, causing radioactive leaks from the inner shell to appear in the inter-containment cavity. If the regular ventilation system is operating, this cavity serves as a decompression chamber and is where the leaks are directed to reach the filter.

The inter-containment cavity would be depressurized by the PFS if the conventional ventilation system fails.

Passive hydrogen recombiners

The RVK-type passive catalytic recombiners of hydrogen are used in the VVER design, and their effective flame-free functioning has been supported for bulk hydrogen concentrations ranging from 0.45% to 16%. Over the containment, there are 160 passive catalytic burners installed. In order to protect the plant from hydrogen explosions in design-basis and beyond-design-basis accidents, the average bulk hydrogen concentration in the containment should not be higher than 6%.

Conclusion

Performance parameters of the passive safety systems utilized in VVER design were selected based on computational simulation of various design-basis and beyond-design-basis accidents, and were validated by simulating the performance of the systems on large-scale test rigs.

Section 3: Design NPP with [WWER] Type Reactor

The target of this assignment is to find (work out) calculation of process to calculate relative rate of flow for each part and determine steam flow at the turbine and verify of efficiency of turbine installation and efficiency power plant and to choose of suitable equipment for the water -steam circuit.

The project to design NPP with WWER according to initial data:

Table 3.1-Initial Data

N_e MW	870	Electrical power
p_0, MPa	6.5	Initial pressure
t_0, °C	280.9	Initial temperature
x_0	1	Initial steam quality
p_c, kPa	4	Condenser Pressure
Superheater	2	Superheater stages
t_{fw}, °C	210	Feedwater temperature
p_d , MPa	0.6	Deaerator Pressure
n HPH	2	Number of HPH
n LPH	4	Number of LPH

3.1 Calculation of main condensate

Main condensate temperature at deaerator inlet

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

Where:

- t_d Deaerator temperature;
- Δt_d Deference temperature; $\Delta t_d = 12 \div 15$ °C;
- Assumption $\Delta t_d = 15$ °C .

$$t_d = f(p_d) = f(0.60) = 158.8 \text{ °C} \;;$$

$$t_{mc} = t_d - \Delta t_d = 160.1 - 15 = 143.8 \text{ °C} \,.$$

Temperature Main condensate after seal coolers and ejector T_{Cse}

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

Where:

- t_c Temperature in condenser ;
- $\Delta t_{cse}$is and it between $\Delta t_{cse} = 3 \div 5$°C , assume $\Delta t_{cse} = 5$;

$$t_c = f(p_c) = f(0.004) = 29\ ℃;$$
$$t_{cse} = t_c + \Delta t_{cse} = 29 + 5 = 34\ ℃;$$
$$h_{cse} = f(t_{cse}) = f(34) = 143\,\frac{kJ}{kg};$$

3.2 Calculation for low-pressure heaters

LP Heater's rises in Temperature $\Delta t_{LPH} = 25 \div 35$;

$$\Delta \mathbf{t_{LPH}} = 28℃\ ;$$
$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}}\ ;$$
$$n_{LPH} = \frac{t_{mc} - t_{cse}}{\Delta t_{LPH}} = \frac{143.8 - 34}{28} = 3.9 \approx 4\ ;$$

LPH's Real temperature rises:

$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}} = \frac{143.8 - 34}{4} = 27.5\ ℃\ .$$

Closed type:

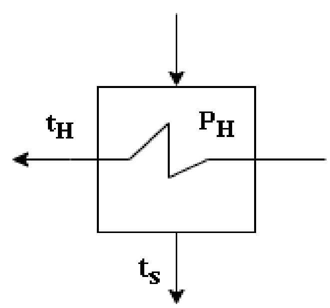

Figure 3.1-closed type reheater.

$$t_{sj} = t_{Hj} + \theta_{LPH};\ p_{Hj} = f(t_{sj})\ ;$$
$\theta = (1 \div 2)$ is subcooled temperature in reheater, assumption 2℃ ;
$t_{Hj} = t_{Hj+1} + \Delta t_{LPH}$; $p_{exj} = (1.02 \div 1.05)p_{Hj}$; assume (1.03).

First RFWH (closed)

$$t_{H6} = t_{cse} + \Delta t_{LPH} = 34 + 27.5 = 61.4\ ℃\ ;$$
$$t_{s6} = t_{H6} + \theta_{LPH} \rightarrow p_{H6} = f(t_{s6}) = f(63.4) = 0.023\ \text{MPa};$$
$$p_{ex6} = (1.03)p_{H6} = 1.03 \cdot 0.023 = 0.024\ \text{MPa}\ .$$

Second RFWH (closed)

$$t_{H5} = t_{H6} + \Delta t_{LPH} = 61.4 + 27.5 = 88.9℃;$$
$$t_{s5} = t_{H5} + \theta_{LPH} \rightarrow p_{H5} = f(t_{s5}) = f(90.9) = 0.072;$$
$$p_{ex5} = (1.03)p_{H5} = 1.03 \cdot 0.072 = 0.074\ \text{MPa}.$$

Third RFWH (closed)

$$t_{H4} = t_{H5} + \Delta t_{LPH} = 88.9 + 27.5 = 116.4℃\ ;$$
$$t_{s4} = t_{H4} + \theta_{LPH} = 116.4 + 2 = 118.4℃\ ;$$

$$p_{H4} = f(t_{s4}) = f(118.4) = 0.188 \text{ MPa};$$
$$p_{ex4} = (1.03)p_{H4} = 1.03 \cdot 0.188 = 0.194 \text{ MPa}.$$

Fourth RFWH (closed)

$$t_{H3} = t_{H4} + \Delta t_{LPH} = 116.4 + 27.5 = 143.8\ ℃;$$
$$t_{s3} = t_{H3} + \theta_{LPH} = 143.8 + 2 = 145.8℃;$$
$$p_{H3} = f(t_{s3}) = f(145.8) = 0.425 \text{ MPa};$$
$$p_{ex3} = (1.03)p_{H3} = 1.03 \cdot 0.458 = 0.438 \text{ MPa}.$$

Deaerator

$$t_d = t_{H3} + \Delta t_d = 143.8 + 15 = 158.8\ ℃;$$
$$p_{exD} = 1.03 \cdot 0.6 = 0.618 \text{ MPa}.$$

Table 3.2-Low pressure heater parameters.

NO	t_{Hj}, ℃	t_{sj}, ℃	p_{Hj}, MPa	p_{exj}, MPa
3	143.8	145.8	0.425	0.438
4	116.4	118.4	0.188	0.194
5	88.9	90.9	0.072	0.074
6	61.4	63.4	0.023	0.024
(cse)	34	-	-	-

3.3 Pressure of Condensate pump

- $p_{cp1} = 4 \dots 5$ bar; (0.5 MPa);
- $p_{cp2} = (1.1 \dots 1.4)p_d$, assumption 1.3 p_d;

$$p_{cp2} = 1.3(p_d) = 1.3(0.60) = 0.780 \text{ MPa}.$$

3.4 High pressure (feedwater) RH

Temperature of feed water pump t_{fwp}

$$t_{fwp} = f\left(p_{fwp}, h_{fwp}\right);$$

Where:

- p_{fwp} feed water's pressure; $p_{fwp} = (1.2 \dots 1.3)\ p_0$, assumption 3;
- h_{fwp} feed water's enthalpy; $h_{fwp} = h'_d + \Delta h_{fwp}$.

Pressure of feed water

$$p_{fwp} = 1.3 \cdot p_0 = 1.3 \cdot 6.5 = 8.45 \text{ MPa}.$$

Enthalpy of feed water

$$h_{fwp} = h'_d + \Delta h_{fwp}.$$

Where:

- h'_dwater in deaerator enthalpy;

$$h'_d = f(p_d) = f(0.60) = 671\ {}^{kj}/_{kg};$$
$$\Delta h_{fwp} = v\left(p_{fwp} - p_d\right).$$

Where:

- (v) specific volume;

$$v = f(p_d) = f(0.60) = 0.0011\ {}^{m^3}/_{kg}\ ;$$

$$\Delta h_{fwp} = v(p_{fwp} - p_d) = 0.0011(8.45 - 0.60) = 8.64\ {}^{kj}/_{kg}\ ;$$

$$h_{fwp} = h'_d + \Delta h_{fwp} = 671 + 8.64 = 679\ {}^{kj}/_{kg}\ ;$$

$$t_{fwp} = f(p_{fwp}, h_{fwp}) = f(8.45, 679) = 159.8℃\,.$$

HPH Temperature's rises $\Delta t_{HPH} = 25 \dots 35$; Assumption $\Delta t_{HPH} = 30℃$;

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

$t_{fwp} = 210\ ℃$, according to the optimal value of feedwater temperature.

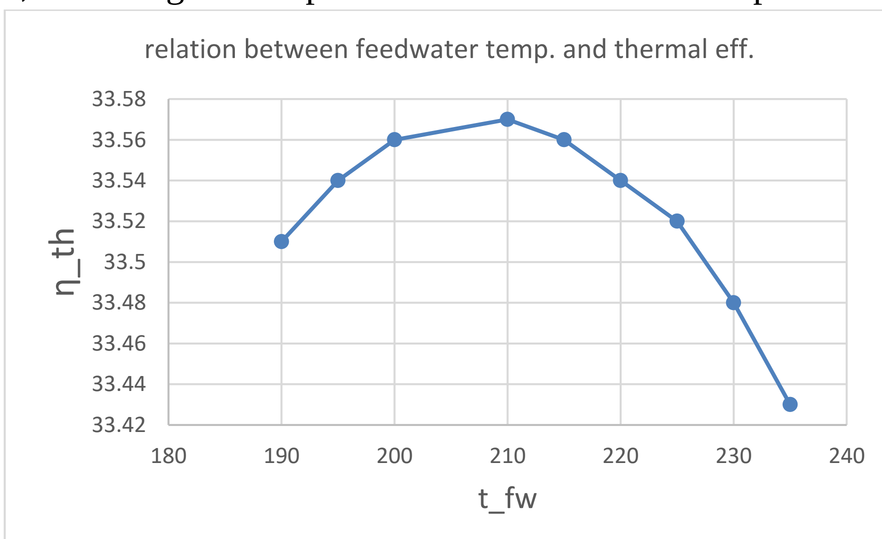

Figure 3.2-Determination of optimal value of temp. feedwater

$$z_{HPH} = \frac{t_{fw} - t_{fwp}}{\Delta t_{HPH}} = \frac{210 - 159.8}{30} = 1.7\ \approx 2\,;$$

Heater's Real temperature rises

$$\Delta t_{HPH} = \frac{t_{fw} - t_{fwp}}{z_{HPH}} = \frac{210 - 159.8}{2} = 25.1\ ℃\,.$$

Closed type:

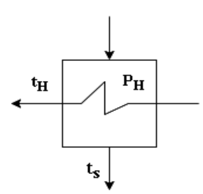

Figure 3.3-closed type reheater.

$$t_s = t_H + \theta_{HPH}; p_H = f(t_s);$$

Where:

- $\theta_{HPH} = (3 \dots 5)$ subcooled temperature in HPH, θ_{HPH} =4 ℃ ;

$$t_{Hj} = t_{Hj+1} + \Delta t_{HPH};\ p_{exj} = (1.02 \div 1.05)p_{Hj};\ \text{assume } (1.03);$$

First high-pressure heater (Closed)

$$t_{H2} = t_{fwp} + \Delta t_{LPH} = 159.8 + 25.1 = 184.9\ ℃\ ;$$

$$t_{s2} = t_{H2} + \theta_{HPH} = 184.9 + 4 = 188.9\ ℃ \rightarrow p_{H2} = f(t_{s2}) = f(188.9) = 1.224\ \text{MPa}\ ;$$

$$p_{ex2} = (1.03)p_{H2} = 1.03 \cdot 1.224 = 1.261\ \text{MPa}.$$

Second high-pressure heater (Closed)

$$t_{H1} = t_{H2} + \Delta t_{HPH} = 184.9 + 25.1 = 210\ ℃;$$

$$t_{s1} = t_{H1} + \theta_{HPH} = 210 + 4 = 214 ℃ \rightarrow p_{H1} = f(t_{s1}) = f(214) = 2.064\ \text{MPa};$$

$$p_{ex1} = (1.03) \cdot p_{H1} = 1.03 \cdot 2.064 = 2.126\ \text{MPa}.$$

Table 3.3- parameters of HPH

NO	t_{Hj} , ℃	t_{sj}, ℃	p_{Hj} , MPa	p_{exj} , MPa
1=fw	210	214	2.064	2.126
2	184.9	188.9	1.224	1.261
T_{fwp}	159.8	–	–	–

3.5 Calculations of Parameters at the turbine entry

Steam pressure is lower before the HPC's nozzles than it is before the turbine. Throttle valve keeps enthalpy constant however make pressure losses 3…5 % of p_0

$$p_{0'} = p_0(0,95 \div 0,97) = p_0\ (0.95) = 6.5 \cdot (0.95) = 6.175\ \text{MPa}.$$

Steam parameters at $0'$(after stop valve)

Table 3.4- parameters after throttle valve

$p_{0'}$, MPa	6.175
$h_{0'} = h_0$, kJ/kg	2779
$t_{0'} = f(p_{0'}, h_{0'})$, ℃	277.5
$S_{0'} = f(p_{0'}, h_{0'})$, kJ/(kg℃)	5.88

3.6 Calculation of processes in Turbine

For HPC

take (absolute) internal efficiency of HPC equal $\eta_{0i}^{HPC} = 0.83$;

Isentropic process 1st extraction where $p_1 = p_{ex1} = 2.126$ MPa;

$$s_{0'} = s_{1t} = 5.88\ {}^{kJ}/_{(kg℃)}\ ;$$

$$h_{1t} = f(p_1, s_{0'}) = f(2.126\ , 5.88\ ) = 2585\ {}^{kj}/_{kg}\ ;$$

$$H_{01}^{HPC} = h_0 - h_{1t} = 2779 - 2585 = 194\ {}^{kj}/_{kg}\ ;$$

$$H_{i1}^{HPC} = H_0^{HPC} \cdot \eta_{0i}^{HPC} = 194 \cdot 0.83 = 161 \ {}^{kj}/_{kg};$$

$$h_1 = h_0 - H_i^{HPC} = 2779 - 161 = 2618 \ {}^{kj}/_{kg}.$$

Isentropic process 2nd extraction where $p_2 = p_{ex2} = 1.261$ MPa, from Table 3.3;

$$s_{0'} = s_{2t} = 5.88 \ {}^{kJ}/_{(kg°C)};$$

$$h_{2t} = f(p_2, s_{0'}) = f(1.261, 5.88) = 2495 \ {}^{kj}/_{kg};$$

$$H_0^{HPC} = h_0 - h_{2t} = 2779 - 2495 = 284;$$

$$H_{i2}^{HPC} = H_0^{HPC} \cdot \eta_{0i}^{HPC} = 284 \cdot 0.83 = 236 \ {}^{kj}/_{kg};$$

$$h_2 = h_0 - H_{i2}^{HPC} = 2779 - 236 = 2543 \ {}^{kj}/_{kg}.$$

Steam quality Exhaust from HPC is, $x^{HPC} = f(P_2, h_2) = f(1.261, 2543) = 0.877$. which is allowable.

Superheating system Properties (S, SH1, SH2)

Separation system

$$p_s = p_2 = 1.261 \text{ MPa};$$

losses in Pressure in separator about 6 %;

$$p_{s'} = (1 - 0.06) \cdot p_s = (1 - 0.06) \cdot 1.261 = 1.185 \text{ MPa}.$$

Enthalpy after separation $h_{s''}$;

$$h_{s''} = f(p_{s'}, x = 1) = f(1.185, x = 1) = 2783 \ {}^{kj}/_{kg}.$$

Superheating parameters

Double-stage reheater

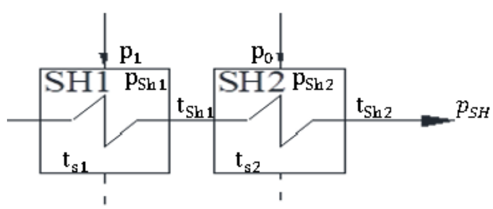

Figure 3.4-superheating system.

- losses in Pressure of superheater p_{SH} almost 95% of $p_{s'}$;

$$p_{SH} = (0.95) \cdot p_{s'} = (0.95) \cdot 1.185 = 1.126 \text{ MPa};$$

- $\Delta t_R = 15 \div 20°C$ for the 1st stage, $\Delta t_R = 15$ °C;
- $\Delta t_R = 10 \div 15°C$ for the 2nd stage, $\Delta t_R = 13$ °C;
- Where 1st stage is heated from extraction from HPC and 2nd stage is heated from fresh steam.

Sh1

$$t_{Sh1} = t_1 - \Delta t_R = 214 - 15 = 199\ ℃;$$

Enthalpy of steam after first superheater h_{SH1};

$$h_{R1} = f(p_{SH}, t_{Sh1}) = f(1.126\ ,199) = 2818\ ^{kj}/_{kg}\ ;$$

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

$$h'_{SH1} = f(t_1) = f(210) = 898\ ^{kj}/_{kg}\ ;$$

Sh2

$$t_{Sh2} = t_o - \Delta t_R = 280.9 - 13 = 267.9\ ℃;$$

Enthalpy of steam after second superheater h_{sh2} ;

$$h_{R2} = f(p_{SH}, t_{sh2}) = f(1.126,267.9) = 2978\ ^{kj}/_{kg}\ ;$$

Enthalpy at the drain second superheater h'_{SH2} ;

$$h'_{SH2} = f(t_0) = f(280.9) = 1241\ ^{kj}/_{kg};$$

For LPC (Low Pressure Cylinder)

Parameters at the LPC entry.

The steam pressure before the nozzles of the LPC is less than after superheater:

Throttle valve which keeps enthalpy constant but make some pressure losses 3÷5% of p_0;

$$p_{SH'} = p_{SH}(0{,}95 \div 0{,}97) = p_{SH}\ (0.95) = 1.126\ (0.95) = 1.070\ \text{Mpa}\ ;$$

At LPC Exhaust

$$p_{c'} = (1.03 \div 1.05)p_c = 1.03\ p_c = 1.03 \cdot 0.004 = 0.00412\ \text{MPa};$$

Table 3.5-Steam parameters.

$p_{SH'}$, MPa	1.070
$h_{SH'} = h_{Sh2}$, kJ/kg	2978
$t_{SH'} = f(p_{SH'}, h_{SH'})$, ℃	266.9
$s_{SH'}, f(p_{SH'}, h_{SH'})$, kJ/(kg℃)	6.965

with absolute internal efficiency $\boldsymbol{\eta_{0i}^{LPC} = 0.80}$;

Isentropic process 3rd extraction where $p_3 = p_{ex3} = 0.438$ MPa , from Table 3.2;

$$s_{SH'} = s_{3t} = 6.965\ ^{kJ}/_{(kg℃)};$$

$$h_{3t} = f(p_3, s_{SH'}) = f(0.438,6.965) = 2785\ ^{kj}/_{kg}\ ;$$

$$H_0^{LPC} = h_{SH'} - h_{3t} = 2978 - 2785 = 193\ ^{kj}/_{kg};$$

$$H_{i3}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 193 \cdot 0.80 = 154\ ^{kj}/_{kg}\ ;$$

$$h_3 = h_{SH'} - H_{i3}^{LPC} = 2978 - 154 = 2824\ ^{kj}/_{kg}\ ;$$

Isentropic process 4rd extraction where $p_4 = p_{ex4} = 0.194$ MPa, from Table 3.2;

$$s_{SH'} = s_{4t} = 6.965 kJ/(kg°C);$$

$$h_{4t} = f(p_4, s_{SH'}) = f(0.194,6.965) = 2638 \ {}^{kj}/_{kg} \ ;$$

$$H_0^{LPC} = h_{SH'} - h_{4t} = 2978 - 2638 \ = 340 \ \ {}^{kj}/_{kg} \ ;$$

$$H_{i4}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 340 \cdot 0.80 = 272 \ \ {}^{kj}/_{kg} \ ;$$

$$h_4 = h_{SH'} - H_{i4}^{LPC} = 2978 - 272 = 2706 \ \ {}^{kj}/_{kg} \ ;$$

Isentropic process 5th extraction where $p_5 = p_{ex5} = 0.074$ MPa, from Table 3.2;

$$s_{SH'} = s_{5t} = 6.965 \ {}^{kJ}/_{(kg°C)};$$

$$h_{5t} = f(p_5, s_{SH'}) = f(0.074,6.965) = 2483 \ \ {}^{kj}/_{kg} \ ;$$

$$H_0^{LPC} = h_{SH'} - h_{5t} = 2978 - 2483 = 495 \ \ {}^{kj}/_{kg} \ ;$$

$$H_{i5}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 495 \cdot 0.80 = 396 \ \ {}^{kj}/_{kg} \ ;$$

$$h_5 = h_{SH'} - H_{i5}^{LPC} = 2978 - 396 = 2571 \ \ {}^{kj}/_{kg} \ ;$$

Isentropic process 6th extraction where $p_6 = p_{ex6} = 0.024$ MPa, from Table 3.2;

$$s_{SH'} = s_{6t} = 6.965 \ kJ/(kg°C);$$

$$h_{6t} = f(p_6, s_{SH'}) = f(0.024,6.965) = 2320 \ \ {}^{kj}/_{kg} \ ;$$

$$H_0^{LPC} = h_{SH'} - h_{6t} = 2978 - 2320 = 658 \ \ {}^{kj}/_{kg} \ ;$$

$$H_{i6}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 658 \cdot 0.80 = 527 \ kJ/kg; \ {}^{kj}/_{kg} \ ;$$

$$h_6 = h_{SH'} - H_{i6}^{LPC} = 2978 - 527 = 2452 \ \ {}^{kj}/_{kg} \ ;$$

Isentropic process D extraction where $p_D = p_{exD} = 1.03 \cdot p_d = 0.618$ MPa;

$$s_{SH'} = s_{6t} = 6.965 \ kJ/(kg°C);$$

$$h_{6t} = f(p_6, s_{SH'}) = f(0.618,6.965 \ ) = 2856 \ \ {}^{kj}/_{kg} \ ;$$

$$H_0^{LPC} = h_{SH'} - h_{6t} = 2978 - 2856 = 123 \ \ {}^{kj}/_{kg} \ ;$$

$$H_{i6}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 123 \cdot 0.80 = 98 \ kJ/kg;$$

$$h_D = h_{SH'} - H_{i6}^{LPC} = 2978 - 98 = 2880 \ \ {}^{kj}/_{kg} \ ;$$

Isentropic process C' point.

$$s_{SH'} = s_{c't} = 6.965 \ \ kJ/(kg°C);$$

$$p_{c'} = (1.03 \div 1.05)p_c = 1.03 \cdot p_c = 1.03 \cdot 0.004 = 0.00412 \text{ MPa};$$

$$h_{c't} = f(p_{c'}, s_{SH'}) = f(0.00412\ ,6.965\ ) = 2102\ \ ^{kj}/_{kg}\ ;$$

$$H_0^{LPC} = h_{SH'} - h_{c't} = 2978 - 2102 = 877\ \ ^{kj}/_{kg}\ ;$$

$$H_{ic}^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 877 \cdot 0.80 = 701\ \ ^{kj}/_{kg}\ ;$$

$$h_{c'} = h_{SH'} - H_{ic}^{LPC} = 2978 - 701 = 2277\ \ ^{kj}/_{kg}\ ;$$

Steam quality Exhaust from LPC $x^{LPC} = f(P_{c'}, h_{c'}) = f(0.00412\ ,2277) = 0.885$;

3.7 Underproduction factor

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

$$0 \le y_j \le 1.$$

For turbine with steam separating and superheating system (HPC, LPC)

- First for HPC

$$H_j = h_0 - h_j\ ;$$

$$H_1 = h_0 - h_1 = 2779 - 2618 = 161\ \ ^{kj}/_{kg};$$

$$H_2 = h_0 - h_2 = 2779 - 2543 = 236\ ^{kj}/_{kg};$$

$$H_i^{HPC} = H_2 = 236\ \ ^{kj}/_{kg};$$

- For LPC

$$H_j = \left(h_{sh2} - h_j\right) + H_i^{HPC}\ ;$$

$$H_D = (h_{sh2} - h_D) + H_i^{HPC} = (2978 - 2880) + 236 = 334\ \ ^{kj}/_{kg}\ ;$$

$$H_3 = (h_{sh2} - h_3) + H_i^{HPC} = (2978 - 2824) + 236 = 390\ \ ^{kj}/_{kg}\ ;$$

$$H_4 = (h_{sh2} - h_4) + H_i^{HPC} = (2978 - 2706) + 236 = 508\ \ ^{kj}/_{kg}\ ;$$

$$H_5 = (h_{sh2} - h_5) + H_i^{HPC} = (2978 - 2582) + 236 = 632\ \ ^{kj}/_{kg}\ ;$$

$$H_6 = (h_{sh2} - h_6) + H_i^{HPC} = (2978 - 2452) + 236 = 763\ \ ^{kj}/_{kg}\ ;$$

$$H_{c'} = (h_{sh2} - h_{c'}) + H_i^{HPC} = (2978 - 2277) + 236 = 937\ \ ^{kj}/_{kg}\ ;$$

$$H_i^{total} = 937\ ^{kj}/_{kg}\ ;$$

$$y_0 = \frac{H_i - H_0}{H_i} = \frac{937 - 0}{937} = 1;$$

$$y_1 = y_{sh1} = \frac{H_i - H_1}{H_i} = \frac{937 - 161}{937} = 0.827;$$

$$y_2 = \frac{H_i - H_2}{H_i} = \frac{937 - 236}{937} = 0.748;$$

$$y_D = \frac{H_i - H_D}{H_i} = \frac{937 - 334}{937} = 0.643;$$

$$y_3 = \frac{H_i - H_3}{H_i} = \frac{547}{937} = 0.583;$$

$$y_4 = \frac{H_i - H_4}{H_i} = \frac{429}{937} = 0.46;$$

$$y_5 = \frac{H_i - H_5}{H_i} = \frac{305}{937} = 0.33;$$

$$y_6 = \frac{H_i - H_6}{H_i} = \frac{174}{937} = 0.18;$$

$$y_{c'} = \frac{H_i - H_6}{H_i} = \frac{0}{937} = 0.$$

Table of Parameters calculations

Table 3.6-The Parameters

No.	Steam Extracted			Heaters Steam in (drain)			Heater water outlet			Steam work Extracted in cylinder	Underproduction factor
	p_j	h_j	t_j	p_{Hj}	t_{sj}	h'_j	p_{wj}	t_{wj}	h_{wj}	H_j	y_j
	KPa	kJ/kg	°C	KPa	°C	kJ/kg	KPa	°C	kJ/kg	kJ/kg	
0	6500	2779	280.9	-	-	-	-	-	-	-	-
0'	6175	2779	277.5	-	-	-	-	-	-	-	1
1	2127	2618	215.5	2065	214.0	916	8450	210.0	900	161	0.8279
2	1261	2543	190.2	1225	188.9	803	8450	184.9	788	236	0.7483
sep	1186	2783	187.4	1186	187.4	796	-	-	-	-	0.7483
sh1	2127	2618	215.5	-	-	923	-	-	-	-	0.8279
sh2	6500	2779	280.9	-	-	1241	-	-	-	-	
D	618	2880	214.0	600	158.8	2756	600	158.8	671	334	0.6437
3	438	2824	183.5	425	145.8	614	780	143.8	606	390	0.5837
4	194	2706	119.8	189	118.4	497	780	116.4	489	508	0.4577
5	75	2582	91.7	73	90.9	381	780	88.9	373	632	0.3257
6	24	2452	64.1	23	63.4	266	780	61.4	258	763	0.1863
C'	4.12	2277	29.5	-	-	-	-	-	-	937	0
C	4	2098	29.0	4	29.0	121	-	-	-	-	

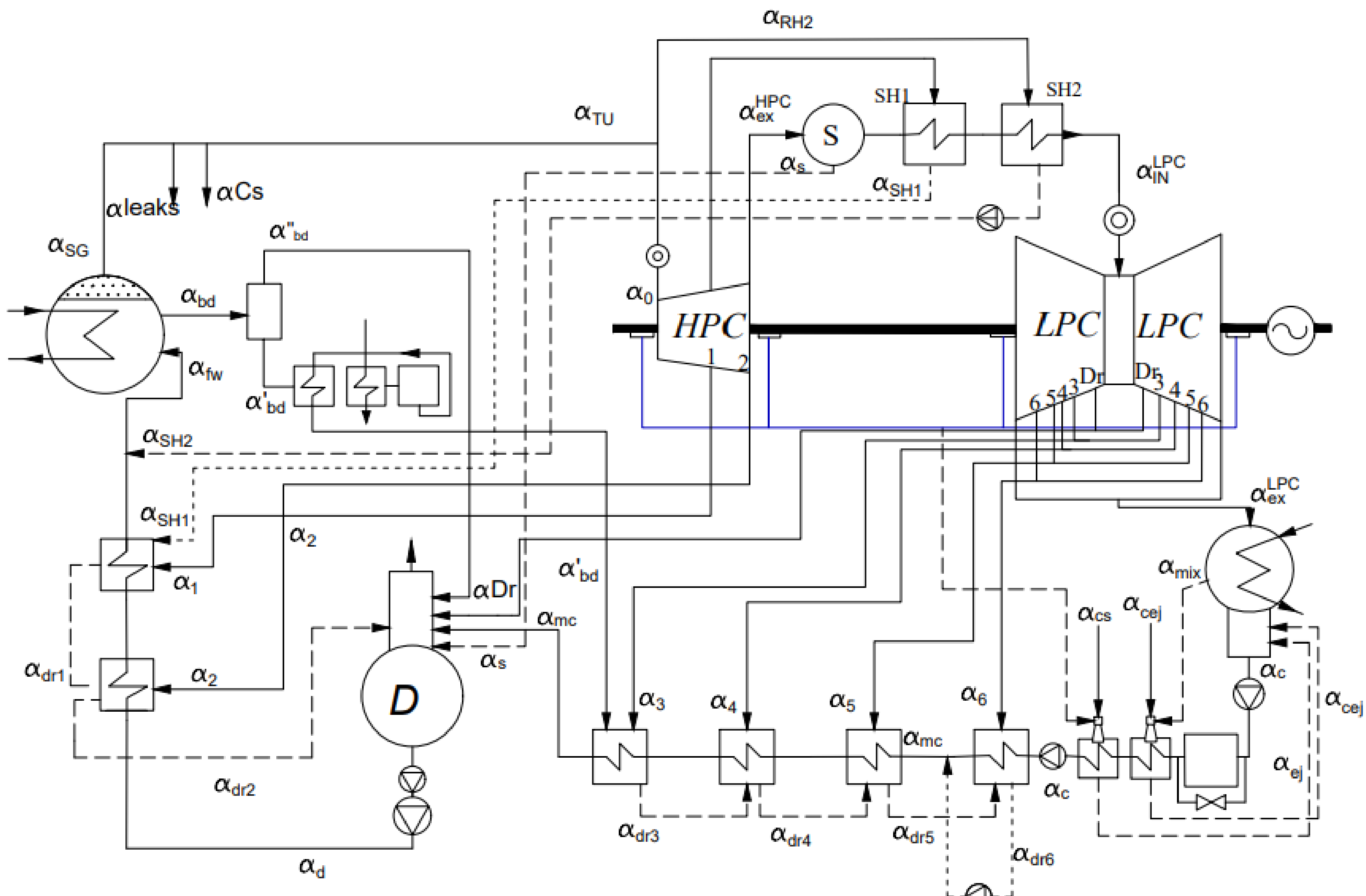

Figure 3.5-NPP Scheme

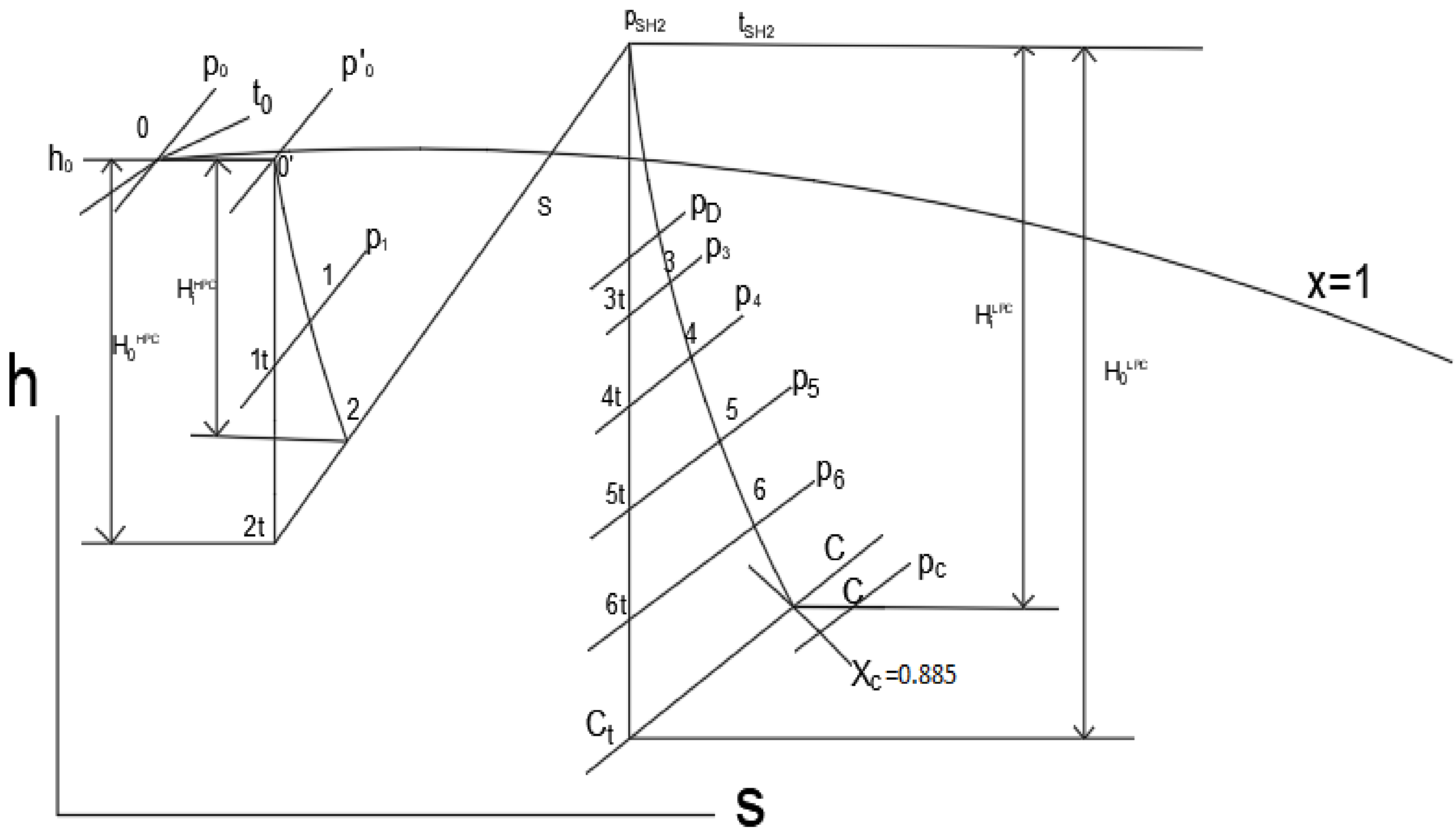

Figure 3.6-h-s Diagram

3.8 Calculation of Relative steam flowrate

Relative feed water flowrate α_{fw} which goes to the SG unit is calculated according to the equations:

$$\alpha_{fw} = \alpha_{SG} + \alpha_{bd} \quad ;$$

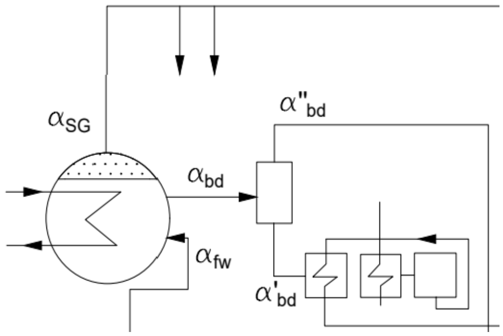

Figure 3.7-SG and blowdown system

Where:

- α_{SG} SG's relative rate steam flow;
- α_{bd} – is a relative blow-down flowrate and equal $\alpha_{bd} = 0.005$.

Relative blow-down flowrate

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

Where:

- α'_{bd} – is a relative blow-down water flowrate;
- α''_{bd} – is a relative blow-down steam flowrate.

Heat balance blow-down tank.

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

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

$$P_{tank} = (1.02 \div 1.08) \cdot P_d = 1.06 \cdot 0.6 = 0.636 \text{ MPa} \;;$$

Where:

- P_d is pressure of deaerator.

$$h''_{bd} = f(P_{tank}, \text{saturation vapour}) = 2759 \; {}^{kJ}/_{kg} \;;$$

$$h'_{bd} = f(P_{tank}, \text{saturation water}) = 680 \; {}^{kJ}/_{kg} \;;$$

$$h'_0 = f(P_0, \text{saturation water}) = 1241 \; {}^{kJ}/_{kg} \;;$$

Material balance equation

$$0.005 = \alpha'_{bd} + \alpha''_{bd} \;;$$

Heat balance equation

$$(0.005 \cdot 1241) = 680 \cdot \alpha'_{bd} + 2759 \cdot \alpha''_{bd} \;;$$

So, the after solve two equation we get.

$$\alpha'_{bd} = 0.00365 \ ;$$
$$\alpha''_{bd} = 0.00134 \ ;$$

Feedwater

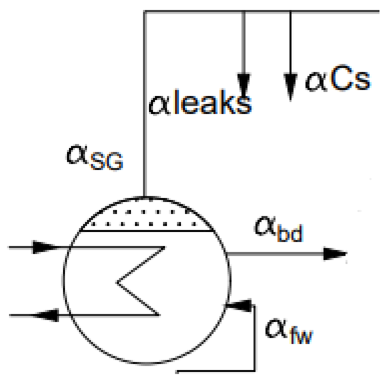

Figure 3.8-feedwater of SG

$$\alpha_{fw} = \alpha_{TU} + \alpha_{leak} + \alpha_{cs} + \alpha_{bld} \ ;$$
$$\alpha_{TU} = \alpha_0 + \alpha_{SH2} \ ;$$

where:

- α_{cs}, is a relative flow-rate of steam out of turbine seals;
- $\alpha_{cs} = 0.005 \div 0.012$;
- α_{leak}, is a relative flow-rate leakage, $\alpha_{leak} \leq 0.01$;
- α_{bld}, is a relative flowrate blowdown, $\alpha_{bld} = 0.005$;

$$\alpha_{fw} = \alpha_0 + \alpha_{SH2} + \alpha_{leak} + \alpha_{cs} + \alpha_{bld};$$
$$\alpha_{fw} = 1 + \alpha_{SH2} + 0.01 + 0.005 + 0.005$$

Mixing point before steam generator (fw)

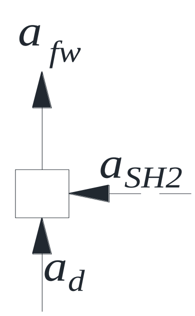

Figure 3.9-mixing point before SG

$$\alpha_{fw} = \alpha_{SH2} + \alpha_d$$

$$\frac{\alpha_{fw} \cdot h_{fw}}{\eta_{oph}} = \alpha_{SH2} \cdot h'_0 + \alpha_d \cdot h_{w1} \ ;$$

$$\frac{\alpha_{fw} \cdot h_{fw}}{0.99} = \alpha_{SH2} \cdot 1241 + \alpha_d \cdot 900$$

we get:

$$\alpha_{SH2} + \alpha_d = 1 + \alpha_{SH2} + 0.01 + 0.005 + 0.005;$$
$$\alpha_d = 1 + 0.01 + 0.005 + 0.005 = 1.02\,.$$

Relative flowrate for the the high-pressure heat exchangers HPH & D

RFWH 1

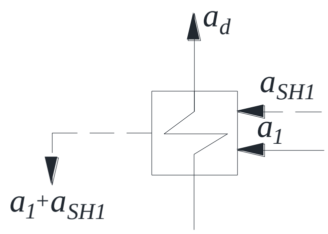

Figure 3.10-1stHigh pressure RH

$$\frac{\alpha_d \cdot (h_{w1} - h_{w2})}{\eta_h} = \alpha_1 \cdot (h_1 - h_{dr1}) + \alpha_{SH1} \cdot (h'_1 - h_{dr1});$$

$$\frac{1.02 \cdot (900 - 788)}{0.98} = \ \alpha_1 \cdot (2618 - 916) + \alpha_{SH1} \cdot (923 - 916).$$

RFWH 2

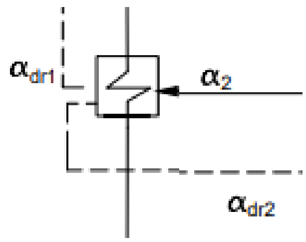

Figure 3.11-2nd High pressure RH

Thermal balance:

$$\frac{\alpha_d \cdot \left(h_{w2} - h_{fwp}\right)}{\eta_h} = \alpha_2 (h_2 - h_{dr2}) + \alpha_{dr1} \cdot (h_{dr1} - h_{dr2});$$
$$\frac{1.02 \cdot (788 - 679)}{0.98} = \alpha_2 (2543 - 803) + \alpha_{dr1} \cdot (916 - 803).$$

High pressure cylinder extraction outlet.

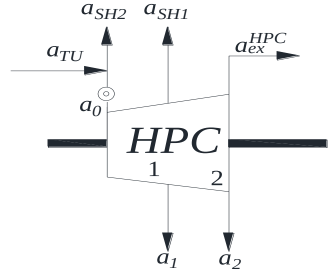

Figure 3.12-HPC of turbine installation

$$\alpha_{ex}^{HPC} = \alpha_0 - \alpha_1 - \alpha_2 - \alpha_{SH1}\,;$$

$$\alpha_{ex}^{HPC} = 1 - \alpha_1 - \alpha_2 - \alpha_{SH1};$$
$$\alpha_{ex}^{HPC} = 1 - \alpha_1 - \alpha_2 - \alpha_{SH1} ;$$

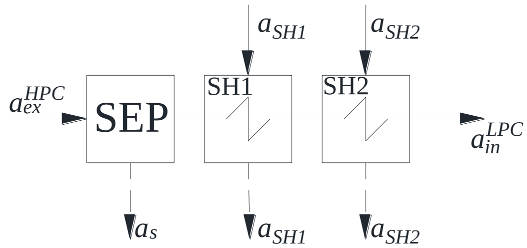

Figure 3.13-superheating equipment

Separator

$$\alpha_{ex}^{HPC} = \alpha_s + \alpha_{in}^{LPC} ;$$
$$\alpha_{ex}^{HPC} \cdot h_2 = \alpha_s \cdot h_s' + \alpha_{in}^{LPC} \cdot h_{asp} ;$$
$$\alpha_{ex}^{HPC} \cdot (2543) = \alpha_s \cdot (796) + \alpha_{in}^{LPC} \cdot (2783) .$$

First Superheater

$$\alpha_{in}^{LPC} \cdot \left(h_{R1} - h_{asp}\right) = \frac{\left(\alpha_{SH1} \cdot (h_1 - h_1')\right)}{\eta_{sh}} ;$$
$$\alpha_{in}^{LPC} \cdot (2818 - 2783) = \frac{\left(\alpha_{SH1} \cdot (2618 - 923)\right)}{0.98}.$$

Second superheater

$$\alpha_{in}^{LPC} \cdot (h_{R2} - h_{R1}) = \frac{\left(\alpha_{SH2} \cdot (h_0 - h_0')\right)}{\eta_{sh}} ;$$
$$\alpha_{in}^{LPC} \cdot (2978 - 2818) = \frac{\left(\alpha_{SH2} \cdot (2779 - 1241)\right)}{0.98} .$$

Deaerator

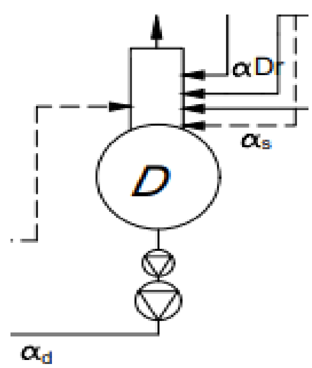

Figure 3.14-Dearator

$$\frac{\alpha_d \cdot h_d' + \alpha_{cej} \cdot h_d''}{\eta_{oph}} = \alpha_{Dr} \cdot h_{Dr} + \alpha''_{bd} \cdot h''_{bd} + \alpha_{mc} \cdot h_{mc} + \alpha_{dr2} \cdot h_{dr2} + \alpha_s \cdot h_s' ;$$

$$\alpha_s + \alpha_{dr2} + \alpha_{mc} + \alpha''_{bd} + \alpha_{Dr} = \alpha_d + \alpha_{cej} ;$$

Where:

- h'_d , h''_d– are saturated water and steam enthalpy values by the deaerator's pressure;
- η_{oph} - is the coefficient, which is taken into consideration the open heater's thermal loss, it is accepted equal 0,99.
- α_{mc} is the relative main condensate flowrate.

$$\frac{1.02 \cdot 671 + 0.002 \cdot 2756}{0.99} = \alpha_{Dr} \cdot 2880 + 0.00134 \cdot 2756 + \alpha_{mc} \cdot 606 + \alpha_{dr2} \cdot 803 \ ;$$

$$\alpha_s + \alpha_{dr2} + \alpha_{mc} + 0.00134 + \alpha_{Dr} = 1.02 + 0.002 \ .$$

Where:

- $\alpha_{dr2} = 0.143;$
- $\alpha_s = 0.103 \ ;$

By solving these two equations

$$\alpha_{mc} = 0.762 \ ;$$
$$\alpha_{Dr} = 0.012.$$

Relative flowrate for the the Low-pressure heat exchangers HPH

RFWH 3

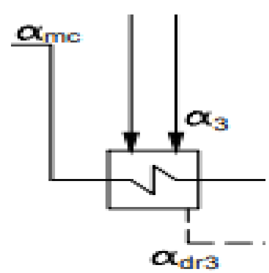

Figure 3.15-3[ed] RH law pressure

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

$$\frac{\alpha_{mc} \cdot (606 - 489)}{0.98} = \alpha_3 \cdot (2824 - 614) + 0.00365 \cdot (0.00365 - 614) \ ;$$

$$\alpha_3 = 0.041 \ .$$

RFWH 4

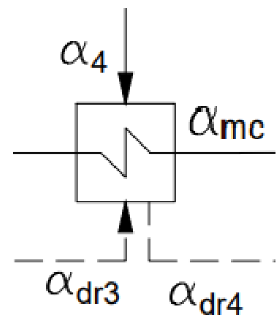

Figure 3.16-4th RH law pressure

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

$$\frac{\alpha_{mc}\cdot(\mathrm{h_{w4}}-\mathrm{h_{w5}})}{0.98}=\alpha_4\cdot(2706-497)+\alpha_{dr3}\cdot(614-497);$$

$$\alpha_4=0.038\,.$$

RFWH 5

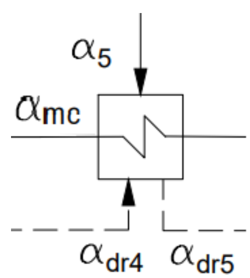

Figure 3.17-5th RH law pressure

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

$$\frac{\alpha_{mc}\cdot(373-\mathrm{h'_{w6}})}{\eta_h}=\alpha_5(2582-266)+\alpha_{dr4}\cdot(497-381)\ ;$$

$$\alpha_5=0.037.$$

Mixing point between RFWH 5 and RFWH 6

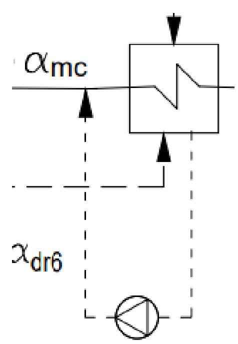

Figure 3.18-mixing point after 6th RH

$$\frac{\alpha_{mc} \cdot h'_{w6}}{\eta_{oph}} = \alpha_c \cdot h_{w6} + \alpha_{dr6} \cdot h_{dr6};$$

$$\alpha_{mc} = \alpha_c + \alpha_{dr6};$$

$$\frac{\alpha_{mc} \cdot h'_{w6}}{0.99} = \alpha_c \cdot 258 + \alpha_{dr6} \cdot 266.$$

RFWH 6

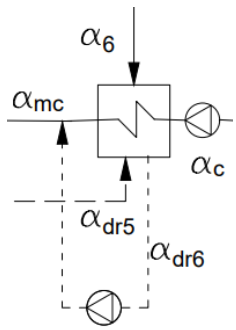

Figure 3.19-6th RH law pressure

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

$$\frac{\alpha_c \cdot (258 - 143)}{\eta_h} = \alpha_6(2452 - 266) + \alpha_{dr5} \cdot (381 - 266);$$

$$\alpha_6 = 0.027.$$

Low pressure cylinder extraction outlet.

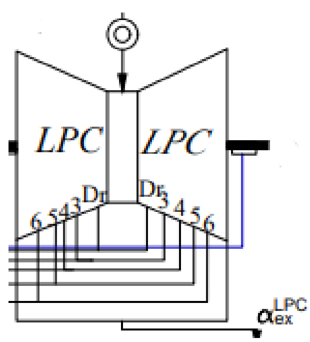

Figure 3.20-LPC of turbine installation

$$\alpha_{ex}^{LPC} = \alpha_{in}^{LPC} - \alpha_{Dr} - \alpha_3 - \alpha_4 - \alpha_5 - \alpha_6.$$

Following the flow after the low-pressure cylinder outlet led us to equation of condenser

Condenser

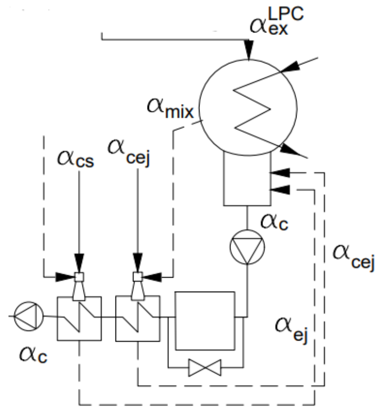

Figure 3.21-condencer.

$$\alpha_c = \alpha_{ex}^{LPC} + \alpha_{cej} + \alpha_{leak} + \alpha_{cs}$$

Where:

- α_c is the relative steam flowrate to the condenser;
- α_{leak} is the relative additional water flow rate =0.01;
- α_{out}^{lpc} is a relative low-pressure turbine's cylinder outlet steam flowrate;

Table of relative flow rates

After solve all equations we got the all value in next table.

Table 3.7-Results relative flow rate.

α_1	0.068	α_{fw}	1.097
α_2	0.06	α_{SG}	1.09201
α_3	0.041	α_{SH1}	0.015
α_4	0.038	α_{SH2}	0.077
α_5	0.037	α_{out}^{Hpc}	0.857
α_6	0.027	α_{TU}	1.077
α_{Dr}	0.012	α_{in}^{lpc}	0.753
α_{dr1}	0.084	α_{out}^{lpc}	0.598
α_{dr2}	0.143	α_{mc}	0.762
α_{dr3}	0.045	α'_{bd}	0.00365
α_{dr4}	0.083	α''_{bd}	0.00134
α_{dr5}	0.12	α_{leak}	0.01
α_{dr6}	0.147	α_{ej}	0.002

α_s	0.103	α_{seal}	0.005
α_c	0.615	α_{mixV}	0.004
α_D	1.02	h_{mc} , kJ/kg	606
h_{fw} , kJ/kg	915	h'_{w6} , kJ/kg	257

Conclusion of part 2

The content of the calculation part is Formation of thermal and material balance equations of each part of NPP and solve them together by equation system and get the value of relative flowrates.

3.9 Determining steam flow to a turbine

$$G_0 = \frac{N_e \cdot 10^3}{H_i^{total} \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j) - \alpha_s \cdot y_s - \alpha_{SH1} \cdot y_{SH1})} \quad ;$$

Where:

- η_m steam turbine's installation mechanical efficiency; $= 0.98$;
- η_g Generator's efficiency $= 0.99$;
- y_j reproduction factor in extractions;
- N_e electric power of NPP;
- H_i^{total} is total internal heat drops in turbine, $^{kJ}/_{kg}$.

$$H_i^{total} = 937 \ ^{kJ}/_{kg} \quad ;$$

Table 3.8-results

No_j	α_j	y_j	$(\alpha_j \cdot y_j)$
1	0.068	0.827921	0.056299
2	0.06	0.748269	0.044896
3	0.041	0.583677	0.023931
4	0.038	0.457738	0.017394
5	0.037	0.325715	0.012051
6	0.027	0.186304	0.00503
Dr	0.012	0.643656	0.007724
S	0.103	0.7483	0.077072
SH1	0.015	0.8279	0.012419
$\sum(\alpha_j \cdot y_j)$			0.256816

$$G_0 = \frac{870 \cdot 10^3}{937 \cdot 0.98 \cdot 0.99 \cdot (1 - 0.2568)} = 1287 \text{ kg/s} \;;$$

Power check

$$N'_e = G_0 \cdot \left[H_i^{total} \cdot \alpha_{exl} + \sum (\alpha_{extj} \cdot H_j)\right] \cdot \eta_M \cdot \eta_g;$$

$$N'_e = 1287 \cdot [937 \cdot 0.598 + 133] \cdot 0.98 \cdot 0.99) = 868.8 \text{ MW};$$

$$\delta N_e = \left|\frac{N_e - N'_e}{N_e}\right| \cdot 100 \;;$$

$$\delta N_e = \left|\frac{870 - 868.8}{870}\right| \cdot 100 = 0.134\% \,.$$

Values of flowrate at the part of NPP

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

Table 3.9-Values of flow rate at all the part of NPP

G_1	87.54	G_{mc}	980.9
G_2	77.24	G_{out}^{Hpc}	1103.2
G_3	52.78	G_{in}^{lpc}	969.3
G_4	48.92	G_{fw}	1412.2
G_5	47.63	G_{SG}	1405.7
G_6	34.76	G_{out}^{lpc}	769.8
G_s	132.6	G_{TU}	1386.4
G_c	791.7	G_{SH1}	19.3
G_D	1313.0	G_{SH2}	99.1
G_{Dr}	15.4	G'_{bd}	4.7
G_{dr1}	108.1	G''_{bd}	1.7
G_{dr2}	184.1	G_{leak}	12.9
G_{dr3}	57.9	G_{mixV}	5.14
G_{dr4}	106.8	G_{ej}	2.57
G_{dr5}	154.5	G_{seal}	6.44
G_{dr6}	189.2		

3.10 Calculation of indicators of thermal efficiency

Thermal loading of a steam generating unit

$$Q_{SG} = G_0 \cdot [\alpha_{SG} \cdot (h_0 - h_{fw}) + \alpha_{bld} \cdot (h'_0 - h_{fw})] \;;$$

Where:

- Q_{SG} in kW;
- G_0 is steam flow to a turbine;
- h_0, h_{fw}, h'_{bd} are enthalpies of steam at the turbine inlet, feed water at the steam generator inlet and blowdown water, kJ / kg;
- α_{SG} , α_{bd} the relative flow rates of steam from the steam generating unit and blowdown.

$$Q_{SG} = 1287 \cdot [1.092 \cdot (2779 - 915) + 0.005 \cdot (1241 - 915)] = 2622 \cdot 10^3 \text{ kW} ;$$

Thermal loading of turbine Q_T

$$Q_T = G_0 \cdot \left[(\alpha_{TU} + \alpha_{cs}) \cdot (h_0 - h_{fw}) + \alpha''_{bd} \cdot (h''_{bd} - h_{fw}) + \alpha'_{bd} \cdot (h'_{bd} - h_{fw}) + \alpha_{mw} \cdot (h_{mw} - h_{fw})\right] ;$$

$$Q_T = 1287 \cdot [(1.077 + 0.005) \cdot (2779 - 915) + 0.00134 \cdot (2759 - 915) + 0.00365 \cdot (680 - 915) + 0.01 \cdot (209 - 915)] \cdot 10^{-3} = 2589 \cdot 10^3 \text{ kW} ;$$

We choose makeup water temperature = 50°C, then $h_{mw} = 209$ kJ/kg.

Turbine Plant efficiency

$$\eta_e = \frac{N_e}{Q_T} = \frac{870}{2589} = 0.336 = 33.6\ \% ;$$

Pipelines Efficiency

$$\eta_{pip2} = \frac{Q_T}{Q_{SG}} = \frac{2589}{2622} = 0.987 ;$$

NPP Gross efficiency

$$\eta_{npp}^{Gross} = \eta_{RS} \cdot \eta_{PiP1} \cdot \eta_{SG} \cdot \eta_{PiP2} \cdot \eta_{TU} = 0.99 \cdot 0.995 \cdot 0.99 \cdot 0.987 \cdot 0.336 = 0.323 = 32.3\ \% ;$$

- η_{RS} is efficiency of reactor system.

NPP Net efficiency

$$\eta_{npp}^{net} = \eta_{npp}^{Gross} \cdot (1 - K_{on}) = 0.323 \cdot (1 - 0.05) = 0.307 = 30.7\% ;$$

Where:

- K_{on} specific flowrate consumption for the station's own needs for two-circuit $\beta_{sp} = 0.05 \div 0.055$.

I will assume $= 0.05$.

Efficiency of a steam generating unit

$$\eta_{SGU} = \eta_{RS} \cdot \eta_{pip1} \cdot \eta_{SG} = 0.99 \cdot 0.99 \cdot 0.99 = 0.970 = 97.0\ \% \quad ;$$

Here:

- $\eta_{RS} = 0.99$, is the efficiency of the reactor unit equipment;
- $\eta_{SG} = 0.985 \dots 0.99$, Steam generator's Efficiency;
- $\eta_{pip1} = 0.99 * 0.995$,Efficiency of pipelines of the primary circuit.

Specific flow-rate of nuclear fuel (natural uranium) at NPP

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

$$b_{nf} = \frac{1000}{24 \cdot 35 \cdot 10^3 \cdot 0.323} \cdot \frac{0.037 - 0.0025}{0.0071 - 0.0025} = 0.0275\ g/(kW \cdot h) \quad ;$$

Here:

- b_{nf} is measured in $g/(MW \cdot h)$;
- $\bar{B}$ - fuel burn-up, accepted for WWER nuclear power plants $\bar{B} = (30\dots40) \cdot 10^3$ MW·day/t;
- x_n, x_e, x_o are uranium-235 content in fresh, natural uranium and in the dump of enrichment production. Accept: $x_n = 3.5\dots4$ % for WWER NPP; $x_e = 0.71$ %; $x_o = 0.25$ %.

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

$$b_{Ndf} = \frac{0.0537}{\eta_{Nb}} = \frac{0.0537}{0.323} \cdot 10^{-6} = 0.1659 \cdot 10^{-6}\ {}^{kg}\!/_{kW \cdot h} \quad ;$$

3.11 Choice of equipment for the second circuit

Pumps

Feed water pump

A volumetric flowrate V, m^3/h.

$$V_{FWP} = 1.05 \cdot \frac{3600 \cdot G_d}{\rho} = 1.05 \cdot \frac{3600 \cdot (1313)}{908.5} = 5203\ \frac{m^3}{h};$$

Where:

- G mass flow rate kg/s;

- ρ density $\frac{kg}{m^3}$;
- A head H

$$H = \frac{\Delta p}{\rho g} = \frac{7672 \cdot 10^3}{908.5 \cdot 9.8} = 861.6 \text{ m};$$

- Δp is a difference pressure in Pa.

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

Δh = the height of deaerator ≈ 14÷24 m, assume 20 m.

$$\Delta p = 8450 - [(600) + (908.5 \cdot 9.8 \cdot 20 \cdot 10^{-3})] = 7672 \text{ kPa}.$$

Condensate pumps

- A volumetric flow rate V, m^3/h.

$$V_{CPi} = \frac{3600 \cdot G_c}{\rho};$$

Where:

- G_c is mass flow rate condenser kg/s;
- A head H

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

- Δp is a difference pressure in Pa;

First condensate pump CP_1

$$\Delta p = p_{cp1} - p_c = 500 - 4 = 496 \text{kPa};$$

$$H = \frac{\Delta p}{\rho g} = \frac{496 \cdot 10^3}{995.9 \cdot 9.8} = 50.8 \text{ m};$$

$$V_{CP1} = \frac{3600 \cdot G_c}{\rho} = \frac{3600 \cdot (791.7)}{995.9} = 2861 \frac{m^3}{h}.$$

Second condensate pump CP_2

$$\Delta p = p_{cp2} - p_{cp1} = 780 - 500 = 280 \text{ kPa};$$

$$H = \frac{\Delta p}{\rho g} = \frac{280 \cdot 10^3}{915.28 \cdot 9.8} = 31.2 \text{ m};$$

$$V_{CP2} = \frac{3600 \cdot G_c}{\rho} = \frac{3600 \cdot 791.7}{915.28} = 3114 \frac{m^3}{h}.$$

The drain pump DP

- A volumetric flow rate V, m^3/h;

$$V_{DP} = \frac{3600(G_{dr6})}{\rho} \ ;$$

$$V_{DP} = \frac{3600 \cdot (189.2)}{981.3} = 690 \, \frac{m^3}{h} \, .$$

- A head H.

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

Where:

- Δp is a difference pressure in Pa.

$$\Delta p = p_{w6} - p_{dr6} \ ;$$

$$\Delta p = 780 - 23 = 757 \text{ kPa} \ ;$$

$$H = \frac{757 \cdot 10^3}{981.3 \cdot 9.8} = 78.7 \text{ m.}$$

Table 3.10-Characteristic of pumps in NPP and choose

PUMPS	Head H, m	Volumetric flow rate V, m^3/h		Type	V, m^3 /h	H,m	No.	Operating	Reserve
Feed water	861.6	5203	Choose pump	ПЭА 1650-80	1650	910	5	4	1
First main condensate	50.8	2861		КсВ 1600-90	1600	90	3	2	
Second main condensate	31.2	3114		КсВ 1600-90	1600	90	3	2	
Drain	78.7	690		КсД 230-115/3	230	115	4	3	

The regenerative heaters

Evaluate heat transfer Area F m^{2}.

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

Where:

- Q heater's heat load;
- K is heat-transfer coeff. $3500 \div 4000 \frac{kW}{m^2K}$, assume $4000 \frac{kW}{m^2K}$;

$$Q = G\Delta h \ ;$$

- Δh Enthalpy's deference between outlet and inlet kg/Kj;
- G mass flowrate of water;
- Logarithmic-temperature difference $\overline{\Delta t}$°C ;

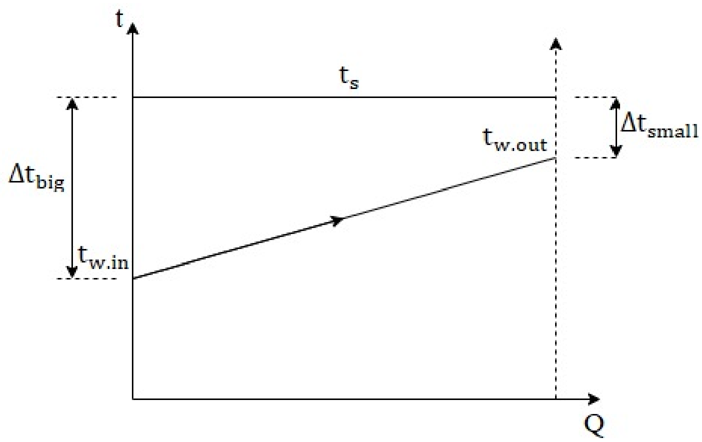

Figure 3.22-- t-Q diagram for regenerative feedwater heater

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

Where:

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

RFWH 6 ‘’closed’’

$$\Delta h = h_{w6} - h_{cse} = 258 - 143 = 115 \ {}^{kj}/_{kg} ;$$

$$Q = G_c \cdot \Delta h = 791.7 \cdot 115 = 90.8 \text{ MW} ;$$

$$\Delta t_{big} = t_{s6} - t_{cse} = 63.4 - 34 = 29.5 \text{ °C} ;$$

$$\Delta t_{small} = t_{s6} - t_{w6} = 63.4 - 61.4 = 2\text{°C} ;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.5 - 2}{\ln\left(\frac{29.5}{2}\right)} = 10.2\text{°C} ;$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{90.8 \cdot 10^6}{4000 \cdot 10.2} = 2225 \text{ m}^2 .$$

RFWH 5 ‘’closed ‘’

$$\Delta h = h_{w5} - h'_{w6} = 373 - 257 = 116 \ {}^{kj}/_{kg} ;$$

$$Q = G_{mc} \cdot \Delta h = 980.9 \cdot 116 = 113.6 \text{ MW} ;$$

$$\Delta t_{big} = t_{s5} - t_{w6} = 90.9 - 61.4 = 29.5 \text{ °C} ;$$

$$\Delta t_{small} = t_{s5} - t_{w5} = 90.9 - 88.9 = 2 \text{ °C} ;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.5 - 2}{\ln\left(\frac{29.5}{2}\right)} = 10.2 \text{ °C} ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{113.6 \cdot 10^6}{4000 \cdot 10.2} = 2783 \text{ m}^2 .$$

RFWH 4 ‘’closed’’

$$\Delta h = h_{w4} - h_{w5} = 489 - 373 = 116 \ ^{kj}/_{kg} ;$$

$$Q = G_{mc} \cdot \Delta h = 980.9 \cdot 116 = 113.6 \text{ MW} ;$$

$$\Delta t_{big} = t_{s4} - t_{w5} = 118.4 - 88.9 = 29.5 \ ℃ ;$$

$$\Delta t_{small} = t_{s4} - t_{w4} = 118.4 - 116.4 = 2 \ ℃ ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.5 - 2}{\ln\left(\frac{29.5}{2}\right)} = 10.2 ℃ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{113.6 \cdot 10^6}{4000 \cdot 10.2} = 2783 \text{ m}^2 .$$

RGFW 3 ‘’closed ‘’

$$\Delta h = h_{w3} - h_{w4} = 606 - 489 = 117 \ ^{kj}/_{kg} ;$$

$$Q = G_{mc} \cdot \Delta h = 980.9 \cdot 117 = 114.9 \text{MW} ;$$

$$\Delta t_{big} = t_{s3} - t_{w4} = 145.8 - 116.4 = 29.5 \ ℃ ;$$

$$\Delta t_{small} = t_{s3} - t_{w3} = 145.8 - 143.8 = 2 ℃ ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.5 - 2}{\ln\left(\frac{29.5}{2}\right)} = 10.2 \ ℃ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{114.9 \cdot 10^6}{4000 \cdot 10.2} = 2813 \text{ m}^2 .$$

For RGFW 2 ‘’HPH’’

$$\Delta h = h_{w2} - h_{fwp} = 788 - 679 = 109 \ ^{kj}/_{kg} ;$$

$$Q = G_d \cdot \Delta h = 1313 \cdot 109 = 143.4 \text{ MW} ;$$

$$\Delta t_{big} = t_{s2} - t_{fwp} = 188.9 - 159.8 = 29.1 \ ℃ ;$$

$$\Delta t_{small} = t_{s2} - t_{w2} = 188.9 - 184.9 = 4 ℃ ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.1 - 4}{\ln\left(\frac{29.1}{4}\right)} = 12.7 \ ℃ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{143.4 \cdot 10^6}{4000 \cdot 12.7} = 2835 \text{ m}^2.$$

For RGFW 1 ‘’HPH’’

$$\Delta h = h_{w1} - h_{w2} = 900 - 788 = 112 \ ^{kj}/_{kg} ;$$

$$Q = G_d \cdot \Delta h = 1313 \cdot 112 = 146.5\ \text{MW};$$

$$\Delta t_{big} = t_{s1} - t_{w2} = 214 - 184.9 = 29.1\ ℃;$$

$$\Delta t_{small} = t_{s1} - t_{w1} = 214 - 210 = 4\ ℃;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29.1 - 4}{\ln\left(\frac{29.1}{4}\right)} = 12.7\ ℃;$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{146.5 \cdot 10^6}{4000 \cdot 12.7} = 2896\ \ m^2.$$

Table 3.11-Characteristic of closed RGFW in NPP

RFWH NO	Δh, kJ/kg	G kg/s	Q,MW	$\overline{\Delta t}$, ℃	F,m^2
6 LPH	115	791.7	90.8	10.2	2225
5 LPH	116	980.9	113.6	10.2	2783
4 LPH	116	980.9	113.6	10.2	2783
3 LPH	117	980.9	114.9	10.2	2813
2 HPH	109	1313	143.4	12.7	2835
1 HPH	112	1313	146.5	12.7	2896

Table 3.12-Characteristic of chosen RGFW in NPP

RFWH NO		Type	G kg/s	F,m^2	no.
6 LPH	Chosen heaters	ПН-3000-25-16-IIIA	1112.5	3000	1
5 LPH		ПН-3000-25-16-IIIA	1112.5	3000	1
4 LPH		ПН-3000-25-16-IIIA	1112.5	3000	1
3 LPH		ПН-3000-25-16-IIIA	1112.5	3000	1
2 HPH		ПВ-2500-97-10A	907.2	2500	2
1 HPH		ПВ-2500-97-10A	907.2	2500	2

Deaerator

A volumetric flow-rate $V, m^3/h$.

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

$$G_d = 1313\ \frac{kg}{s};$$

$$V_D = \frac{3600 \cdot 1313}{908.5} = 5202 \frac{m^3}{h}.$$

Deaerator's volume

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

where:

- τ How long it takes to fill a deaerator with water ≈ 5 mins ;
- k Deaerator coeff. storage = 1.15 ;

$$v = \frac{1313 \cdot (5 \cdot 60) \cdot 1.15}{908.5} = 498.6\ m^3.$$

Table 3.13-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-6400	1805,5	0.87	КДП-6400-А-4; vertical	4	400	250	36.0	7.0

Section 4: Design calculation of the turbine condenser

Finding a condenser's geometrical dimensions and operational qualities is the goal of calculation.

Nuclear power plants' strong modern steam turbines often include several double-flow low-pressure cylinders. Each cylinder's steam is sent to a different condenser. Therefore, you must first ascertain the turbine's total quantity of exhaust steam outputs.

The condenser of a steam turbine plant must provide pressure p_c behind the turbine with the following initial parameters: inlet cooling water temperature tw1, steam flow to the condenser

The material and dimensions $d_{out}\text{x}\delta_{wall}$ of the tubes and the number Z of passages for the cooling water are known.

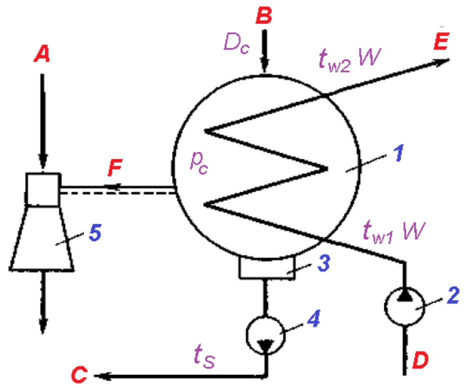

Figure 4.1- Schematic diagram of the condensing unit:
1 — condenser; 2 — circulation pump; 3 — hotwell (standpipe); 4 — condensate pump; 5 — air pump (ejector);
A — supply of the working fluid (steam or water) to the ejector; B — steam from the turbine; C — into the regeneration system; D and E - inlet and outlet of cooling water; F - line for removing the vapor-air mixture from the condenser

4.1 Calculation of the Number of Flows in the LPC

4.1.1 **Maximum power of a single-flow turbine, MW**

$$N_i^{max} = \frac{m1}{2 \cdot 10^{-3} \cdot \pi} \cdot k_{unl} \cdot H_i \cdot \frac{[\sigma] \cdot c_2}{\rho_{mat} \cdot n^2 \cdot v_2};$$

$$N_i^{max} = \frac{1.1}{2 \cdot 10^{-3} \cdot \pi} \cdot 2.3 \cdot 937 \cdot \frac{[450] \cdot 257}{7800 \cdot 25^2 \cdot 29.9} = 298.6 \text{ MW};$$

where:

- $m1 = 1.1 \dots 1.3$ is coeff. takes into consideration power generation by steam streams of regenerative bleed-offs, assumption 1.1;
- $k_{unl} = 2.3 \dots 2.4$ is unloading coeff. which depends on the geometric characteristics of the blades of the last stage of the turbine; assumption it 2.3;
- H_i is extracted steam work in turbine, 937 $^{kJ}/_{kg}$;
- $[\sigma]$ is allowable tensile stress for the material of the blades. For stainless steel $[\sigma] = 450$ MPa;

- $\rho_{mat} = 7800\ {}^{kg}/_{m^3}$ Stainless steel density of the blade material;
- n is rotor's rotation frequency, $25\ {}^{rev}/_{s}$;
- $v_2 = f(p_{c'}, h_{c'})$ specific volume of steam at turbine's outlet of the last stage of the, ${}^{m^3}/_{kg}$;

$$v_2 = f(0.00412\,, 2277) = 29.9\ {}^{m^3}/_{kg}.$$

- c_2 steam's output speed, m/s. according to the permitted power loss at the output speed;

4.1.2 **Steam's output speed**

$$\Delta h_{os} = \frac{c_2^2}{2000}\ ;$$

$$c_2 = \sqrt{\Delta h_{os} \cdot 2000} = \sqrt{33 \cdot 2000} = c_2 = 257\ {}^{m}/_{s}\ ;$$

- $\Delta h_{os} = 20 \div 35\ {}^{kJ}/_{kg}$, assume it $33\ {}^{kJ}/_{kg}$.

4.1.3 **Number of Flows of Spent Steam going to the Condenser**

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

$$i = \frac{870}{0.98\ \cdot\ 0.99\ \cdot 298.6} = 3.1 = 4.$$

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

For that I will take (Two) condensers;
where:

- N_i^{max} maximum power of a single-flow turbine, 298.6 MW;
- N_e turbine's total electric power, 870 MW;
- η_m turbine's mechanical efficiency of the unit, 0.98;
- η_g Generator efficiency, 0.99.

4.1.4 **Exhaust steam flow per condenser**

$$G_{c1} = \frac{2 \cdot G_c}{i}\ ;$$

$$G_{c1} = \frac{2 \cdot 791.7}{4} = 395.9\ {}^{kg}/_{s}$$

where:

- $G_c = 791.7\ {}^{kg}/_{s}$,is total exhaust steam flow;
- i = 4 is Number of flows of spent steam going to the condenser.

4.1.5 **Initial data for the calculation of the condenser**

Table 4.1-Initial data

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	$G_{c1}, {}^{kg}/_{s}$	395.9
Condenser pressure	p_c, MPa	0.004
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1}, °C	13
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

Notes:

- density for cooling water $\rho_w = 1000 \ {}^{kg}/_{m3}$;
- average heat-capacity for cooling water $c_w = 4.19 \ {}^{kJ}/_{kg}$;
- The factor that accounts for the contamination of pipes is equal to $a_0 = 0.65\ldots0.85$, $a_0 = 0.80$.

4.2 Determining the characteristics of a condenser

4.2.1 **Flow rate of cooling water per condenser**

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

$$W_1 = 60 \cdot 395.9 = 23751 \, {}^{kg}/_{s} \ ;$$

where:

- $m = (40 \ldots 70)$ is cooling ratio for double way condensers ($z = 2$), ${}^{kg}/_{s}$.

4.2.2 **The number of heat transfer tubes**

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

$$n_{tube} = \frac{4 \cdot 23751 \ \cdot 2}{\pi \cdot (0.026)^2 \cdot 1000 \cdot 2} = 44757 \text{ pcs} \ ;$$

where:

- z is number of tube-side passes for cooling water;

$$d_{in} = d_{out} - (2 \cdot \delta_{wall}) \ ;$$

$$d_{in} = 28 - (2 \cdot 1) = 26 \text{ mm}.$$

- d_{inn} is the inner diameter of the tubes;
- w_w is speed of water in tubes, ${}^{m}/_{s}$.

4.2.3 **Cooling water heating in the condenser, °C**

$$\Delta t_w = \frac{r}{c_w \cdot m} \ ;$$

$$\Delta t_w = \frac{2156}{4.19 \cdot 56} = 8.6\ ℃\,.$$

where:

$$r = h'' - h' = 2277 - 121 = 2156\ ^{kJ}/_{kg}\ ;$$

$$h'' = f(p_c) = 2277\ ^{kJ}/_{kg}\ ;$$

$$h' = f(p_c) = 121\ ^{kJ}/_{kg}\,.$$

- r is latent-heat vaporization under pressure p_c, kJ/kg;
- $c_w = 4.19$ is heat-capacity of (cooling water), $^{kJ}/_{(kg\ °C)}$.

4.2.4 **Temperature of the cooling water at the condenser outlet, ºC**

$$t_{w2} = t_{w1} + \Delta t_w\ ;$$

$$t_{w2} = 13 + 8.6 = 21.6\ ℃\,.$$

4.2.5 **The Heat power that is transferred to the cooling water in the condenser, kW**

$$Q_{w1} = W_1 \cdot c_w \cdot \Delta t_w\ ;$$

$$Q_{w1} = 23751\ \cdot 4.19 \cdot 8.6 = 853292\ \text{kW}.$$

4.2.6 **Average temp. difference, ºC**

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)}\ ;$$

$$\Delta t_{avr} = \frac{8.6}{\ln\left(\frac{29\ - 13}{29\ - 21.6}\right)} = 11.1\ ℃\,.$$

where:

- $t_s = f(p_c) = 29$ ℃, is saturation temp. at condenser pressure p_c.

4.2.7 **Specific-vapor load of the condenser $\boldsymbol{d_c}$. Initially set in the range of 40 ... 60 $\boldsymbol{^{kg}/_{(m^2\ \cdot\ h)}}$, have to check**

$$d_c = 44\ \ ^{kg}/_{(m^2\ \cdot\ h)}\ ;$$

The overall heat transfer coeff. is calculated using one of two expressions. $t_{w1} =$ 18 ℃. So, we will use the following expression:

If $t_{w1} \leq 35$ ℃

$$k = 4070 \cdot a \cdot \left(\frac{1{,}1 \cdot w_w}{d_{inn}^{0{,}25}}\right)^x \cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2\right] \cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{35}\right)\right] \cdot \Phi_d\ ;$$

$$k = 4070 \cdot 0.68 \cdot \left(\frac{1.1 \cdot 2}{26^{0{,}25}}\right)^{0.301} \cdot \left[1 - \frac{0.52 - 0.002 \cdot 44 \cdot \sqrt{0.68}}{1000} \cdot (22)^2\right] \cdot \left[1 - \frac{2-2}{10} \cdot \left(1 - \frac{13}{35}\right)\right] \cdot 1 = 2154\ ^{W}/_{(m^2 \cdot ℃)}\ ;$$

where:

- k - in $W/(m^2 \cdot °C)$;

$$x = 0.12 \cdot a \cdot (1 + 0.15 \cdot t_{w1}) = 0.12 \cdot 0.68 \cdot (1 + 0.15 \cdot 18) = 0.301\ ;$$
$$a = a_0 \cdot a_m = 0.80 \cdot 0.85 = 0.68\ ;$$

- x is coeff. pollution of tubes and tube material;
- $a_0 = 0.65 \ldots 0.85$ is coeff. tube contamination;
  Assume it 0.80 ;
- a_m is correction factor the tube material, For stainless steel =0.85 ;
- d_{inn} tubes inner diameter of the = 26 mm ;
- w_w tubes speed of water 2 m/s;
- t_{w1} is the temperature of the cooling water at the inlet to the condenser, 13 °C ;
- $z = 2$ number of tube-side passes for cooling water;
- $\Phi_d = 1$ When designing condensers.

4.2.8 **Heat transfer surface area, m²**

$$F = \frac{Q_w}{k \cdot \Delta t_{avr}}\ ;$$
$$F = \frac{853292 \cdot 10^3}{2154 \cdot 8.6} = 35584\ m^2.$$

4.2.9 **The length of the heat-transfer tubes**

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}}\ ;$$
$$L = \frac{35584}{44757 \cdot \pi \cdot 0.028} = 9.87\ m < 16\ m;$$

Where:

- $d_{out} = 0.028$ m, tubes outer diameter;

4.2.10 **calculated value of the specific steam load of the condenser**

$$d_c^{calk} = \frac{3600 \cdot G_{c1}}{F}\ ;$$
$$d_c^{calk} = \frac{3600 \cdot 395.8}{35584} = 40.05\ kg/(m^2 \cdot h).$$

4.2.11 **The obtained value d_c^{calk} compared with the specified in paragraph**

$$\left|\frac{d_c^{calk} - d_c}{d_c^{calk}}\right| \cdot 100 = \left|\frac{44 - 40.05}{40.05}\right| \cdot 100 = 0.4\ \%\ .$$

- The calculated value d_c^{calk} compared by the specified d_c.
- If there (more than 2%) error, it is necessary to assign $d_c = d_c^{calk}$ and repeat the calculation,

Table 4.2-Summrize results and check error

dc, $kg/(m^2 \cdot h)$	44	40.05

$k, {}^{W}/_{(m^2 \cdot °C)}$	2154.7	2146.0
F, m^2	35584	35727
L, m	9.04	9.08
$d_c^{calk}, kg\ /\ (m^2 \cdot h)$	40.05	-
ERROR %	9.87	0.40

4.2.12 **Mass of condenser tubes**

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot \left(d_{out}^2 - d_{inn}^2\right)}{4} \cdot \rho_{mat}\ , kg\ ;$$

$$M_{tube} = 44757 \cdot 9.08 \cdot \frac{\pi \cdot (0{,}028^2 - 0{,}026^2)}{4} \cdot 7800 = 268766\ kg\ .$$

where:

- L, d_{out} and d_{inn} are in m;
- ρ_{mat} pipe material density, kg/m³. for stainless steel tubes $\rho_{mat} = 7800\ {}^{kg}/_{m^3}$;

4.2.13 **Cost of condenser tubes**

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}, M\ R\ ;$$

$$C_{tube} = \frac{268766\ \cdot 355}{10^6} = 95\ M\ R\ .$$

where:

- c_{mat} is cost of one kg of tube, rub/kg. for stainless steel tubes $c_{mat} = 350 \dots 400\ {}^{rub}/_{kg}$;
- Cost of the condenser

$$C_{cond} = K_c \cdot C_{tube}, M\ R;$$

$$C_{cond} = K_c \cdot C_{tube} = 1.75 \cdot 95 = 167\ M\ R.$$

where:

- $K_c = 1.75 \dots 2$ is coeff. empirical.

4.3 Hydraulic calculation of the condenser

4.3.1 **Pressure losses in the condenser along the cooling water path**

Determine the pressure loss that occurs while cooling water moves through a condenser by doing a hydraulic calculation on it.

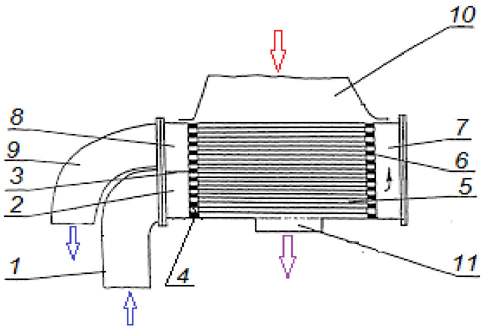

Figure 4.2- the condenser

A two-way condenser with straight tubes has the following hydraulic resistance representation:

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr} = 7000 + 25841 = 32841 \text{ Pa};$$

where:

- Δp_{loc} losses of local-pressure;
- Δp_{fr} friction-losses in condenser tubes;
- $\Delta p_{wch.in}$ is local-hydraulic-resistance at the water inlet to the tubes from the water chamber;
- $\Delta p_{wch.out}$ local-hydraulic-resistance at the water outlet from the pipes to the water chamber;
- Δp_{turn} local-hydraulic-resistance from turning the water in the water chamber;

calculation of losses local pressure:

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2}, \text{pa};$$

where:

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn};$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2};$$

$$\Delta p_{loc} = \big((2 \cdot 0.5) + (2 \cdot 1) + 0.5\big) \cdot \left(\frac{1000 \cdot 2^2}{2}\right) = 7000 \text{ Pa}.$$

Table 4.3- values coef. of local resistance

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

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2}, \text{pa};$$

$$\Delta p_{fr} = 0.037 \cdot \frac{2 \cdot 9.08}{0.026} \cdot \frac{1000 \cdot 2^2}{2} = 32841 \text{ Pa}.$$

where:

- L tubes length heat transfer, 9.08 m;
- $d_h = d_{inn} = 0{,}026$ is characteristic-size, m ;
- $\xi_{fr} = 0{,}035 \ldots 0{,}037$ is coefficient of friction. 0.037.

4.3.2 **Pump's Power of the condenser**

$$N_p = \Delta p_\Sigma \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000}\text{, kW ;}$$

$$N_p = 26836 \ \cdot \ \frac{23751}{1000 \cdot 0.86 \cdot 1000} = 907\text{ kW.}$$

where:

- Δp_Σ is total hydraulic-resistance;
- $\eta_p = 0.86 \dots 0.88$ pump's efficiency.
- Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp}\text{ , (kW} \cdot \text{h) ;}$$

$$E_p = 907 \ \cdot 7000 = 6348862\text{ (kW} \cdot \text{h) .}$$

where:

- $\tau_{rp} = 6500 \dots 7000$ h, is number of hours of use of rated power.

4.3.3 **The cost of electricity for pumping water through the condenser**

$$C_{el} = {E_p \cdot T_{el}}/{10^6}\text{ , M R ;}$$

$$C_{el} = \frac{6348862 \ \cdot 16}{10^6} = 102\text{ M R .}$$

where:

- $T_{el} = 14 \dots 16 \ \frac{\text{rub}}{(\text{kW} \cdot \text{h})}$, tariff electricity for NPP.

4.4 Design calculation of the turbine condenser Variant 2

4.4.1 **Initial data of calculation of the second variant**

Table 4.4-Initial data condenser NO. 2

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	G_{c1}, ${kg}/{s}$	395.9
Condenser pressure	p_c, MPa	0.004
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1}, °C	13
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	28×2
Tube material		stainless steel

Determining the characteristics of a condenser

4.4.2 **Flow rate of cooling water per condenser**

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

$$W_1 = 60 \cdot 395.9 = 23751 \ {kg}/{s}\text{ .}$$

4.4.3 **The number of heat transfer tubes, pieces**

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

$$n_{tube} = \frac{4 \cdot 23751 \cdot 2}{\pi \cdot (24 \cdot 10^{-3})^2 \cdot 1000 \cdot 2} = 52528 \text{ pcs} .$$

$$d_{inn} = d_{out} - (2 \cdot \delta_{wall}) ;$$

$$d_{inn} = 28 - (2 \cdot 2) = 24 \text{ mm} .$$

4.4.4 **Cooling water heating in the condenser, ºC**

$$\Delta t_w = \frac{r}{c_w \cdot m} ;$$

$$\Delta t_w = \frac{2156}{4.19 \cdot 60} = 8.6 \text{ ℃} ;$$

$$r = h_c'' - h_c' = 2277 - 121 = 2156 \ {}^{kJ}/_{kg} ;$$

$$h_c'' = 2277 \ {}^{kJ}/_{kg} ;$$

$$h_c' = f(p_c) = 121 \ {}^{kJ}/_{kg} .$$

4.4.5 **Temperature of the cooling water at the condenser outlet, ºC**

$$t_{w2} = t_{w1} + \Delta t_w ;$$

$$t_{w2} = 13 + 8.6 = 21.6 \text{ ℃} .$$

4.4.6 **The Heat power that is transferred to the cooling water in the condenser**

$$Q_{w2} = W_1 \cdot c_w \cdot \Delta t_w ;$$

$$Q_{w2} = 23751 \cdot 4.19 \cdot 8.6 = 853292 \text{ kW} .$$

4.4.7 **The average temperature difference, ºC**

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)} ;$$

$$\Delta t_{avr} = \frac{8.6}{\ln\left(\frac{29 - 13}{29 - 21.6}\right)} = 11.1 \text{ ℃} ;$$

where:

- $t_s = f(p_c) = 29$ ℃.

4.4.8 **Specific vapor load of the condenser d_c. Initially set in the range of 40 ... 60 kg / (m² · h), and then must be checked**

$$d_c = 44 \ {}^{kg}/_{(m^2 \cdot h)} ;$$

The overall heat transfer coefficient (ВТИ formula) is calculated using one of two expressions

$t_{w1} = 18$ °C. So,

If $t_{w1} \leq 35$ ℃

$$k = 4070 \cdot a \cdot \left(\frac{1{,}1 \cdot w_w}{d_{inn}^{0{,}25}}\right)^x \cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2\right] \cdot$$
$$\cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{35}\right)\right] \cdot \Phi_d \ ;$$

$$k = 4070 \cdot 0.68 \cdot \left(\frac{1{,}1 \cdot 2}{24^{0{,}25}}\right)^{0.301}$$
$$\cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot 44 \cdot \sqrt{0{,}68}}{1000} \cdot (22)^2\right]\left[1 - \frac{2-2}{10} \cdot \left(1 - \frac{13}{35}\right)\right] \cdot 1$$
$$= 2165 \ {}^{W}\!/_{(m^2 \cdot {}^\circ C)} \ ;$$

where:

- k - in ${}^{W}\!/_{(m^2 \cdot {}^\circ C)}$;

  $x = 0.12 \cdot a \cdot (1 + 0.15 \cdot t_{w1}) = 0.12 \cdot 0.68 \cdot (1 + 0.15 \cdot 18) = 0.301$;
- d_{inn} is the inner diameter of the tubes $= 24$ mm ;

Heat transfer surface area, m²

$$F = \frac{Q_{w2}}{k \cdot \Delta t_{avr}} \ ;$$

$$F = \frac{853292 \cdot 10^3}{2165 \cdot 11.1} = 35413 \ m^2.$$

The length of the heat transfer tubes, m

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}} \ ;$$

$$L = \frac{35413}{52528 \cdot \pi \cdot 0{,}028} = 7.67 \ m < 16 \ m \ .$$

The calculated value of the specific steam load of the condenser, $\boldsymbol{{}^{kg}\!/_{(m^2 \cdot h)}}$

$$d_c^{calk} = \frac{3600 \cdot G_{c1}}{F} \ ;$$

$$d_c^{calk} = \frac{3600 \cdot 395.9}{35413} = 40.24 \ {}^{kg}\!/_{(m^2 \cdot h)}.$$

The obtained value $\boldsymbol{d_c^{calk}}$ must be compared with the specified in paragraph

$$\left|\frac{d_c^{calk} - d_c}{d_c^{calk}}\right| . 100 = \left|\frac{40.24 - 44}{40.24}\right| . 100 = 0.38 \ \% \ .$$

Table 4.5-Summrize results and check error.

dc, ${}^{kg}\!/_{(m^2 \cdot h)}$	44	40.24
k, ${}^{W}\!/_{(m^2 \cdot {}^\circ C)}$	2165.1	2156.8
F, m^2	35413	35549
L, m	7.67	7.70
d_c^{calk}, kg / $(m^2 \cdot h)$	40.24	-
ERROR %	9.34	0.38

4.4.9 **Mass of condenser tubes**

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot \left(d_{out}^2 - d_{inn}^2\right)}{4} \cdot \rho_{mat}\text{, kg};$$

$$M_{tube} = 52528 \cdot 7.7 \cdot \frac{\pi \cdot (0{,}028^2 - 0{,}024^2)}{4} \cdot 7800 = 515030\text{ kg}.$$

4.4.10 **Cost of condenser tubes**

$$C_{tube} = M_{tube} \cdot c_{mat}/10^6\text{, M R};$$

$$C_{tube} = \frac{515030 \cdot 355}{10^6} = 183\text{ M R}.$$

4.4.11 **Cost of the condenser**

$$C_{cond} = K_c \cdot C_{tube}\text{, M R};$$

$$C_{cond} = K_c \cdot C_{tube} = 1.75 \cdot 183 = 320\text{ M R}.$$

4.4.12 **Hydraulic calculation of the condenser**

$$\Delta p_\Sigma = \Delta p_{loc} + \Delta p_{fr};$$

$$\Delta p_\Sigma = 7000 + 23734 = 30734\text{ Pa}.$$

Calculation of local pressure losses

$$\Delta p_{loc} = \xi_{loc} \cdot {}^{\rho_w \cdot w_w^2}/_2\text{, pa};$$

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn}$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot {}^{\rho_w \cdot w_w^2}/_2$$

$$\Delta p_{loc} = \left((2 \cdot 0{,}5) + (2 \cdot 1) + 0{,}5\right) \cdot {}^{(1000 \cdot 2^2}\Big/_{2)} = 7000\text{ Pa};$$

$$\Delta p_{fr} = \xi_{fr} \cdot (2 \cdot L/d_h) \cdot \left(\frac{\rho_w \cdot w_w^2}{2}\right)\text{, pa};$$

$$\Delta p_{fr} = 0{,}037 \cdot (2 \cdot 7.7/0{,}024) \cdot \left({}^{1000 \cdot 2^2}/_2\right) = 23734\text{ Pa}.$$

4.4.13 **Power of the pump for pumping water through the condenser**

$$N_p = \Delta p_\Sigma \cdot \left({}^{W}/_{\rho_w \cdot \eta_p \cdot 1000}\right)\text{, kW};$$

$$N_p = 30734 \cdot \left({}^{23751}/_{1000 \cdot 0{,}86 \cdot 1000}\right) = 849\text{ kW}.$$

4.4.14 **Electric power consumption for the circulation pump drive**

$$E_p = N_p \cdot \tau_{rp}\text{, (kW} \cdot \text{h)};$$

$$E_p = 849 \cdot 7000 = 5941517\text{ (kW} \cdot \text{h)}.$$

4.4.15 **The cost of electricity for pumping water through the condenser**

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}\text{, M R};$$

$$C_{el} = \frac{5941517 \cdot 16}{10^6} = 95\text{ M R};$$

Table 4.6-Results of variant calculations of the condenser

Parameter \ Options	Option 1	Option 2
	$d_{out} = 28$ mm $\delta_{wall} = 1$ mm	$d_{out} = 28$ mm $\delta_{wall} = 2$ mm

G_{c1}, kg/s	395.9	395.9
p_c , kPa	4	4
Tube material	Stainless steel	Stainless steel
n_{tube} , pcs	44757	52528
F , m^2	35727	35549
l_{tubes} , m	9.08	7.7
W_1, kg/s	23751	23751
M_{tubes}, kg	268766	515030
C_{tube}, M R	95	183
C_{cond}, M R	167	320
N_p, kW	907	849
E_p, kW·h	6348862	5941517
C_{el}, M R	102	95

Section 5: Design Calculation of a Saturated Steam Generator

5.1 Thermal Calculation of the SG of Saturated Vapor

Table 5.1-Initial data

Parameter	Denomination , units	Value
Coolant	-	Water
SG Thermal power	Qsg , MW	$\frac{2622}{4} = 655.5$
steam Mass-flow	D2, $^{kg}/_{s}$	351.4
Coolant flowrate	G1, $^{kg}/_{s}$	2703
Coolant pressure at the inlet to the SG	P_1, MPa	16.56
Coolant temperature at the inlet to the SG	t_1', °C	329.7
Coolant temperature at the outlet of the SG	t_1'', °C	299.7
Steam pressure at the SG	P_{st} or P_2, MPa	6.89
Steam temperature at the outlet of the SG	t_{st} or t_s, °C	284.8
Feed water temperature	tfw, °C	210
Blowdown flow rate, % (as a percentage of mass flow of steam)	α_{bd}, %	0.5

$$P_2 = 1.06 \cdot P_0 = 1.06 \cdot 6.5 = 6.89 \text{ MPa} ;$$
$$t_{s2} = f(P_2) = f(6.89) = 284.8 \text{ °C} ;$$
$$t_1'' = t_{s2} + \Delta t_{EV}^{min} = 284.7 + 15 = 299.7 \text{ °C} ;$$
$$\Delta t_{EV}^{min} = 10 \dots 15 \text{ °C} ;$$

$$t_1' = t_1'' + \Delta t_R = 299.7 + 30 = 329.7\ ^\circ C\ ;$$
$$\Delta t_R = 30\ ^\circ C\ ;$$
$$t_{s1} = t_1' + \delta t_b = 329.7 + 21 = 350.7\ ^\circ C\ ;$$
$$\delta t_b = 15 \ldots 25\ ^\circ C\ ;$$
$$P_1 = f(t_{s1}) = f(350.7) = 16.56\ \mathrm{MPa}\ .$$

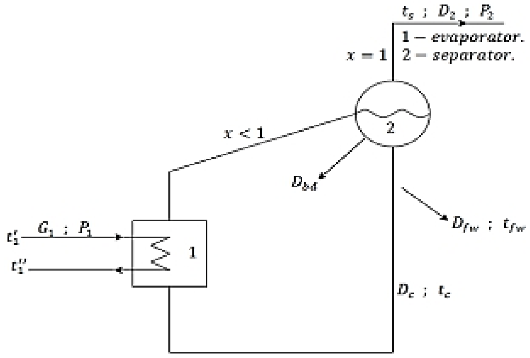

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Figure 5.1-SG without ec

5.1.1 **Coolant-Flowrate**

$$Q_{Sg} = G_1(h_{1inl} - h_{1out})\ ;$$
$$G_1 = \frac{Q_{sg}}{(h_{1inl} - h_{1out})} = \frac{655.5 \cdot 10^3}{(1512 - 1335)} = 2703\ {}^{kg}/_{s}\ .$$
$$h_{1inl} = f(p_1,\ t_1') = f(16.56, 329.7) = 1512\ {}^{kJ}/_{kg}\ ;$$
$$h_{1out} = f(p_1,\ t_1'') = f(16.56{,}299.7) = 1335\ {}^{kJ}/_{kg}.$$

5.1.2 **Steam Flow-Rate**

$$G_{SG} = 1405.7\ {}^{kg}/_{s}\ ;$$
$$D_2 = \frac{G_{SG}}{Z_{loop}} = \frac{1405.7}{4} = 351.4\ {}^{kg}/_{s}.$$

where:

- D_2 steam generator steam flow-rate, ${}^{kg}/_{s}$;
- G_{SG} turbine installation steam flow-rate, ${}^{kg}/_{s}$;
- $D_{bd} = \left(\frac{\alpha_{bd}}{100}\right) \cdot D_2$ is flow-rate of blow-down water;

$$D_{bd} = \left(\frac{0{,}5}{100}\right) \cdot 351.4\ = \ 1.75\ {}^{kg}/_{s}.$$

5.1.3 **Flowrate FeedWater.**

$$D_{fw} = D_2 + D_{bd}\ \ \mathrm{kg/s}\ ;$$
$$D_{fw} = 351.4 + 1.75 = 353.1\ {}^{kg}/_{s}.$$

5.1.4 **Building a tQ Diagram.**

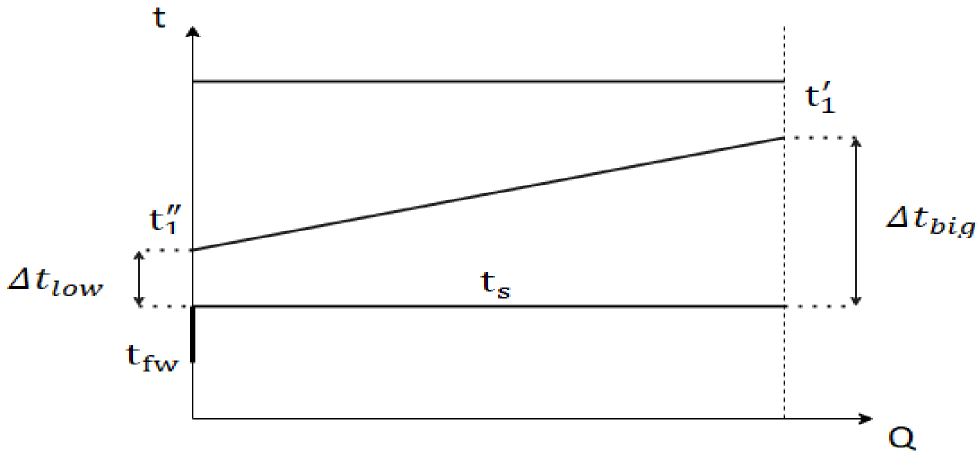


Figure 5.2- SG tQ Diagram

5.1.5 **Choice of Tube of collectors Material.**

I will concentrate prototype.

- 08X18H10T heat transfer surface tubes;
- 10ГН2МФА the heat carrier collector, 08X18H10T clad on the side.

5.1.6 **Calculation of the Wall Thickness of the Tubes of the Heat Transfer Surface of the Steam Generator.**

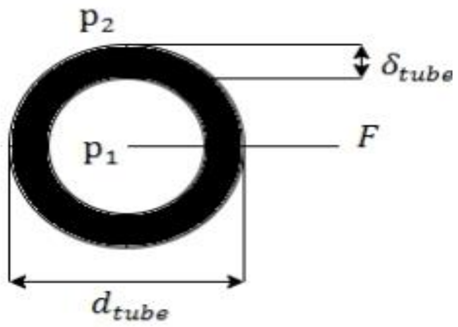


Figure 5.3-Cross-Section of Heating Surface

To calculate the nominal wall thickness of tubes, use the formula:

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

where:

- d_{out} tube outer diameter, mm.
- $\varphi = 1$ is coefficient of strength (load factor);
- $p_{calc} = 0{,}9 \cdot 1{,}25 \cdot p_1$ (design) pressure, MPa
- $p_{calc} = 0.9 \cdot 1.25 \cdot (16.56) = 18.63$ Mpa;
- $$t_{tube.max} = 0{,}5 \cdot (t_1' + t_s) = 0{,}5 \cdot (329.7 + 284.8) = 307.2℃\ .$$
- 16 mm horizontal WWER SG (diameter of the tubes);
- $[\sigma]$ is nominal stress design, MPa.

$$\delta_{tube} - c = {p_{calc} \cdot d_{out}}/{2 \cdot \varphi \cdot [\sigma] + p_{calc}} = {18.63 \cdot 16}/{2 \cdot 1 \cdot [91] + 18.63} = 1.48\ mm\ ;$$

$$\delta_{tube} = {p_{calc} \cdot d_{out}}/{2 \cdot \varphi \cdot [\sigma] + p_{calc}} + c = 1.48 + 0{,}294 = 1.78 \approx 1.8\ mm.$$

5.1.7 **Calculate Nominal Stress Design**

This stress design is defined as the minimum of two value

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

where: relevant safety factors

- $n_{sl} = 2.6$;
- $n_{0,2} = 1.5$;

From Initial Data

- $t_{1.max} = t_1' = 329.7$ °C;
- $t_{2.max} = t_s = 284.8$ °C;

$$t_{tube.max} = \frac{329.7 + 284.8}{2} = 307.2 \text{ °C};$$

08H18N10T Russia produces steam generator tubes using type steel.

Table 5.2-Melting point of metals

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

at a temperature of 307.2 °C, Choose data:

- $\sigma_{sl} = 363$ MPa;
- $\sigma_{0.2} = 137$ Mpa;

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{363}{2.6} = 140 \text{ MPa}; \quad , \qquad \frac{\sigma_{0,2}}{n_{0,2}} = \frac{137}{1.5} = 91 \text{ MPa};$$

Then I will Compare the calculated values.

Nominal voltage tolerance is equal to a lower value $[\sigma] = 91$ MPa;

- σ_{sl} is shakedown limit of material design;

$$t_{calk} = t_{tube.max}, \text{Mpa};$$

- $\sigma_{0,2}$ is yield point of the material the design

$$t_{calk} = t_{tube.max}, \text{Mpa};$$

$$C_1 = 0{,}185;$$

$$C_2 = 0;$$

$$C_3 = 0;$$

$$C_4 = 0{,}0065;$$

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

$$C = 0.185 + 0{,}1093 = 0{,}294.$$

Table 5.3-Permissible deviations

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 %

- It is taken largest of the two values calculated by the formulas:

$$[\delta_{tube} - C] \leq 0{,}75 \cdot 10^{-2} \cdot a = 0{,}75 \cdot 10^{-2} \cdot (0.15) = 1.125 \cdot 10^{-3};$$

$$C_4 = (\delta_{tube} - C) \cdot \left[\frac{1.5 \cdot \left(\frac{a}{100}\right) - 2 \cdot \left(\frac{\delta_{tube} - C}{d_{out}}\right)}{1.5 \cdot \left(\frac{a}{100}\right) - \left(\frac{\delta_{tube} - C}{d_{out}}\right)} \right];$$

if $[\delta_{tube} - C] > 0.75 \cdot 10^{-2} \cdot a$

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

$$C_4 = 1.521 \cdot \left[1 - 2 \cdot \left(1 - \frac{20}{100}\right) \cdot \frac{2 \cdot \left(\frac{48}{16}\right) + 1}{4 \cdot \left(\frac{48}{16}\right) + 1} \right] = 0.1093\,.$$

where:

- $R_b = (1{,}9 \ldots 3{,}5) \cdot d_{out} = 2{,}1 \cdot d_{out} = 3 \cdot 16 = 48$ mm;
- a is ovality of the tube in the bent section, %;
- b is relative decrease in wall thickness in the stretched part of the bent section, %;

accepted

- $a = 5 \ldots 15\ \% = 15\%$;
- $b = 10 \ldots 30\ \% = 20\ \%$.

$$d_{in} = d_{out} - (2 \cdot \delta_{tube}) = 16 - (2 \cdot 1.8) = 12.40 \text{ mm}.$$

5.1.8 **Determining the Number of Tubes**

$$N_{tube} = \frac{G_1}{\rho_{avr} \cdot w \cdot f_{1tube}} = \frac{3703.4}{696.26 \cdot 5 \cdot (1{,}2 \cdot 10^{-4})} = 8813 \text{ pcs};$$

where:

- G_1 is coolant flow, $^{kg}/_{s}$;
- $\rho_{avr} = f(p_1,\ t_{1avr})$ is the average density of the coolant;

$$\rho_{avr} = f(16.56, 314.7) = 696.26\ ^{kg}/_{m^3};$$

$$t_{1av} = \frac{329.7 + 299.7}{2} = 314.7\ ^\circ\text{C}\,.$$

$$w = 5\ ^{m}/_{s};$$

$$f_{1tube} = \frac{\pi \cdot d_{in}^2}{4} = \frac{\pi \cdot 12{,}40^2}{4} = 124.01 \text{ mm}^2 = 1{,}2 \cdot 10^{-4} \text{ m}^2.$$

- f_{1tube} is cross-section area of one tube, m^2.

5.1.9 **Calculation of Heat Transfer in a Steam Generator**

Determination of average temperature head in a steam generator

$$\Delta t_{avr} = \frac{\Delta t_{hig} - \Delta t_{low}}{\ln\left(\frac{\Delta t_{hig}}{\Delta t_{low}}\right)} = \frac{44.9 - 14.9}{\ln\left(\frac{44.9}{14.9}\right)} = 27.2\ ^\circ\text{C};$$

where:

- $\Delta t_{hig} = t_1' - t_s$ is highest temperature head;

$$\Delta t_{hig} = 329.7 - 284.8 = 44.9\ ℃;$$

- $\Delta t_{low} = t_1'' - t_s$ is lowest temperature head.

$$\Delta t_{low} = 299.7 - 284.8 = 14.9\ ℃.$$

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

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

$$\alpha_{1avr} = 0{,}021 \cdot \left(\frac{0{,}5332}{12{,}40 \cdot 10^{-3}}\right) \cdot (519263)^{0{,}8} \cdot (0.91)^{0{,}43}$$

$$\alpha_{1avr} = 32388\ {}^{W}/_{(m^2 \cdot ℃)}.$$

$$\nu_{1avr} = f(p_1,\ t_{1avr}) = f(16.56{,}314.7) = 1.194 \cdot 10^{-7}\ {}^{m^2}/_{s};$$

$$\lambda_{1avr} = f\,(16.56, 314.7) = 0.5332\ {}^{W}/_{(m \cdot ℃)};$$

$$Pr_{avr} = f\,(16.56{,}314.7) = 0.91;$$

$$Re_{avr} = \frac{w \cdot d_{in}}{\nu_{1avr}} = \frac{5 \cdot 12.40 \cdot 10^{-3}}{1{,}194 \cdot 10^{-7}} = 519263;$$

5.1.10 **Determination of the heat transfer coefficient from the walls of the tubes to the working fluid**

$$q_{in} = 3 \cdot 10^5\ {}^{W}/_{m^2};$$

$$\alpha_{2in} = \frac{10{,}45}{3{,}3 - 0{,}0113 \cdot (t_s - 100)} \cdot q_{in}^{\ 0{,}7}\left({}^{W}/_{m^2}\right).$$

$$t_{tube.in} = t_s + 0{,}3 \cdot (t_1' - t_s), ℃;$$

$$\lambda_{wal.in} = 14{,}48 + 0{,}0156 \cdot t_{tube.in}, {}^{W}/_{(m \cdot ℃)};$$

- Calculate the heat transfer coefficient

$$k_{in} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{tube}}{\lambda_{tube.in}} + 2 \cdot R_{ox} + \frac{1}{\alpha_2}\right]^{-1}, {}^{W}/_{(m^2 \cdot ℃)};$$

Calculate the heat flow:

$$q'_{in} = K_{in} \cdot (t_1' - t_s), {}^{W}/_{m^2};$$

make comparison of heat flow q'_{in} with the one set earlier q_{in}.

Table 5.4-Results heat transfer coefficient

		First iteration	Second iteration
Inlet	q_{in}, W/m^2	$3 \cdot 10^5$	277479
	α_{2in}, $W/(m^2 \cdot ℃)$	58819.7	55692.9
	t_{tube}^{in}, ℃	298.3	298.3
	λ_{wal}^{in}, $W/(m \cdot ℃)$	19.1	19.1
	k_{in}, $W/(m^2 \cdot ℃)$	6174.4	6138.3
	q'_{in}, W/m^2	277479	275854

	q'_{in}/q_{in}	0.92	0.99

$$q_{out} = 6 \cdot 10^4 \ \ ^{W}/_{m^2};$$

$$\alpha_{2out} = {}^{10.45}/_{3{,}3 - 0.0113 \ \cdot \ (t_s - 100)} \cdot q_{out}{}^{0{,}7}, {}^{W}/_{(m^2 \cdot °C)};$$

$$t_{tube.in} = t_s + 0{,}3 \cdot (t'_1 - t_s), °C;$$

$$\lambda_{wal.in} = 14{,}48 + 0{,}0156 \cdot t_{tube.in}, {}^{W}/_{(m \cdot °C)};$$

- heat transfer coefficient

$$k_{out} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{tube}}{\lambda_{tube.in}} + 2 \cdot R_{ox} + \frac{1}{\alpha_2}\right]^{-1}, {}^{W}/_{(m^2 \cdot °C)};$$

- heat flow

$$q'_{out} = k_{out} \cdot (t''_1 - t_s), {}^{W}/_{m^2}.$$

Table 5.5-Results heat transfer coefficient.

		First iteration	Second iteration
Outlet	q_{out}, W/m^2	$6 \cdot 10^4$	75414
	α_{2out}, $W/(m^2 \cdot °C)$	19065	22375
	t_{tube}^{out}, °C	289.3	289.3
	λ_{wal}^{out}, $W/(m \cdot °C)$	19	19
	k_{out}, $W/(m^2 \cdot °C)$	5047.9	5253.6
	q'_{out}, W/m^2	75414	78488
	q'_{out}/q_{out}	1.25	1.04

5.1.11 **Calculation of the average overall heat transfer coefficient**

For this, the values of k_{in} and k_{out} are compared.

If $\left|\frac{k_{in}-k_{out}}{k_{out}}\right| \leq 0.25$, then $k_{avr} = 0{,}5 \cdot (k_{in} + k_{out})$;

$$\left|\frac{k_{in} - k_{out}}{k_{out}}\right| = \left|\frac{6138.3 - 5253.6}{5253.6}\right| = 0{,}16.$$

So that, I will calculate with this formula

$$k_{avr} = 0.5 \cdot (k_{in} + k_{out}) = 0.5 \cdot (6138.3 + 5253.6) = 5696 \ W/(m^2 \cdot °C);$$

5.1.12 **Area of the heat exchange surface**

$$F = \frac{k_{sf} \cdot Q_{sg}}{k_{avr} \cdot \Delta t_{avr}} = \frac{1.1 \cdot 655.5 \cdot 10^3}{(5696 \cdot 10^{-3}) \cdot 27.2} = 4647 \ m^2;$$

where:

- $k_{sf} = 1{,}05 \ldots 1{,}10$ is the safety factor for taking into account deposits and plugged tubes, and we assumed it by $k_{sf} = 1.1$;
- k_{avr} is the average heat transfer coefficient, ${}^{kW}/_{(m^2 \cdot °C)}$;

- Q_{sg} is thermal power of the steam generator, kW;
- Δt_{avr} is average temperature head in the steam generator, °C.

5.1.13 **Calculate the average length of one tube of the steam generator**

$$l_{avr} = \frac{F}{\pi \cdot d_{avr} \cdot N_{tube}} = \frac{4647}{\pi \cdot (14.28 \cdot 10^{-3}) \cdot 8813} = 11.83 \text{ m};$$

$$d_{avr} = 0.5 \cdot (d_{out} + d_{in}) = d_{in} + \delta_{tube}$$

$$d_{avr} = 0,5 \cdot (16 + 12,40) = 14.20 \text{ mm} = 0,0142 \text{ m};$$

- N_{tube} total number of tubes $= 8813$ pcs ;

5.2 Design Calculation Saturated Horizontal SG with U-Shaped Tubes

5.2.1 **Calculation of the Wall Thickness of the Collector, m**

$$\delta_{coll} = \frac{p_{1calk} \cdot D_{col}^{in}}{2 \cdot \varphi_{\min} \cdot [\sigma] - p_{1calk}};$$

$$\delta_c = \frac{18.63 \cdot 0.9}{2 \cdot 0.36 \cdot (215) - 18.63} = 0,123 \text{ m};$$

where:

- $p_{1calk} = 0.9 \cdot 1.25 \cdot p_{1avr} \approx 0.9 \cdot 1.25 \cdot p_1$ is the rated pressure, MPa;

$$P_{1\ calc} = 0.9 \cdot 1.25 \cdot 16.56 = 18.63 \text{ MPa};$$

$$D_{col}^{in} = 0,90 \text{ m};$$

- $[\sigma] = 215$ MPa is nominal stress design for steel 10ГН2МФА;
- φ_{min} is minimum coefficient of strength. Let's accept the smallest value.

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} \text{ and } \varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2};$$

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} = \frac{0,025 - (16 \cdot 10^{-3})}{0,025} = 0,36;$$

$$\varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2} = \frac{2 \cdot (0,025 - (16 \cdot 10^{-3}))}{0,025} = 0,72;$$

So $\varphi_1 < \varphi_2$, then then. $\varphi_{min} < \varphi_1$

$$\varphi_{min} = 0,36;$$

5.2.2 **Outer Diameter of the Collector, m.**

$$D_{col}^{out} = D_{col}^{in} + 2 \cdot \delta_{coll};$$

$$D_{col}^{out} = 0.90 + 2 \cdot 0.123 = 1,15 \text{ m}.$$

5.2.3 **Step s2 on to the Outer Diameter, m**

$$s_{2out} = s_2 \cdot \frac{D_{col}^{out}}{D_{col}^{in}};$$

$$s_{2out} = 0.025 \cdot \left(\frac{1.15}{0.90}\right) = 0.0318 \text{ m}.$$

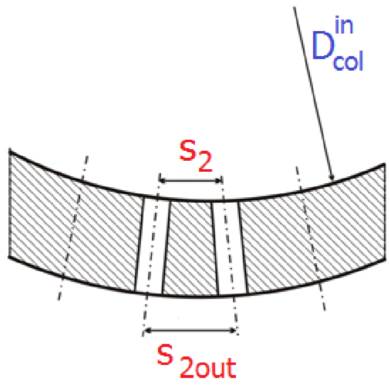


Figure 5.4-Fragment wall of collector.

5.2.4 **The length of the arc along the Collector Occupied by Tubes of the Upper Row, m**

$$L_{c1} = \pi \cdot D_{col}^{out};$$
$$L_{c1} = \pi \cdot 1.15 = 3.599 \text{ m}.$$

5.2.5 **Number of Tubes in the Upper Row, pcs**

$$N_{tube1} = \frac{L_{c1}}{s_{2out}};$$
$$N_{tube1} = \frac{3.599}{0.0318} = 113 \text{ pcs}.$$

5.2.6 **The Maximum Width of the Tube Bundle at the Level of the Upper-Row of Tubes, m**

$$B_{bund}^{max} = N_{tube1} \cdot S_{2b} + 3 \cdot B_{cor};$$
$$S_{2b} = 0.030\ m;$$
$$B_{bund}^{max} = 113 \cdot 0.030 + 3 \cdot 0.5 = 3.84 \text{ m}.$$

where $B_{cor} = (0{,}15\ldots0{,}2)$ Assumption 0.15 m.

5.2.7 **Width of the Heat Exchange Tube Bundle Package, m**

$$B_{pack} = \frac{B_{bund}^{max} - 3 \cdot B_{cor}}{2};$$
$$B_{pack} = \frac{3.84 - (3 \cdot 0.15)}{2} = 1.7 \text{ m}.$$

5.2.8 **Distance between the axis of collector, m**

$$B_{dac} = 2 \cdot B_{pack} + 2 \cdot B_{cor};$$
$$B_{dac} = (2 \cdot 1.7) + (2 \cdot 0{,}15) = 3.69 \text{ m}$$

5.2.9 **Width of Submerged Perforated Plate, m**

$$B_{pp} = (1{,}05\ldots1{,}1) \cdot B_{bund}^{max};$$
$$B_{pp} = 1.05 \cdot (3.84) = 4.03 \text{ m}.$$

5.2.10 **SG Vessel Width at Level Perforated Plate, m**

$$B_{ves.in} = B_{pp} + 2 \cdot B_{gap};$$
$$B_{gap} = 0.25\ m;$$
$$B_{ves.in} = 4.03 + (2 \cdot 0.25) = 4.53 \text{ m}.$$

where:

- $B_{gap} = (0{,}25\ldots0{,}3\ )$ m

5.2.11 **Height of the location of the submerged perforated plate relative to the horizontal axis of the SG vessel, m**

$$h_{pp} = h_0 + h_1 - h_{wl};$$
$$h_{pp} = 0.2 + 0.2 - 0.1 = 0.3 \text{ m}.$$

where:

- $h_0 = (0{,}2\ldots0{,}35)$ is height of the arrangement of the upper row of tubes relative to the horizontal axis of the SG; $h_0 = 0.2$ m ;
- $h_1 = (0{,}2\ldots0{,}35)$ is the height of the location of the weight level of water above the upper row of tubes; $h_1 = 0.2$ m;
- $h_{wl} = 0.05 \ldots 0.1$ m is height of the weight level above the submerged perforated plate. $h_{wl} = 0.1$ m.

5.2.12 **The Distance of the Lower Row of Pipes of the Heat Exchange Surface from the Lower Generatrix of the Steam Generator Vessel**

- $h_{dlr} = 0{,}08 - 0{,}120$ m

$$h_{dlr} = 0.12 \text{ m}.$$

5.2.13 **Internal Diameter of the Steam Generator Vessel, m**

$$D_{ves.in} = \sqrt{4 \cdot h_{pp}^2 + B_{ves.pp}^2};$$
$$D_{ves.in} = \sqrt{4 \cdot 3 + 4{,}53^2} = 4.57 \text{ m}.$$

5.2.14 **Area of the Evaporation Surface, m²**

$$F_{es} = B_{pp} \cdot (l_{tube} + D_{col}^{out})$$
$$F_{es} = 4.03 \cdot (11.82 + 1.15) = 52.3 \text{ m}^2.$$

5.2.15 **Superficial Steam Velocity, $\boldsymbol{m/s}$**

$$w_o'' = \frac{D_2}{F_{es} \cdot \rho_2''};$$
$$w_o'' = \frac{D_2}{F_{es} \cdot \rho_2''} = \frac{351.4}{52.3 \cdot 35.88} = 0.187 \text{ m/s}.$$

where:

- ρ_2'' of the working fluid, kg/m^3;

$$\rho_2'' = f(p_2) = f(6.89) = 35.88 \text{ kg/m}^3.$$

5.2.16 **The True Volumetric Vapor Content in the Water Layer above the Submerged Perforated Plate, m**

$$\varphi_{bub} = \frac{w_0''}{w_0'' + (0.65 - 0.039 \cdot p_2)};$$
$$\varphi_{bub} = \frac{0.187}{0.187 + (0.65 - 0.039 \cdot 6.89)} = 0.329 \text{ m}.$$

5.2.17 **Actual (real) Water Level above the Submerged Perforated Plate, m**

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

$$h_{real} = \frac{0.1}{(1 - 0{,}329)} = 0.149 \text{ m.}$$

5.2.18 **Height of Steam Volume, m**

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

$$h_{sv} = \frac{4.57}{2} - (0.3 + 0.149 + 0.4) = 1.43\ m\,.$$

Where:

- $h_{srp} = 0{,}35\ldots0{,}4$; is vertical distance from the steam-receiving perforated plate to the inner surface of the SG vessel, m;

$$h_{sv} = 1.82 \gg 0.4 \text{ m} \qquad \text{so} \qquad h_{sv} \gg 0.4 \text{ m.}$$

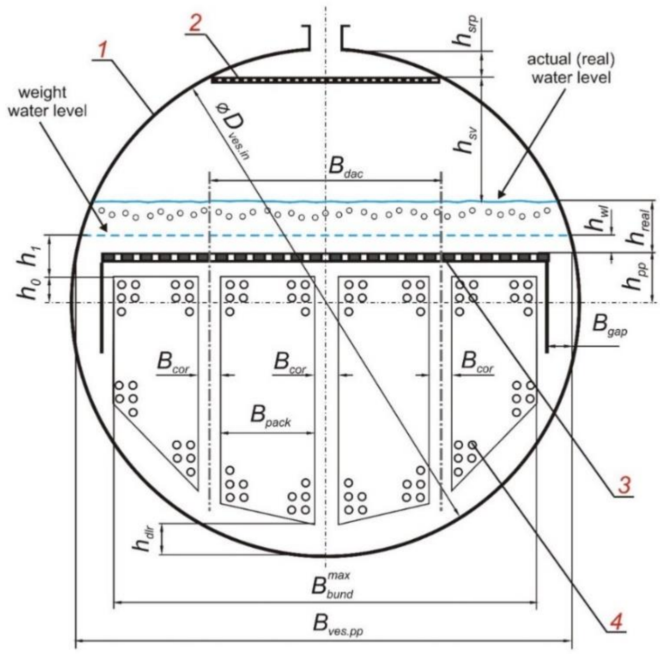


Figure 5.5- Cross section of horizontal VVER SG
1 is vessel; 2 is steam-receiving perforated plate; 3 is submerged perforated plate;
4 are heat exchange tubes

5.2.19 **Characteristics of steam outlet nozzles**

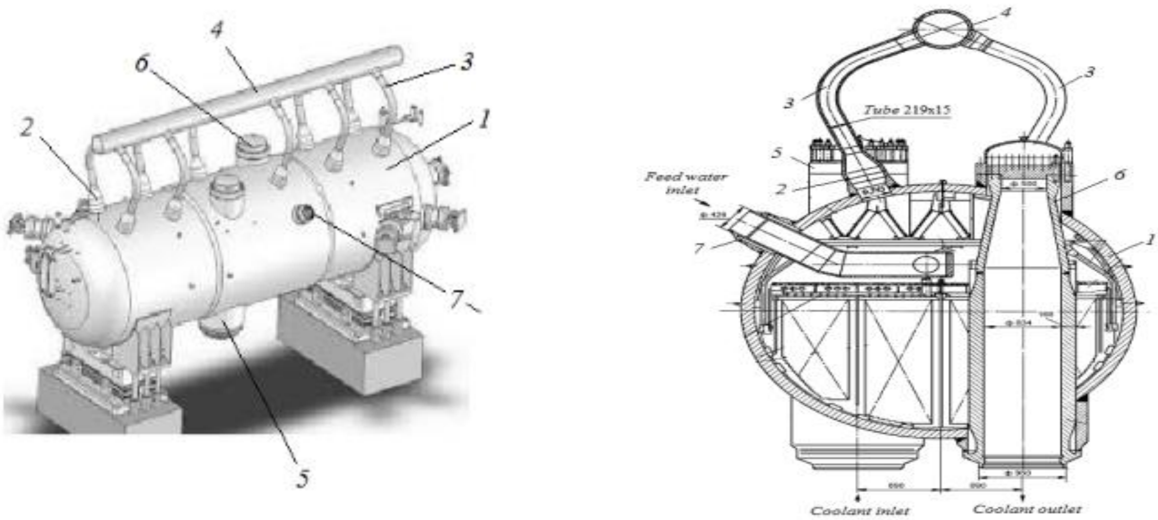


Figure 5.6-Exterior (a) and Cross section (b) of a horizontal steam generator:

The inner diameter of the steam outlet nozzles

$d_{noz.in}$ can be determined from the following continuity equation

$$N_{noz} \cdot \frac{\pi \cdot d_{noz.in}^2}{4} \cdot w_{noz} = \frac{D_2}{\rho''};$$

$$d_{noz.in} = \sqrt{\frac{4 \cdot D_2}{\pi \cdot \rho'' \cdot N_{noz} \cdot w_{noz}}};$$

$$d_{noz.in} = \sqrt{\frac{4 \cdot 351.4}{\pi \cdot 35.88 \cdot 10 \cdot 30}} = 0{,}203 \text{ m}.$$

where:

- $N_{noz} = (8\ldots10)$, N_{noz}=10 pc. is number of steam outlet nozzles;
- $w_{noz} = 30\ldots40$, w_{noz}= 30 $^{m}/_{s}$. is steam speed in steam outlet nozzles;

$$\rho_2'' = f\,(6.89) = 35.88 \ ^{kg}/_{m^3}.$$

5.2.20 **Characteristics of the feed pipe**

The inner diameter of the feed $d_{fw.in}$ can be determined from the following continuity equation.

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

$$\frac{\pi \cdot d_{fw.in}^2}{4} \cdot 5 = \frac{353.18}{856.7};$$

$$d_{fw.in} = 0{,}324 \text{ m}.$$

where:

- $w_{fw} = (4\ldots5)\ w_{fw} = 5\ \text{m/s}$ is feed water speed in feed pipe;
- $D_{fw} = D_2 + D_{bd}$ is mass flow of feed water, $^{kg}/_{s}$;

$$D_{fw} = 351.43 + 1.75 = 353.18 \ ^{kg}/_{s};$$

- $\rho_{fw} = f(p_2,\ t_{fw}) = f\,(6.89, 210) =\ 856.7\ {}^{kg}/_{m^3}$ is density of feed water, ${}^{kg}/_{m^3}$.

5.3 Mechanical Calculation Saturated Horizontal SG with U-Shaped Tubes

The mechanical calculation's goals are to figure out the wall thickness of the major components of the steam generator and their static strengths. In a horizontal steam generator, a substantial volume of heat transfer from the wall to the working fluid takes place at boiling conditions. The computation process is interactive as a result, and it includes the following steps:

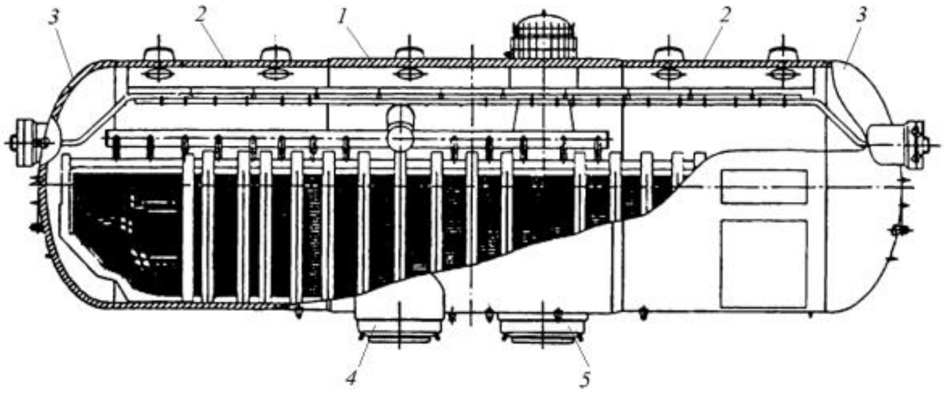


Figure 5.7- Longitudinal section of a horizontal steam generator:

5.3.1 **Calculation of the Wall Thickness of the Side Shell**

The following formula should be used to calculate the nominal wall thickness of the side shell (vss).

$$\delta_{vss} = {}^{p_{calc} \cdot D_{ves,in}}\Big/_{2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C\,;$$

$$\delta_{vss} - c = \frac{7.75\ \cdot\ 4.57}{2 \cdot 1 \cdot (181.15) - 7{,}75} = 0{,}1\ \text{m} = 100\ \text{mm}.$$

$$\delta_{vss} = 100\ \text{mm}.$$

where:

- $\boldsymbol{\varphi}$ is coefficient of strength. $\varphi = 1$;
- $p_{calc} = 0.9 \cdot 1.25 \cdot p_2$ (design) pressure;
- $[\sigma]$ nominal stress-design, MPa.

$$[\sigma] = \min\left\{\frac{\sigma_{sl}}{n_{sl}};\ \frac{\sigma_{0.2}}{n_{0.2}}\right\}\ ;$$

Where:

- $n_{sl} = 2{,}6$ and $\sigma_{0,2} = 1{,}5$ are relevant safety factors;
- $\sigma_{0,2}$ is yield point of the tube's material at the design temperature $t_{calk} = t_s$, MPa;

From initial data

- $t_{calk} = t_s$= 284.8 ºC;

From (table 2.6), select

σ_{sl}= 471MPa $\qquad$ $\sigma_{0,2}$= 304 MPa;

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{471}{2,6} = 181.15\ \text{MPa} \qquad \frac{\sigma_{0,2}}{n_{0,2}} = \frac{304}{1,5} = 202,67\ \text{MPa};$$

Table 5.6-Mechanical properties of steel 10ГН2МФА

t_{calc}, °C	100	150	200	250	300	350
σ_{sl}, MPa	510	510	510	491	471	491
$\sigma_{0,2}$, MPa	323	314	304	304	304	294

Calculation of the Wall Thickness of the Central Shell

The following formula should be used to calculate the nominal wall thickness of the central shell (vcs).

$$\delta_{vcs} = {p_{calc} \cdot D_{ves.in}} / {2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C\,;$$

$$\delta_{vcs} = \frac{7.75 \cdot 4.57}{2 \cdot 0.75 \cdot [181.15] - 7.75} + 0 = 0.134\ \text{m}.$$

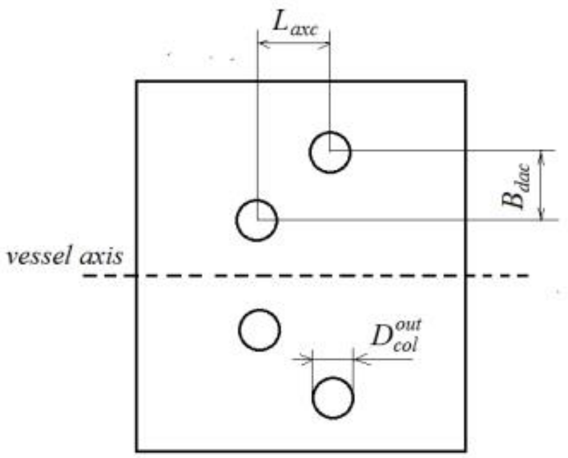


Fig. 2.8- calculation of the strength coefficient

Four large-diameter holes in the center of the shell allow coolant collectors to pass through. Therefore, the coefficient $\varphi = \min\{\varphi_1,\ \varphi_2,\ \varphi_3\}$

$$\varphi_1 = \frac{2 \cdot L_{axc} - D_{col}^{out}}{2 \cdot L_{axc}} = \frac{2 \cdot 2.29 - 1.15}{2 \cdot 2.29} = 0.75\,;$$

$$\varphi_2 = \frac{2 \cdot (2 \cdot B_{dac} - D_{col}^{out})}{2 \cdot B_{dac}} = \frac{2 \cdot (2 \cdot 3.69 - 1.15)}{2 \cdot 3.69} = 1.69\,;$$

$$\varphi_3 = \frac{1 - \frac{D_{col}^{out}}{L_{axc}} \cdot \frac{1}{\sqrt{1+m^2}}}{\sqrt{1 - 0,75 \cdot \left(\frac{m^2}{1+m^2}\right)^2}} = \frac{1 - \frac{1.15}{2.29} \cdot \frac{1}{\sqrt{1+1.61^2}}}{\sqrt{1 - 0.75 \cdot \left(\frac{1.61^2}{1+1.61^2}\right)^2}} = 0,94\,;$$

$$\varphi_2 > \varphi_3 > \varphi_1;$$

because of φ_1 is minimum so we used it.

where:

- δ_{vcs} is in m;

$$m = \frac{B_{dac}}{L_{axc}} = \frac{3.69}{2.29} = 1.61\ \text{m}\,;$$

- $L_{axc} \approx 2 \cdot D_{col}^{out}$ is axial distance, m;

$$L_{axc} = 2 \cdot 1.15 = 2.29 \text{ m};$$

5.3.2 **Calculation of the Thickness of Bottom**

$$\delta_{bot} = \frac{p_{calk} \cdot D_{ves.in}}{4 \cdot \varphi \cdot [\sigma]} \cdot \frac{D_{ves.in}}{2 \cdot h};$$

$$\delta_{bot} = \frac{7.75 \cdot 4.57}{4 \cdot 1 \cdot [181.15]} \cdot \frac{4.57}{2 \cdot 1.017} = 0.136 \text{ m}.$$

$$\frac{h}{D_{ves.in}} \geq 0.2$$

$$\frac{h}{4.57} \geq 0.2;$$

$$h = 0.2 \cdot 5.09 = 0.915 \text{ m}.$$

- $\varphi = 1$ is coefficient of strength;

5.4 Hydraulic Calculation of the Steam Generator

SG hydraulic calculations serve to ascertain the pressure losses that occur as the coolant travels through it. Main circulation tubes link the reactor and the steam generator. The hot circulation pipeline is where the coolant enters the intake collector. In the output collector, the coolant is collected after passing through the heat exchange tubes and being dispersed across them. The coolant travels to the cold circulation pipeline from the output collector.

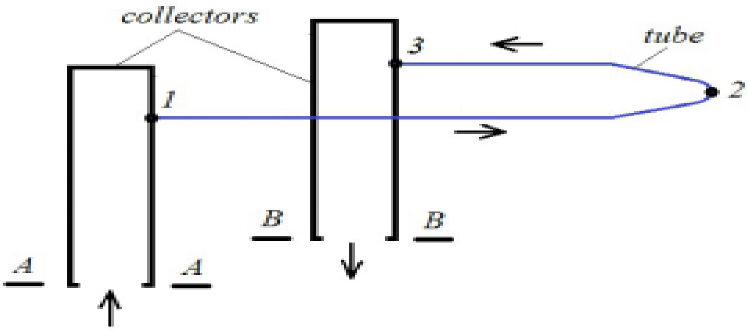


Figure 5.8- Flow coolant circulation in horizontal SG

Hydraulic resistance of the horizontal SG along the coolant:

$$\Delta p_{\Sigma} = \Delta p_{col.in} + \Delta p_{col.out} + \Delta p_{tube};$$

Where:

- $\Delta p_{col.in}$ and $\Delta p_{col.out}$ are hydraulic resistances of the input and output collectors;

$$\Delta p_i = \Delta p_{fr.i} + \Delta p_{loc.i} + \Delta p_{cpd.i} + \Delta p_{acc.i};$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2};$$

- $\rho_{avr} = f(p_1, t_{1avr})$ Average density of the coolant in the SG, $^{kg}/_{m^3}$.

$$\rho_{avr} = f(p_1, t_{1avr}) = 696.25 \ ^{kg}/_{m^3};$$

W is the characteristic velocity of the coolant, $^{m}/_{s}$;

$$w_{col} = \frac{4 \cdot G_{col}}{\rho_{avr} \cdot \pi \cdot \left(D_{col}^{in}\right)^2} ;$$

ξ_{fr} is coefficient of friction;

$$\xi_{fr} = 0.11 \cdot \left[\left(\frac{\Delta}{d_h}\right) + \left(\frac{68}{Re}\right)\right]^{0.25} ;$$

- Δ is absolute surface roughness, m. For collectors made of perlite steel;
- $\Delta_{col} \leq 0.1 \cdot 10^{-3}$ m; for tubes made of austenitic steel $\Delta_{tube} \leq 0.05 \cdot 10^{-3}$ m;
- $Re = \frac{w \cdot d_h}{\nu_{avr}}$ is Reynolds number.
- $\nu_{avr} = f(p_1, t_{1avr})$ average kinematic viscosity of the coolant in the SG.

5.4.1 **For the plot lifting movement of the coolant in the inlet collector.**

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{in} \cdot w^2}{2} ;$$

$$D_{col}^{in} = 0{,}9 \text{ m} ;$$

$$\rho_{in} = f(p_1, t'_1) , \text{kg}/\text{m}^3 ;$$

$$\rho_{in} = f(16.56{,}329.7) = 656.3 \ \text{kg}/\text{m}^3 ;$$

$$w_{col.in} = \frac{4 \cdot G_{col}}{\rho_{in} \cdot \pi \cdot \left(D_{col}^{in}\right)^2} , \text{m}/\text{s} ;$$

$$w_{col.in} = \frac{4 \cdot 3703.3}{656.3 \cdot \pi \cdot (0.9)^2} = 8.87 \ \text{m}/\text{s} ;$$

$$d_h = D_{col}^{in} = 0.9 \text{ m} ;$$

$$L \approx \frac{D_{ves.in}}{2} , \text{m} ;$$

$$L \approx \frac{4.57}{2} = 2.28 \text{ m} ;$$

$$\nu_{in} = f(p_1, t'_1) , \text{m}^2/\text{s} ;$$

$$\nu_{in} = f(16.56{,}329.7) = 1.17 \cdot 10^{-7} \ \text{m}^2/\text{s} ;$$

$$Re = \frac{w_{col.in} \cdot d_h}{\nu} ;$$

$$Re = \frac{8.87 \cdot 0.9}{1.17 \cdot 10^{-7}} = 68263407 ;$$

$$\xi_{fr.col} = 0.11 \left[\left(\Delta/d_h\right) + \left(68/Re\right)\right]^{0{,}25} ;$$

$$\xi_{fr.col} = 0.11\left[\left(0.0001/0.9\right) + \left(68/68263407\right)\right]^{0{,}25} = 0.0113 ;$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{in} \cdot {w_{col.in}}^2}{2} ;$$

$$\Delta p_{fr} = 0.0113 \cdot \frac{2.28}{0.9} \cdot \frac{656.3 \cdot 8.87^2}{2} = 0.743 .$$

5.4.2 **For the plot movement of the coolant in heat exchange tubes**

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2} \;;$$

$$D_{col}^{in} = 0.9 \text{ m} \;;$$

$$\rho_{avr} = f(p_1,\ t_{1avr}) \,, {}^{kg}/_{m^3} \;;$$

$$w_{tube} = 5 \ {}^{m}/_{s} \,;$$

$$d_h = d_{in} = 12.40 \text{ mm} \,;$$

$$L = l_{avr} = 11.8 \text{ m} \,;$$

$$\nu_{avr} = f(p_1,\ t_{1avr}) \,, {}^{m^2}/_{s} \,;$$

$$Re = \frac{w_{tube} \cdot d_h}{\nu} \,;$$

$$\xi_{fr.col} = 0.11 \left[\left({}^{\Delta}/_{d_h} \right) + \left({}^{68}/_{Re} \right) \right]^{0,25} \;;$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot {w_{tube}}^2}{2} \,, \text{pa} \,.$$

5.4.3 **Downward movement of the coolant in the output collector**

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{out} \cdot w^2}{2} \;;$$

$$D_{col}^{in} = 0.9 \text{ m} \;;$$

$$\rho_{out} = f(p_1, t''_1) \,, {}^{kg}/_{m^3} \;;$$

$$w_{col.out} = \frac{4 \cdot G_{col}}{\rho_{out} \cdot \pi \cdot \left(D_{col}^{in}\right)^2} \,, {}^{m}/_{s} \;;$$

$$d_h = D_{col}^{in} = 0.9 \text{ m} \;;$$

$$L \approx \frac{D_{ves.in}}{2} \,, \text{m} \,;$$

$$\nu_{out} = f(p_1,\ t''_1), {}^{m^2}/_{s} \,;$$

$$Re = \frac{w_{col} \cdot d_h}{\nu} \,;$$

$$\xi_{fr.col} = 0.11 \left[\left({}^{\Delta}/_{d_h} \right) + \left({}^{68}/_{Re} \right) \right]^{0,25} \;;$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{out} \cdot {w_{col.out}}^2}{2} .$$

5.4.4 **calculation of local pressure losses**

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_{avr} \cdot w^2}{2} \,;$$

Table 5.7-The values of the coefficient of local resistance

Type of local resistance	Coefficient value ξloc
Inlet of the coolant to the tubes from the collector	0.5
Output of the coolant from the tubes to the collector	1
Rotation of the coolant in U-shaped tubes	0.5

5.4.5 **For the Plot Inlet of the Coolant to the Tubes from the Collector (Point**

$$\Delta p_{loc} = \xi_{loc.in} \cdot \frac{\rho_{avr} \cdot w_{col}^2}{2}, \text{Pa} .$$

5.4.6 **For the plot Output of the coolant from the tubes to the collector**

$$\Delta p_{loc} = \xi_{loc.out} \cdot \frac{\rho_{avr} \cdot w_{col}^2}{2}, \text{Pa}.$$

Table 5.8- result

	ρ	w	d_h	ν	Re	ξ_{fr}	L	Δp_{fr}
fr inlet collector	656.3	8.87	0.90	$1.17 \cdot 10^{-7}$	68263408	0,0113	2,28	743
fr in H.ET	696.25	5	0.0124	$1{,}19 \cdot 10^{-7}$	521008	0,03309	11.8	274698
fr outlet collector	729.1	7.98	0.9	$1{,}22 \cdot 10^{-7}$	58880521	0,0113	2,28	669
							sum	276110

	loc	Δp_{loc}
ξ_{tube}^{in}	0,5	4352
ξ_{tube}^{out}	1	8703
SUM	-	13055

Then:

$$\Delta p_{total} = 276110 + 13055 = 289165 \text{ Pa}.$$

Table.2.9- results of hydraulic calculation of the horizontal steam generator

№	Plot name	Type of hydraulic Resistance.	Characteristic coolant velocity, m/s	Characteristic dimensions, m	Pressure losses, Pa
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} =8.87 m/s (The continuity equation for the collector)	$d_h = D^{in}_{col}$ =0.9 m $L \approx \frac{D_{ves.in}}{2}$ =4.57 / 2 =2.28 m (Section 2 "Design calculation")	743
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 m/s (Section 1.4. «Thermal calculation»)	$d_h = d_{in}$ =0.0124 (Section 1.3. «Thermal calculation»)	4102
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 m/s (Section 1.4. «Thermal calculation»)	$d_h = d_{in}$ =12.4 mm $L = l_{avr}$ = 11.8 m (Section 1.3. «Thermal calculation»)	274698
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 m/s (From section 1.4. «Thermal calculation»)	$d_h = d_{in}$ =0.0124 m (From section 1.3. «Thermal calculation»)	9114
5	Downward movement of the coolant in the output collector (from point 3 to section B-B)	Pressure drops due to friction. Friction factor $\xi_{fr.col}$ (Altshul formula)	w_{col} =7.98 m/s (From the continuity equation for the collector)	$d_h = D^{in}_{col}$ = 0.9 m $L \approx \frac{D_{ves.in}}{2}$ = 4.57 / 2 =2.28 m (Section 2 " Design calculation")	669

5.5 Calculation of Separation in a Horizontal Saturated Steam Generator

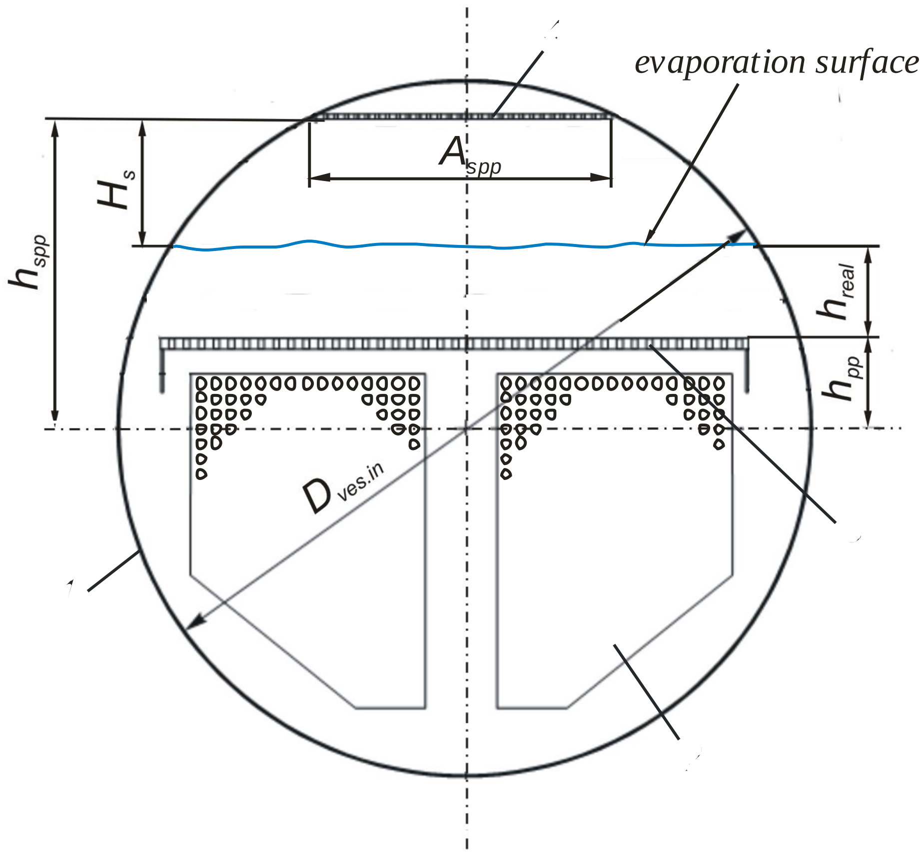


Figure 5.9- calculation separation

Basic data for the calculation:

- D_2 is mass flow of working fluid (steam); D_2 = 351.4 $^{kg}/_{s}$;
- p_2= 6.89 MPa is working medium pressure;
- w_0'' = 0.172 m/s; is superficial steam velocity. Determination of the Area Steam-Receiving Perforated Plate

$$F_{spp} = A_{spp} \cdot l_{avr} = 2.4 \cdot 11.8 = 28.48 \text{ m}^2 .$$

where:

- $A_{spp} = 2 \cdot \sqrt{\left(\frac{D_{ves.in}}{2}\right)^2 - \left(h_{spp}\right)^2}$ is width of the steam-receiving perforated plate;

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{4.57}{2}\right)^2 - (1.943)^2} = 2.4 \text{ m}^2;$$

$$h_{spp} = (0{,}8\ldots0{,}85) \cdot \frac{D_{ves.in}}{2};$$

$$h_{spp} = (0{,}85) \cdot \frac{4.57}{2} = 1.943 \text{ m}.$$

5.5.1 **Distance (height) from the Evaporation Surface to Steam-Receiving Perforated Plate**

$$H_s = h_{spp} - h_{pp} - h_{real} = 1.943 - 0.3 - 0.149 = 1.49\text{ m};$$

where:

- $h_{pp} = 0.3$ m;
- $h_{real} = 0{,}149$ m ;

5.5.2 **Steam Velocity before Steam-Receiving Perforated Plate**

$$w''_{spp} = \frac{D_2}{\rho'' \cdot F_{spp}} = \frac{351.4}{35.88 \cdot 28.48} = 0.34\text{ m/s};$$

where:

- $\rho'' = f(p_2) = 35.88\ {}^{kg}/_{m^3}$, is vapor density at saturation at pressure.

5.5.3 **Determining the Critical Height of the Steam Volume**

$$H_{sv}^{cr} = 0.087 \cdot [w''_0 \cdot F(p)]^{1,3};$$

$$H_{sv}^{cr} = 0.087 \cdot [0.187 \cdot 12.26]^{1,3} = 0.256\text{ m};$$

$$F(p) = 3.45 \cdot 10^3 \cdot \left[\frac{\rho'' \cdot (\rho')^2}{(\rho' - \rho'')^6}\right]^{0,25};$$

$$F(p) = 3.45 \cdot 10^3 \cdot \left[\frac{35.88 \cdot (741.6)^2}{(741.6 - 35.88)^6}\right]^{0,25} = 12.26;$$

where:

- $\rho'' = f(p_2) = 35.88\ {}^{kg}/_{m^3}$ is vapor density at saturation at pressure;
- $\rho' = f(p_2) = 741.6\ {}^{kg}/_{m^3}$is water density at saturation at pressure.

5.5.4 **Steam moisture at the top of the steam volume**

$H_s > H_{sv}^{cr}$, then

$$Y = M \cdot 10^{-4} \cdot \frac{(w''_0)^{2,76}}{H_s^{2,3}};$$

$$Y = 26.68 \cdot 10^{-4} \cdot \left(\frac{(0.187)^{2,76}}{1.49^{2,3}}\right) = 1.039 \cdot 10^{-5}\ \%;$$

$$M = 2{,}05 - (3{,}049 \cdot p_2) + (0{,}9614 \cdot p_2^2);$$

$$M = 2{,}05 - (3{,}049 \cdot 6.89) + (0{,}9614 \cdot 6.89^2) = 26.68;$$

5.6 Calculation of Thermal Insulation of the Steam Generator

To minimize heat loss to the environment while the power unit is operating, the steam generator has thermal insulation. Thermal insulation is also required to safeguard people from burns when they come into touch with hot surfaces.

Use MTP-as brand mats composed of ultra-thin glass fiber as a thermal insulator for the NPP steam generator.

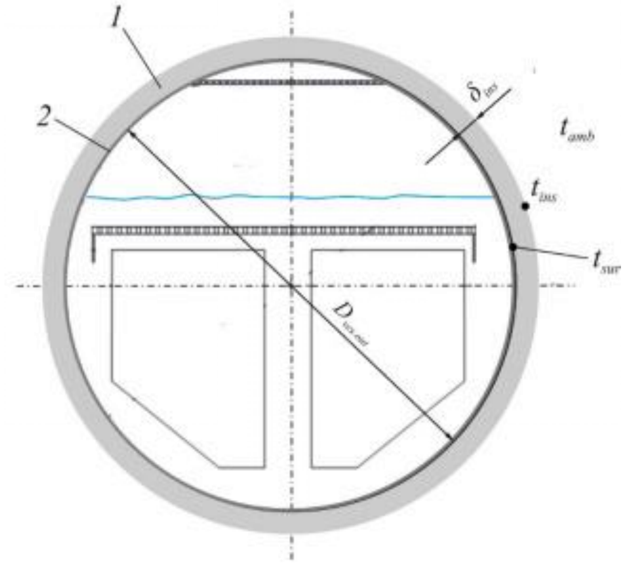


Figure 5.10- Design of single-layer thermal-insulation with a coating layer

- for insulated surfaces located in closed rooms 45 °C;

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

$$\delta_{ins} = \frac{0.0689 \cdot (284.7 - 45)}{7 \cdot (45 - 24)} = 0.112 \text{ m}.$$

Where:

- $\delta_{ins}$is the thickness of the insulation layer, m;
- d_{ins} is outer diameter of insulation, m;
- $d_{out} = D_{ves.out} = D_{ves.in} + (2 \cdot \delta_{vss}) = 4.57 + (2 \cdot 0.1) = 4.77$ m;
- is diameter of the external insulated object, m;
- $\delta_{vss} = 0.1$ m is the central shell's wall thickness of the steam generator vessel, m;
- $t_{sur} = t_s$= 284.7 °C is surface temperature of the insulated object, °C;
- in practical calculations, an equal temperature of the medium (coolant);
- $t_{amb} = 20 \ldots 25$ °C,
- $\alpha_{out} = 6 \ldots 10 \ {}^{W}\!/_{(m^2 \cdot k)}$;
- α_{out} is the coefficient of heat transfer from the insulation surface to the surrounding air;
- λ_{ins} is coefficient of thermal conductivity of the insulation layer, ${}^{W}\!/_{(m \cdot K)}$. It determined by the formula:

$$\lambda_{ins} = 0.0002 \cdot t_{ins}^{avr} + 0.036 \,;$$

$$\lambda_{ins} = 0{,}0002 \cdot (164.8 + 0.036) = 0.0689 \ {}^{W}\!/_{(m \cdot K)} \,;$$

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

$$t_{ins}^{avr} = 0{,}5 \cdot (284.7 + 45) = 164.8 \text{ °C} \,.$$

Section 6: Calculation of WWER Reactor

Initial data

Prototype - heterogeneous thermal reactor: WWER- 870

Table 6.1-Initial data of WWER-870 reactor

Thermal power	2676 MW
Specific power intensity of the core	105 MW / m^3
Fuel material	UO_2
Fuel enrichment (by 235U)	4.5 %.
Moderate	water
Coolant	water
Coolant parameters	
pressure of the coolant at the inlet to the core	16.56 MPa
the temperature of the coolant at the inlet of the core	299.7 ºC
the temperature of the coolant at the outlet of the core.	329.7 ºC

Characteristics of fuel assembly:

The initial data missing for the calculation should be taken according to the characteristics of the prototype.

Table 6.2-Main characteristics of FA.

№	Feature name. unit	Denomination	Prototype WWER
1	Type of FA		Triangular
2	The size of the key. mm	h_{sk}	need to calculate
4	Lattice (grid) pitch (absolute). mm	s	12.75
5	Pitch-to-diameter ratio (relative pitch (spacing))	$\frac{s}{d_{clad}}$	need to calculate
6	Total number of rods. pc.	n_r	331
7	- number of fuel rods. pc.	n_{fuel}	need to calculate
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
16	Outer diameter of fuel pellets (tablets). mm	d_{fp}	need to calculate
17	Diameter of the hole in the fuel pellet. mm	d_0	1.4
18	Material of the fuel cladding		Zr+1% Nb
19	Material of the fuel pellets		UO_2
20	Gas inside the fuel rod		helium

6.1 Thermal Calculation of Reactor

6.1.1 **Geometric Dimensions of The Fuel Assembly**

The size of the key

Table 6.3-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

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

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

The size of the key, m

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

$$h_{sk} = \frac{\sqrt{3}}{2} \cdot 267.75 + 12.75 = 244.62\ \text{mm}\ .$$

Pitch-to-diameter ratio (relative pitch (spacing))

$$s_{rel} = \frac{s}{d_{clad}}\ ;$$

$$s_{rel} = \frac{12.75}{9.1} = 1.401\ .$$

Number of fuel rods, pc

$$\mathrm{n_{fuel}} = n_r - n_{cr} - n_{c.tube}\ ;$$

$$n_{fuel} = 331 - 12 - 1 = 318\ .$$

Outer diameter of fuel pellets (tablets), mm

$$\mathrm{d_{fp}} = \mathrm{d_{clad}} - 2\delta_{\mathrm{clad}} - 2\delta_{\mathrm{gg}}\ ;$$

$$\mathrm{d_{fp}} = 9.1 - 2 \cdot 0.65 - 2 \cdot 0.1 = 7.6\ \text{mm}.$$

6.1.2 **Cell area, m^2 Triangular fuel assembly**

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

$$\mathrm{f_{ca}} = 6 \cdot \sqrt{\frac{1}{3} \cdot \left(\frac{244.62 \cdot 10^{-3}}{2}\right)^2} = 0.0518\ \text{m}\ .$$

6.1.3 **Cell flow section (clear area) of a fuel assembly, m²**

$$\mathrm{f_{col1}} = \mathrm{f_{ca}} - \frac{\pi}{4} \cdot \left(\mathrm{n_{fuel}} \cdot \mathrm{d_{clad}^2} + \mathrm{n_{cr}} \cdot \mathrm{d_{cr.tube}^2} + \mathrm{n_{c.tube}} \cdot \mathrm{d_{c.tube}^2}\right)\ .$$

Where:

- n_{fuel} is number of fuel rods. pc;
- n_{cr} is - number of control rods. pc;
- $n_{c.tube}$ is number of central tubes. pc;
- d_{clad} is the outer diameter of the fuel cladding. m;
- $d_{cr.tube}$ is the outer diameter of the tube for the control rod. m;
- $d_{c.tube}$ is outer diameter of the central tube. m.

$$f_{col1} = 0.0518 - \frac{\pi}{4}(318 \cdot (9.1 \cdot 10^{-3})^2 + 12 \cdot (12.6 \cdot 10^{-3})^2 + 1 \cdot (13.3 \cdot 10^{-3})^2);$$

$$f_{col1} = 0.029 \text{ m}.$$

6.1.4 **Geometric dimensions of the core**

The volume of the reactor core. m³

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

Where:

- Q_r is thermal power of reactor, MW;
- q_v - is volumetric heat release in the core, MW/m³;

$$V_{core} = \frac{2676}{105} = 25.48 \text{ m}^3.$$

6.1.5 **Coolant saturation temperature t_{s1} as a function of pressure p_{col}**

$$t_{s1} = f(p_{col}) = 350.1\ ℃.$$

6.1.6 **Outlet temperature °C**

$$t_{out} = 329.7\ ℃.$$

6.1.7 **Inlet temperature °C**

$$t_{in} = 299.7\ ℃.$$

6.1.8 **Coolant flow through the reactor (from the heat balance equation) kg/s**

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

Where:

- Q_r in kW;
- $h_{in} = f(p_{col}.\ t_{in})$ and $h_{out} = f(p_{col}.\ t_{out})$ are enthalpy of coolant at the reactor inlet and outlet. kJ / kg;

$$h_{out} = (16.56\ .329.7) = 1512\ \frac{kj}{kg};$$

$$h_{in}(16.56\ .\ 299.7\ ) = 1335\ \frac{kj}{kg};$$

$$G_1 = \frac{2676 \cdot 10^3}{(1512 - 1335)} = 15.11 \cdot 10^3\ \frac{kg}{s}.$$

6.1.9 **Cross-sectional area of reactor core for coolant passage (from continuity equation) m²**

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

Where:

- w_{col} is the average velocity of the coolant in the reactor core. m/s;
- $\bar{\rho}_{col}$ is the average density of the coolant in the reactor. kg / m3. Find the pressure p_{col} and the average temperature $\bar{t}_{col}$ of the coolant.

$$F_{csa} = \frac{15.11 \cdot 10^3}{5 \cdot 696.2} = 4.34 \text{ m}^2.$$

6.1.10 **The number of fuel assemblies**

Where:

- f_{col1} is cell flow section (clear area) of a fuel assembly, m².

$$n_{fa} = \frac{F_{csa}}{f_{col1}} \ ;$$

$$n_{fa} = \frac{4.34}{0.029} = 147 \ .$$

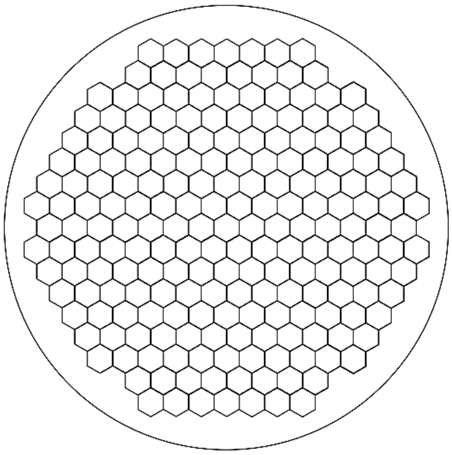


Figure 6.1- An image of the FA configuration in the VVER reactor.

6.1.11 **Cross-sectional area of the core, m²;**

$$F_{core} = 1.05 \cdot n_{fa} \cdot f_{ca} \ .$$

Where:

- f_{ca} is cell area, m²;

$$F_{core} = 1.05 \cdot 147 \cdot 0.0518 = 8 \ m^2 \ .$$

6.1.12 **Diameter of the core (from geometric equality), m**

$$S_{core} = \frac{\pi \cdot D_0^2}{4} = F_{core} = 1.05 \cdot n_{fa} \cdot f_{ca} \ ;$$

$$8 = \frac{\pi \cdot D_0^2}{4} \ ;$$

$$D_0^2 = \frac{8 \cdot 4}{\pi} \ ;$$

$$D_0 = 3.19 \ m \ .$$

6.1.13 **Height of cylindrical core, m**

$$H_0 = (0.9 \ldots 1.1) \cdot D_0 \ ;$$

$$H_0 = 1 \cdot 3.19 = 3.19 \ m \ .$$

6.1.14 **Effective height of the core**

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

$$H_{eff} = 3.19 + 2 \cdot 0.1 = 3.39 \ m \ .$$

6.1.15 **Control calculation of the core volume**

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

$$V_{core}^{con} = \frac{\pi \cdot (3.19)^2}{4} \cdot 3.19 = 25.55 \ m^3 \ .$$

6.1.16 **Check Relative error should be less than 3%;**

$$\delta = \left|\frac{V_{core}^{con} - V_{core}}{V_{core}}\right| \leq 0.03\,;$$

$$\delta = \left|\frac{25.55 - 25.48}{25.48}\right| \cdot 100 = 0.26\,\%\,.$$

6.1.17 **Calculation of fuel rod with maximum power**

The distribution of coolant parameters along the height of the fuel rod

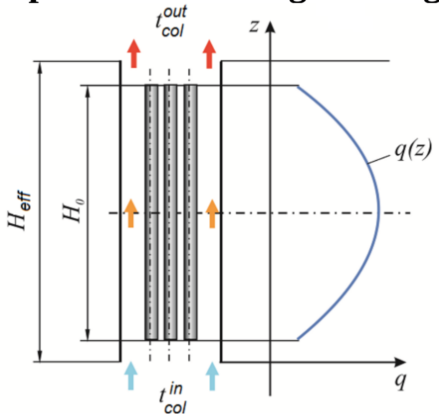


Figure 6.2-The distribution of coolant parameters along the height of the fuel rod.

6.1.18 **The average linear heat flux $\bar{q}_l$ by 1 m fuel element, kW/m (fuel)**

$$\bar{q}_l = \frac{10^3 \cdot Q_r}{H_0 \cdot n_{fa} \cdot n_{fuel}}\,;$$

$$\bar{q}_l = \frac{10^3 \cdot 2676}{3.19 \cdot 147 \cdot 318} = 17.9\,{}^{kw}/_{m}\,.$$

6.1.19 **Axial nuclear peaking factor**

$$k_z = \frac{\pi \cdot H_0}{2 \cdot H_{eff} \cdot \sin\left(\frac{\pi \cdot H_0}{2 \cdot H_{eff}}\right)}\,;$$

$$k_z = \frac{\pi \cdot 3.19}{2 \cdot 3.39 \cdot \sin(\frac{\pi}{2} \cdot \frac{3.19}{3.39})} = 1.48\,.$$

- Radial nuclear peaking factor, $k_r = 1.3$.

6.1.20 **Linear heat flux in the central plane of the reactor for fuel rod with maximum power. kW/m (fuel);**

$$q_{i0} = \bar{q}_l \cdot k_r \cdot k_z\,;$$

$$q_{l0} = 17.9 \cdot 1.48 \cdot 1.3 = 34.5\,{}^{kw}/_{m}\,.$$

6.1.21 **The flow rate of the coolant per fuel rod with maximum power kg/s;**

$$g_M = \frac{G_1}{n_{fa} \cdot n_{fuel}}\,;$$

$$g_M = \frac{15.11 \cdot 10^3}{147 \cdot 318} = 0.323\,\frac{kg}{s}\,.$$

The reactor core (fuel rods) is divided by height into 6 sections and at the boundaries of the sections (7 points in total) determine the linear heat flux kW/m;

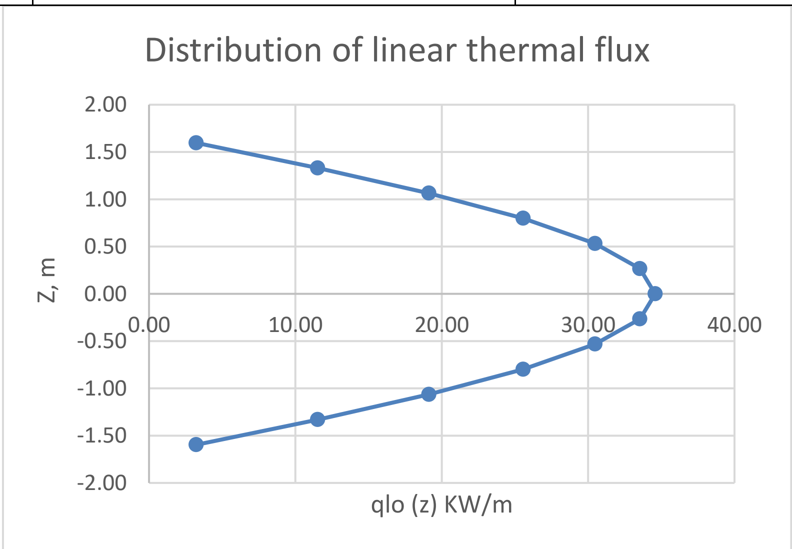
$$q_l(z) = q_{l_0} \cdot \cos\left(\frac{\pi \cdot z}{H_{eff}}\right).$$

z is the value of the coordinate height. m. Varies in the range from to $z = -\frac{H_0}{2}$ to $z = +\frac{H_0}{2}$;

$$Z = \frac{\frac{3.19}{2}}{6} = 0.266\,.$$

Table 6.4-Distribution of linear thermal flux

NO	Z, m	$q_{l0}(z)$, KW/m
1	-1.60	3.22
2	-1.33	11.52
3	-1.06	19.12
4	-0.80	25.57
5	-0.53	30.47
6	-0.27	33.54
7	0.00	34.58
8	0.27	33.54
9	0.53	30.47
10	0.80	25.57
11	1.06	19.12
12	1.33	11.52
13	1.60	3.22



Graph 6.1- Distribution of linear thermal flux.

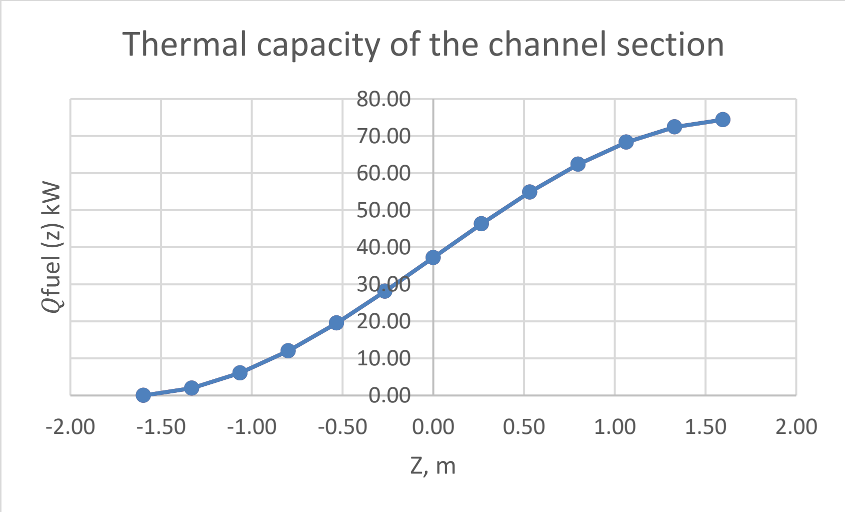
Thermal power of the fuel element from the entrance to the reactor core to each coordinate value Z

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

Table 6.5-Distribution of thermal capacity

NO	Z, m	$Q_{fuel}(z)$. kW
1	-1.60	0.00
2	-1.33	1.97

3	-1.06	6.07
4	-0.80	12.04
5	-0.53	19.54
6	-0.27	28.10
7	0.00	37.20
8	0.27	46.31
9	0.53	54.87
10	0.80	62.36
11	1.06	68.34
12	1.33	72.44
13	1.60	74.41



Graph 6.2- Thermal capacity of the channel section

Coolant enthalpy h(z) for each value of the coordinate z from the equation of heat balance

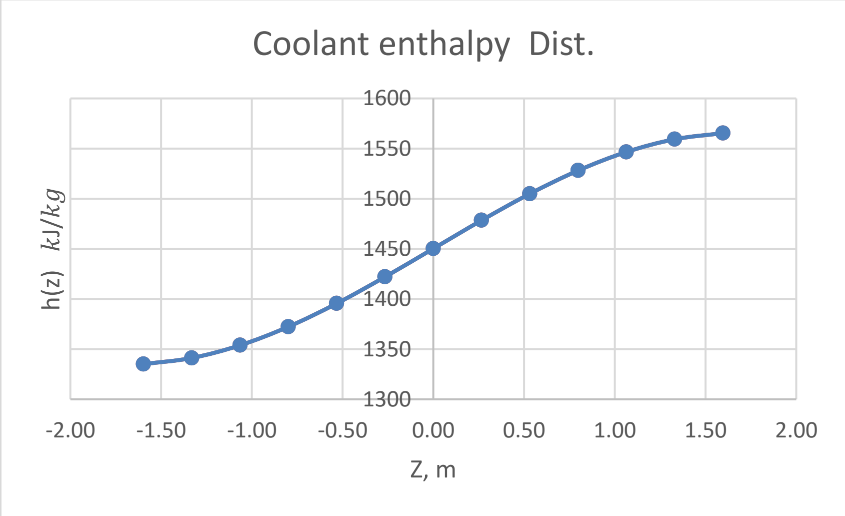
$$Q_{FA}(z) = G_{cool} \cdot [h(z) - h_{in}]\,;$$

$$[h(z)] = \frac{Q_{FA}(z)}{G_{cool}} + h_{in}\,.$$

Table 6.6-Enthalpy of the coolant at each(z)

NO	Z, m	$h(z).\frac{kJ}{kg}$
1	-1.60	1335
2	-1.33	1341
3	-1.06	1354
4	-0.80	1372
5	-0.53	1396
6	-0.27	1422
7	0.00	1450
8	0.27	1478
9	0.53	1505
10	0.80	1528

11	1.06	1547
12	1.33	1559
13	1.60	1565



Graph 6.3- Coolant enthalpy Dist.

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

$$x(z) = \frac{h(z) - h'}{h'' - h'} ;$$

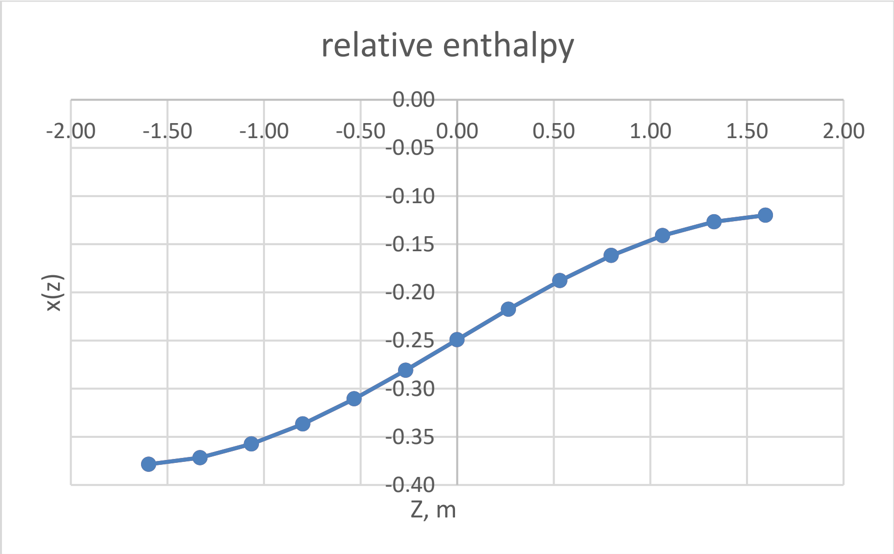
$$h'' = f(p_{in}. x = 1) = 2580.8 \text{ kj/kg} ;$$

$$h' = f(p_{in}. x = 0) = 1649.67 \text{ kj/kg} .$$

$h''. h'$ are enthalpies of steam and water at saturation point under pressurep_{col}^{in}.

Table 6.7-Relative enthalpy of the coolant at each (z).

NO	Z, m	$h(z).\frac{kj}{kg}$	x(z)
1	-1.60	1335	-0.38
2	-1.33	1341	-0.37
3	-1.06	1354	-0.36
4	-0.80	1372	-0.34
5	-0.53	1396	-0.31
6	-0.27	1422	-0.28
7	0.00	1450	-0.25
8	0.27	1478	-0.22
9	0.53	1505	-0.19
10	0.80	1528	-0.16
11	1.06	1547	-0.14
12	1.33	1559	-0.13
13	1.60	1565	-0.12



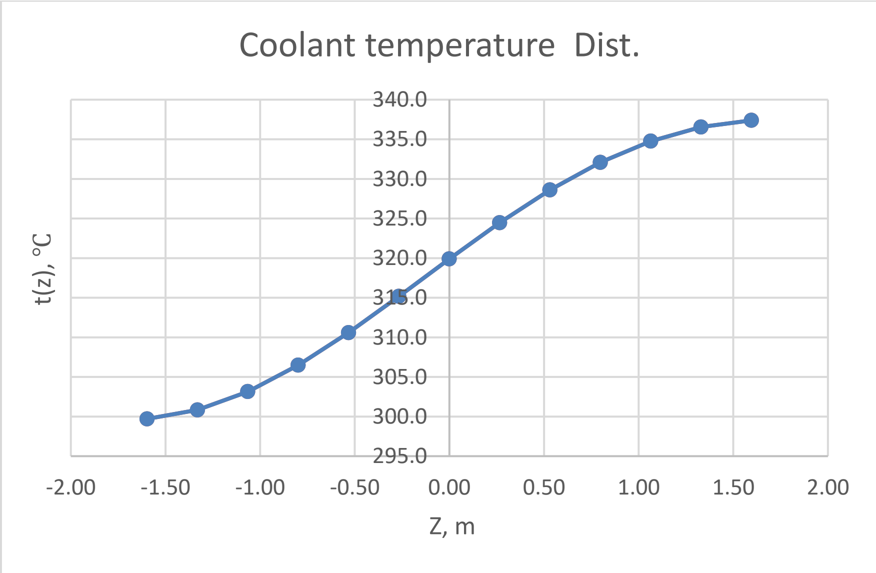
Graph 6.4- relative enthalpy Dist.

Coolant temperature $t(z)$ for each coordinate value z as a function of enthalpy $h(z)$ and pressure

$$t(z) = f\left(p_{col}.h(z)\right).$$

Table 6.8-Coolant temperature.

NO	Z, m	$h(z).\frac{kj}{kg}$	$t(z)\,.\,℃$
1	-1.60	1335	299.7
2	-1.33	1341	300.8
3	-1.06	1354	303.2
4	-0.80	1372	306.5
5	-0.53	1396	310.6
6	-0.27	1422	315.2
7	0.00	1450	319.9
8	0.27	1478	324.5
9	0.53	1505	328.6
10	0.80	1528	332.1
11	1.06	1547	334.8
12	1.33	1559	336.6
13	1.60	1565	337.4



Graph 6.5-Coolant temperature Dist.

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

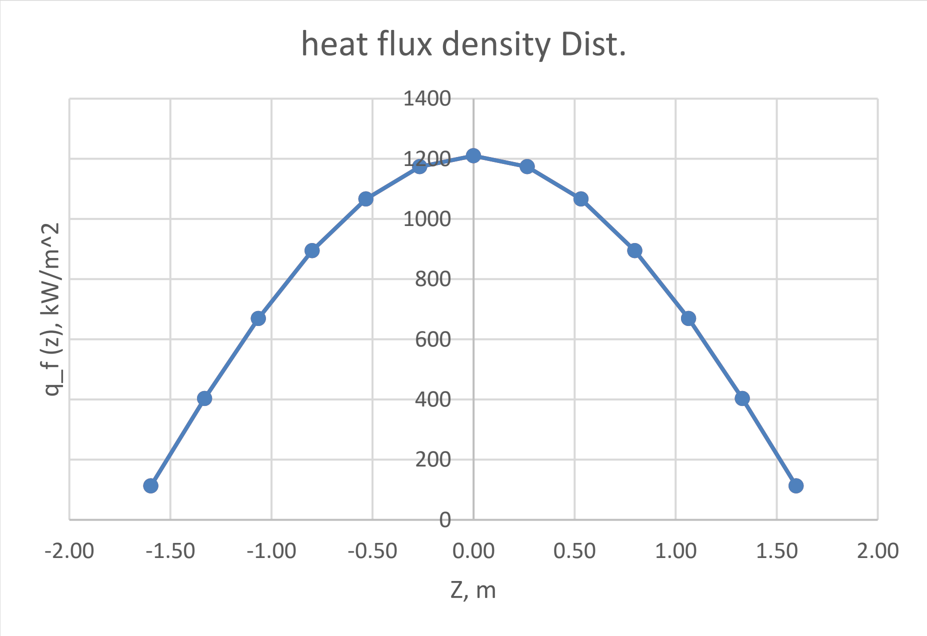
$$q_f(z)\cdot d_{fr}\cdot H_0\cdot n_{fr} = q_l(z)\cdot H_0\cdot n_{fr};$$

$$q_f(z) = \frac{q_l(z)}{\pi\cdot d_{fr}};$$

- d_{clad} is the outer diameter of the fuel cladding. d_{fr} = 9.1 mm

Table 6.9-heat flux density $q_f(z)$.

NO	Z, m	$q_l(z)$. KW/m	$q_f(z)$. kW/m^2
1	-1.60	3.22	113
2	-1.33	11.52	403
3	-1.06	19.12	669
4	-0.80	25.57	895
5	-0.53	30.47	1066
6	-0.27	33.54	1174
7	0.00	34.58	1210
8	0.27	33.54	1174
9	0.53	30.47	1066
10	0.80	25.57	895
11	1.06	19.12	669
12	1.33	11.52	403
13	1.60	3.22	113



Graph 6.6- heat flux density Dist.

The calculation results must be entered in the table

Table 6.10-The results of calculations.

NO	Z, m	$q_l(z)$. KW/m	$Q_{fuel}(z)$ kW	$[h(z)].\frac{kj}{kg}$	x(z)	t(z). °C	$q_f(z)$. kW/m^2
1	-1.60	3.22	0.00	1335	-0.38	299.7	113
2	-1.33	11.52	1.97	1341	-0.37	300.8	403
3	-1.06	19.12	6.07	1354	-0.36	303.2	669
4	-0.80	25.57	12.04	1372	-0.34	306.5	895
5	-0.53	30.47	19.54	1396	-0.31	310.6	1066
6	-0.27	33.54	28.10	1422	-0.28	315.2	1174
7	0.00	34.58	37.20	1450	-0.25	319.9	1210
8	0.27	33.54	46.31	1478	-0.22	324.5	1174
9	0.53	30.47	54.87	1505	-0.19	328.6	1066
10	0.80	25.57	62.36	1528	-0.16	332.1	895
11	1.06	19.12	68.34	1547	-0.14	334.8	669
12	1.33	11.52	72.44	1559	-0.13	336.6	403
13	1.60	3.22	74.41	1565	-0.12	337.4	113

6.1.22 **Critical heat flow and reserve before the heat exchange crisis in the central plane of the reactor (at z=0)**

Critical heat flow, MW/m²

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

Where:

- ρ is coolant pressure. MPa;
- x is relative enthalpy of the coolant;
- (ρw)Is mass velocity. kg/(m²·s). Can be calculated from the parameters at the reactor inlet.

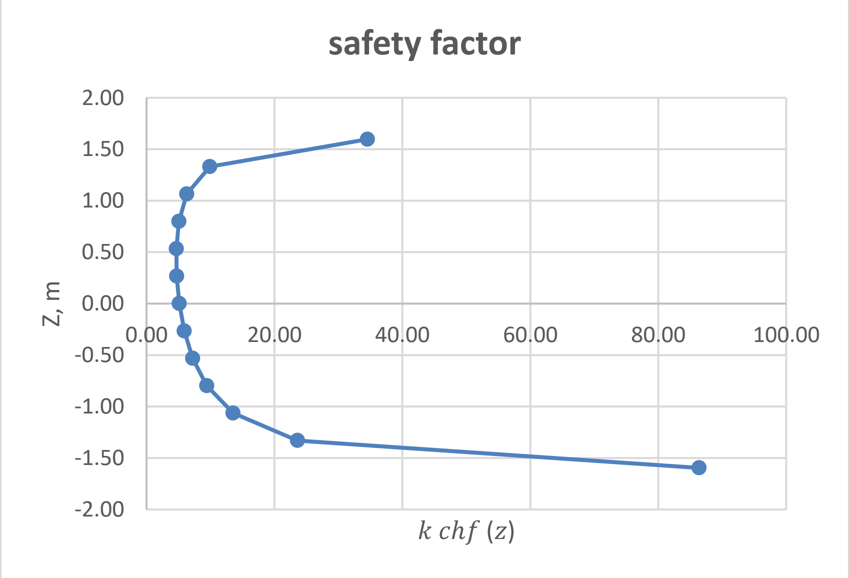
$$(\rho w) = w_{in} \cdot \rho_{in} = 730.7 \cdot 5 = 3646\,;$$
$$m = 0.311 \cdot (1 - x) - 0.127\,;$$
$$m = 0.311 \cdot \big(1 - (-0.25)\big) - 0.127 = 0.26\,;$$
$$n = 0.105 \cdot p - 0.5\,;$$
$$n = 0.105 \cdot 16 - 0.5 = 1.23\,.$$

Critical heat flux ratio (calculate the safety factor)

$$K_{chf}\,(z) = \frac{q_{cr}(z)}{q_f(z)}\,.$$

Table 6.11-The results of calculations.

No	Z, m	$qf(z).\,kW/m^2$	$q_{cr}(z)\,.\,MW/m^2$	$k_{chf}(z)$
1	-1.60	113	9.75	86.40
2	-1.33	403	9.52	23.61
3	-1.06	669	9.06	13.54
4	-0.80	895	8.43	9.42
5	-0.53	1066	7.70	7.22
6	-0.27	1174	6.94	5.91
7	0.00	1210	6.20	5.13
8	0.27	1174	5.54	4.72
9	0.53	1066	4.98	4.67
10	0.80	895	4.54	5.07
11	1.06	669	4.21	6.29
12	1.33	403	3.99	9.91
13	1.60	113	3.90	34.54



Graph 6.7- the safety factor along the height of the reactor core.

6.1.23 **Temperature of fuel elements (cladding) in the central plane of the reactor (at z=0)**

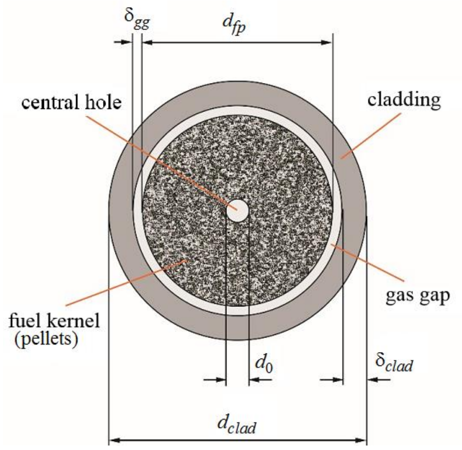


Figure 6.3-Fuel rods cross section of conventional traditional design.

6.1.24 **Hydraulic diameter for infinite bundle array fuel rods**

for triangular fuel assembly:

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

$$d_h = 9.1 \cdot \left(\frac{2 \cdot \sqrt{3} \cdot (1.401)^2}{\pi} - 1 \right) = 10.60 \text{ mm} = 0.0106 \text{ m} .$$

Where:

- $s_{rel} = \frac{s}{d_{clad}}$ is relative pitch (spacing);
- s is lattice (grid) pitch (absolute). m;
- d_{clad} is the outer diameter of the fuel cladding. m.

6.1.25 **Thermophysical characteristics of the coolant in the central plane of the reactor**

- the Prandtl number Pr;
- kinematic viscosity ν. m²/s;
- thermal conductivity λ. W/(m·K) ;
- Define as a function of pressure p_{col} and temperature t (at z=0);

$$\text{from } f(p_0.t_0 \text{ at } z = 0) ;$$
$$pr = 0.94 ;$$
$$v = 1.19 \cdot 10^{-7}\, m^2/s ;$$
$$\lambda = 0.52 \frac{W}{m \cdot K} .$$

Table 6.12-characteristics of the coolant.

NO	Z, m	t(z) . ℃	ρ. kg/ m^3	v . m^2/s	λ W/(m. K)	Pr
1	-1.60	299.7	729.1	$1.22\cdot 10^{-7}$	0.5624	0.8571
2	-1.33	300.8	726.8	$1.22\cdot 10^{-7}$	0.5604	0.8601
3	-1.06	303.2	722.0	$1.21\cdot 10^{-7}$	0.556	0.8670
4	-0.80	306.5	714.9	$1.21\cdot 10^{-7}$	0.5497	0.8779
5	-0.53	310.6	705.8	$1.20\cdot 10^{-7}$	0.5416	0.8937
6	-0.27	315.2	695.1	$1.19\cdot 10^{-7}$	0.5321	0.9147
7	0.00	319.9	683.4	$1.19\cdot 10^{-7}$	0.5219	0.9411
8	0.27	324.5	671.3	$1.18\cdot 10^{-7}$	0.5113	0.9726
9	0.53	328.6	659.6	$1.17\cdot 10^{-7}$	0.5012	1.0077
10	0.80	332.1	649.0	$1.17\cdot 10^{-7}$	0.4922	1.0438
11	1.06	334.8	640.3	$1.16\cdot 10^{-7}$	0.4849	1.0770
12	1.33	336.6	634.2	$1.16\cdot 10^{-7}$	0.4799	1.1026
13	1.60	337.4	631.2	$1.16\cdot 10^{-7}$	0.4776	1.1158

The velocity of the coolant for the fuel rod with maximum power, m/s;
Where:

- w_{col} is the average velocity of the coolant in the reactor core, m/s.

If FA is jacketless.

$$w_{col}^{max} = w_{col}\ ;$$

$$w_{col}^{max} = w_{col} = 5\ \frac{m}{s}.$$

The Reynolds Criterion

$$Re = \frac{w_{col}^{max_h}}{\nu}.$$

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

$$Nu = A_1 \cdot\ Re^{0.8}\ \cdot Pr^{0.4}\ ;$$

here $A_1 = 0.0165 + 0.02 \cdot \left(1 - \frac{0.91}{s_{rel}^2}\right) \cdot s_{rel}^{0.15}\ ;\ A_1 = 0.0267$.

Heat transfer coefficient, W/(m²·K);

$$\alpha = \frac{Nu \cdot \lambda}{d_h}.$$

Table 6.13-Heat transfer properties.

NO	Z, m	Re(z)	Nu(z)	$\alpha(z). W/(m^2 \cdot K)$
1	-1.60	434394	814	43173
2	-1.33	435107	817	43138
3	-1.06	436899	822	43076
4	-0.80	439069	829	42973
5	-0.53	441628	839	42841
6	-0.27	444590	851	42710

7	0.00	447214	865	42571
8	0.27	449869	881	42459
9	0.53	452170	897	42387
10	0.80	454106	913	42362
11	1.06	455666	927	42376
12	1.33	456451	937	42393
13	1.60	456844	942	42420

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

$$t_{clad}^{out} = t + \frac{q_{l0}}{\pi \cdot d_{clad} \cdot \alpha}.$$

Where:

- q_{l0} is linear heat flux in the central plane of the reactor for fuel rod with maximum power. W/m (fuel);
- d_{clad} is the outer diameter of the fuel cladding. M;

Important! The maximum temperature of the outer surface of the fuel cladding t_{clad}^{out} should not exceed the maximum for zirconium alloys in the water coolant (360 ... 365 ° C**).**

Table 6.14-The results of outer temperature of cladding over the values of z.

No.	Z, m	$q_{l0}, \frac{Kw}{m}$	$\alpha, W/(m^2 \cdot K)$	t_{clad}^{out}, °C
1	-1.60	3.22	43173	302.3
2	-1.33	11.52	43138	310.2
3	-1.06	19.12	43076	318.7
4	-0.80	25.57	42973	327.3
5	-0.53	30.47	42841	335.5
6	-0.27	33.54	42710	342.7
7	0.00	34.58	42571	348.3
8	0.27	33.54	42459	352.1
9	0.53	30.47	42387	353.8
10	0.80	25.57	42362	353.2
11	1.06	19.12	42376	350.6
12	1.33	11.52	42393	346.1
13	1.60	3.22	42420	340.1

The temperature of the inner surface of the cladding of a fuel rod, ºC;

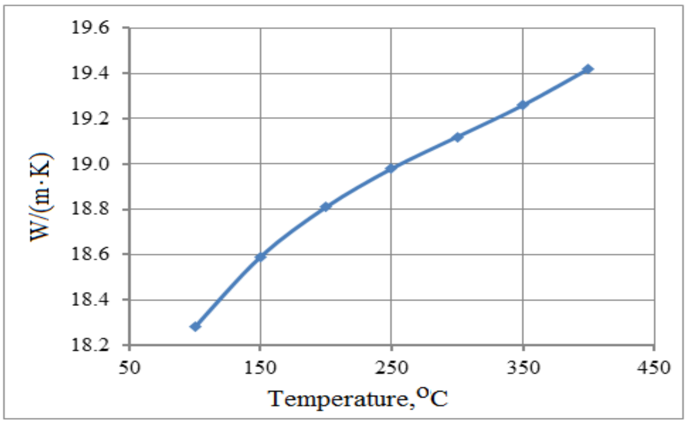
$$t_{clad}^{in} = t_{clad}^{out} + \frac{0.94 \cdot q_{l0}}{\pi \cdot \bar{d}_{clad}} \cdot \frac{\delta_{clad}}{\lambda_{clad}}.$$

Where:

- $\bar{d}_{clad} = d_{clad} - \delta_{clad}$ is average cladding diameter. m;

$$\bar{d}_{clad} = d_{clad} - \delta_{clad} = 9.1 - 0.65 = 8.45\ mm = 0.00845\ m.$$

λ_{clad} is thermal conductivity of the cladding material. W/(m·K). Determine by fig 8.



Graph 6.8- The dependence of thermal conductivity of zirconium alloy on temperature.

Table 6.15-The results of inner temperature of cladding over the values of z

No.	Z, m	$ql0\,.\frac{Kw}{m}$	$\alpha.W/(m^2 \cdot K)$	$t_{clad}^{out}.\,°C$	$t_{clad}^{in}.\,°C$
1	-1.60	3.22	43173	302.3	306.2
2	-1.33	11.52	43138	310.2	324.0
3	-1.06	19.12	43076	318.7	341.6
4	-0.80	25.57	42973	327.3	357.9
5	-0.53	30.47	42841	335.5	372.0
6	-0.27	33.54	42710	342.7	382.8
7	0.00	34.58	42571	348.3	389.7
8	0.27	33.54	42459	352.1	392.3
9	0.53	30.47	42387	353.8	390.2
10	0.80	25.57	42362	353.2	383.8
11	1.06	19.12	42376	350.6	373.4
12	1.33	11.52	42393	346.1	359.8
13	1.60	3.22	42420	340.1	343.9

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

$$t_{fp}^{out} = t_{clad}^{in}(z) + \frac{0.94 \cdot q_{l0}}{\pi \cdot \bar{d}_{gg} \cdot \alpha_{gg}} \;;$$

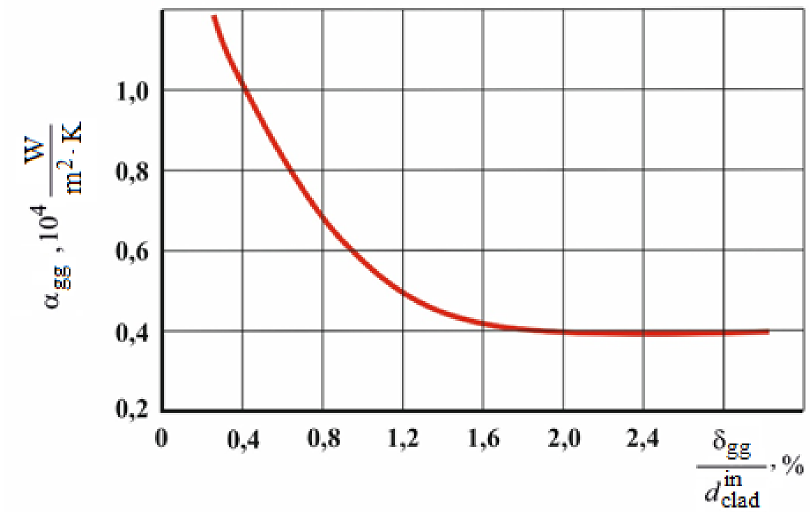
Where:

- α_{gg} is conductivity of the gas gap (contact layer cladding-fuel pellets), W/(m²·K).

Determined according to (graph 9).

$\bar{d}_{gg} = d_{clad}^{in} - \delta_{gg}$ is average gas gap diameter, m;

$$\bar{d}_{gg} = d_{clad}^{in} - \delta_{gg} = 7.6 - 0.1 = 7.5\ \text{mm}\,.$$



Graph 6.9- 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.

Because $\frac{\delta_{gg}}{d^{in}_{cl}} = 1.3$ % , we will take $\alpha_{gg} = 4500 \frac{W}{(m^2 \cdot k)}$.

Table 6.16-The results of temperature of surface of fuel pellet over the values of z.

No.	Z, m	$ql0. \frac{Kw}{m}$	$\alpha. W/(m^2 \cdot K)$	t^{in}_{clad} . °C	t^{out}_{fp}. °C
1	-1.60	3.22	43173	306.2	334.8
2	-1.33	11.52	43138	324.0	426.1
3	-1.06	19.12	43076	341.6	511.2
4	-0.80	25.57	42973	357.9	584.7
5	-0.53	30.47	42841	372.0	642.2
6	-0.27	33.54	42710	382.8	680.3
7	0.00	34.58	42571	389.7	696.5
8	0.27	33.54	42459	392.3	689.7
9	0.53	30.47	42387	390.2	660.5
10	0.80	25.57	42362	383.8	610.6
11	1.06	19.12	42376	373.4	543.0
12	1.33	11.52	42393	359.8	462.0
13	1.60	3.22	42420	343.9	372.5

Temperature in the center of the fuel pellets or on the surface of the central hole of the core

$$t_0 = t^{out}_{fp} + \frac{0.94 \cdot q_{l0}}{4 \cdot \pi \cdot \lambda_{fp}} \cdot \left(1 - \frac{2 \cdot d_0^2}{d_{fp}^2 - d_0^2} \cdot \ln \frac{d_{fp}}{d_0}\right);$$

$$\lambda_{fp} = 0.942 \cdot 10^{-10} \cdot \left(\overline{T}_{fp}\right)^3 + \frac{5500}{\left(500 + \overline{T}_{fp}\right)};$$

$$\overline{T}_{fp} = t^{out}_{fp} + 273.15 = 691.9 + 273.15 = 952.75 \text{ K};$$

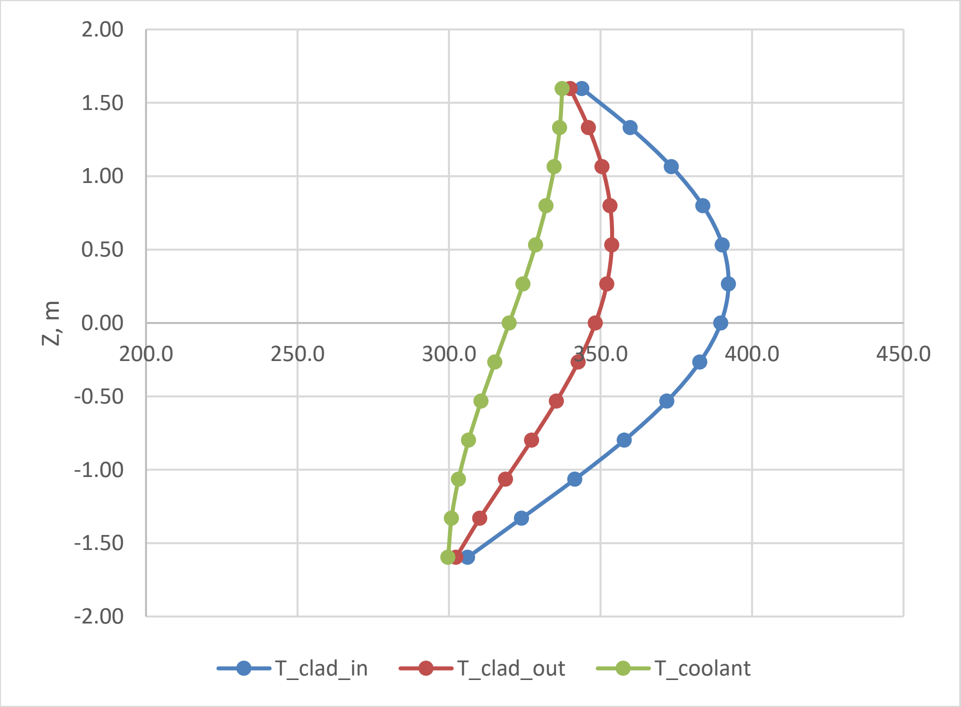
- calculate the coefficient λ_{fp} and temperature t_0 ;
- specify the average temperature of the fuel pellets;

- The iterative calculation ends when the temperature value t_0 in this step differs from the corresponding value t_0 in the previous step by less than3 %;
- Important! The maximum temperature of the fuel core shall not exceed the maximum permissible temperature for ceramic fuel (2600 °C).

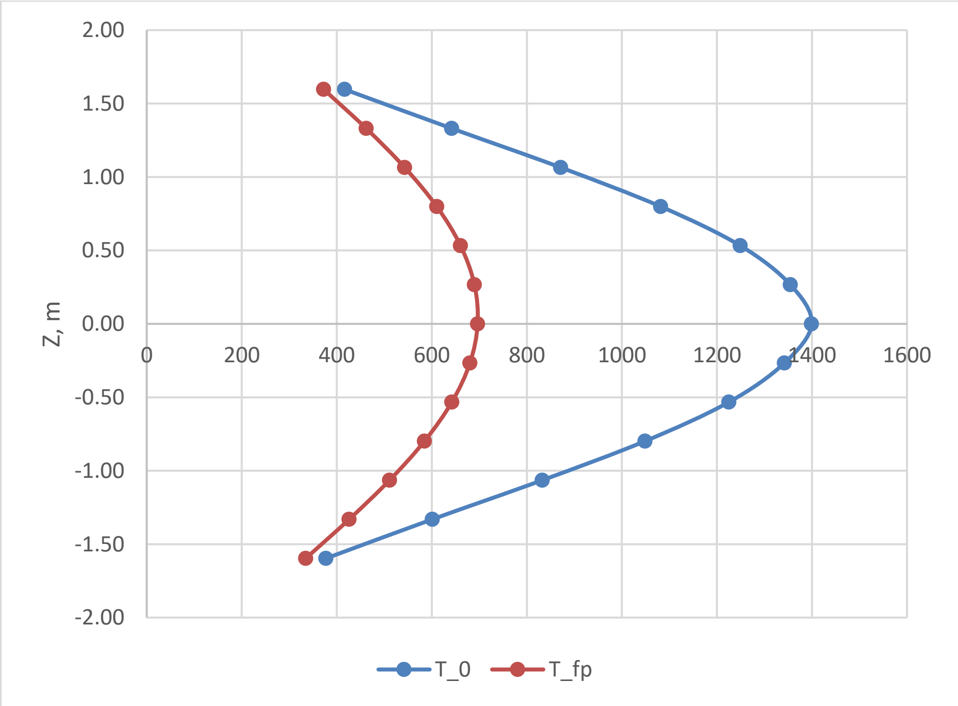
$$\mathrm{Iteration(n)} = \frac{1393 - 1380.7}{1393} \cdot 100 = 0.9\ \%\ .$$

Table 6.17-The results of the maximum temperature of fuel pellet over the values of z.

No.	Z	t_0. °C	t_{fP} . °C	λ_{fp}
1	-1.60	378	630	4.892
2	-1.33	602	787	4.320
3	-1.06	836	945	3.886
4	-0.80	1055	1090	3.581
5	-0.53	1235	1207	3.388
6	-0.27	1354	1284	3.282
7	0.00	1399	1315	3.245
8	0.27	1366	1295	3.268
9	0.53	1259	1228	3.357
10	0.80	1088	1119	3.528
11	1.06	874	980	3.804
12	1.33	643	825	4.203
13	1.60	417	668	4.737



Graph 6.10- The Distribution of $t(z).\ t_{cl}^{in}$ *and* t_{cl}^{out} *along the height of the reactor core.*



Graph 6.11- The Distribution of t_0 and t_{fp} along the height of the reactor core.

6.2 Hydraulic calculation of the reactor

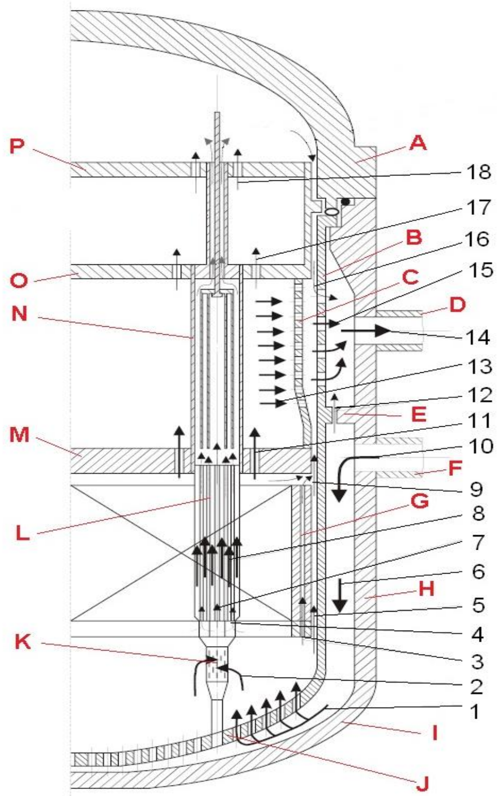


Figure 6.4- Coolant circulation diagram in a VVER reactor

6.2.1 **The diameter of the pipes for inlet and outlet of the coolant $d_{pip.in}$.**

We define from the continuity equation

$$\frac{\pi \cdot d_{pip.in}^2}{4} \cdot w_{pip} \cdot 2 \cdot n_{loop} = \frac{G_1}{\rho_{avr}};$$

$$d_{pip.in} = \sqrt{\frac{G_1 \cdot 4}{\rho_{avr} \cdot w_{pip} \cdot 2 \cdot n_{loop} \cdot \pi}} = \sqrt{\frac{15.11 \cdot 10^3 \cdot 4}{696.2 \cdot 10 \cdot 2 \cdot 4 \cdot \pi}} = 0.5879 \text{ m.}$$

Where:

- G_1 is the mass flow rate of the coolant. kg/s;
- w_{pip}=10…12 m/s is coolant velocity in pipes for inlet and outlet of the coolant;
- n_{loop} is number of loops;
- $\rho_{avr} = f(p_{col}.\ t_{avr})$ is the average density of the coolant.

6.2.2 **The inner diameter of the reactor vessel $D_{ves.in}$.**

We define from the continuity equation

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

$$D_{ves.in} = \sqrt{\frac{G_1 \cdot 4}{\pi \cdot \rho_{in} \cdot w_{gap}} + D^2_{pit}} = \sqrt{\frac{215.11 \cdot 10^3 \cdot 4}{\pi \cdot 729.1 \cdot 6} + 3.67^2} = 4.228 \text{ m .}$$

Where:

- $D_{pit} = (1{,}1 \ldots 1{,}15) \cdot D_0$ -the outer diameter of the reactor pit (core barrel);

$$D_{pit} = 1.15 \cdot 3.19 = 3.67 \text{ m.}$$

- w_{gap}=6…8 m/s is coolant velocity in the gap reactor vessel - reactor pit.
- $\rho_{in} = f\left(p_{col}, t_{in}\right)$

We are checking. The diameter $D_{ves.in}$ should be equal to

$$D_{ves.in} = (1.1 \ldots 1.2) \cdot D_{pit} = 1.1515 \cdot 3.67 = 4.228 \text{ m.}$$

6.2.3 **Inner diameter of protective tube block shell $D_{ptb.in}$**

$$D_{ptb.in} = (1{,}0 \ldots 1{,}05) \cdot D_0$$

$$D_{ptb.in} = 1.04 \cdot D_0 = 1.04 \cdot 3.19 = 3.32 \text{ m .}$$

6.2.4 **The speed of the coolant in the protective tube block w_{ptb}**

we define from continuity equation:

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

$$w_{ptb} = \frac{G_1}{\rho_{out} \cdot \left(\frac{\pi \cdot D^2_{ptb.in}}{4} - n_{pt} \cdot \frac{\pi \cdot d^2_{pt.out}}{4}\right)} = \frac{15.11 \cdot 10^3}{656.3 \cdot \left(\frac{\pi \cdot 3.32^{\ 2}}{4} - 910 \cdot \frac{\pi \cdot 0.115^2}{4}\right)}$$
$$= 2.98 \ \frac{\text{m}}{\text{s}}.$$

where:

- $n_{pt} = n_{fa.cr}$ is number of protective tubes;
- $n_{fa.cr}$ is number of fuel assemblies having control rods. Can be adopted according to the prototype; 91 for WWER-1000);

- $d_{pt.out}$ is outer diameter of protective tube (115 mm for WWER-1000).

$$\xi_{fr} = 0.11 \cdot \left(\left(\frac{\Delta}{d_h}\right) + \left(\frac{68}{Re}\right)^{0.25}\right) \text{ where } \Delta \text{ is } 0.00002;$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{H}{d_h} \cdot \frac{\rho \cdot w^2}{2} ;$$

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

For gap between the core barrel and vessel

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

$$d_h^{gap} = 4.228 - 3.67 = 0.557 \text{ m} ;$$

$$H_{gap} \approx H_0 = 3.19 \text{ m} ;$$

$$v = v_{in} = 1.221 \cdot 10^{-7} \text{ m}^2/s;$$

$$Re_{gap} = \frac{w_{gap} \cdot d_h^{gap}}{v_{in}} = \frac{6 \cdot 0.557}{1.221 \cdot 10^{-7}} = 2.737 \cdot 10^7 .$$

For fuel assembly

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

$$d_h^{fa} = 9.1 \cdot 10^{-3} \cdot \left(\frac{2 \cdot \sqrt{3} \cdot 1.401^2}{\pi} - 1\right) = 0.0106 \text{ m};$$

$$H_{fa} \approx 1.1 \cdot H_0 = 1.1 \cdot 3.19 = 3.512 \text{ m} ;$$

$$v = v_{avg} = 1.188 \cdot 10^{-7} \text{ m}^2/s ;$$

$$Re_{FA} = \frac{w_{cool} \cdot d_h^{fa}}{v_{avg}} = \frac{5 \cdot 0.0106}{1.188 \cdot 10^{-7}} = 446.3 \cdot 10^3 ;$$

For the protective tube block

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

$$d_h^{PTb} = \frac{\left(\frac{\pi}{4}\right) \cdot \left((4.228^2) - (91 \cdot 0.115^2)\right)}{\pi \cdot \left(4.228 + (91 \cdot 0.115)\right)} = 0.283 \text{ m} ;$$

$$H_{PTB} \approx 1.5 \cdot H_0 ;$$

$$H_{PTB} = 1.5 \cdot 3.19 = 4.78 \text{ m} ;$$

$$v = v_{out} = 1.171 \cdot 10^{-7} \text{m}^2/s ;$$

$$Re_{PTB} = \frac{w_{PTB} \cdot d_h^{PTb}}{v_{out}} ;$$

$$Re_{PTB} = \frac{2.98 \cdot 0.283}{1.171 \cdot 10^{-7}} = 7.299 \cdot 10^6.$$

Table 6.18-results for ΔP_{fr} and ΔP_{loc}.

	Movement of coolant	ξ_{fr}	ΔP_{fr}. Pa
1	gap between the core barrel and vessel	0.00866	651

2	in fuel assembly	0.02337	67347
3	in the protective tube block	0.01040	513
		ξ_{loc}	ΔP_{loc}, Pa
4	through inlet pipes (nozzle)	0.75	27342
5	through the perforated bottom of core barrel	0.5	6562
6	inlet to fuel assemblies	1.5	18799
7	outlet of fuel assembly	0.4	43747
8	through the perforated shell of PTU	0.5	1552
9	through the perforated shell of core barrel	0.5	1463
10	through outlet pipes (nozzle)	1	32816
		$\sum \Delta P$	200794

6.3 Strength calculation of a reactor (reactor vessel)

The purpose of strength calculation of reactor is calculated the inner diameter of the reactor vessel $D_{ves.in}$ .The thickness of the reactor vessel and the thickness of the vessel bottom.

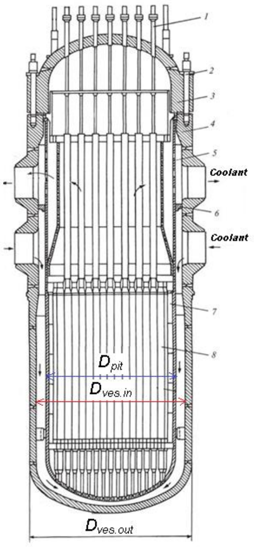


Figure 6.5- Longitudinal section of a WWER reactor

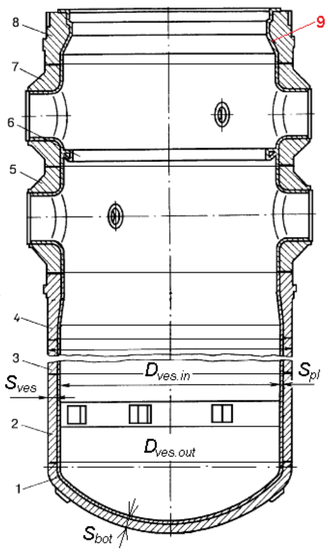


Figure 6.6- WWER reactor vessel

6.3.1 the inner dimeter of the reactor vessel $D_{ves.in}$

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

Where:

- $D_{pit} = (1.1\ldots1.15) \cdot D_0$ -the outer diameter of the reactor pit (reactor shaft. core barrel).

$$D_{pit} = 1.15 \cdot 3.19 = 3.67 \text{ m} ;$$

$$D_{ves.in} = 4.228 \text{ m} .$$

6.3.2 The thickness of the reactor vessel.

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

Where:

- $p_{des} = 1.25 \cdot 0.9 \cdot p_{cool}$ is design pressure, MPa;

$$p_{des} = 1.25 \cdot 0.9 \cdot 16.56 = 18.63 \text{ MPa} .$$

- φ = 1 is joint efficiency (load factor);

Calculate nominal stress design

$$[\sigma] = \min\left\{\frac{\sigma_{sl}}{n_{sl}};\ \frac{\sigma_{0.2}}{n_{0.2}}\right\} .$$

Where:

- n_{sl}=2.6 and $n_{0.2}$=1.5 are relevant safety factors;
- σ_{sl}= R^T_m is shakedown limit of steel 15X2HMΦA from Table 1 for average temperature;
- $\sigma_{sl} = R^T_m = 500 \text{ MPa}$;
- $\sigma_{0.2}$= $R^T_{p0.2}$ MPa is yield point of steel 15X2HMΦA from Table for average temperature.
- $\sigma_{0.2} = R^T_{0.2} = 402 \text{ MPa}$;

Table 6.19-Mechanical properties of steels for reactor vessels

Steel grade	Characteristic	Temperature, °C					
		100	150	200	250	300	350
15X2HMΦA	R^T_m, MPa	529	519	510	500	500	491
15X2HMΦA-A	$R^T_{p0.2}$, MPa	421	412	402	402	402	395

$$[\sigma] = \min\left\{\frac{500}{2.6} = 192.3;\ \frac{402}{1.5} = 268\right\} ;$$

$$s_{ves} = \frac{18.63 \cdot 4.228}{2 \cdot 1 \cdot [192.3] - 18.63} = 0.215 \text{ m} .$$

6.3.3 **The thickness of the vessel bottom**

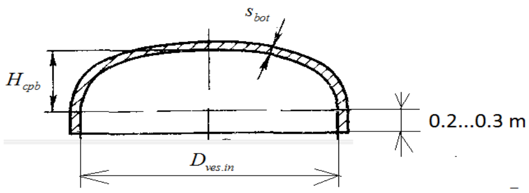


Figure 6.7- To bottom calculation

$$s_{bot} = \frac{p_{des} \cdot D_{ves.in}}{4 \cdot \varphi \cdot [\sigma] - p_{des}} \cdot \frac{D_{ves.in}}{2 \cdot H_{cpb}} .$$

Where:

- $H_{cpb} = (0.2\ldots0.5) \cdot D_{ves.in}$ is height of the elliptical part of the bottom.

$$H_{cpb} = 0.2 \cdot 4.228 = 0.84 \text{ m} ;$$

$$s_{bot} = \frac{18.63 \cdot 4.228}{4 \cdot 1 \cdot 192.3 - 18.63} \cdot \frac{4.228}{2 \cdot 0.84} = 262 \text{ m} .$$

6.3.4 **Reactor vessel outer diameter**

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

Where:

- s_{pl}= 0.007…0.009 m is thickness of anti-corrosion platin.

$$D_{ves.out} = 4.228 + 2 \cdot 0.215 + 2 \cdot 0.009 = 4.677 \text{ m}.$$

Section 7: Financial management, resource efficiency and resource saving

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

7.1 Competitiveness analysis of technical solutions

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

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

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

- C - $C = \sum W_i \cdot P_i$, the competitiveness of research or a competitor;
- Wi– criterion weight;
- Pi – point of i-th criteria.

With the help of this study, the scientific project was updated to enhance the designs and increase its success. The advantages and disadvantages of the comparison structures required to be assessed in order to analyze this alteration. Utilizing all relevant data on market developments (Table 1).

Table 6.20-The results of calculations of the competitive structures of the condenser

	Design options	
	Condenser (Option 1)	Condenser (Option 2)
	dout = 28 mm ; δwall = 1 mm	dout = 28 mm ; δwall = 2 mm
C_{cond} , million RUB	167	320
C_{el} , million RUB	102	95

Notes:

- C_{cond} is cost of the condenser;

- C_{el} is the cost of electricity for pumping water through the condenser.

A steam turbine condenser (the study's subject) uses two different kinds of heat exchange tubes. As a result, data on two choices for the condenser's design with various heat exchange tube sizes will be used to compare them. Leningrad Metal Plant produces condensers for NPP turbines.
The analysis is carried out using a scorecard. The scorecard is shown in Table 5.2

Table 6.21-Evaluation card for comparison of competitive technical solutions

Items to assess	Value of criteria	Points		Competitiveness	
		P_f	P_{il}	C_f	C_{il}
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0,23	3	4	0.69	0.69
2. Dimensions and weight	0,12	3	3	0.36	0.36
3. safety	0,05	3	4	0.2	0.2
4. Lifetime	0,15	4	3	0.6	0.6
5. Reliability	0,2	2	4	0.8	0.8
Economic performance indicators					
1. Price	0,2	4	2	0.6	0.4
2. Maintenance	0,02	3	4	0.06	0.08
3. The competitiveness of the product	0,03	3	3	0.09	0.09
Total	1	–	–	2.95	3.22

Analysis conclusion
where

- Pi –is point of i-th criteria.
- P_f - is worked before optimization
- P_{i1} work after optimization

The findings indicate that option 1's competitiveness was 2,95 while option 2's was 3,22. In terms of technical and economic indicators of resource efficiency, the researched scientific advancement (condenser design), which employs tubes with $d_{out} = 28$ mm; $\delta_{wall} = 2$ mm, is competitive and more reliable.

7.2 SWOT analysis

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

Table 6.22-SWOT analysis

	Strengths: S1. reliable design of condenser S2. Not complex for manufacturing S3. Low maintenance and repair costs	**Weaknesses:** W1. Accidental leakage of of tubes of heat exchange surface W2. large area of the building where the equipment is located W3. External water source and purification systems
Opportunities: O1. More reliable and operation high efficiency. O2. No need to get special material for exchange surface. O3. Decrease the overall costs of the facility	1) Development and improve of equipment industry in nuclear power plants 2) Efficiency is the criteria for using the material and their ease of maintenance. 3) Reducing the dimensions of equipment and reducing the mass will improve operating costs and reduce CO_2 emissions."	1) Air inlet filters should be installed on condenser air intakes to prevent particulate matter from entering the system and causing damage. 2) The working environment must be suitable to the application to maintain normal functioning of the machine. 3) Condenser systems must be inspected and serviced annually to maintain their performance.
Threats: T1. Chemical spills or leaks from condenser T2. Damaging of tubes due to disasters T3. Breakdown of the exchange surfaces	1) Chemical spills and leaks cause large amounts of damage to the systems' cooling coils and other parts of the system. 2) Tubes tend to corrode over time as they are exposed to water and temperature changes 3) May breakdown due to large sizes and lack of proper maintenance	1) Environmental safety must not be neglected because of the external factors such as high temperature or humidity. 2) Need of large equipment to occur purification of water occurring in the building where such equipment exists (inadequate water supply) 3) Properly maintain the machine and keep it running smoothly by making sure there are no cracks in its casing.

7.3 Project Initiation

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

Table 6.23-Stakeholders of the project

Project stakeholders	**Stakeholder expectations**
Tomsk polytechnic university, Design, Operation and Engineering of Nuclear Power Plants.	To get condenser High efficiency

Table 6.24-Purpose and results of the project

Purpose of project:	Save energy costs for running circulation pumps, and boost condenser usage efficiency. Provide reliable condensers for nuclear power plants turbine installations.
Expected results of the project:	According to the calculations and analysis the expectation to get high efficiency of NPP by reducing energy consumption.
Criteria for acceptance of the project result:	The main thing to reduce the losses of energy in turbine installation is to design condenser with more reliable parameters to get high efficiency.
Requirements for the project result:	Calculate carefully the initial parameters for equipment.
	Design equipment with high efficiency
	Complete the project on exact time
	Stability of technological equipment

The organizational structure of the project

It is necessary to solve some questions: who will be part of the working group of this project, determine the role of each participant in this project, and prescribe the functions of the participants and their number of labor hours in the project.

Table 6.25-Structure of the project

№	Participant	Role in the project	Functions	Labor time, hours
1	Shahin. Y. R.	Project Executor	Work on project Development	462
2	Gubin. V.E	Project Manager	Coordination of work activities and assistance in project implementation	42
Total				504

So, the time spent for the Work

- for my Supervisor (Project Manager) $21 \cdot 2 = 42$ hours;
- for me as an Engineer (Project Executor) $77 \cdot 6 = 462$ hours.

Project limitations

Project limitations are all factors that can be as a restriction on the degree of freedom of the project team members.

Table 6.26-Project limitations

Factors	**Limitations / Assumptions**
3.1. Project's budget	300 000 RUB
3.1.1. Source of financing	Rosatom scholarship
3.2. Project timeline:	1 AUG 2022 – 20 JAN 2023
3.2.1. Date of approval of plan of project	1 AUG 2022
3.2.2. Completion date	30 DEC 2022

Project Schedule

As part of planning a science project, you need to build a project timeline and a Gantt Chart.

Table 6.27-Project Schedule

	Job title	Duration, working days	Start date	Date of completion	Participan T
1	Drawing up the technical assignment	7	1 AUG	9 AUG	SV
2	Literature review	13	15 AUG	31 AUG	ENG
3	Selection of the research field	5	6 SEP	12 SEP	SV
4	Calendar planning	4	15 SEP	20 SEP	SV
5	Description of the design object	12	22 SEP	7 OCT	ENG
6	Statement of the design problem	11	10 OCT	24 OCT	ENG
7	Development of the calculation model	10	26 OCT	10 NOV	ENG
8	Variational calculations of the object	4	10 NOV	15 NOV	ENG
9	Evaluation of calculation results	5	15 NOV	21 NOV	SV
10	Comparative calculations of economic efficiency object	6	23 NOV	30 NOV	ENG
11	Choosing the optimal design	10	2 DEC	15 DEC	ENG
12	Drawing up a final report	11	16 DEC	30 DEC	ENG

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 6.28-Duration of the project

№	Activities	Participants	T_c, Days	Duration of the project														
				Aug			Sep			Oct			Nov			Dec		
				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	Drawing up the technical assignment	Supervisor	10															
2	Literature review	Engineer	20															
3	Selection of the research field	Supervisor	10															
4	Calendar planning	Supervisor	10															
5	Description of the design object	Engineer	20															
6	Statement of the design problem	Engineer	20															
7	Development of the calculation model	Engineer	10															
8	Variational calculations of the object	Engineer	10															
9	Evaluation of calculation results	Supervisor	10															
10	Comparative calculations of economic	Engineer	10															
11	Choosing the optimal design	Engineer	10															
12	Drawing up a final report	Engineer	10															

Engineer ■ Supervisor ■

7.4 Scientific and technical research budget

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

To form the final cost value, all calculated costs for individual items related to the manager and the student are summed.

In the process of budgeting, 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.

Table 6.29-Material costs

Name	Unit of measurement	Number	Price per unit, RUB	Material costs, RUB
Paper	Pack	1	250	250
Pens	Unit	4	70	280
Pencils	Unit	1	100	100
Ruler	Unit	1	50	50
Printing	Page	350	2	700
Folder	Unit	4	10	40
Stapler	Unit	1	120	120
Staples	Pack	1	50	50
Total				1 590

Costs of special equipment

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

Table 6.30-Costs of special equipment (+software)

№	equipment identification	Quantity of equipment	Price per unit, rub.	Total cost of equipment, rub.
1	Laptop	1	28 000	28 000
2	Microsoft-Windows 10-Professional x64	1	4 500	4 500
3	AutoCAD 2023	1	2000	2000
4	Microsoft-Office 2021-Home	1	3000	3000
Total, RUB				37 500

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:

$$S_b = S_d \cdot T_w ;$$

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 an participant, rub.
- The average daily salary is calculated by the formula:

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

where

- S_m – monthly salary of an participant, rub.;
- M – the number of months of work without leave during the year:
- at holiday in 48 days, M = 11.2 months, 6 day per week;
- F_v– valid annual fund of working time of scientific and technical personnel (251 days).

Monthly salary is calculated by formula:

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

where

- S_{base} – base salary, rubles;
- $k_{premium}$ – premium rate;
- k_{bonus} – bonus rate;
- k_{reg} – regional rate.

Table 6.31-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	W_{base}, rub.
Project Executor	19 200	0	1.05	1.3	26 208	1 169	77	90 013
Project Manager	37 500				51 187.5	2 284	21	47 964

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:

$$W_{add} = k_{\text{extra}} \cdot W_{base};$$

$$W_{add,Eng} = 0.1 \cdot 90\ 013 = 9\ 001.3 \text{ rub} ;$$

$$W_{add,SV} = 0.1 \cdot 47\ 964 = 4796.4 \text{ rub.}$$

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:

$$P_{social} = k_b \cdot (W_{base} + W_{add});$$

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 6.32-Labor tax

	Project leader	Engineer
Coefficient of deductions, %	27.1	
Salary (basic and additional), rubles	52 760.4	99 014.3
Labor tax, rubles	14 298	26 832.8

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:

$$C_{\text{ov}} = k_{ov} \cdot (W_{\text{base}} + W_{add});$$

Where

- k_{ov} – overhead rate

Table 6.33-Overhead

	Project leader	Engineer
Overhead rate,%	55	
Salary, rubles	52 760.4	99 014.3
Overhead, rubles	29 018.2	54 457.8

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, kW;

F_{eq} − Equipment usage time, hours

- For Engineer $C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.3 \cdot 462 = 803\ rub.$
- For supervisor $C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.3 \cdot 42 = 73\ rub.$

Formation of budget costs

The calculated cost of research is the basis for budgeting project costs. Determining the budget for the scientific research is given in the table 15.

Table 6.34-Items expenses grouping

Name	Cost, rubles
1. Material costs	1 590
2. special equipment	37 500
3. Basic salary, SV	47 964
4. Additional salary, SV	4 796.4
5. Basic salary, Eng	90 013
6. Additional salary, Eng	9 001.3
7. Labor tax, SV	26 832.8
8. Labor tax, Eng	14 298
9. Overhead, SV	29 018.2
10. Overhead, Eng	54 457.8
Total planned costs	**310 675.1**

Conclusion

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

These stages includes:

- development of a common economic project idea, formation of a project concept;
- organization of work on a research project;
- identification of possible research alternatives;
- research planning;
- assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;
- determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

Section 8: Social Responsibility

8.1 Legal and organizational issues of occupational safety

The projected work area, law norms of labor legislation.

Nuclear power plant atomic control plant security may be a complex field related to the security, wellbeing and well-being of individuals at work. It tells the methodology and strategies in put to guarantee the wellbeing and security of representatives inside the work environment. Atomic control plant security incorporates the mindfulness of workers with respect to fundamental security information, work environment dangers, danger related risks, usage of danger avoidance, execution of hone of fundamental safer methods, strategies, forms and security culture within the work environment. It moreover incorporates security rules and directions generally outlined on the premise of current government arrangements. Each organization builds up a number of security rules and controls for its workers. Security preparing and instruction are given to workers on a normal premise with. the point of teaching them and upgrading them with the most recent security measures. NPP safety is approximately putting an conclusion to representative wounds and ailments within the working environment.[7]

GOST 12.2.003-91 Occupational safety standards system. Industrial equipment. General safety requirements.[8]

GENERAL PROVISIONS

- Production equipment must ensure the safety of workers during installation (dismantling), commissioning and operation, both in the case of autonomous use and as part of technological complexes, subject to the requirements (conditions, rules) provided for by the operational documentation
- The safety of the design of production equipment is ensured by:

1) the choice of operating principles and design solutions, energy sources and characteristics of energy carriers, parameters of work processes, control system and its elements;

2) minimization of consumed and accumulated energy during the operation of the equipment;

3) the choice of components and materials for the manufacture of structures, as well as those used during operation;

4) the choice of manufacturing processes;

5) the use of built-in protective equipment for workers, as well as information tools that warn of the occurrence of dangerous (including fire and explosion hazard) situations;

- Safety requirements for production equipment of specific groups, types, models (brands) are established on the basis of the requirements of this standard, taking into account:

  1) features of the purpose, performance and operating conditions;

  2) test results, as well as analysis of hazardous situations (including fire and explosion hazards) that occurred during the operation of similar equipment;
- Each technological complex and autonomously used production equipment must be completed with operational documentation containing requirements (rules) that prevent the occurrence of dangerous situations during installation (dismantling), commissioning and operation.
- Production equipment must meet safety requirements during the entire period of operation, provided that the consumer fulfills the requirements established in the operational documentation.

GENERAL SAFETY REQUIREMENTS

- Requirements for the design and its individual parts

Materials of construction of production equipment should not have a dangerous and harmful effect on the human body in all specified modes of operation and envisaged operating conditions, as well as create fire and explosion hazard situations.

The design of production equipment must exclude, in all intended modes of operation, loads on parts and assembly units that can cause damage that poses a danger to workers.

- **Job Requirements**

The design of the workplace, its dimensions and the mutual arrangement of elements (controls, information display tools, auxiliary equipment, etc.) must ensure safety when using production equipment for its intended purpose, maintenance, repair and cleaning, and also meet ergonomic requirements.

The dimensions of the workplace and the placement of its elements should ensure the performance of work operations in comfortable working positions and not impede the movements of the worker.

When designing a workplace, it should be possible to perform work operations in a sitting position or when alternating sitting and standing positions, if the performance of operations does not require constant movement of the worker.

- **Control system requirements**

The control system must ensure its reliable and safe operation in all envisaged operating modes of production equipment and under all external influences stipulated by the operating conditions. The control system must exclude the creation of dangerous situations due to a violation by the worker (workers) of the sequence of control actions.

- **Requirements for protective equipment included in the design and signaling devices**

The design of protective equipment should provide the ability to control the fulfillment of their purpose before and (or) during the operation of production equipment.

Protective equipment must fulfill its purpose continuously during the operation of production equipment or when a dangerous situation arises.

The action of protective equipment should not be terminated before the end of the action of the corresponding dangerous or harmful production factor.

The failure of one of the means of protection or its element should not lead to the termination of the normal functioning of other means of protection.

- **Design requirements that contribute to safety during installation, transportation, storage and repair**

If it is necessary to use lifting equipment during installation, transportation, storage and repair on production equipment and its individual parts, places for connecting lifting equipment and the mass to be lifted must be indicated.

The points of connection of lifting means must be chosen taking into account the center of gravity of the equipment (its parts) so as to exclude the possibility of damage to the equipment during lifting and moving and provide a convenient and safe approach to them.

The design of production equipment and its parts must ensure the possibility of their reliable fastening on a vehicle or in a packaging container.

Assembly units of production equipment, which can spontaneously move during loading (unloading), transportation and storage, must have devices for fixing them in a certain position.[8]

Federal Law of November 21, 1995 N 170-FZ On the Use of Atomic Energy [9]

General Provisions.

- **Article 1.** Legislative, Legal and Other Acts of the Russian Federation in the Sphere of the Use of Atomic Energy Relations arising in the use of atomic energy for peaceful and defence purposes shall be regulated by the present Federal Law, other law and other legal acts of the Russian Federation. The activities associated with the development, manufacture, testing, operation and utilization of nuclear weapons and nuclear power installations of a military nature shall be carried out on the basis of other federal laws and shall not be in the sphere of the validity of this Federal Law.

- **Article 2.** Principles and Tasks of the Legal Regulation in the Sphere of Atomic Energy Use The basic principles of the legal regulation of the use of atomic energy include: - safety during the use of atomic energy and protection of individuals, population at large and the environment against radiation danger; - access to information on the use of atomic energy, if this information does not contain state secrets; - the participation of individuals, profit-making and non-profit organizations (hereinafter referred to as organizations) and other legal entities in the discussion of state policy, drafts of federal laws and other legal acts of the Russian Federation, and also in the practical activity in the sphere of the use of atomic energy.
- **Article 3.** The Objects of the Application of this Federal Law The objects of the application of this Federal Law are as follows: nuclear installations mean structures and complexes with nuclear reactors, including atomic power stations, ships and other crafts, spacecrafts and flying vehicles, other transportation and transportable facilities; structures and complexes with industrial, experimental and research nuclear reactors, critical and subcritical nuclear beds; structures, complexes, proving grounds, plants and devices with nuclear charges for peaceful uses; other structures containing nuclear materials, complexes and plants for the production, use, processing and transportation of nuclear fuel and nuclear materials;

  nuclear materials: denote the materials containing or capable of reproducing fissionable nuclear substances.

  radioactive substances: denote the substances with ionizing irradiation that do not belong to nuclear materials.

  radioactive waste: denotes nuclear materials and radioactive substances whose further use is not envisaged. The inclusion of said objects in the listed categories shall be determined by the organization that uses them and fixed in a relevant document in the order, prescribed by the federal executive bodies in the sphere of state safety regulation in the use of atomic energy (hereinafter referred to as state safety regulation bodies).
- **Article 4.** The Types of Activity in the Sphere of Atomic Energy Use The present Federal Law shall extend to the following types of activity in the sphere of atomic energy use: the siting, designing, building, operating and the withdrawal from operation of nuclear installations, radiation sources and storage points; the development, production, testing, transportation, storage, utilization and use of nuclear charges for peaceful uses, and the handling with them; the handling with nuclear materials and radioactive substances during the prospecting and extracting mineral resources that contain these materials and substances and during the

production, use, processing, transportation and storage of nuclear materials and radioactive substances; the provision of safety during the use of atomic energy;

- **Article 5.** Ownership of Nuclear Materials, Nuclear Installations, Storage Points, Radiation Sources and Radioactive Substances Nuclear materials may be in federal ownership or in the ownership of legal entities. A list of nuclear materials which may be solely in federal ownership shall be endorsed by the President of the Russian Federation. A list of Russian legal entities (that is, of legal entities established in compliance with the legislation of the Russian Federation), which may have nuclear materials in ownership, shall be endorsed by the President of the Russian Federation.

The Rights of Organizations, Including Public Associations and Individuals in the Use of Atomic Energy

- **Article 1.** The Rights of Organizations, Including Public Associations, and Individuals to Get Information about the Use of Atomic Energy Organizations, including public associations, and individuals shall have the right to request and receive in the statutory manner and within their jurisdiction from the corresponding executive bodies and organizations information about the safety of nuclear installations, radiation sources and storage points, planned for building, designing, operating and withdrawing from operation, except for information comprising state secrets.
- **Article 2.** The Rights of Organizations, Including Public Associations, and Individuals to Take Part in the Formation of Policies in the Sphere of Using Nuclear Energy Organizations, including public associations and individuals shall have the right to take part in the discussion of the drafts of legislative acts and programmes on the use of atomic energy and also in the discussion of the questions concerning the siting, designing, building, operating and withdrawing from operation of nuclear installations, radiation sources and storage points.

- **State Management of Atomic Energy Use**

- **Article 1.** State Administration Bodies in Charge of Atomic Energy Use The state management of the atomic energy use shall be implemented by the federal executive bodies and the State Atomic Power Corporation Rosatom (hereinafter also referred to as the bodies managing the atomic energy use) in the order prescribed by this Federal Law, other federal laws and other normative legal acts of the Russian Federation.

State Regulation of Safety in the Use of Atomic Energy

- **Article 1.** State Regulation of Safety in the Use of Atomic Energy The state regulation the safe use of atomic energy shall provide for the activity of the appropriate federal executive bodies and the State Atomic Power Corporation Rosatom to organize the drafting, approval and enforcement of norms and rules in the sphere of the use of atomic energy. These bodies shall to issue permits (licenses) for the right to use atomic energy, supervise safety, carry on the expert examination and inspection, and exercise control over the development and realization of measures on the protection of the workers of the facilities using atomic energy and of the population and the environment in case of accidents during the use of atomic energy.

Features of the labor legislation in relation to the specific conditions of the project.

Employment at nuclear plants may include obligations and benefits related to issues by the following state or company: forms, regulations, and rates of wages for workers, engineers, and managers; disbursement of interest and compensation working and leisure hours, including matters relating to the granting and duration of leave.

The procedure for informing employees of the implementation of the collective agreement; The obligation to refrain from a strike if the relevant terms and conditions of the agreement are observed [10]

Basic Objectives of NPP Safety

The basic objectives of NPP safety are as follows:

- Preservation of and assistance for employees' or workers' health and well-being
- Enhancing workability of employees by ensuring a safe and congenial work environment
- Growth of the organization that remains free from prospective hazards and mishaps
- Encouraging a favorable social climate in the organization that motivates the employees to work efficiently towards organizational progress and prosperity
- Secure the health and safety of workers and workplace by eliminating or minimizing risks
- Achieve higher productivity among the employees by providing a safe and secure environment
- Focus on employees safety and health arising from chemicals and hazardous elements. [11]

8.2 Occupational safety.

Occupational safety is understood as a system of organizational measures and technical means that prevent or reduce the possibility of exposure of workers to dangerous harmful production factors arising at nuclear power plants during work activity.

In our work, it is essential to distinguish perilous and hurtful components that will emerge when working with a data framework. Subsequent selection is carried out using GOST 12.0.003–2015 "Hazardous and harmful production factors. Classification". The results of the selection are shown in the table below.[6]

Occupational safety and health (OSH are a multidisciplinary field concerned with the safety, health, and welfare of people at work. It is commonly referred to as occupational health and safety (OHS), occupational health or workplace health and safety (WHS).

The main purpose of occupational safety

The goal of occupational safety and health (OSH) programs is to foster a safe and healthy work environment. OSH may also protect co-workers, family members, employers, customers, and many others who might be affected by the workplace environment. [12]

The main focus in occupational health is on three different objectives:

- the maintenance and promotion of workers' health and working capacity;
- the improvement of working environment and work to become conducive to safety and health and
- development of work organizations and working cultures in a direction that supports health and safety at work and in doing so also promotes a positive social climate and smooth operation and may enhance the productivity of the undertakings.[12]

Analysis of harmful and dangerous factors that can be created.

All dangers in nuclear plants are divided into several categories, the basis of their classification lies in determining their effect on certain organs of the human body, as well as the method of affecting them

Table 8.1-Potential hazardous and harmful production factors

Factors	Stages of work			Legislation documents
	Developing	Manufacturing	Operation	
Increased pressure of vapors or gases in vessels	+			GOST 12.2.003-91 Occupational safety standards

				system. Industrial equipment. General safety requirements
Increased level of noise;	+	+		SP 51.13330.2011 Noise protection.
Increased level of vibration;	+	+		GOST 12.1.012-90 Vibrational safety. General requirements;
Sharp edges, burrs on equipment, tools.	+	+	+	GOST 12.2.003-91 Occupational safety standards system. Industrial equipment. General safety requirements
Increased levels of electromagnetic radiation.			+	SanPiN 2.2.4.1329-03 Requirements for protection of personnel from the impact of impulse electromagnetic fields
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;

- **Increased pressure of vapors or gases in vessels**

Dangerous gases and confined spaces are a dangerous mix. It can take only a few seconds for workers to succumb to a hazardous atmosphere, if vapor pressure exceeds the thermodynamic equilibrium value, condensation occurs in presence of nucleation sites. This principle is indigenous in cloud chambers, where ionized particles form condensation tracks when passing through.

Source equipment

In the nuclear power plants, we have a lot of equipments that can occurs increase of steam pressure on it such as the vessel of steam generator and the heat exchange tubes, also on the condenser we must keep the pressure in the lowest value to get more efficiency.

Ways to improve we fix a pressure gauges and valves in the tubes and vessels.

Factors impact vapor pressure

Vapor pressure is the pressure caused by the evaporation of liquids. Three common factors that influence vapor press are surface area, intermolecular forces and temperature. The vapor pressure of a molecule differs at different temperatures. [13]

To minimize the impact

- Ventilation needed
- Use of mechanical devices that withstand pressure.

- **Increased level of noise**

Continual exposure to noise can cause stress, anxiety, depression, high blood pressure, heart disease, and many other health problems. Some people are at higher risk for hearing loss, including those who: are exposed to loud sounds at home and in the community.

Source equipment

For industrial and energy enterprises with a maximum linear dimension up to 300 m inclusive - equivalent sound power levels and maximum sound power levels in eight octave frequency bands with geometric mean frequencies of 63-8000 Hz and radiation directivity factor in the direction of the calculated point (1 if the directivity factor is unknown). It is allowed to represent noise characteristics in terms of equivalent corrected sound power levels, dBA, and maximum corrected sound power levels, dBA.

Harmful effects of noise in the workplace

Loud noise can create physical and psychological stress, reduce productivity, interfere with communication and concentration, and contribute to workplace accidents and injuries by making it difficult to hear warning signals.

Direct Effects

There's an immediate effect on the acoustic nerves and, as a result, the rest of the nervous system. A fluid-filled inner-ear organ called the cochlea converts sound vibrations into electrical impulses that go directly to the brain. Constant noise, especially when it's loud, can overload and compromise that nerve-based connection, leading to hearing loss.

Norms

Normalized parameters of constant noise at design points are sound pressure levels, dB, in octave frequency bands with geometric mean frequencies of 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. Sound levels may be used for approximate calculations., dBA.

Normalized parameters of non-constant (intermittent, fluctuating in time) noise are equivalent sound pressure levels, dB, in octave frequency bands with geometric mean frequencies of 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz and maximum sound levels, dB and equivalent, dBA.[14]

Control of noise emissions

Most often it is the 'path of noise' that is controlled by use of acoustic enclosures, barrier walls, duct silencers and other similar noise control treatments.[15]

- **Increased level of vibration**

Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS). Workers affected by HAVS commonly report: attacks of whitening (blanching) of one or more fingers when exposed to cold.

Source Equipment

In Power plants the equipments which might cause vibration such as the turbine blade when it damaged and the main pumps in the circulation pipelines and the shaft of electric generator

When two or more rotating machines are connected:

- Unbalance.
- Resonance.
- Loose parts.
- Bearing damage.
- Damaged or worn-out gears.

Vibration - Health Effects

Vibration induced health conditions progress slowly. In the beginning it usually starts as a pain. As the vibration exposure continues, the pain may develop into an injury or disease. Pain is the first health condition that is noticed and should be addressed in order to stop the injury.

Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS). Workers affected by HAVS commonly report:

- attacks of whitening (blanching) of one or more fingers when exposed to cold
- tingling and loss of sensation in the fingers
- loss of light touch
- pain and cold sensations between periodic white finger attacks
- loss of grip strength
- bone cysts in fingers and wrists [16]

Vibration Control

- Vibration control should be carried out:

at workplaces in the production process - to assess the vibration safety of labor;

when monitoring the quality of machines and the technical condition of operated machines and equipment - to assess their vibration safety.

- Vibration measuring equipment must comply with the requirements of GOST 12.4.012 and have a valid verification certificate.
- Vibration control is carried out at points for which sanitary and technical standards are established in the directions of the coordinate axes established by this standard.

- The method and device for mounting the vibration transducer should not affect the nature of the controlled vibration and introduce errors into the measurements. The preferred mounting for the vibration transducer is a threaded stud.[17]

Minimize the effect of vibrations

The following precautions help to reduce whole-body vibration exposure:

1. Limit the time spent by workers on a vibrating surface.
2. Mechanically isolate the vibrating source or surface to reduce exposure.
3. Ensure that equipment is well maintained to avoid excessive vibration.
4. Install vibration damping seats. [18]

➢ **Sharp edges, burrs on equipment, tools**

Although many processes can be used for deburring, not all of them are equally efficient or applicable to any given case. The 5 most common ways of removing burrs and edges are vibratory finishing, barrel tumbling, manual deburring, thermal energy deburring, and electromechanical deburring.[19]

- Manual deburring: A skilled craftsperson can remove burrs by hand using specialized manual deburring tools. Manual deburring is flexible and cost-effective, but it requires a significant investment of time, making it unsuitable for finishing a large quantity of parts.
- Thermal energy method: Also known as the thermal deburring, this method uses a combustive reaction to burn away burrs in a sealed chamber. Thermal deburring can quickly target burrs on multiple surfaces and many pieces at once.
- Electromechanical deburring: Metal burrs can be dissolved using an electrical current combined with a salt or glycol solution. Electromechanical deburring is useful for small, precision pieces that require deburring in hard-to-reach places.

Source Equipment

In power industry there are a lot of metal constructions which sharp edges might happen.

Burrs are most commonly created by machining operations, such as grinding, drilling, milling, engraving or turning. It may be present in the form of a fine wire on the edge of a freshly sharpened tool or as a raised portion of a surface; this type of burr is commonly formed when a hammer strikes a surface.

Ways to improve

Rough edges are imperfections known as burrs, and the process of removing them is called deburring.

Burrs are caused from operations such as machining, shearing sheet metals, and trimming forgings and castings. They can be reduced or eliminated by not using dull tools, removing them manually with files/scrapers, and mechanically by using wire brushes, abrasive belts, electropolishing, abrasive blasting, and so on.

- **Electromagnetic fields**

Electromagnetic field, a property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced. An electric field can be produced also by a changing magnetic field.

Source Equipment

At power stations, turbines turn their rotors to produce electricity by electromagnetic induction.

Also, we have some other equipments which might cause electromagnetic field for example Motors, generators and Transformers.

An electromagnetic field, is generated when charged particles, such as electrons, are accelerated. All electrically charged particles are surrounded by electric fields. Charged particles in motion produce magnetic fields.

To minimize the impact

Traditionally, magnetism is activated in an electromagnet by passing a current through a coil around a magnetic material. This coil generates a magnetic field. The new method uses a capacitor, a device used to generate an electric field, to control the magnetism of a magnetic material.

Typical materials used for electromagnetic shielding include sheet metal, metal screen, and metal foam. Common sheet metals for shielding include copper, brass, nickel, silver, steel, and tin. [20]

- **Increased voltage in an electrical circuit** [21]

Electric current is able to create severe burns in the body. The reason is hidden in the power dissipation across the body´s electrical resistance. Shock can cause: cardiac arrest, burns to tissues and organs, muscle spasms, serious effects to the nervous system and other unexpected consequences.

Source Equipment

A step-up transformer increases the voltage of the current as it leaves the power plant. After the voltage has been increased, less current travels through the high-voltage power lines. This reduces the amount of power that is lost due to resistance of the power lines.

To minimize the impact

- Providing insulating materials and providing insulating clothing.

8.3 Environmental safety.

Environmental impact of nuclear power

The environmental impact of nuclear energy results from the nuclear fuel cycle, operation, and the effects of nuclear accidents. However, there is the potential for a "catastrophic hazard" in the event of a containment failure, which can occur in nuclear reactors by heating smelting fuels and releasing large amounts of fission products into the environment. It is of three types, including atmosphere, hydrosphere, and lithosphere.[22]

- **Atmosphere affect**

Emissions from ventilation systems and the radioactive wastes, spent (used) reactor fuel.

- **Hydrosphere affect**

During the cooling process, the water becomes contaminated with radionuclides and must be filtered to remove as many radionuclides as possible.

- **Lithosphere affect**

nuclear waste can cause changes in the availability of elements such as nitrogen, carbon and sulfur.

Radioactive waste

Radioactive waste includes any material that is either intrinsically radioactive, or has been contaminated by radioactivity, and that is deemed to have no further use. Government policy dictates whether certain materials – such as used nuclear fuel and plutonium – are categorized as waste.

Types of Radioactive Waste

The main consideration for defining and categorizing waste is long term safety of disposal. Waste is classified according to its potential hazard and this determines the containment and isolation required. Within the nuclear energy sector, a rough categorization divides nuclear waste into low level, intermediate level and high level wastes. This categorization varies slightly from country to country, but in principle the main criteria for determining the type of waste are derived from radioactive content and half-life, i.e. the time taken for the waste to lose half of its radioactivity.

- Low and intermediate level wastes arise mainly from routine facility maintenance and operations.
- Low level waste can be contaminated clothing such as protective shoe covers, floor sweepings, paper and plastic. Intermediate level waste can be, for example, reactor water treatment residues and filters used for purifying a reactor’s cooling water. The radioactivity ranges from just above nature’s background level to more elevated radioactivity in certain cases

- High level waste consists mostly of spent fuel from reactors. Some countries also reprocess spent fuel, which gives rise to additional types of high-level waste. All of this high level waste and spent fuel, when declared as waste, poses a sufficiently high enough radiological risk that a high degree of isolation from the biosphere is required for a long period of time. [23]

Radioactive Waste Disposal

The world has over half a century's knowledge and experience on how to deal with nuclear waste. Good practices developed over the years are being used throughout the whole cycle of electricity production to help ensure the safety of people and the environment from possible effects of harmful radiation.

Disposal of low and intermediate level radioactive wastes is already implemented in several countries. Usually these facilities are at, or near, the surface, but some intermediate level waste that contains long lived radioactivity requires disposal at greater depths, of the order of tens of meters to a few hundred meters

High level radioactive waste is presently temporarily stored in storage facilities. Several options are being examined and research for implementing disposal is being conducted in many countries with nuclear power. In every option, deep geological disposal is the preferred final end point.

In the nuclear energy sector, good waste management, resulting in safe disposal, also considers financial implications. The objective is to have enough funds to execute activities (waste disposal, decommissioning, human resources, etc.) required once electricity production of a facility has ceased.[23]

Power plant emission

Radioactive gases and effluents

Most commercial nuclear power plants release gaseous and liquid radiological effluents into the environment as a byproduct of the Chemical Volume Control System.

Civilians living within 50 miles (80 km) of a nuclear power plant typically receive about 0.1 μSv per year. For comparison, the average person living at or above sea level receives at least 260 μSv from cosmic radiation.

All reactors are to have a containment building. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment. If a person is to worry about an energy source that releases large amounts of radiation into the environment, they should worry about coal-fired plants.

Waste heat

As with all thermoelectric plants, nuclear power plants need cooling systems. The most common systems for thermal power plants, including nuclear, are:

- Once-through cooling, in which water is drawn from a large body, passes through the cooling system, and then flows back into the water body.
- Cooling pond, in which water is drawn from a pond dedicated to the purpose, passes through the cooling system, then returns to the pond.
- Cooling towers, in which water recirculates through the cooling system until it evaporates from the tower.

Nuclear plants exchange 60 to 70% of their thermal energy by cycling with a body of water or by evaporating water through a cooling tower. This thermal efficiency is somewhat lower than that of coal-fired power plants, thus creating more waste heat.

8.4 Emergency safety.

The NPP emergency planning procedures on protection of personnel and population in the event of an accident at the NPP considering radiological consequences of accidents shall be developed and made available. Plans shall be elaborated on the basis of NPP design characteristics and parameters, criteria for decision making relating to arrangements on protection of population in case of an accident at the NPP taking into account economic, natural and other site-specific features and extent of actual hazard of occurrence of the emergency situation.

The emergency plan on protection of population to be elaborated in the established order by competent bodies in case of an accident shall suggests co-ordination of actions to be undertaken within the site and in the whole territory by civil defense and emergency control bodies, local self-control bodies as well as ministries and departments involved in implementation of measures on protection of population and mitigation of accident consequences. [24]

Fire safety assessments and operational experience gained from events in nuclear energy Factories have shown that fires and explosions have a high potential to severely affect safety from NPP. Since a fire can occur at any time in the plant, the fire protection of the nuclear power plant is important Throughout its life, that is, from the design stage to operation and even decommissioning.

Fire safety in national nuclear plants is addressed in IAEA safety standards publications covering design and safe operation of nuclear power plants. [11] Other IAEA public publications provide more details guidelines for fire safety assessment and for fire safety reviews. In this it documents the analysis of the aforementioned fire experience as an essential tool to meet the following objectives:

- To conduct a safety review of the procedures in place at the operating stations (operational safety objective).
- To conduct a periodic safety review of fire safety issues in design and operation.
- To support probabilistic fire risk analysis of new and existing plants targeting
- Better identify aspects of fire safety and prioritize safety improvement tasks.

To achieve these goals, a broad track record of experience derives from fire events in surrounding plants the world is strongly encouraged to create a reliable database that will enable fire safety experts to make recommendations for current and future factories and can be used for statistics purposes. Events must be collected and analyzed by fire safety experts to derive them recommendations for current and future plants. [25]

In this regard, the international atomic energy agency has begun a systematic process of collecting data on events in this framework the objectives of this task are: to collect and evaluate. Operational experience on fires and explosions in factories in a systematic way to obtain information necessary for a comprehensive safety analysis; to use lessons learned from past events. For operational feedback; and successfully applied in plants to avoid, or at least, reduce the frequency of events.[26]

Conclusion

The calculations show a design for a nuclear power plant with four loops of a horizontal steam generator and 870 MW of electric power. In the thermal part of calculation of NPP the main goal is to determine what relative flow rate calculations for each part and determine steam flow at the turbine and verify of efficiency of turbine installation and efficiency power plant and to choose of suitable equipment for the water -steam circuit. VVER-870 with saturated steam turbine with low speed that was divided into high pressure part and two low-pressure which drives an electrical generator. The following parameters were used to create the design:

Table 9.1-The main parameters and features of NPP

Electrical power	N_e MW	870
Initial pressure	p_0, MPa	6.5
Pressure of condenser	p_c, kPa	4
Pressure of deaerator	p_d , MPa	0.6
Stage of reheat	N_{stage}	Double

Through the Calculation I find out number of LPH it will be 4 LPH, and calculate the real temperature rises after each heater it would be $\Delta t_{LPH} = 27.5$ ℃.

Using the optimal value of feedwater temperature $t_{fwp} = 210$ ℃, I find out number of high-pressure heaters it will be 2 HPH, and the Real temperature rises after each heater $\Delta t_{HPH} = 25.1$ ℃.

After getting the values of relative flowrates I determined steam flow to a turbine $G_0 = 1287$ kg/s ; the find Values of flow rate at all the part of NPP.

Table 9.2 -The main results of Calculation of indicators of thermal efficiency

SG Thermal capacity	Q_{SG}, kW	$2622 \cdot 10^3$
Thermal loading of turbine	Q_T, kW	$2589 \cdot 10^3$
Turbine Plant efficiency	η_e, %	33.6
NPP Gross efficiency	η_{npp}^{Gross}, %	32.3

Calculation of processes in Turbine

for Low Pressure Cylinder I calculated the Isentropic process of extractions from LPC with absolute internal efficiency $\eta_{0i}^{LPC} = 0.80$.

So, I find out that the Exhaust steam quality from LPC,$x^{LPC} = 0.885$;

For High Pressure Cylinder the Isentropic process of extractions from LPC with absolute internal efficiency $\eta_{0i}^{HPC} = 0.83$.

A condenser's efficiency and cost were established for two different condenser alternatives, which were then compared. In order to choose the condenser with wall thickness 2 mm.

For Steam Generator According to project calculation based on the type of horizontal steam generator. One of the basic and essential components of equipment in the NPP is the steam generator.

The "Horizontal steam generator" concept, which related to heat exchange technology, can be applied to nuclear power plant steam producing facilities.

A horizontal steam generator's vessel is a massive, thick-walled vessel. It has a bottom, two side shells, and a middle shell. Welding is used to join every component to the other components.[26]

Horizontal steam generators are preferred in the Russian nuclear sector. In Russia, steam generator tubes are constructed of steel of such 08H18N10T type.

The calculation of the thermal part of the SG To evaluate the primary dimensions of the heat exchange surface, a steam generator's thermal calculation is performed.

As the Calculation of mechanical part of Horizontal SG of Saturated Vapor with U-Shaped Tubes, the results of mechanical analysis are to evaluate static strength and the wall thickness of these components.

Table 9.3-The Final results calculation of SG.

Thermal Power of reactor.	Q_R, MW	2676
Number of loops	Z_{loop}	4
Mass flow rate of steam.	$D_2, {}^{kg}/_{s}$	351.4
Coolant flow	$G_1, {}^{kg}/_{s}$	2703
The inlet pressure of Coolant to SG	P_1, MPa	16.56
Feed water temperature.	t_{fw}, °C	210
Number of SG tubes	N_{tube}, pcs	8813

So, the summarize of the calculations show a design for a nuclear power plant VVER with 4 loops of a horizontal steam generator and an electric power of 870 MW.

Through cancelations of the work, I find that all results are in the acceptable rang according to the standards, The efficiency of NPP is 32.3%.

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APPENDICE-A

1. ФЮРА.311115.001. ТЗ Turbine installation.
2. ФЮРА.693410.002.ВО Horizontal Steam Generator.
3. ФЮРА.693100.003.ВО Nuclear reactor.
4. ФЮРА.693450.004.ВО Condenser.