«VVER-TOI» Design

ATOMENERGOPROEKT



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ATOMENERGOPROEKT State Atomic Energy Corporation "Rosatom"



Atomenergoproekt –

is an engineering Company, the General Designer of the NPPs. It carries out a full complex of works and services in the field of NPP construction, including:

- siting activities;
- development of the predesign, design and working documentation;
- working out of complex information model of NPP, including 3D-designing;
- engineering researches;
- ecological monitoring;
- substantiation of radiation, nuclear and ecological safety;
- design supervision of the NPPs construction and support of their operation;
- arrangement and performance of civil and erection works, deliveries of equipment and materials;
- NPPs commissioning and their putting into operation;
- prolongation of NPPs terms of operation;
- power units decommissioning.

JSC «Atomenergoproekt» is the General Designer of Kurskaya, Smolenskaya, Balakovskava, Novovoronezhskaya, Bilibinskaya NPPs, NPP «Bushehr» in Iran, NPP «Kudankulam» in India, NPP «Akkuvu» in Turkey. Under this Company designs the NPP «Kozloduy» in Bulgaria, NPP "Temelin» in Czechia, Zaporozhye NPP in Ukraine have been constructed. JSC «Atomenergoproekt» is the General Designer and General Contractor of construction of the Novovoronezhskaya NPP-2 (2 power units with VVER-1200 reactors based on the «AES-2006» design). The Company performs a full complex of engineering services, including engineering researches, construction, deliveries, commissioning and putting into operation.

In 2012 the Company has been defined as the General Designer of the Smolenskaya NPP-2.

According to the State Corporation «Rosatom» decision the management contour of the JSC «Atomenergoproekt» in 2012 the JSC «NIKIMT-Atomstroy», JSC «Energospetsmontazh», JSC «VNIPIET», JSC «NPK Dedal», JSC SSMU «Lenatomstroy», JSC « SPb NIII «EIZ», JSC Siberian «Orgstroyproekt» have been included, that has allowed to expand and strengthen the Company engineering competence.

JSC»Atomenergoproekt» has developed a number of unique nuclear power plants designs of VVER technology, corresponding to all Russian and international safety requirements and the requirements certificated by the European Utility Requirements Club (EUR).

At present the JSC «Atomenergoproekt» as the General Designer has finished working out of standard optimized and information-based design of the power unit of VVER technology («VVER-TOI» Design). VVER-TOI is an evolutionary design executed in the modern information environment. In its basis the decisions of the «AES-2006» design improved on separate technical and economic parameters have been put.

The "VVER-TOI" Design, as the basic design for serial construction of power units of new generation, provides perfection of management by the NPP construction in Russia and increase of competitiveness of the Russian export offers at a foreign market. Design implementation will allow to lower expenses for designing, construction, operation, service and decommissioning of power units with VVER reactors, providing safety enhancement of the NPP, considering the events which have occurred at "Fukushima» Nuclear Power Plant.

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General features of the project

Design purposes:

- Working out of standard design of the NPP power unit of the big power, capable to compete to actively developing and recognized leaders in the field of nuclear power engineering on all indicators: regarding technical decisions, technical and economic characteristics of the power unit, decisions on safety, terms of the nuclear power plant construction;
- Creation and introduction during implementation of the design of modern information technologies of designing, design and management of the information on the object at all stages of its life cycle;
- Actualization of its normative-legal base regarding elimination of the positions which have become outdated and constraining the development for possibility of application in the Project of innovative technologies of designing and construction.



General features <u>o</u>f the projec







Basic results of «WER-TOI» Design implementation

- VVER technology power unit design of big power with competitive technical and economic characteristics has been developed. The Design documentation (DD) on the power unit and the project of the construction arrangement (POS) has been executed in the modern information environment (3D and multi-D designs);
- unique complex control system of the information on the power unit at design and construction stages has been created, allowing not only to carry out development and designing of the facility with the use of the most up-to-date information technologies, but also to exercise complex administration of the information on all components of the NPP power unit (directly from the power unit design in a 3D format, purchases and deliveries of the real equipment, management of terms, resources, cost at the nuclear power plant construction, before data verification and requirements management to the Design);
- complex of databases on the equipment and materials used at working out of the information model of the VVER-TOI power unit has been implemented;

 uniform information field for work of all Design participants (Design web portal) has been created;

- actualization of existing normative-legal base of the Russian Federation on elimination of the positions which have become outdated and constraining development for application possibility in the Design of new technologies of designing and construction has been performed;
- complete set of methodological documents necessary for work in the new information field, for the further duplicating of information system of the Design at nuclear power plant construction sites has been developed.

Basic directions of design decisions optimization:

general lay out and transport;

- technological decisions of the nuclear power plant main buildings and structures;
- NPP safety concept taking into account the experience of events at «Fukushima» nuclear power plant;
- architectural-construction and lay out decisions;
- electrotechnical and I&C decisions.

As a result of working out of optimizing technical decisions complex, in «VVER-TOI» Design it was possible to reach following values of technical and economic indicators which put the Design on the industry-leading positions at the world market. **Main design technical and economic indicators**

Characteristic name	Value
Service life: power unit, reactor plant, years	60
Power unit power, MW: – installed capacity (guarantee mode) – heat generation	1255 3312
Power unit gross efficiency (factor) for mid-annual conditions, %	37,9
Availability factor (at fuel cycle of 18 months),%	93
Possible range of power change (load-follow mode), %	100-50-100
DBE, points as per MSK-64 scale	7
SSE, points as per MSK-64 scale: – basic design – option (as per Customer requirement)	8 9 (до 0,41 g)
Aircraft crash: – design initiating event, t – beyond design basis initiating event, t	20 400
Auxiliary power consumption, %	6,47
Quantity of solid radioactive waste (SRW), generated at power unit operation (for one power unit)): – low level, m3/year – medium-active, m3/year – high-active, m3/year	30 14 0,5
Specific area of the occupied site, m2/MW	200
Construction period, months	48/40



Safety systems configuration

"VVER-TOI" Power Unit Safety Provision»

he special attention within the limits of the «VVER-TOI» Design implementation is assigned to safety increase of the power unit. In the design the full complex of the technical decisions is implemented, allowing to provide the NPP safety and exclude radioactive substances release above permitted norms in environment in the conditions of external (natural and technogenic) influences in combination with internal initiating events and additional failures.

The concept of safety provision is based on application of safety systems (SS), using different principles of operation: active and passive.

Thus, all safety functions are provided by independent operation of active and passive safety systems.

Safety systems of VVER-TOI power unit

HP active part of Emergency Core Cooling System (ECCS)	Two-channel active system (2 channels of 100 % each)
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System of emergency boron injection	Two-channel active system (2 channels of 100 % each)
System of emergency Steam Generator (SG) cooling down	Closed two-channel active system (2 channels of 100 % each)
ECCS Passive part (HA-1)	Passive four-channel system (4 channels of 33 % each)
System of core passive flooding (HA-2, HA-3)	Passive four-channel system (4 channels of 33 % each)
Passive Heat Removal System (PHRS)	Passive four-channel system (4 channels of 33 % each) with two air cooling heat exchangers in each channel
Annulus Passive Filtration System (PFS)	Annulus Passive Filtration System with filtration unit





Passive safety systems used in the «VVER-TOI» Design

Safety systems configuration



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Main technical decisions on safety systems

Emergency Core Cooling System (ECCS)

Active part of ECCS is intended for core coolant safety level maintenance in reactor plant and fuel pool and removal of residual heat emissions in modes with primary coolant leaks.

System of core passive flooding

The system of a passive core flooding is a passive part of Emergency Core Cooling System (ECCS), having in its structure **Hydro Accumulators (HAs)** of first, second and third stages.

Hydro Accumulators of 1st stage (HA-1) are necessary for reactor core emergency flooding by boric acid solution at primary pressure less than 5,9 MPa.

System of Hydro Accumulators of 2nd stage (HA-2) is intended for maintenance of primary coolant inventory necessary for reliable heat removal from reactor core at pressure drop in the primary circuit of less than 1,5 MPa.



System of Hydro Accumulators of 3rd stage (HA-3) is intended for maintenance of reactor core coolant level at Beyond Design Basis Accidents (BDBA) with primary coolant leaks and failure of active safety systems after depletion of boric solution reserve in HA-2



Emergency boron injection system

The system carries out reactor plant transit to subcritical state.

SGs Emergency cooling system

The system is intended to remove reactor core residual heat and cool down the RP in case of emergency, by condensing steam from SGs in the heat exchanger, cooled with intermediate circuit water, and condensate return to SGs.

Passive heat removal system

The Passive heat removal system is intended to ensure reactor residual heat long-term removal, including such removal when power sources (inclusive of emergency ones) are unavailable – both with tight and leaky primary circuit.





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Incorporation of external natural and anthropogenic impacts

Civil constructions of civil and structures, as well as equipment, processs pipelines, other lines and structures of VVER-TOI-based NPPs are designed to incorporate the possibility of resistance to seismic impacts up to 8

points, MSK 64 scale. To ensure the possibility of NPP construction at sites with higher seismic parameters, the possibility of resistance to seismic impacts up to 9 points, MSK 64 scale, is ensured, with no essential reconsideration of volumetric, planning, routing and other underlying design solutions.



Hurricanes, tornados. Design wind velocity: 56 m/s



Flooding, probability: > 0.01



Shock wave with front pressure 30 kPa



SSE seismic impact, intensity: 8 points, MSK-64 scale



AC (aircraft weight: 400 t; fall rate: 200 m/s)



AC protection

Among the design additional advantages are solutions, related to the resistance to AC-induced impacts; incorporated here are both crash of military aircraft (weight: 20 t) and crash of heavy-weight (up to 400 t) airplane.

The developed arrangement solutions provide the decrease in dynamic impact on equipment installed inside the reactor building and radioactive material non-escape to atmosphere.

To this effect, external fencing structures are separated, with contraction joint and the annulus, from the building internal structures, so that rule out dynamic impact direct transfer to NPP components and internal structures.

Hydrogen explosion protection

Envisaged as per "VVER-TOI" design are localizing systems, providing protection against hydrogen explosion; moreover, measures are elaborated to prevent the accumulation of explosive mixtures. The RP building consists of two containments as follows: primary, made of prestressed reinforced concrete and designed to withstand internal pressure 0.4 MPa, with reliability coefficient 1.5 and inner tight steel lining; and secondary, made of reinforced concrete and designed to withstand external anthropogenic and natural impacts. Installed inside the primary containment are passive recombiners for hydrogen catalytic burning, designed to prevent hydrogen content buildup to dangerous concentration in all the emergency modes, inclusive of BDBA.

Thus, both possible hydrogen explosion and reactor building damage are excluded. Hence, any possibility of excessive radioactive material escape to atmosphere is ruled out.

Additional protection is provided by the annulus atmosphere rarefaction with the use of both active and passive systems (Annulus passive filtration system).



Reactor corium confinement and cooling system

To confine radioactive materials within localization boundaries, the Corium catcher (CC) is installed in the Reactor cavity. The CC is intended to confine and cool the corium in case of severe BDBAs, fraught with reactor code damage.

The catcher provides the protective barrier integrity retaining and thus rules out radioactive material release to atmosphere even in case of hypothetic BDBAs.

Improvement of WER-TOI power unit stability to extreme impacts

To improve NPP resistance to low-probability hypothetic events, like those at "Fukushima" NPP, and extend NPP self-sufficiency period in case of BDBA, "VVER-TOI" design envisages the implementation of some additional engineering measures, intended, first of all, to ensure heat removal from Fuel pond (FP) and pressure buildup limitation inside the containment.

To extend NPP self-sufficiency period in case of initiating events, related to the primary circuit untightness, certain measures have been taken to provide reactor make-up with an eye towards the core heat removal, through the use of alternative circuit for heat removal to outer atmosphere, and by involvement of available safety equipment and additional engineered features (see the figure below). Envisaged as well is long-term monitoring of safety and other parameters, enabling to obtain actual information on power unit current state.



Probabilistic safety assessment

Based upon adopted solutions as to "VVER-TOI" power unit safety assurance, the Probabilistic safety assessment (PSA) was done.

Proceeding from the values obtained as per the PSA, it can be concluded that a higher safety level is provided for "VVER-TOI" design, as compared with other designs, particularly, allowing for conservative approach to BDBA initiating events occurrence assessment.



Moreover, assessment results are sufficient to affirm that the Technical assignment requirement for the Core damage occurrence is met with an appreciable margin.



"VVER-TOI" NPP construction plan

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he "VVER-TOI"-based NPP construction plan was developed so that to ensure construction pace acceleration and thus provide 48-month period for the main power unit construction, with serial unit constructed within 40 months.

All the underlying solutions, pertaining to "VVER-TOI"-based NPP construction organization, as well as construction practices applied, are intended to reduce labor inputs, shorten construction period and reduce the number of civil and production personnel employed. The construction plan development involved the determination of civil-and-erection duration and labor inputs, work processes and procedures, and the number of personnel employed.

Listed below are underlying principles of "VVER-TOI"based NPP construction:

- transfer of major labor inputs, related to NPP construction, to shop conditions (minimal amount of site fabrication of components);
- supply of ready-to-install equipment assemblies and spools from shop to site;
- concurrent installation of capital equipment with the use of high-capacity building cranes;
- automatic and robotized welding methods;
- possibility of fabrication of large-size wall/floor reinforcing systems with permanent formwork, with coupled connections and installed embedded parts and penetrations, ready for concreting;
- use of self-compacting concretes to practically exclude labor inputs for newly placed concrete vibration;
- use of high-capacity building cranes and transportation facilities capable of handling large-size heavy blocks;



- timely procurement of materials, structures and equipment;
- nearly full-scope construction of civil-and-erection facilities half a year prior to foundation slab concreting commencement, so that to ensure the completion of the first-year civil-and-erection works;
- production line method of construction;
- full-amount WD issuance prior to related work commencement;
- availability of skilled civil-and-erection personnel.

The "VVER-TOI" design implementation involved the tune-up of information system for the construction plan development, so that ensure civil-and-erection works visualization and optimize construction management. Moreover, simulators were developed, as well as exemplary video guides to train civil-and-erection personnel, e.g., the unique IT-simulator of tower crane was designed and constructed for training crane operators.

Developed as well are civil-and-erection works visualization tools to demonstrate civil-and-erection progress in time.



Regulatory and legal 20

Regulatory and legal framework updating

o optimize the current RF Regulatory and legal framework, certain currently applicable Regulatory documents were analyzed and updated within the "VVER-TOI" design. The documents of the following types were affected:

- Regulatory and technical documents, related to the strength, longevity and useful life of equipment/ pipeline components.
- Regulatory and technical documents, related to NPP operation technical control.
- Russian codes and rules on the whole, in terms of harmonization with IAEA standards.
- Regulatory and technical documents on NPP civil design



- Regulatory and technical documents on fire safety.
- Standards on Design and Working documentation, development, draw-up and turn-over, with the use of state-of-the-art information technologies.

Updated draft versions of documents as above are currently under approval with supervisory authorities concerned.

Modern information technologies in "VVER-TOI" Design

mong top-priority tasks, successfully implemented in "VVER-TOI" Design, was the development of innovative technologies. providing the Design implementation in stateof-the-art information environment, with the possibility of data management throughout the power unit life cycle. The one-off integrated system of power unit data management with no analogs worldwide has been developed within the Design under the guidance of JSC "Atomenergoproekt". Entire Design data accumulation within the integrated information environment turned out conductive for appreciable increase in the quality of design efforts, development of standardized engineering and arrangement solutions, and creation of the single information-based model of invariable design section, available for replication at different NPP sites.













The developed information system enables integrated data management with respect to all the components of NPP unit (starting from the power unit 3D model, data retrieval from the power unit information-based model with the view of Design and Working documentation development, manufactured equipment purchase and supply, schedule control, NPP construction cost and resource management, and onwards, up to data verification and control of requirements for the Design).

The Design information-based system core component is the engineering data management system, enabling design data accumulation, storage and loss-free transfer, with no re-entry, throughout the power unit life cycle, starting from design basis up to the project de-commissioning.

Fata exchange between territorially separated Design participants was implemented on the basis of the integrated Web-portal, as well intended to ensure access to the power unit information-based model, reporting documentation archive keeping, and Design management processes.

Advantages of NPP unit designing with the use of information-based model

- Data loss-free exchange at different stages of NPP life cycle, with no re-entry.
- Issued design documentation quality improvement due to optimization of circuitry and arrangement solutions.
- Set-up of system for modification management in course of project design and construction.
- Power unit design and construction period reduction.
- Set-up of system for the management of design deviations at project construction stage.
- Optimized utilization of manpower and financial resources.
- Design and construction management optimization.

Conclusion

he "VVER-TOI" Design has been developed to integrate the optimal information solutions and engineering approaches, elaborated of late by JSC "Atomenergoproekt" experts. Inherent in the Design are appreciable improvement of basic performance and cost parameters as compared to reference design "AES-2006", as well as incorporation of more stringent safety requirements; it is noteworthy that the developed design solutions enable reduce VVER-TOI-based NPP construction cost and shorten construction period thereof. The integrated power unit data management system, developed within the Design framework, is in fact one-off solution with no analogs worldwide.

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The following tasks are currently under implementation by JSC "Atomenergoproekt" within the framework of "VVER-TOI" Design development:

- Obtaining of solution as to "VVER-TOI" design applicability for NPP construction licensing from "Rostekhnodzor";
- Design international certification with IAEA and EUR;
- "VVER-TOI" basic design configuration management with the view to replication for particular NPP sites;
- Development of invariable design sections for "Nizhny Novgorod", "Kursk-2", and "Smolensk-2" NPPs on the basis of "VVER-TOI" prototype design.



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