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Computer Codes for HTGR Verification and Validation

Multinational Design Evaluation Programme (MDEP), High-Temperature Gas-Cooled Reactor (HTGR) Workshop, 18-20 March 2024, Online

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Objectives and Structure

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Objectives

1. Introduce the main stages of verification, validation and certification of computer codes in the Russian Federation.
2. Introduce a progress report on verification and validation of computer codes used for HTGR design justification.

Report Structure

1. Terms and Definitions
2. General provisions
3. Certification procedure
4. Requirements for verification materials
5. HTGR computer codes
6. Examples of experimental data used for code validation
7. Panned experiments for code validation

Terms and Definitions

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Computer code certification[1] is a regulated procedure aimed at recognizing that a computer code can be used in the declared application area and that the code can provide the values of design parameters with a certain error

Computer code verification[2] is a process aimed at verifying that a computer code operates properly without programming errors

Computer code validation[2] is a process aimed at justifying that a computer code adequately simulates a physical phenomenon and at estimating the error of computational analysis results by comparing the specified calculation results with measurements taken at experimental facilities

Computer code cross-verification[2] is a process aimed at contrasting the computer code calculation results with calculation results obtained from an already-certified computer code

1 НП-001-15 **Federal rules and regulations in nuclear energy use "General regulations for ensuring safety of nuclear power plants"**

2 РБ-166-20 Recommendations for the assessment of errors and uncertainties in the results of calculated safety analyses of nuclear power plants

General Provisions

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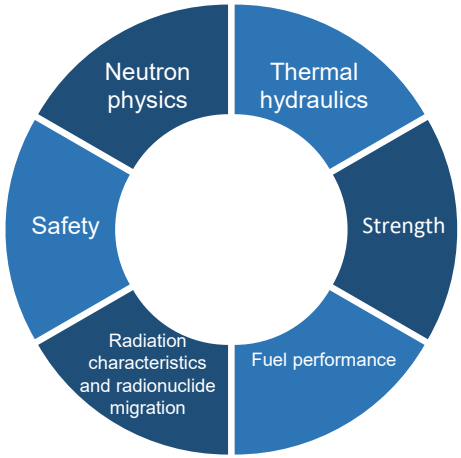
- Reactor
- Reactor unit
- Reactor Core
- Heat-exchanging equipment (HT-IHX, HT-PHX, SG)
- Circulation compressors (Primary Circulation Compressor, Circulation Compressor)
- Reactor cavity cooling system
- Shutdown cooling system (SCS)
- CPS



Regulatory Documentation Requirements

According to the requirements set forth in the Federal rules and regulations in the field of nuclear energy use and in compliance with licensing conditions for designing and engineering of nuclear facilities, all programs used for justifying and ensuring the safety of nuclear facilities shall be certified.

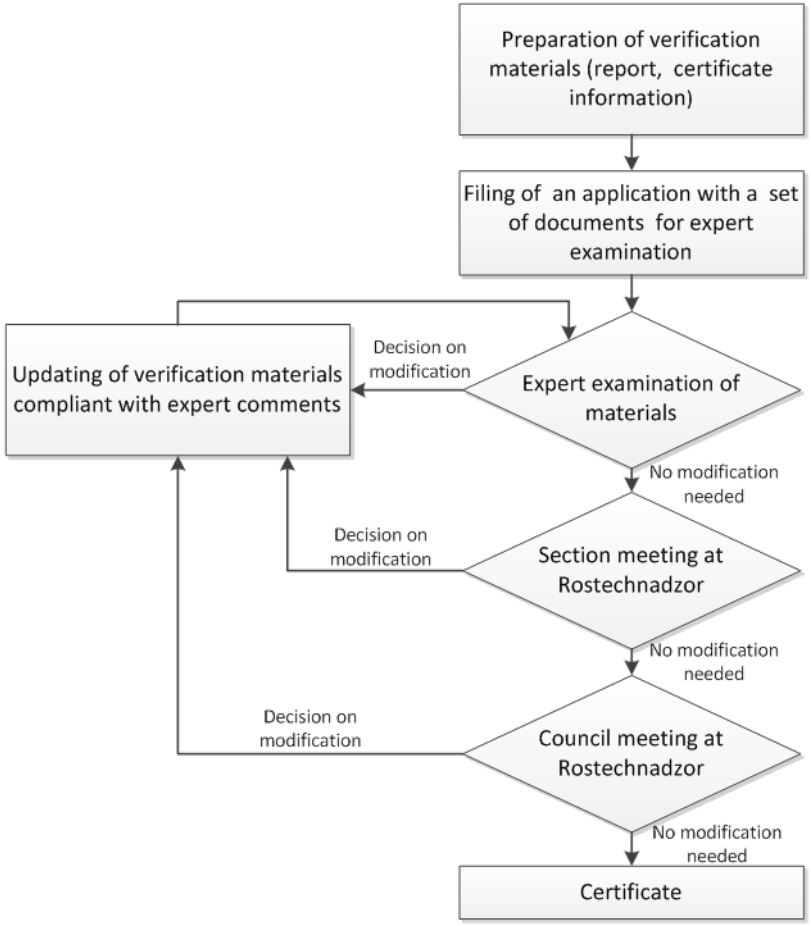
The requirements for code verification and certification are given in the documents below:

- No. 170-ФЗ “On Nuclear Energy Use”;
- НП-001-15 “General Safety Provisions for Nuclear Power Plants”;
- НП-082-07 “Nuclear Safety Rules for Reactor Installations of Nuclear Power Plants”.

Objective

The objective of the certification procedure is to assess the possibility of using the computer code in the declared application area in order to develop computational models of processes that affect the safety of nuclear power facilities.

Certification Procedure



- SEC NRS acting on behalf of Rostechnadzor is responsible for code certification.
- SEC NRS-based Expert Council jointly with its sections for different areas is responsible for code certification. The Council and sections are made up of leading specialists from industry organizations, institutes of the Russian Academy of Sciences, universities, and SEC NRS.
- The code is reviewed and its certificate is prepared compliant with the "Procedure for expert examination of computer codes...";
- For expert examination of a code, its verification materials are prepared and sent to Federal Budgetary Institution SEC NRS.

Requirements for Verification Materials

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List of main documents for expert examination

- An application for expert examination of a computer code;
- A document verifying exclusive or nonexclusive rights to use a computer code;
- A computer code verification report;
- Materials required for a computer code testing;
- Information on the computer code application area to be reflected in the certificate.

Computer code verification report is the main substantiating document and it is drafted compliant with the “Procedure for expert examination of computer codes...”

<u>Verification and validation activities are carried out based on:</u>

1. A benchmark with analytical and theoretical solutions;
2. A benchmark with similar results obtained from previously certified codes (cross-verification);
3. A benchmark with the results of experimental studies;
4. A benchmark with the data obtained at reactor plants.

HTGR Computer Codes (1)

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Computer Code	Scope of Application	Verification and Certification Status
Neutron Physics		
MCU-HTR	Calculation of neutronic characteristics of the reactor and/or its components in real three-dimensional geometry using the Monte Carlo method	The code has been verified and reviewed by experts in SEC NRS 
JAR-HTR	Calculation of reactor core and reactor neutronic characteristics	The code has been verified and reviewed by experts in SEC NRS 
JARWT software package	Combined neutronic and thermal-hydraulic analysis of a reactor with burnup level	The code has been verified and reviewed by experts in SEC NRS 
PRIZMA and RISK package	Calculations of neutron transport and nuclide kinetics	Verified, certified 
Thermal Hydraulics		
ANSYS	Heat transfer in reactor components and reactor plant equipment, heat transfer by radiation between reactor components	Verified, certified 
FlowVision	Thermal hydraulics of gas coolant, heat transfer by radiation between reactor components, mixing of different-temperature coolant flows, natural circulation of coolant	Verified, certified 
Piping Systems Fluid Flow	Hydraulic analyses of reactor cooling circuits and cooling systems	Verified, certified 

HTGR Computer Codes (2)

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Computer Code	Scope of Application	Verification and Certification Status
Strength		
ANSYS	Stress-strain state and natural frequencies of the reactor plant vessel and in-vessel equipment under static and dynamic loadings	Verified, recertification procedure in progress 
DINARA	Loads produced by external dynamic (seismic) effects acting on the pressure vessel unit and in-vessel equipment	Verified, certified 
DELTA	Selecting the basic dimensions, resistance of components of the reactor plant equipment and pipelines operating under pressure	Verified, certified 
Fuel Performance		
ASTRA+Manag9	Calculation of molecular-phase structure of fuel, pressure under protective shells of fuel particles	Verification report under development 
GOLT-v3	Analyses of fuel particle thermal and mechanical properties, and of fuel particle fracture probability	Verification report under development 
UZOR 1.0	Analysis of fuel compact thermal and mechanical properties. Calculation of kinetics of shape change and stress-strain state of graphite stack blocks and fuel assembly stack in the core under conditions of external loads, thermomechanical loads induced by neutron irradiation	Verified, recertification procedure in progress 

HTGR Computer Codes (3)

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Computer Code	Scope of Application	Verification and Certification Status
Radiation Characteristics and Radionuclide Migration		
DORT	2D calculations of reactor biological shielding	The code has been verified and reviewed by experts in SEC NRS 
TORT	3D calculations of reactor biological shielding	The code has been verified and reviewed by experts in SEC NRS 
ORIGEN	Calculation of radiation characteristics	The code has been verified and reviewed by experts in SEC NRS 
HEZ	Calculation of ingress, transport and migration between circuits of fission products, tritium, and graphite dust.	Preparation of materials for verification report is in progress 
Safety		
VIBROS 2.2	Radiation conditions at the place of location in cases when radioactive substances are released into the atmosphere	Verified, certified 
CRISS 6.0	System reliability analysis and probabilistic safety analysis	Verified, certified 
RASNAR-GAZ	Calculation of transient and emergency modes of a reactor plant with a high-temperature gas-cooled reactor	The code has been verified and reviewed by experts in SEC NRS 

Examples of Experimental Data Used for Code Validation (1)

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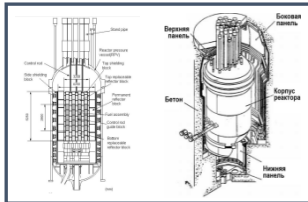
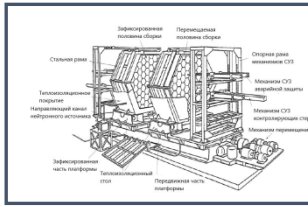
	Experimental studies performed at the critical test facility ASTRA (Russia) [*neutron physics*]
	Benchmarks based on experimental studies performed at the HTTR reactor (Japan)[1,2] [*neutron physics, thermal hydraulics, safety*]
	Benchmark based on experimental studies performed at the VHTRC Critical Assembly (Japan)[3] [*neutron physics*]

1 Evaluation of high temperature gas cooled reactor performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, IAEA – TECDOC – 1382, 2003.

2 International Handbook of Evaluated Criticality Safety Benchmark Experiments, HTTR-GCR-RESR-001, 002, 003, 2013.

3 Yasuda H., Yamane T., Sasa T. VHTRC Temperature Coefficient Benchmark Problem, JAERI-DATA/Code 94-013, 1994.

Examples of Experimental Data Used for Code Validation (2)

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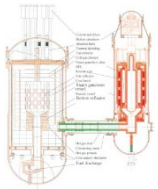
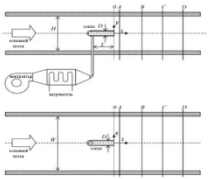


Benchmark based on experimental studies performed at the HTR-10 reactor (China)[1,2] [*neutron physics, safety*]



Experimental studies of mixing different-temperature gas flows (Italy)[3] [*thermal hydraulics*]

Experimental studies performed in the helium loop of HE-FUS 3 (Italy)[4,5] *[safety]*

1 International Handbook of Evaluated Criticality Safety Benchmark Experiments, IEU-COMP-THERM-010-001, 2007.

2 Benchmark Problem of the HTR-10 Control Rod Withdrawal without Scram (Ver. 2003-12).

3 F. Satta, G. Tanda. Aerodynamic and thermal characteristics of a hot jet in parallel flow. Journal of Applied Fluid Mechanics, Vol. 9, No. 5, pp. 2105-2110-2016.

4 P. Meloni, F.S. Nitti, “Pre-Test Analysis for an Experimental Campaign in the Upgraded HE-FUS3 Loop”, ENEA Reports, 2010.

5 P. Meloni, M. Polidori, “HE-FUS3 Experimental Campaign for the Assessment of Thermal-Hydraulic Codes: Post-Test Analysis”, ENEA Reports, 2009.

Planned Experiments for Code Validation

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As part of the R&D program, it has been planned to obtain new experimental data aimed at verification and validation of computer codes for HTGR.

For example, the following experiments studying thermal-hydraulic processes have been planned and are in progress.

- Experimental studies of HTGR CPS absorber rods characteristics [thermal hydraulics]
- Experimental studies of HTGR heat-exchange equipment models [thermal hydraulics]
- Experimental studies of nonisothermal gas flows mixing in the HTGR lower plenum [thermal hydraulics]

Conclusion

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The main stages and requirements for verification, validation and certification of computer codes adopted in the Russian Federation compliant with the requirements set forth in the regulatory documentation are described.

Summarized data on the computer codes used for the HTGR design. Progress analysis was performed for verification and certification of the codes. A list of 20 computer codes has been compiled for thermal-hydraulic, strength, and neutronic calculations, analyses of radiation characteristics, radionuclide transport, fuel performance and safety.

Information on the experimental data and benchmarks applied to validate the computer codes, as well as information on the planned experiments and the new ones in progress under the HTGR project.

Thank you for your attention!

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