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R&D for Design Substantiation of a Nuclear Process and Power Station with HTGR

MDEP High-Temperature Gas-Cooled Reactor (HTGR) Workshop

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General Information on the Design of NPPS with HTGR and CPP

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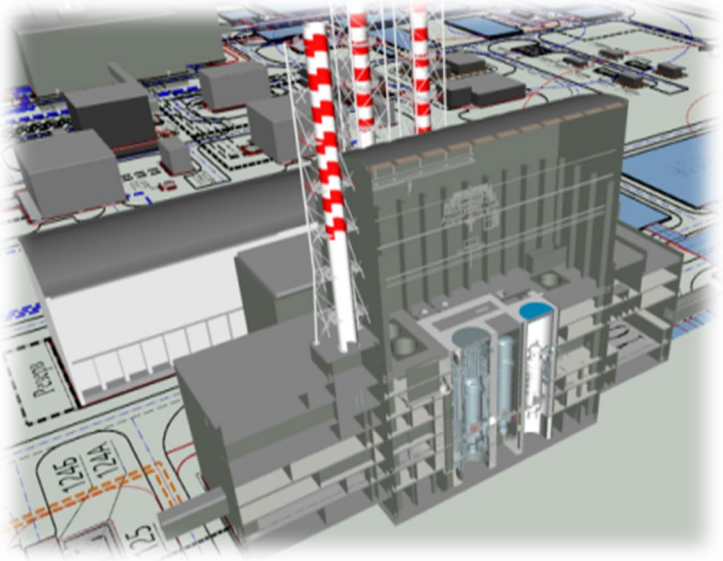
DEVELOPMENT OBJECTIVE: A large-scale production of hydrogen containing products powered by a Nuclear Power and Process Station (NPPS) with HTGR and net-zero CO_2 emissions

Commissioning of the first pilot demonstration unit as part of the FOAK NPPS in 2035

- demonstrate a large-scale production of hydrogen-containing products with net-zero CO_2 emissions
- justify the HTGR safe integration with a hydrogen production chemical plant
- gain experience in licensing of a new type of nuclear power stations operated for power and process sector



Status of R&D on HTGR reactor plant and NPPS

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- A detailed design of HTGR reactor plant main equipment has been developed along with the design analytical substantiation; the safety analysis has been prepared,
- The main computer codes have been verified,
- The capability of equipment manufacturing has been confirmed,
- The R&D stages focused on justifying the qualification of fuel, graphite, composites and metallic materials intended for high temperatures have been performed,
- The main engineering solutions for NPPS have been elaborated and the PSAR documentation has been developed,
- An integrated programme for analytical and experimental development has been set up,

Status of R&D for RSS absorber elements and burnable absorber compact

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- Draft technical specification for the Reserve Shutdown System (RSS) absorber elements has been developed.
- Manufacturing technologies have been mastered followed by fabrication of preproduction models of RSS absorber elements
- The characteristics of RSS absorber element preproduction models have been studied (such as geometry, absorber volume fraction, matrix density, and strength).
- Burnable absorber compacts with different ratios of natural and artificial graphite have been manufactured and studied.
- The technology of burnable absorber compact manufacturing has been optimized, which resulted in shorter manufacturing time and lower reject rate.
- The Terms of Reference for industrial equipment intended for burnable absorber compact manufacturing have been prepared.

Blanks for small balls made of boron carbide

Burnable absorber

Status of R&D for Fuel

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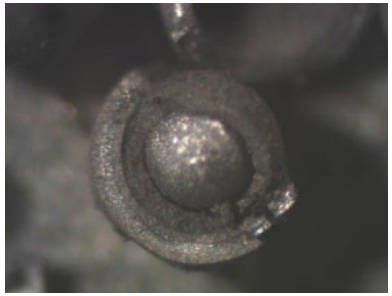
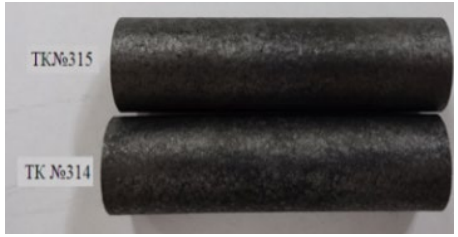
- The list of procedures and approaches that ensure qualification of coated fuel particles, fuel compacts and graphite materials has been drawn up.
- Fuel compacts intended for irradiation tests and examinations have been manufactured.
- Irradiation tests of coated fuel particles and compacts have been performed. The results of preproduction model irradiation tests have demonstrated the performance of coated fuel particle design with burnup levels close to design-basis values.
- Data on optimizing the manufacturing technology have been obtained based on the results of pre-irradiation and post-irradiation examinations of fuel particles and compacts.
- The technology of uranium recycling during scrap and debris reprocessing during steps of fuel manufacturing has been experimentally justified.
- Recommendations on production scaling have been formulated.



Coated Fuel Particle



Fuel Compacts

R&D Status for Reactor-Grade Graphite

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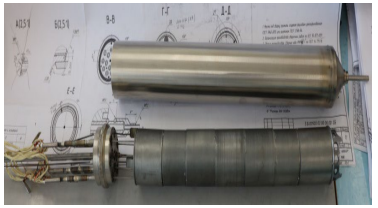
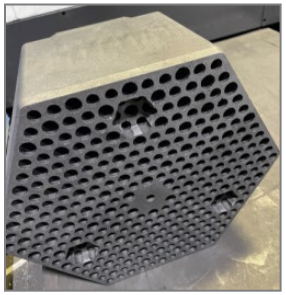
- Irradiation tests of **experimental graphite samples** and **sealed (bonded) graphite compounds** at temperatures in the range of (828-972) °C have been completed. The design value of neutron fluence (E>0.18 MeV) on the samples was achieved;
- Post-irradiation examinations of experimental graphite samples have been finalized;
- Samples of large-size block-type reactor-grade graphite have been manufactured for irradiation tests, pre-irradiation and post-irradiation examinations;
- Pre-irradiation examinations of large-size block-type graphite samples have been performed (concerning graphite physical appearance, integrity, size, mass, density, dynamic modulus of elasticity, temperature coefficient of linear expansion, thermal diffusivity, specific heat capacity, strength limits). All values meet the requirements;
- **A graphite block mockup has been manufactured;**
- The technology of manufacturing large-size block-type reactor-grade graphite for HTGR is under further development.



Testing of graphite samples, a capsule with samples prepared for irradiation



Graphite block mockup

Large-sized block

Status of R&D on High-Temperature Materials

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- Qualification tests have been performed for advanced heat-resistant alloy and its welded joints made by argon-arc welding. The total time frame of the tests exceeds 7000 hours. The maximum test duration is 3500 hours.
- Coated welding electrodes have been developed to weld parts made of ХН55МВЦ grade alloy between each other and parts made of 08Х18Н10Т and 12Х18Н10Т grade steel. Additionally, a draft of technical specifications for a pilot batch of coated welding electrodes has been developed.
- Process documentation has been developed for manufacturing of the required range made of ХН55МВЦ grade alloy.
- Draft technical specifications for the required range made of ХН55МВЦ grade alloy have been formalized.

Alloy billets

Welding of the qualification sample from rolled sheets

ЧС57 alloy samples after testing

Samples of the welded joints after testing

R&D Status for the Chemical Process Part

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- Laboratory studies of catalysts for steam and steam-oxygen methane reforming, mid/low temperature reforming were carried out; various operation modes of the process flow intended for hydrogen production and of separate units have been tried out;

- FEED materials on the CPP concept have been developed, including the process flow, preliminary designs for non-standard equipment, safety analysis of the natural gas reforming unit was performed using HAZOP and SIL procedures, the shock wave pressures on the HTGR reactor building during explosions of individual CPP units have been analyzed, and a preliminary scheme of the CPP master plan has been drawn up.

Laboratory-scale test facility

Membrane unit of the laboratory-scale test facility

R&D Status for Hydrogen Safety

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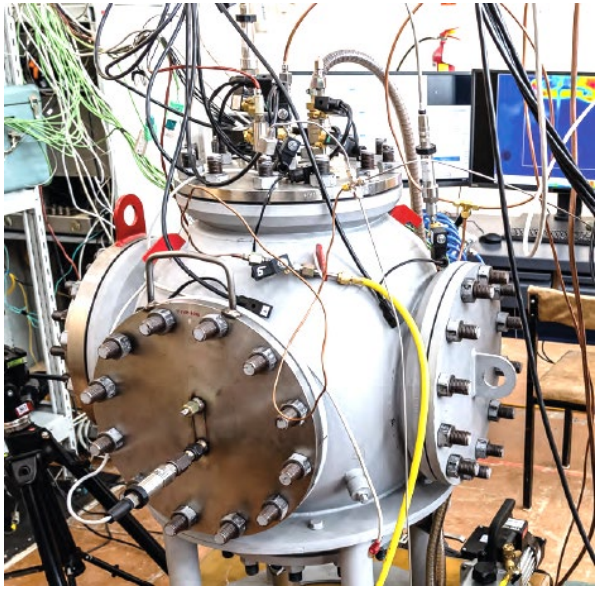
- A database of experimental data for verification of computational models has been created.
- Software ensuring work with the experimental database has been developed.
- Procedures and models for quantitative safety analysis have been evolved.
- Proposals have been worked out concerning draft regulations, harmonized with the international approach and aimed at safety assurance of hydrogen energy.



Regulatory Provisions for the NPPS Design with HTGR and CPP

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The design of the HTGR reactor plant has been developed on the basis of the existing regulatory framework for NPPs

Inter-Industry Working Group

Objectives:

- analyze the sufficiency of the Russian legislation, of the requirements set forth in the federal rules and regulations
- provide regulatory framework for the NPPS design development

- ☑ The reactor plant design documentation has been analyzed for compliance with the regulatory requirements. The identified deviations mainly relate to the type of fuel and coolant.
- ☑ The applicability of the requirements of most federal rules and regulations has been confirmed;
- ☑ Taking into account the specific features of the HTGR reactor plant design, the following has been formulated:
  - proposals for amendments to the key federal rules and regulations;
  - proposals for the development of new federal rules and regulations.

Conclusion

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- Hydrogen energy development is under the State Control.
- The level of technology readiness and the existing cooperation of key equipment developers enable the use of the production facilities available in the Russian Federation.
- R&D work has been deployed in the following key areas:
  - tryout of technology aimed at manufacturing of fuel and key components of the reactor core;
  - high-temperature materials and reactor-grade graphite;
  - obtaining of properties and characteristics of heat-resistant alloy and graphite followed by qualification activities;
  - computer code verification and qualification.
- The integrated programme for analytical and experimental development has been worked out to confirm the operability and design characteristics of the equipment within the framework of bench tests.
- The detailed design of the HTGR reactor plant has been developed compliant with the requirements of modern rules and regulations for the nuclear installations. The identified deviations mainly relate to the type of fuel and coolant. The work on amendments to federal rules and regulations / development of new federal rules and regulations has been organized.

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Thank you
for your attention

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