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Prospects of VVER-SKD reactor in a closed fuel cycle

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Abstract

At the new centure's begin eight countries with developed nuclear power industry took part under the aegis of the IAEA in research of innovative nuclear reactors and fuel cycles to choose a nuclear power system with fast reactors based on a closed fuel cycle (CFC) and to perform joint R&D in this direction. An agreement was reached on the use of based on proven technologies CNFC-FR (Closed Nuclear Fuel Cycles and Fast Reactors), as a reference system for common assessment.

Common principles, however, did not eliminate among participating countries essential discrepancies neither in existing nuclear power systems nor in development strategies, which has led to discrepancies in implementation of CFC. Gas and lead coolant are proposed along with sodium, and nitride (more dense) as well as metallic fuel – along with MOX, so the different fuel cycles.

Since 2000, IV-generation reactors cooled with water at supercritical state (SCWR – Supercritical Water-Cooled Reactors) are developed in many countries. Construction of demonstration facilities are planned to 2025, followed by commercial nuclear power systems. Development of SCWR will correct the development of nuclear power industry strategy and the CFC in several countries.

This paper considers characteristics of CFC implementation in Russia, milestones, dates, problems arising. The use of fast neutron spectrum SCWR reactors within CFC is justified.

Keywords: International forum Gen-IV; Fast reactor; Sodium; Lead; Supercritical water; MOX fuel; Closed fuel cycle; Spent nuclear fuel; Transmutation of minor actinides.

Introduction

In January 2000, the "International forum Generation-IV" (GIF) was started by the USA Department of Energy (DOE), with the aim to initiate and steer R&D on nuclear power facilities of fourth generation, by identifying potential fields of international cooperation [1].

Main directions of R&D for gen-IV reactors are defined by the goal of GIF, which is to provide:

- sustainable development to satisfy society's energy demand without damaging the natural environment, by ecologically rational generation of energy and long-lasting nuclear fuel together with decrease of nuclear waste amount;
- safety and reliability of nuclear power facilities, guarantying exceptionally low probability and degree of core damage;
- economical competitiveness of nuclear power facilities, because of beneficial lifecycle cost as compared to another energy sources, and due to level of financial risk, comparable to other energy projects;
- nonproliferation of nuclear weapon and nuclear weapon materials, together with improvement of physical protection against terrorism [2].

The assessment has been made by a group of 100 experts – leading specialists in nuclear power engineering – resulted in a choice of six base concepts of gen-IV reactors, to be developed in the framework of GIF. In the present work only three of them, developed to the most extent, are considered: sodium-cooled reactors (SFR), lead-cooled (LFR) and reactors with supercritical water (SCWR).

Another research was conducted (2005–2007) under the direction of IAEA, the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), with participation of eight

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countries with developed nuclear power. The task was to define a nuclear power system based on a closed fuel cycle (CFC) with fast-spectrum reactors, milestones and dates of its implementation, and to identify fields of cooperate R&D. The participating countries agreed to apply as a reference for comparison the "reference system" CNFC-FR (Closed Nuclear Fuel Cycles and Fast Reactors), ready for deployment in next 20–30 years and based on proven technologies of sodium coolant, pellet MOX fuel and improved technology of water treatment [3].

Both above mentioned programs aimed to identify promising directions of nuclear power future development, taking into account the necessity to close the fuel cycle and organization of international cooperation for solving the above mentioned problems.

One of the promising gen-IV reactors identified in the GIF program, is the supercritical water (SCW) cooled reactor, SCWR. Conceptual designs of SCWR are being elaborated by more than 45 organizations in 16 countries with developed nuclear power.

Starting 2000, the international symposium on supercritical water-cooled reactors is organized every two years, with about 100 contributions (presentations). The most recent, ISSCWR-7 was held in Helsinki, on 15–18 March 2015.

The SCWR concept is based on the once through coolant scheme, with SCW as coolant. Implementation of such reactor will increase the thermal efficiency factor up to 44–45%, increase fuel breeding ratio, decrease metal intensity and amount of construction, and enhance ecology.

The countries participating in SCWR development within GIF consider the development of a reactor with thermal neutron spectrum based on existing experience with PWR and BWR, as a top-priority task. On the next stages, after technology has been settled, transition to fast-spectrum reactor is assumed.

A thermal-spectrum SCWR is characterized by significantly improved plant economy, requires however enriched uranium that is followed by increased amount of spent fuel and minor actinides. In general, such a reactor will not satisfy one of the far goals – the closing of fuel cycle.

Development of SCWR raises several scientific and technical problems to solve, such as:

- Development and verification of neutronics, hydrodynamics and thermal physics computational codes specific to SCW,for fuel assembly (FA) and whole reactor core.
- Design of fuel pins and assemblies and justification of its operational availability.
- Analysis of reactor stability at normal operation and during accident transients.
- Choice of high-temperature resistant materials for fuel pins, featuring high corrosion- and crack resistance.
- Justification and development of optimal water chemistry regime.

Some problems are investigated at stand and loop experimental facilities, however, to solve the bunch of problems as a whole, to justify the SCWR technology and for later licensing, an experimental test facility is needed.

In the GIF roadmap, the main effort for the next 10 years targets the development of a small-power experimental reactor. The completion of the concept design is planned for the first 5 years, while for the next 5 years – detailed design and construction of the facility.

Present work describes characteristics of nuclear power development in Russia and prospects of gen-IV reactors applied to CFC, milestones, dates of implementation and problems arising. The SCWR development prospects and their use in CFC-based nuclear power systems are justified.

Characteristics of nuclear power development and closure of fuel cycle in Russia

An increase of nuclear energy fraction is planned from 16% (23 GWel) to 25% (80 GWel) to 2050, in order to decrease fossil fuel consumption.

Possible programs with commissioning of 1,2 GWel/year (one BN-1200 per year) are considered, together withconstruction and commissioning of the BREST lead-cooled reactors.

Peculiar is the concept of on-site fuel cycle facility, including non-aqueous treatment of MOX, nitride and metal fuel including vibrocompaction.

The goals of such a program is to develop the nuclear power system that includes sodium- and lead-cooled NPPs with fast neutron spectra, nuclear fuel recycling (reprocessing) and refabricating facilities, removal of radioactive wastes from the technological cycle, that meets the following requirements:

- Elimination of accidents requiring evacuation and relocation of inhabitants.
- Closure of nuclear fuel cycle to full utilization of uranium energy potential.
- Technological foundation of nonproliferation (subsequent rejection on uranium enrichment in nuclear power industry, weapon Pu breeding in blankets and isolation during radwaste handling, shortening of nuclear material transportation).
- Reaching a balance between radioactivity of disposed radwaste and mined uranium.
- Fast reactor NPPs capital cost reduction (at least to the level of fossil-fueled power plants) due to technological and design solutions inherent to fast neutron reactors only.

The following implementation plan of major components of this system is assumed [4,5].

The BN-800 reactor is commissioned in 2014, supplemented to 2017 with the 1st stage of the on-site nuclear fuel cycle facility for MOX, and to 2020 – for nitride fuel. The BREST-OD-300 detailed project design shall be ready to 2016, and it shall be constructed, together with its on-site fuel cycle facility for nitride fuel, to 2020. Completion of the whole platform, including BN-1200, is planned to 2025.

Major parts of the fuel cycle shall be located on two sites: at the Beloyarsk NPP with BN-600 and BN-800 reactors, where the BN-1200 reactor and its on-site fuel cycle facility is planned, and in Seversk on the site of "Siberian Chemical Combine" (SKhK),