WWR-K Reactor Safety Reassessment

Sh. Gizatulin, Ye. Kenzhin, D. Nakipov, D. Nugumanov, B. Nurgozhayev, A. Shaimerdenov, M. Tulegenov

The Institute of Nuclear Physics, Ministry of Energy,
1 Ibragimov st., 050032, Almaty - Republic of Kazakhstan

Abstract. WWR-K reactor is a unique multipurpose research reactor in the Republic of Kazakhstan. The first physical start-up of the WWR-K reactor had been carried out in October of 1967. WWR-K is a water-water heterogenic reactor with thermal neutrons and design power of 10 MWt and U-235 enrichment of 36 %. It worked without any deviations and emergencies till 1988. After Chernobyl accident in April of 1988 it was adopted by regulatory body of the former Soviet Union the decision to shutdown it permanently in order to carry out works on enhancing of seismic safety of the reactor. Since 1998 the reactor had been put into commission at the power 6 MWt. Since 2003 it was began feasibility studies on conversion from high enriched uranium fuel to low enriched uranium fuel with preservation of operation and experimental features. As a result of these studies it had been designed a new fuel assembly named after VVR-KN. A new reactor core had been elaborated. Life test of three lead test assemblies was carried out and it was reached more 50% of U-235 their burnup. Conversion of the reactor had being carried out within the framework of the IAEA program “Russian Research Reactor Fuel Return” and the International Program on Reduced Enrichment for Research and Test Reactors (RERTR). Taking into account Fukushima Daiichi Accident it had been adopted the decision alongside with the conversion to carry out modernization of the reactor systems under the abovementioned programs. I&C, emergency cooling, emergency core sprinkling, primary cooling, secondary cooling, radiation monitoring, gas and aerosol emissions monitoring systems have been modernized. Physical and power startups of the reactor had been successfully carried out in the first half of 2016. Since September of 2016 the WWR-K reactor operation with low enriched uranium fuel was started.

1. WWR-K reactor safety reassessment in the light of the accident at the Fukushima NPP

The largest radiation accident at the Fukushima-1 of the maximum 7 point level according to International Nuclear Event Scale, occurred on March 11, 2011 as a result of Japanese ever strongest earthquake followed by tsunami, which led to failure of the external units of power supply and backup diesel generators and caused the loss of efficiency of all normal and emergency cooling systems, which resulted in the melting of the reactor cores at nuclear power reactors 1, 2 and 3 during the first days of the accident. Japanese nuclear engineers estimate that bringing the object into a stable, safe condition may require up to 40 years [link: Fukushima Nuclear Accident Analysis Report, June 20, 2012, Tokyo Electric Power Company, Inc].

The Fukushima NPP accident calls for necessity of critical review of measures on prevention of the same or similar accidents and timely response to emergency situations to eliminate the consequences of arising accident that makes to take a fresh look at the state of nuclear and radiation safety in the Republic of Kazakhstan including the entire list of measures to ensure nuclear and radiation safety of nuclear facilities, starting from the stage of site selection, design, licensing, commissioning, operation, safety assessment and inspections, emergency preparedness plans and emergency response programs, procedures for warning and informing, as well as the further.

As to lessons learned from the accident at the Fukushima NPP (Japan) for WWR-K reactor one can highlight two items:

1.1 Improvement of regulatory framework of Kazakhstan;

1.2 WWR-K reactor modernization.

This article one can consider as a logical supplementary material to the article of Mr. A. Shaimerdenov [1].

1.1 Improvement of regulatory framework of Kazakhstan

Since 2011 development and updating of legislation in the field of nuclear energy use in the Republic of Kazakhstan is in a progress.

Kazakhstan ratified some international IAEA conventions such as Convention on Nuclear Safety [2], Joint convention on the safety of spent fuel management and on the safety of radioactive waste management [3], Vienna Convention on Civil Liability for Nuclear Damage, Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage and the Convention on Supplementary Compensation for Nuclear Damage [4], Convention on assistance in the case of a nuclear accident or Radiological Emergency [5], Convention on early notification of a Nuclear Accident [6].

The second important step was the adoption of the Law of Republic of Kazakhstan "On civil protection"[7]. The Law “On Civil Protection” regulates public relations arising in the course of the activities on civil protection and it is aimed at: prevention and elimination of natural and man-made disasters and their consequences, emergency medical and psychological assistance to populations in the emergency area, provision of fire and industrial safety, as well as determine the main tasks, organizational principles and functioning of civil defense of the Republic of Kazakhstan. The Law provides formation, storage and use of state material reserves, and organization and activities of rescue services and units.

The more important step in Kazakhstan legislation is the adoption of a new law “On atomic energy use” in 2016 [8]. As result of the adoption of this new law, a number of new legislative documents had been elaborated [9-26].

Taking into account abovementioned further updating of emergency preparedness plan and emergency response program for the nuclear power and research reactors is in progress.

Plan of measures for protection of personnel and public from radiation accident and its consequences should be developed pursuant to current rules and regulations in the field of nuclear energy use, which are in force in the Republic of Kazakhstan. The plan provides for immediate actions on accident mitigation, restriction and elimination, protection of personnel and public from the consequences of accident as well as procedure for warning and notification of the off-site authorities providing them with technical assistance and recommendations on protective measures.

Procedure for warning and informing is also subject to updating. The content of the notification must include:

- name of the institution, departments and time of an accident occurrence;
- characteristics of the source of ionizing radiation;
- description of accident and characteristics of technological process in which the accident occurred;
- organizational activities conducted, composition of the steering group, who organized the steering group , staffing and number of work teams;
- scale and contamination levels of territory, work surfaces, equipment, etc., the number of victims and their levels of exposure;
- information about possible consequences of accident and preventive measures.

List of organizations subject to notification for interaction in elimination of accident and its consequences:

1. Committee for atomic and energy supervision and control of ME RK;
2. Committee of Industrial Development and Industrial Safety MID RK;
3. The Department of Emergency Situations of the city;
4. Department of Consumer Rights Protection of the city and of Committee for Consumer Rights Protection MNE RK;
5. City department of Ecology Committee;
6. Akimat of the respective district of the city.

To acquire the staff skills and abilities for independent, quick and technically correct actions in the event of process disturbances by applying technical rules of operation, and safety and maintenance instructions, operating personnel must be trained and regularly participate in emergency drills in accordance with the technical regulation "Nuclear and radiation safety”.

Periodicity of emergency response drills is determined by the schedule approved by enterprise director or chief engineer.

Combination of emergency and fire drills is acceptable.

Heads of enterprise and operating and maintenance personnel should take part in the emergency response trainings.

By decision of head of organization and structural unit, other employees may be involved for conduct and participation in emergency drills.

Emergency response drills are one of the mandatory forms of work with personnel.

Emergency response drills include the following tasks:

- check staff's ability to correctly perceive and analyze information about technological violations, and based on this information make optimal solution on elimination of these violations by means of specific action or giving of specific instructions;
- provide formation of clear operational decision-making skills in any situation and in the shortest time;
- development of organizational and technical measures aimed at improving the level of professional training and trouble-free operation of reactor.

Trainings are conducted with conventional reproduction of reactor disruptions, simulation of prompt actions at workplace to eliminate accidents and emergencies, assessment of activity of participants, and registration of permit and routing.

Head of training, the participants of training and intermediaries who perform supervisory functions are main participating persons during training.

The training effectiveness depends on the relevance of the theme, the quality of progrram development, training participants and the necessary means to carry out the training, the proximity of the accident simulation to real one, proper and objective assessment of the actions of participants and the training analysis.

To respond to radiation accidents and other radiological emergencies and in accordance with the Law of the Republic of Kazakhstan "On Radiation Safety of the Population" a specialized emergency rescue team (hereinafter SERT) should be established by the order of enterprise head. SERT is the enterprise division and not part of the State Emergency management system. Therefore, SERT’s range of tasks is limited to the territory of sanitary and surveillance zone of enterprise. SERT’s activities directed to perform work on prevention and conduct of emergency and rescue operations during elimination of radiation accidents and other radiological emergencies.

SERT is provided with rescue equipment and outfit, radiometric, dosimetry, and other electronic devices, specialized vehicles, communications equipment, ensuring continuous communication in any conditions, the necessary computer equipment, navigation systems, and individual protective means.

SERT activities is focused on solving the following objectives:

- participation in assessment, localization and elimination of consequences of radiation accidents and other radiological emergencies;
- dosimetry control and monitoring of radiation situation at the site of emergency work and surrounding area;
- conducting a comprehensive survey to assess the radio-ecological situation in the area of the accident;
- ensuring of radiation safety for personnel and public during the rescue operations.

General responsibilities of SERT staff to ensure the implementation of the tasks assigned:

- implement the work on the prevention of radiation accidents and other radiological emergencies;
- organize the recruitment of team with qualified personnel, to conduct regular systematic training and education of personnel;
- train personnel to observe safety rules during rescue operations;
- plan and organize equipping of team with special equipment, apparatus, tools and outfit to carry out rescue operations using means of communication, notification and transportation;
- establish and maintain a reserve of material resources for rescue operations;
- organize and provide interaction with organizations and enterprises involved in the elimination of consequences of radiation accidents and other radiological emergencies;
- carry out individual dosimetry control of personnel involved in the rescue operations;
- carry out explanatory work among the population, including through the mass media, on the issues of people life and health protection while in radiation accidents;
- carry out other functions assigned to it by the management

Depending on the situation, the team operation is carried out in three modes:

- mode of daily activities;
- high-availability mode;
- emergency mode (emergency, accident)

Decision on the measures undertaken for protection of population is made depending on the results of comparison of the calculated doses with dose criteria. According to the analysis conducted of a particular radioactive contamination, refinement of calculated doses is carried out, comparing them with the criteria and decision is made on measures for population protection.

Deputy director of the enterprise is the person responsible for putting into effect "Plan of measures for the protection of workers and the public from radiation accident and its consequences," as well as for investigation and elimination of consequences of radiation accidents in the reactor.

Deputy director of enterprise makes a decision on implementation of "Action Plan for the protection of workers and the public from radiation accident and its consequences" based on the analysis of information received from the chief engineer and the chief of the Radiation Safety Department (or their deputies).

In spite of adopted abovementioned documents [2-26] there is a gap connected with the operation of the reactor. There is technological procedure of RR WWR-K operation, ISM-TR-03-15.01-42-01-2016 [27], approved by Institute. This technological procedure is bases on documents which are not adopted juridical in Kazakhstan. They are documents of the former Soviet Union and Russian Federation. But according to item 19 of Technical Regulations “Nuclear and Radiation Safety” “List of used engineer-technical norms and rules for constructions, systems and elements of nuclear, radiation and electro-physical facilities corresponding to requirements of technical regulations or international requirements or requirements adopted in the origin country is defined by project enterprise and operator approves it with regulatory body in the sphere of atomic energy use". On the basis of the item 19 of abovementioned technical requirement the Institute of nuclear physics made a list of documents [28] used for safety operation of the reactor and approved it with the Committee for Atomic and Energy Supervision and Control (CAESC) of the Ministry of Energy of the Republic of Kazakhstan in October of 2016 which is the regulatory body. List of documents contains as national documents as some documents of the former Soviet Union and Russian Federation. Works on elaboration, update and adoption of documents are in a progress.

1.2 WWR-K reactor modernization

The research reactor (RR) WWR-K is located in Alatau settlement near Almaty, (Fig.1 and Fig.2). Operator – RSE Institute of Nuclear Physics of the ME RK. It is tank type reactor with thermal neutrons spectra. Coolant and moderator are desalinated water, reflector is desalinated water and/or beryllium. The reactor was put into operation in 1967, operated on the thermal power of 10 MW up to 1988 without deviation from the normal operation [26]. The Research Manager of the RR WWR-K project is a Russian Research Center "Kurchatov Institute", the Chief Designer of the reactor – NIKIET, the General Designer of the WWR-K – SSDI. All of these organizations are located in the Russian Federation.

In addition to fundamental nuclear physical and materials scientific researches and in-situ tests, the reactor is used for production of medical and industries radioisotopes and neutron activation analysis.

Fig.1. Front view

Fig.2 Central hall

The reactor is equipped with hydraulic tube, pneumatic tube, universal loop facility, the installation of neutron radiography, facility for the analysis of uranium containing samples by delayed neutron technique, in-core installations for testing of construction materials for the long-term strength and creep, a chain of hot cells for work with highly active materials.

After Chernobyl accident in April of 1988 it was adopted by regulatory body of the former Soviet Union the decision to shut down it permanently in order to carry out works on enhancing of seismic safety of the reactor.

From 1988 to 1998 the works were conducted at WWR-K to improve security in conditions of high seismicity (calculations and studies, improvement of structures, duplication of systems responsible for the security, processing of the new documentation). By changing the configuration of the core the thermal power has been reduced to 6 MW without loss of neutron flux.

The most important historical phases of RR WWR-K are shown in fig.3.

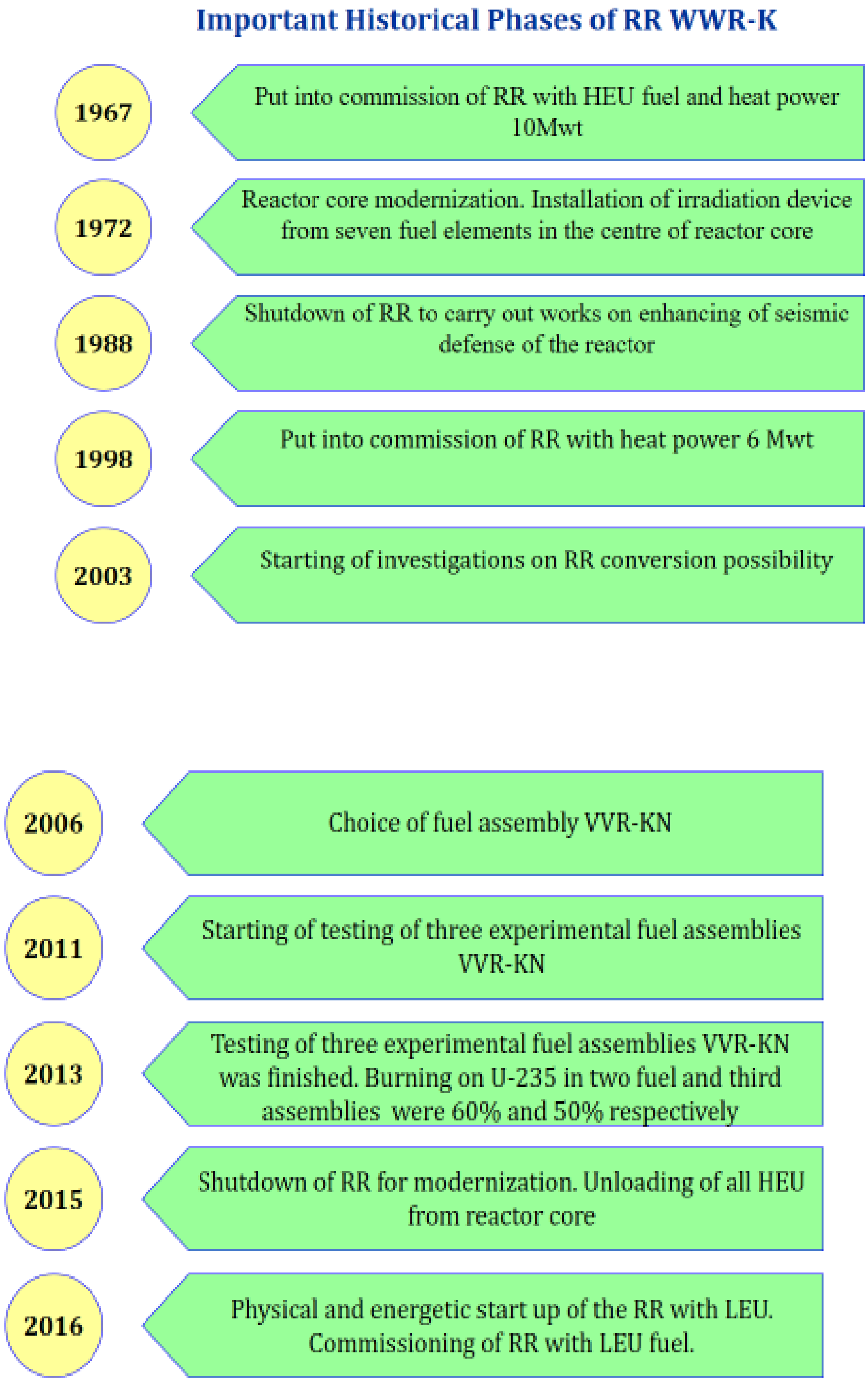

Fig. 3. History of WWR-K

The service life of WWR-K is defined by chief designer, based on the number of 20 daily cycles of loading of pipelines and must not exceed 716 cycles since 21.10.67. So far the remaining life of the reactor is 124 loading cycles corresponding to 13 years of the reactor operation at maximum load. To extend the service life of the WWR-K technical examination of the reactor vessel and pipelines of the primary circuit was conducted in 2015.

From 1967 to 2016 the WWR-K reactor has used the fuel assemblies of VVR-C type, UO_2 –Al with 36% enrichment. VVR-C fuel assembly contains five tube fuel elements. Conversion of WWR-K reactor was carried out in the framework of an international RERTR program.

From 2003 to 2008 the Institute of Nuclear Physics (INP) of the Republic of Kazakhstan with the financial support of the Nuclear Threat Initiative (NTI, USA) conducted the studies on the selection of the fuel composition and the fuel assembly design for the transfer of WWR-K reactor to a low enrichment fuel. Computational studies considered uranium fuel compositions (uranium dioxide and uranium-molybdenum alloy dispersed in an aluminum matrix), as well as the fuel assemblies (FA) of various designs [29-37].

As a result of the research the FA was selected with fuel composition based on uranium dioxide dispersed in an aluminum matrix, with a uranium density of 2.8 g/cm^3 and 19.7% enrichment by uranium-235, the most optimal in terms of technical and economic indicators. VVR-KN FA is given in figure 4.

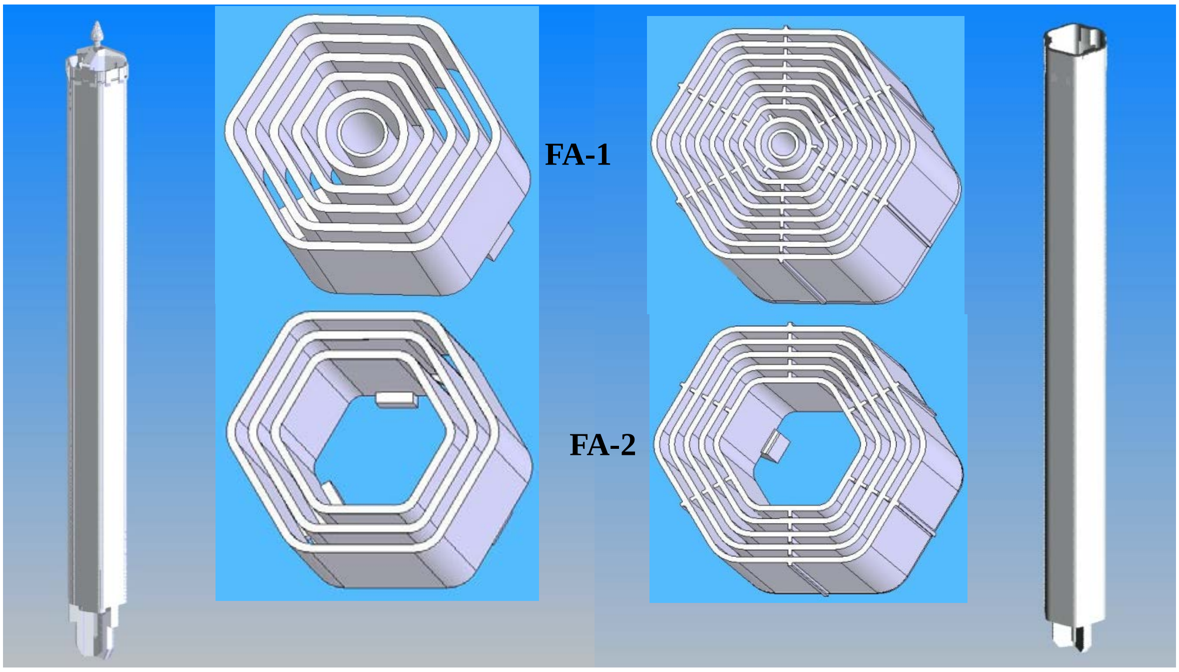

Fig.4. VVR-C (left) and VVR-KN (right) FA

Comparison of technical characteristics of LEU VVR-KN fuel assembly and HEU VVR-C fuel assembly is shown in Table 1.

Table 1. LEU VVR-KN FA versus HEU VVR-C FA

VVR-C	Parameter	VVR-KN
36	Enrichment in U-235, %	19.7
UO_2-Al	Fuel composition	UO_2-Al
1.3	Uranium density, g·cm^{-3}	2.8
	Amount of U-235, g	
111	in FA-1	245
86	in FA-2	198
	Number of fuel elements	

5 3	in FA-1 in FA-2	8 5
2.3	Thickness of fuel element, mm	1.6
0.9	Thickness of fuel meat, mm	0.7
0.7	Thickness of fuel element clad, mm	0.45

Following requirements of regulatory documents, life test of a batch of lead test assemblies (LTA) is to be performed prior to starting FA industrial production. Life test of three VVR-KN-type LTAs was carried out in the WWR-K reactor core in a period from 2011 to 2013. The life test lasted 480 effective days. The average burnup ~50% in uranium-235 was reached in all three FAs [38-42].

Taking into account of Fukushima accidents and conversion it was adopted the decision to increase production capacity of pumps of emergency cooldown and put into operation uninterruptible power supply.

Four cooling towers had been put into operation instead of eight old one.

One of the most important items is the provision of the radiation safety of personnel, population and environment. As an example of this provision is the automatic system of radiation control.

With account of Fukushima lessons the conversion of the main reactor systems responsible for safety had been updated. As it was reflected in the report of the IAEA Integrated Safety Assessment of Research Reactor (INSARR) mission held from 27 February to 3 March 2017 safety level of the RR WWR-K corresponds to international requirements.

Prior the physical startup of the reactor, Safety analysis report of the WWR-K reactor with LEU was developed. SAR includes such main chapters as principles of safety assurance, analysis of potential accidents, operational limits and safe operation limits, nuclear safety, etc.

On March 31, 2016, the core of a research reactor WWR-K was loaded with first FA of low enrichment fuel, which marked the beginning of work on the physical start of the reactor. During the physical start-up an work load of the reactor core was formed, which consisted of 17 FA-1 and 10 FA-2; the neutron-physical characteristics of the core were identified. Power start-up of the reactor took place in June 2016.

After the conversion of the WWR-K reactor, thermal neutron flux density was double increased in the center of core.

In accordance with legislation after physical and power startups of reactor WWR-K some amending had been put in safety analysis report. Now the updated SAR is under consideration of regulatory body.

Operation of the WWR-K reactor with LEU fuel was started from 1 September 2016.

2 Conclusion

Upgrade of RR WWR-K safety systems carried out during 2015-2016 allowed to increase nuclear and radiation safety. Successful physical and power startups of RR WWR-K with LEU fuel in February and June of 2016 gave the beginning to commission of the reactor since 1 September 2016. Safety reassessment of WWR-K RR carried out related HEU/LEU conversion and feedback at the accident of Fukushima Daiichi NPP.

The main conclusion of the IAEA INSARR mission is that a good work on modernization of safety systems is carried out which could increase the level of reactor safety. In spite of some notifications and recommendation of INSARR mission the safety level of RR WWR-K is correspond to international level of safety.

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