RECOMMENCEMENT OF THE WWR-M NUCLEAR RESEARCH REACTOR OPERATION AFTER FOUR YEARS SHUTDOWN

V. GAVRILYUK, M. Lisenko, 
Yu. Mahlers, O. Scherbachenko
Institute for Nuclear Research, 
Academy of Science of Ukraine, 
Kiev, Ukraine

Abstract

Kiev Institute for Nuclear Research possesses a Soviet WWR-M research reactor, which was commissioned in February 1960. This reactor was shut down in December 1993 under the guidance of the Ministry of Environmental Protection and Nuclear Safety (MEPNS) of Ukraine. The purpose of the shutdown was the matching of reactor systems to the norms, rules and nuclear, radiation, general engineering and fire standards existing at that time in Ukraine. Modern system of the reactor physical protection was created. Fresh nuclear fuel storage was modernized. System of emergency power supply of the reactor was upgraded. Ventilating system possibilities were extended. Reactor vessel, control and safety systems were carefully tested. Modern fire control system was installed in the reactor building. Start of the reactor using the same zone configuration after four years shutdown shown significant reactivity margin decreasing. It was determined that the main reason of reactivity decreasing was accumulation of $^1$H isotope in the beryllium reflector of the reactor.

1. INTRODUCTION

Research reactor WWR-M located in the Institute for Nuclear Research National Academy of Science of Ukraine, Kiev, Ukraine (KINR) was brought into operation in February 1960. There is serial research reactor WWR-M Soviet Union production [1]. Reactor was visited at that time by the celebrated Academician Kurchatov, which fact is displayed at the entrance to the reactor building. Owner of the reactor is the National Academy of Sciences of Ukraine. Operator of the reactor is KINR.

2. DESCRIPTION OF THE REACTOR

Main technical characteristics of the reactor are the following:

- Thermal power: 10000 kW
- Maximum neutrons flux: $1.1 \times 10^{14}$ n/sm²•s
- Moderator and coolant: light water
- Enrichment of the fuel by $^{235}\text{U}$: 36 %
- Number of horizontal channels: 10
- Number of vertical channels: 39

KINR research reactor operated successfully until 1993 completing a broad range of applications, dominated by materials research associated with the development of nuclear power. A considerable amount of pure nuclear research of high quality was carried out during that time. It is multi-purpose reactor with consideration of training, isotope production for industry and medicine, neutron radiography, neutron activation analysis, material modification, filtered mono-energetic beams, irradiation applications for sterilization of medical equipment as well as fundamental researches. There was no failure, nuclear or radiation accidents during the reactor operation period.
3. LEGISLATION BASIS THAT REQUIRED KINR RESEARCH REACTOR SYSTEMS RECONSTRUCTION

Prior to Ukraine’s proclamation of independence on August 24, 1991, the Parliament of Ukraine in the declaration of its sovereignty on June 16, 1990 had pledged that Ukraine would follow three non-nuclear principles: not to accept, not to produce, and not to acquire nuclear weapons.

The Parliament of Ukraine adopted the statement of non-nuclear status on October 24, 1991. Paragraph 3 of this statement reads: “Ukraine will pursue a policy directed to eliminate all nuclear weapons and their components from its territory. Ukraine intends to implement this policy rapidly, taking into account legal, technical, financial, administrative, and other issues, properly ensuring ecological safety.” Paragraph 7 of the statement says: “Ukraine intends to accede to the Nonproliferation Treaty as a non-nuclear weapons state and to conclude an appropriate Safeguards Agreement with the International Atomic Energy Agency (IAEA).”

During the first years of independence, KINR received the attention of inspectors from Ukrainian regulatory bodies and the IAEA. Requirements suddenly had increased but the Institute’s severely limited budget did not permit addressing them. Significant financial resources were required in order to install modern nuclear material protection, control, and accounting (MPC&A) systems to help secure nuclear material at the nuclear reactor.

3.1 Bilateral Agreements

On October 25, 1993 Ukrainian Ministry of Foreign Affairs signed the “Agreement between the USA and Ukraine Concerning Assistance to Ukraine in the Elimination of Strategic Nuclear Arms and the Prevention of Proliferation of Weapons of Mass Destruction”. This agreement, called hereinafter the Umbrella Agreement, established the legal framework for cooperation between the USA and Ukraine on the “establishment of measures against the proliferation of nuclear weapons from Ukraine, and technology and expertise related to such weapons.”

On December 18, 1993, the “Agreement between Department of Defense of the USA and the Ukrainian State Committee on Nuclear and Radiation Safety Concerning the Development of State Systems of Control, Accounting, and Physical Protection of Nuclear Materials to Promote the Prevention of Nuclear Weapons Proliferation from Ukraine” was signed in Washington, D.C. Hereinafter called the Implementing Agreement, this document defined the ways and means by which the objectives of the Umbrella Agreement would be met with regard to MPC&A. The United States Department of Energy (DOE) was designated as the implementing agency for the USA.

4. RECONSTRUCTION AND MODERNIZATION OF THE REACTOR SYSTEMS

WWR-M reactor located in KINR was closed in December 1993 under the guidance of the Ministry of Environmental Protection and Nuclear Safety of Ukraine pending a safety review. The purpose of the shutdown was the matching of reactor systems to the norms, rules and nuclear, radiation, general engineering and fire standards existing at that time in Ukraine.

After the shutdown all nuclear fuel was unloaded from the reactor core and loaded into the nuclear spent fuel storage. The distilled water was used for the filling of the reactor's primary loop. During the above-stated condition of the reactor, the water-chemical regime was supported in the correspondence with design requirements.

The operator developed the reactor reconstruction program to meet the Nuclear Regulatory Body requirements. This program was executed.
4.1. Physical protection system upgrades

In 1994, American and Ukrainian nuclear safeguards and security experts began to collaborate to improve the protection, control, and accountancy of nuclear materials at the research reactor of the KINR.

A delegation of Ukrainian physical protection specialists visited the USA on November 30 - December 7, 1994 to examine physical protection measures applied to nuclear material at Sandia National Laboratories, the Waterford NPP, and Argonne National Laboratory. The technical working group decided to adopt the American threat concept for protecting nuclear material, using both 10 CFR 73.1 and the IAEA’s INFCIRC/225, Rev.3, as guidelines. This decision expedited the installation

By the end of June 1995, a physical protection system design had been jointly developed, agreed upon, and documented. DOE designated Sandia as the lead laboratory to manage the implementation of the design. The project was coordinated with the appropriate regulatory, licensing, and inspection bodies in Ukraine [2-4].

Sandia’s proposal to subcontract the installation and integration of the physical protection systems to the Advantor Corporation (USA) was approved by Ukraine. By then the American experts, the specialists from KINR, and employees of the State Committee on Nuclear and Radiation Safety in Ukraine had reached a complete understanding on a design concept.

By late summer 1997, the physical protection upgrades at the research reactor were nearing completion and Advantor had begun to train the staff in operating and maintaining the systems. The MPC&A systems at the reactor were placed into operation on October 21, 1997, and have been operated continuously ever since. By a decree of the Ukrainian government, the facility is guarded by a special unit of the Ministry of Internal Affairs of Ukraine. The Ukrainian government provides funding for these operations. A joint (Ukrainian and American) commission of experts performed a thorough acceptance test of the reactor's Physical Protection System prior to its commissioning.

KINR research reactor Physical protection system upgrades were made in the frame of bilateral Agreements mentioned above.

4.2. Reactor systems modernization and testing

Lots of the KINR research reactor systems were modernized and tested during the shutdown period.

4.2.1. Reactor vessel and associated piping

The reactor vessel and portion of the primary loop have not been touched since the reactor entered operation in 1960. Portions of the piping and the heat exchangers have been replaced, though, in 1989-1990. Owing to concerns about the integrity of the rest of the primary system, visual inspection of the reactor vessel was carried out and some welding of the piping and vessel have been examined radiographically. All of these failed to show any sign of degradation in the integrity of the checked components. Integrity of the piping is also checked by increasing the pressure in them and searching for leaks. None was found.

Concern about the integrity of the horizontal channels because of their original thin walls led to check their thickness with ultrasound. No increased thinning was found. There inspection (welding, visual inspection of tank) are carried out every four years by agreement with the regulatory body. The last inspection was carried out in 1996 and the next one is scheduled for 2000.
The result obtained give a reasonable assurance that the reactor vessel and primary loop are fit for operation.

4.2.2. Instrumentation and control system

The reactor core of the WWR-M reactor is surrounded by ten ionization chambers, most of which were included in the original design. The new neutronic measurement channels were installed at the time of upgrades or by regulatory demand. The ionization chambers were replaced according to their lifetime. The electronic of the six most important channels remain untouched. The technological instrumentation is also almost original, only a few new measurements were introduced.

Instrumentation and equipment of the reactor control and safety system was tested during the shutdown period by using the special procedure of NIKIET, Russia. Finally, over-all testing of this system was provided by using special methodic.

4.2.3. Emergency power supply

The emergency power supply of the reactor has been improved by adding new battery station VARTA - Vb2312. The battery allows providing coolant circulation in the primary loop of the reactor during the 25 minutes. This time is enough for emergency cooling of the reactor core.

Additionally, old overhauled 100kW diesel generator was installed to improve the reliability of the power supply.

4.2.4. Fire control system

Fire control system of the reactor building was modernized by means the installation of new modern fire control system. This new system is correspond to the existing in Ukraine fire control regulation norm and rules.

4.2.5. Ventilation system

Ventilation system possibilities of the reactor building were extended in accordance to the existing Ukrainian norm.

4.2.6. Fresh nuclear fuel storage

Fresh nuclear fuel storage was modernized to meet the IAEA requirements as for nuclear material security at the nuclear reactors.

4.3. Summary of the reactor systems modernization

Years of the shutdown period were dedicated to a thorough assessment of the reactor's safety, several improvements were introduced in the reactor's instrumentation and emergency power supply. Many tests were conducted to verify the integrity of the welds in the reactor vessel and primary loop. Positive conclusions on these analysis and tests were obtained.

In December 1997, the Administration of Nuclear Regulation MEPNS of Ukraine granted permission to start operation again for a limited time until 01.01.2000 on conditions that improvement continue and that a program for renovating the reactor control system be started soon.

Reactor staff tutoring and training has been provided to keep the staff qualification during the reactor shutdown period.
5. RECOMMENCEMENT OF THE REACTOR OPERATION

In the middle of 1997 the reconstruction of the WWR-M reactor systems in accordance to the requirements of the Regulatory Body was completed. The program of the WWR-M reactor core loading by using earlier unloaded fuel was developed. In November 1997 the program was agreed by Administration of Nuclear Regulatory Body of Ukraine, and the staff of the reactor has begun the fulfillment of this work.

The experimental results, obtained at the moment when the reactor was shutdown in 1993, were taken as the basis of the safety. The reactivity margin determined experimentally before unloading of the fuel (04.01.1994) was equaled to $5.86\beta_{\text{eff}}$. The efficiency of the regulatory and emergency rods was also experimentally determined earlier. Simultaneously the efficiency of the rods was calculated. The experimental and calculation results were within the limits of errors.

The analysis has shown that the stored fuel assemblies are in the correspondence with the rules requirements. Simultaneously, the tests of the equipment and reactor systems were carried out. The outcomes of the tests were subjected to the examination by the Regulatory Body and accepted as positive results.

After loading of the fuel assemblies into the core, the reactor was started at the minimal referencing power level. The experimental determinations of the efficiency of regulatory and emergency rods were performed.

The regulatory rods efficiency has appeared to be equivalent to experimental value from 04.01.1994 within the limits of experimental error. At the same time, experimental determination of the reactivity margin ($3.76\beta_{\text{eff}}$ at 22.12.1997) has big difference with the value measured in 1994. Additional calculations of the isotopes with high thermal neutron capture cross section in the loaded fuel could not explain the reactivity losses.

Hereinafter, it was determined that the main reason of reactivity decreasing after the four years reactor shutdown is the accumulation of $^{1}\text{H}$ isotope in the reactor reflector in the result of the following nuclear reactions:

\[ ^{4}\text{Be} + ^{0}\text{n} \rightarrow ^{2}\text{He} + ^{2}\text{He}; \]

\[ ^{2}\text{He} \rightarrow ^{0}\beta + ^{3}\text{Li}; \quad (T_{1/2} = 0.8 \text{ s}) \]

\[ ^{3}\text{Li} + ^{0}\text{n} \rightarrow ^{4}\text{He} + ^{1}\text{H} \quad (\sigma(n,\alpha) = 945 \text{ barn}) \]

\[ ^{1}\text{H} \rightarrow ^{3}\text{He} + ^{0}\beta \quad (T_{1/2} = 12.35 \text{ year}) \]

The $^{2}\text{He}$ isotope has very high thermal neutron capture cross section (5500 barn).

After the explanation of the reactivity losing the reactor was up to 3000 kW power level (16.02.1998), as it was agreed with Nuclear Regulatory Body.

At 06.04.1998 three spent triple fuel assemblies were changed by new in the reactor core. The reactivity limit was experimentally determined after this operation. It was increased up to $5.54\beta_{\text{eff}}$. The reactor was up to power level 10000 kW and was the subject of comprehensive tests during 64 hours. All parameters of the reactor were in the limits of technological norms.
6. UTILISATION

6.1. Training

It was stated that training was an important component of the use of the reactor and students from the technical institutes were invited to experience the start-up procedures of the reactor. Further, experience was gained by NPP operators at this reactor.

6.2. Production of isotopes

Production of a wide variety of potential sources can be provided. $^{192}$Ir sources could be produced. The specific activity will be high enough for use in local industrial irradiators for material non-destructive testing by gamma radiography.

Technetium has been produced by neutron capture and the local hospitals needs may be supplying. There is regenerating old $^{60}$Co sources can be provided. $^{131}$I is another isotope that can be successfully produced. $^{32}$P, $^{90}$Sr, $^{127}$Xe may be produced as well. $^{125}$I production is based on the conventional Xe technique.

6.3. Material modification

Material modification has been focused on silicon doping which has been successfully achieved. However, the ingot diameter is limited to 100 mm.

6.4. Neutron radiography

In 1984 horizontal beam port number 5 was equipped with a static neutron radiography system. This equipment is planning to be used it in future for fundamental investigations.

6.5. Neutron activation analysis

Neutron activation analysis has been used for geological researches.

6.6. Filtered Monoenergetic Beams

There is an area of special capability in providing filtered beams of mono-energetic neutron beams. The second horizontal beam line is fitted with a selection of $^{44}$Sc, $^{54}$Fe, or $^{57}$Fe filters. The current possible concept is to introduce boron neutron capture therapy (BNCT) as a reactor service to the medical fraternity.

7. CONCLUSIONS

- WWR-M research reactor located in KINR, installed in the sixties, has been closed down during the four year period from 1993 till 1997 pending the safety review for testing and matching to the Ukrainian nuclear regulation norms and rules requirements.
- Lots of the reactor systems upgrades and modernization were made on the reactor during this period to the level accepted for re-licensing.
- On the base of mentioned above test results and the results of additional tests conducted by independent expert from Administration of Nuclear Regulatory Body of Ukraine, the permission for KINR reactor operation was granted by Nuclear Regulatory Body of Ukraine.
- It was determined that the accumulation of $^3$H isotope in the WWR-M reactor beryllium reflector leads to the significant reactivity decreasing in case of the long term reactor shutdown period.
• KINR research reactor is under operation now and utilizing for several scientific and industrial needs.

• Future analysis, including that of the reactor vessel material and primary pipe-work, if successful, as well as need to upgrade the reactor control and safety system could lead to extension of the license to operate the reactor beyond January 2000.

REFERENCES


