Researches on Problems of Safety of Nuclear Power Reactors on the Igr Reactor: the Result of Medium Scale In-Pile Experiment Realised Under the Eagle-Project

Yu.S. Vassiliev[1], A.D. Vurim[1], V.A. Gaidaichuk[1], A.A. Kolodeshnikov[1], V.A. Pakhnits[1] A.V. Pahnits[2], A.S. Marinin[2], G.V. Shapovalov[2], J.V. Logachev[2] K. Konishi[3], J.I. Sato[3], S. Kubo[4], S. Kotake[4], K. Koyama[5]

[1] IAE NNC, Republic of Kazakhstan, [2] IAE NNC, Republic of Kazakhstan
[3] JAEA, O-arai, Japan, [4] JAPC, Japan, [5] ARTECH, Japan

Abstract – The report contains results of material trailing process under irradiation of the graphite pulse nuclear reactor IGR.

IGR reactor facility is located on Semipalatinsk Nuclear Test Site and includes IGR research reactor and systems, providing its operation and safety and loop devices with gaseous and water coolant.

IGR reactor is a pulse uranium-graphite thermal self-shutdown reactor of heat capacity type with graphite moderator and reflector [1].

IGR reactor stacking consists of graphite columns, has dimensions of 2400×2400×4500 mm and is enclosed in a cylindrical steel housing with a 3100 mm diameter and a 4500 mm height.

The reactor core presents the stack of graphite blocks with a 100×100×150 mm size assembled as columns and it has a cubic shape with a 1.4 m side. Graphite reactor core blocks are impregnated with uranyl nitrate of a 3.1 gr concentration of uranium per a kg of graphite. Upper and bottom columns parts consists of unimpregnated with uranium blocks and form upper and bottom parts of the reflector which is also a thermal insulation between a hot reactor core and supporting constructions. A lateral reflector is assembles of graphite blocks with a 200×200×600 mm size. Central columns are placed on a mobile metal table and form mobile part of a rector core with a 800×800 mm cross-section. The table is mounted on a vertical hollow steel column connected with a housing bottom by rubber bellows. While lowering the mobile reactor core part enters into a bottom reflector cavity. Angular columns of the mobile part and the neighbouring columns of the fixed part consist of unimpregnated with uranium graphite blocks. Fixed parts of the reactor core assembled of unimpregnated blocks have channels for rods inserting of control and protection system. Operation rods part is assembled of hinged together graphite modules filled with pellets of graphite/gadolinium oxide mixture (gadolinium content is 0.02 gr/cm^3).

Vertical tubes are in the water to locate counters and ion chambers. From the inside a lateral concrete shield is lined with metal. A water layer over vessel cover (about ~0.5 m) and steel dismountable metal construction with a total thickness of 400 mm (biological shield plate) is a top shield. Drives of the reactor control system are located on the plate. Vertical steel tubes are run from the vessel cover and bottom accordingly to channels in a graphite stack to insert control rods.

The interest to the IGR reactor of researchers providing reactor material investigations is based on the fact that technical reactor characteristics allow to model severe accidents in a wide range of the main defining values, such as time (from one tenth to hundreds of seconds), thermal neutron flux fluence (to $3.7\cdot10^{16}$ n/cm^2), maximal flux of thermal neutrons at the mode of neutron burst (to $0.7\cdot10^{17}$ n/cm$^2\cdot$s), maximal flux of fast neutrons at the mode of neutron burst (to $1.1.7\cdot10^{15}$ n/cm$^2\cdot$s), power of γ-radiation dose ($2\cdot10^6$ rad/s).

Practically it is possible to make destructive thermal loads in fuel elements of different fuel compositions and enrichment, i.e. from CANDU reactor fuel elements with fuel of natural enrichment to reactor fuel elements of space nuclear engines with 90% enriched fuel, from fuel elements of zero burn-up to PWR fuel elements with fuel burn-up of 65 MW/day.kg of U. Technological systems of the reactor complexes provide capability to operate with gaseous (nitrogen, hydrogen, helium, argon, water steam) and liquid (water, sodium, lead) coolants.

The reactor IGR operates at two main modes: the neutron burst mode and the controlled pulse mode which parameters are defined by the given control law. The combined mode which is a combination of two main ones is a special case of the controlled pulse mode. At any operating mode the parameters of neutron flux in the reactor IGR can exceed the analogous parameters for power reactors ten times what provides the capability to conduct the dynamic tests of structure materials of power reactor in the direct in-pile experiments.

The values of power, reserved heat and time are included in the range of operating parameters of the IGR reactor that allows conduct the investigations of fuel elements behavior for the most typical transient and accidental modes. While studying reactivity accidents the fuel elements behavior can be investigated with the margin up to the values of reserved heat equal to 100kJ/g of ^{235}U at typical energy release pulse duration from tenth fractions till several seconds. While studying LOCA type accidents required modeling of fuel elements insufficient cooling modes with residual energy release power the IGR reactor provides the capability of tests with duration till several hundreds of seconds. This approach is qualified for fuel elements of any type, and the higher nuclear fuel enrichment in fuel elements the testing modes can be more durable and higher energy release power in them can be obtained.

In 80-s all these factors predetermined the program of full-scale ampoule testing of power reactor fuel elements in the IGR reactor. It was the period, when the IAE NNC RK began to participate in the program of investigating the nuclear power safety problems in the CIS.

The ampoule tests methodology was determined by the concrete purposes connected with the development and verification of the calculated codes and also by the task of obtaining the threshold destructive characteristics for Russian materials and fuel element constructions adequate to the world ones envisaged by design licensed criteria [2].

While forming testing procedure of single fuel elements at the initial stage it was used the experience of similar investigations conducted in SPERT, TREAT [3] and NSRR [4] reactors.

Subsequently various researches of materials behaviour in conditions of the big heat, neutron and gamma-ray loadings have been executed.

EAGLE experimental program is latest one [5, 6, 7].

This program is dedicated to show the experimental evidence for the elimination of the re-criticality issue in the sodium cooled fast reactors.

As an important safety issue of LMFBRs (Liquid Metal Fast Breeder Reactors), severe re-criticality events in the postulated CDAs (Core Disruptive Accidents) have been studied so far. Within this conventional approach, the reactor was designed so that such energetics, if any, could be accommodated within the primary boundary. However, such energetics in the safety evaluation was given as a result of very conservative assumptions because of absence of experimental evidences to treat it in a more realistic way. In the present approach, it is intended to show that the re-criticality issue (i.e., energetics challenging the integrity of the primary boundary) does not exist with a combination of design consideration to eliminate the energetics and getting experimental evidences to ensure effectiveness of this concept. Furthermore, elimination of such re-criticality issue would improve public understanding on the safety level of LMFBRs [8, 9, 10].

Elimination of the re-criticality issue can be achieved by establishing a clear logic based on some experimental evidences that show the reactor core shall have an inherent nature to prevent severe re-criticality under the degraded condition. Molten fuel would escape from the core with the accumulated energy in the course of the core melting process through most likely escape paths which are dependent on the reactor design. As an option to enhance the escaping characteristic, FAIDUS (Fuel Assembly with Inner Duct Structure) and several other optional designs are under consideration [11, 12]. The fundamental mechanism of the fuel escape will be confirmed by the evidences from the EAGLE (Experimental Acquisition of Generalized Logic to Eliminate re-criticalities)-project thereby demonstrating the effectiveness of the FAIDUS-type concept.

More than 100 parameters of experimental devices are registered under tests performance, including temperature, pressure (also impulses of rapidly variable pressure), local neutron flux, void sensor signals in coolant (for sodium), acoustical signals, coolant level position (for sodium). Satisfactory quality of experiment results interpretation and regeneration of sequence of events proceeding during its performance are gained by way of using of direct measurements of experimental parameters, of PTE results and calculated modeling of test performance conditions.

The conduction of the EAGLE in-pile tests, especially ID, made great progress on the experimental capabilities and techniques which include power control with large amount of molten mobile fuel, application of small neutron detectors for fuel motion detection, safety treatment of sodium.

References

[1] I.V. Kurchatov, S.M. Fainberg., N.A. Dollezhal et al. Pulse Graphite IGR Reactor. Report №322a., *in Third International Conference on Peaceful Application of Atomic Energy.,* Geneva, 1964.

[2] V.G.asmolov, L.A.Egorova, V.A.Pavshuk et.al. Reactor dynamic tests of thermodissipating elements. 2^d Deutch-Russian seminar, Harshing 17–21.04.1989.

[3] P.E. Mak Donald, S.L. Seiffrt, Z.R. Martinson, P.K. McCardell, D.F. Owen, S.K. Fukura. Nuclear Safety **21**, 5 (1980).

[4] M. Ishicawa, T. Inabe, Advances in Nuclear Sciense and Tecnology **11**, Plenum Press, New York, London, 1979.

[5] K. Konishi, et al., EAGLE Project: Experimental; Study on Elimination of the Re-criticality Issue during CDAs. (1) Predictive Analysis of Fuel Discharge and Quenching Phenomena in the Inpile Tests. Fall Meeting of the Atomic Energy Society of Japan, Hokkaido/Japan, **I21**, 2001.

[6] S. Kubo, et al., AGLE Project: Experimental Study on Elimination of the Re-criticality Issue during CDAs. (3) Program and Results of non-sodium tests for out-of-pile tests. Annual Meet-

ing of the Atomic Energy Society of Japan, Kobe/Japan, **J39**, 2002.

[7] K. Kamiyama, et al., EAGLE Project: Experimental Study for Advanced Safety of Fast Reactors, – Progress on the out-of-pile experiments and results of the melt discharge experiment – (Joint research document), JNC Report, JNC TY9400 2004-030, February, 2005.

[8] H. Endo, et al., A. Study of the Initiating Phase Scenario of Unprotected Loss-of-Flow in a 600MWe MOX Homogeneous Core, in IAEA IWGFR Technical Committee Meeting on Material-Coolant Interactions and Material Movement and Relocation in LMFR, PNC-OEC, Japan, 1994.

[9] H. Niwa, A Comprehensive Approach of Reactor Safety Research Aiming at Elimination of Recriticality in CDA for Commercialization of LMFBR, in Proc. Int. Symp. on the Global Environment and Nuclear Energy System, Tsuruga/Japan, 1996.

[10] S. Kotake, et al., The R&D issues necessary to achieve the safety design of Commercialized Liquid Metal cooled Fast Reactors, in OECD/NEA/CSNI Workshop on Advanced Nuclear Rector Safety Issues and Research Needs, OECD, Paris, France, 18-20 February 2002.

[11] T. Inagaki, K. Aizawa, et al., Role and Approach to the Recriticality Elimination with Utilizing the In-pile Test Reactor IGR, in 2nd Int. Conf. on Non-Proliferation Problem, Kurchatov, Republic of Kazakhstan, 1998.

[12] H. Endo, et al., Progress in Nuclear Energy **40**, 577 (2002).