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IRT- SOFIA, HEU TO LEU CONVERSION: REGULATORY APPROVAL TASKS SOLUTION

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ABSTRACT

The HEU to LEU conversion of the IRT - Sofia research reactor of the Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Science, Sofia, Bulgaria was jointly studied with the RERTR Program at Argonne National Laboratory (ANL). The main purpose of the collaboration consisted in accomplishment of safety analyses and preparation of documents used for regulatory approval tasks solution. Main steps and results of the collaboration concerning preparation of the IRT - Sofia Safety Analyses Report (SAR) including Operating Limits and Conditions (OLC) are presented in this paper. The documents have been prepared by INRNE in accordance with the European nuclear safety requirements as well as the International Atomic Energy Agency (IAEA) recommendations. This activity finalization together with approval of the IRT – Sofia Environmental Impact Assessment Report (EIAR) in 2009 is the basis for successful regulatory approval and issue of license for completion of the reactor refurbishment and commission.

1. Introduction

The IRT2000 research reactor at INRNE, Sofia was operated until fall 1989 when its operation was temporally stopped for safety improvement. Before that it had been planed (according to the project developed from 1982) the reactor reconstruction to 5 MW power level using IRT2M type (HEU) fuel already received from the former Soviet Union by that time. However in 2001 the Bulgarian government took a decision about the reactor refurbishment to 200 kW power level. A new reconstruction project IRT – Sofia was started and among others the project activities preparation of documents required for regulatory approval was foreseen. The initial Safety Analyses Report (SAR, v.0) was submitted to Bulgarian Nuclear Regulatory Agency (NRA) in December 2003. The SAR v.1 and v.2 (submitted during 2004) first of all addressed corresponding NRA comments. The IRT – Sofia operation and safety in these versions were analyses for IRT2M (HEU) fuel. The SAR v.3 [1] submission (in October 2005) was mainly connected with conversion from HEU to LEU fuel. This version included first results of the conversion study.

Bulgaria participation in the RERTR Program was initiated in 2003 by feasibility study of the IRT – Sofia conversion from HEU to LEU fuel and was continued by evaluation the IRT – Sofia characteristics important for safety analyses in close collaboration between Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Science and the RERTR Program at Argonne National Laboratory (ANL). The results of this collaboration were first of all used for preparation of documents needed for regulatory approval.

The specificity of IRT – Sofia conversion consists in the fact that it has been never operated with HEU fuel. The IRT2M (HEU) fuel was already returned from Bulgaria back to Russia (under Russian Research Reactor Fuel Return (RRRFR) project) as far back, as December 2003.

2. Steps, content and results of conversion study

The RERTR Program at ANL has been performing safety analysis conversion studies for research reactors for a long time, and INRNE demonstrated its readiness for collaboration by preliminary conversion evaluations [2]. The joint study of IRT – Sofia began with neutronics analyses. The joint work included creation of common calculational models based on the best available data for reactor components and materials, especially INRNE information on documentation and sketch materials of the IRT-Sofia research reactor corresponding to IRT-5000 Project [3]. As a calculation tool appropriate for criticality and beam tube performance evaluation the MCNP code [4] was selected, reactivity coefficients and kinetic parameters were calculated used the MCNP5 code [5] and the REBUS PC [6] together with WIMS ANL [7] – were used for fuel cycle calculation.

The first results concerning the IRT – Sofia conversion were presented in 2004 [8]. It was demonstrated that IRT4M LEU fuel is suitable for replacement of IRT2M HEU fuel in IRT – Sofia core design. The IRT4M fuel became commercially available just soon after this demonstration and up to now it still left to be the only LEU fuel available for Russian research reactors originally designed for IRT2M/3M (HEU) type fuel. The results [9] of following neutronics analyses showed that in the frames of conversion the IRT2M fuel assemblies could not be directly substituted by the IRT4M fuel assemblies and definite modification of the IRT – Sofia core configuration was needed. A set of possible IRT – Sofia initial LEU core configurations were analyzed and the most appropriate was selected. Selection of the initial core configuration was carried out in close collaboration with scientists from RRC “Kurchatov Institute”, Russian Federation. The selected configuration was highly recommended by Russian specialists on the base of their long time experience and provided by the INRNE/ANL calculation results for beam tubes performance and initial excess reactivity value for analyzed configurations. The first neutronics results obtained for selected initial core configuration were used in the IRT – Sofia SAR v. 3 submitted to NRA in 2005. Additional results of the IRT – Sofia LEU core performance study [10] were obtained during the next year.

The following study of IRT–Sofia, neutronics as well as thermal-hydraulics and accident analyses ,required for IRT–Sofia safety substantiation were continued after additional data needed for analyses became available. These data included updated information about control rods' construction from ŠKODA JS a.s., Plzeň [11], power and coolant flow measurement uncertainty data from JSC "SNIIP" [12], Moscow, and RCC 'Kurchatov Institute", Moscow [13] and were received during 2006 - 2007. Also in 2007 JSC "SNIIP" provided data about the reactor safety system characteristics used in accident analyses and in 2008 OAO "TVEL" provided actual IRT4M fuel data [14].

Thermal-hydraulic steady-state analyses were carried out using the PLTEMP/ANL code [15]. The results of calculation study [16-18] demonstrated that in steady-state condition and at least up to 1MW reactor power level just one pump in the primary coolant circuit is sufficient for the IRT – Sofia safe operation (Figure 1).

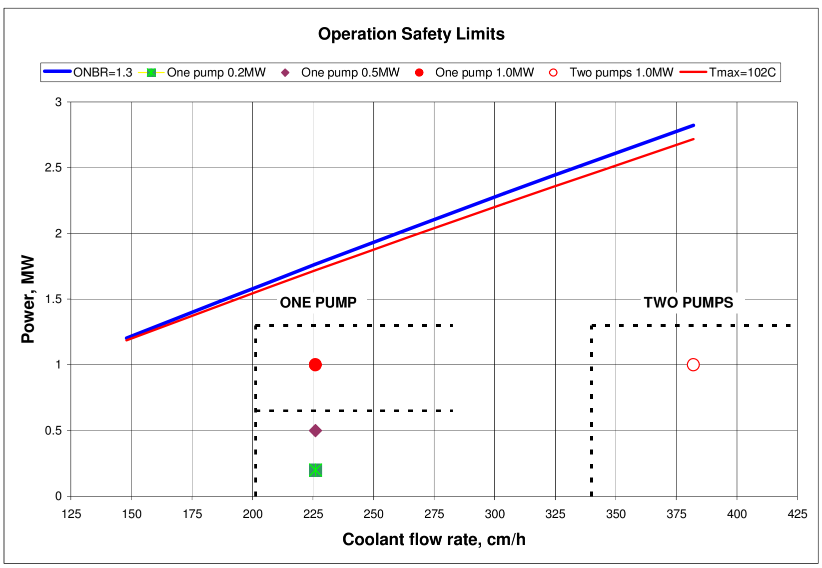

Fig 1. Reactor power limits for achievement of ONBR=1.3 and of 102°C [14]
(the dashed lines describe the limiting power and flow rate values that include the scram level and power/flow rate uncertainty [12, 13])

These results of the steady-state thermal-hydraulic analyses were intended for the IRT – Sofia SAR v.3 updating. In the framework of this updating the review and reassessment of Operating Limits and Conditions (OLC) were foreseen as well. The OLC modification in accordance with international requirements contained in the IAEA safety standards [19] was started in 2006. The improved OLC was prepared and is treated now as a part of the SAR and a separate document simultaneously that makes its usage more convenient. The experience of Portugal specialists [20] was also adopted and used for this document preparation. The OLC structure is in a good consistency with the IAEA safety requirements [21] helping to select initiating events used in accident analyses in the SAR.

In the framework of accident analyses the following scenarios were analyzed to assess the response of the reactor to the specified conditions, and specifically to determine if any fuel damage occurs as a result of the accident: 1) Insertion of reactivity by: uncontrolled withdrawal of a control rod from its critical position; disengagement of the aluminium follower of one control rod; ejection of a movable experiment; flooding of the air gap of one water "displacer" core element; cold water injection into the inlet of the core; 2) Loss of forced flow (LOF) accident as a result of loss of the offsite electricity supply; and loss of forced flow accident due to break of a pipe in the primary circuit system; 3) Blockage of inner coolant channel of a fuel assembly; 4) Unbalanced control rods positioning; 5) Core loading accident; 6) Loss of coolant accident (LOCA); 7) Accidental drop of fresh fuel assembly to the spent fuel storage; 8) Blockage of fuel assembly: Beyond Design Basis Accident (BDBA) involving postulated release of radioactivity. These analyses (except loss of forced flow accident due to break of a pipe in the primary circuit system) were completed [17, 14] .as far back, as fall 2009.

Transient analyses for the insertion of reactivity and loss of forced flow accidents were performed using the PARET/ANL (v 7.3) code [22]). For description of the blockage of inner coolant channel of a fuel assembly accident steady-state thermal-hydraulic calculation was sufficient. Additional MCNP [4] neutronics calculations were required for determination of the control rods differential worth and analyses of accidents connected with unbalanced control rods positioning; and core loading. It was substantiated that LOCA accident could not happen at IRT – Sofia as a result of a single passive failure. Neutronics calculations by the SCALE code system [23] also were additionally performed for description of accidental drop of fresh fuel assembly to the spent fuel storage. The BDBA accident in which one fuel assembly is assumed to melt and release of radioactivity occurs was analyzed using methodology and tool developed in ANL [24, 25].

According to analysis presented in the SAR v.3 the Loss of Coolant Accident (LOCA) could occur as the result of break of a beam tube with consequent loss of coolant; i.e. a single passive failure. However the IRT – Sofia is designed [26] to preclude this initiator to occur after a single failure for the beam tube (rupture of the beam tube with guillotine separation). The horizontal channels are connected to the bottom section of the pool by flanges (free flange made of stainless steel EN 10088-2-1.4541) and screw nipples. The construction of these horizontal channels includes two systems for providing a hermetic system (Figure 2).

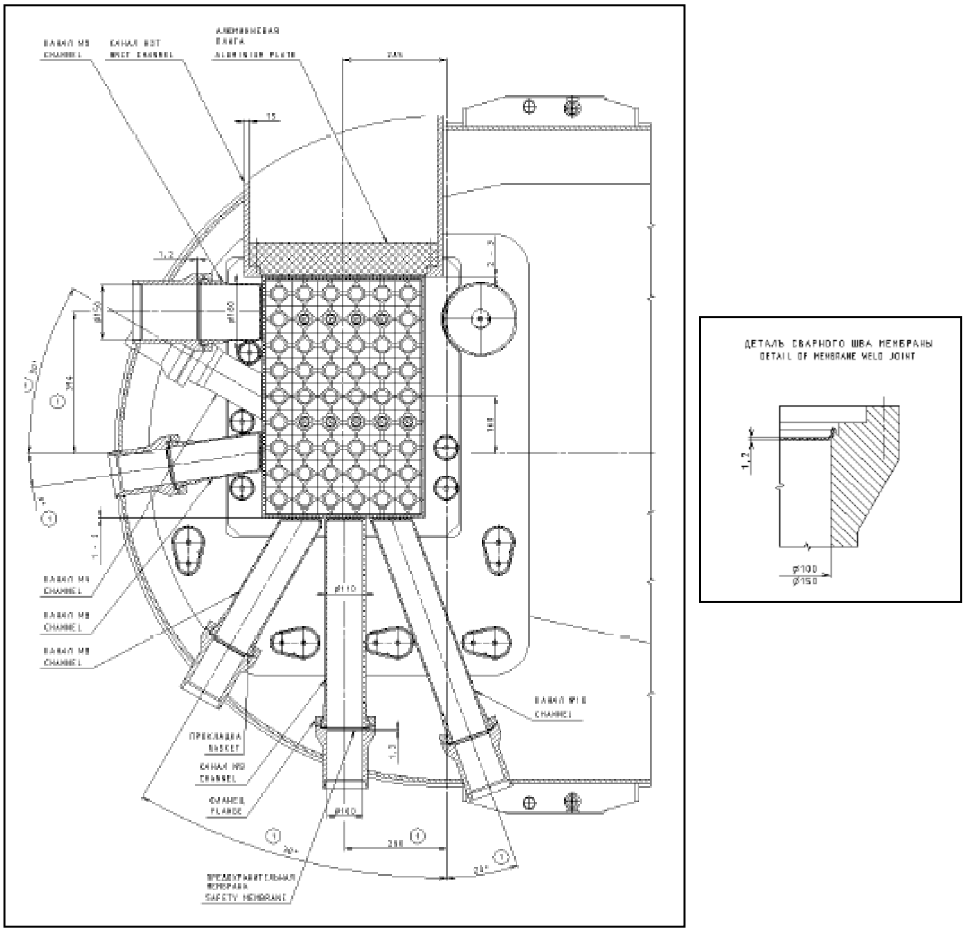

Figure 2 – IRT – Sofia beam tubes design

The first system is the classical flange-joint between aluminium and stainless steel part of the beam tubes. This joint has comb gasket (graphite gasket plate between stainless steel flanges). Stability of the pressing force of screw bolts is provided by a special spring washer. The second system is provided by protection membranes made of stainless steel with 1.2 mm thickness and located at the entrance of the stainless steel part of the beam tube. The first system provides hermeticity for normal operating conditions and for accidents in which the mechanical integrity of the channel tube and the flange joint is preserved. The second system guarantees hermeticity even in the case of a guillotine break of the aluminium part of the beam tube. The stainless steel membrane is protected against mechanical impacts and it has sufficient thickness to resist the water column pressure.

Based on this design the break of a horizontal beam tube will not, by itself, cause a loss of coolant accident. A second passive failure; i.e. the break of the membrane is also required. Special emergency procedure is developed to limit consequences (possible leakage) of this kind of failure.

The results of the last analysed accident - loss of forced flow due to break of a pipe in the primary circuit system, were obtained March 2010. This accident analysis completion became possible after receiving expert's conservative evaluation [27] of the accident condition (a linear downward flow through the core that slows down to zero flow over a period of 2 sec). Figure 3 shows the clad surface/fuel/coolant temperature for the hottest fuel tube and channel during the accident.

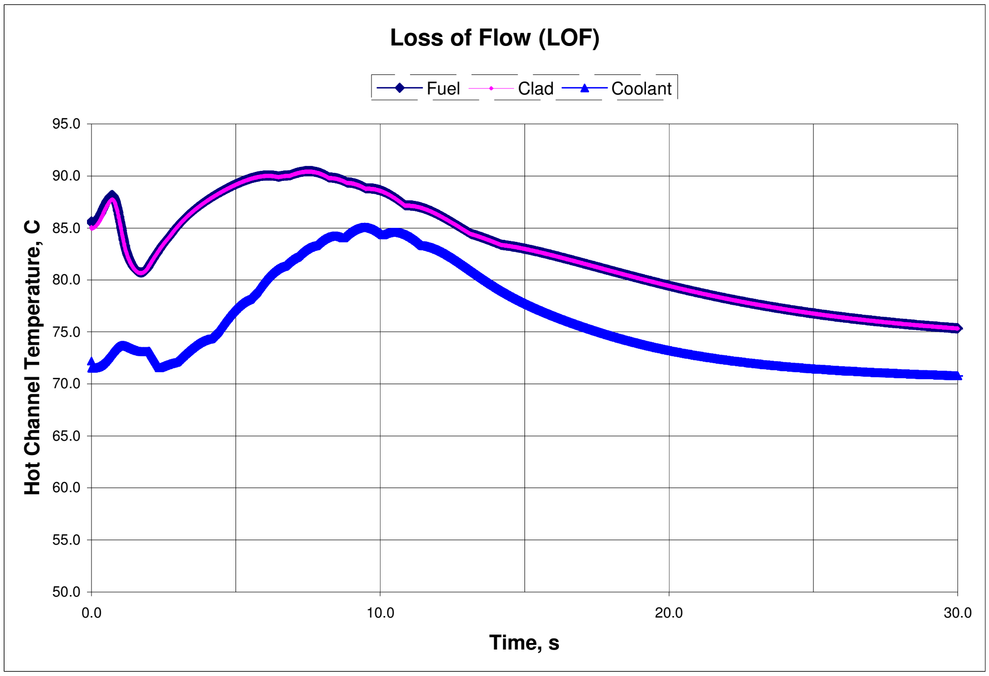

Figure 3 - Loss of Flow (inlet pipe break): Clad surface/fuel/coolant Temperature

These results show that the maximum temperature on the clad surface during this transient is less than 91°C; this temperature is below the temperature for onset of nucleate boiling (117°C) and well below the clad softening temperature limit of 425°C. The similar results for the maximum clad temperature were obtained for the previously analysed transients also [18].

The results of accident analyses demonstrated the IRT - Sofia Safety System capability to work properly providing safe operation during the accidents analyzed. The calculated effective (whole body) and thyroid doses for exposed workers and the members of the public during the BDBA accident are below the limits set by the Bulgarian Law and the European Council directive at any location inside or outside of the reactor building. Considering the conservative approach taken for the calculation of the fission product inventory and the meteorological conditions, doses for more realistic conditions will be significantly lower than those that were calculated.
It has to be noted that the IRT – Sofia design development is continuing till now first of all because of the BNCT beam tube optimization [28]. The optimization analyses show that BNCT beam tube cross section extension needs to be twice as large as that used in the present safety analyses. It was also found during optimization that the IRT – Sofia core criticality and power distribution are not changed in the limits of calculation accuracy for this range of the BNCT beam tube cross section variation. That let us to conclude that the obtained results for safety analyses are also valid for the optimised the NBCT beam tube design as well.

3. State of conversion and other tasks of regulatory approval

In March 2010 all calculations used for updating of the IRT – Sofia SAR v.3 were finalized. These calculation results were used by INRNE for preparation of the English version of the SAR sections (including the OLC section that could be used as a separate document) related to the HEU to LEU conversion of IRT – Sofia. This document is already translated to Bulgarian and is in a process of joining with the other sections of the IRT – Sofia SAR v.3 not related to the fuel conversion. The final document will be submitted to the NRA for operating license approval.

An additional improvement of the IRT – Sofia SAR includes new assessment of radioactive effluents and corresponding public doses evaluation during normal reactor operation. These evaluations results are presented in reference 29.

Concerning progress in solution of other tasks of regulatory approval it has to be said that simultaneously with the above mentioned activities the IRT – Sofia Environmental Impact Analyses Report (EIAR) requested by the NRA was prepared and successfully approved by the Bulgarian Ministry of Environment in March 2010.

In 2008 a successful repatriation of the spent HEU fuel used for IRT2000 operation to Russian Federation was realized under DOE financed contract. So the NRA requirement for starting of dismantling activities of IRT – Sofia refurbishment was fulfilled and dismantling itself was successfully completed in April 2010. The acceptance of the regulatory approval for the refurbishment itself is expected to be received soon. INRNE is working in close collaboration with the NRA representatives on this task successful finalization.

The inspection of the IRT-4M LEU fuel produced for IRT – Sofia at Novosibirsk Chemical Concentrates Plant was successfully realized in June 2010 and the fuel is expected to be delivered to Bulgaria in October 2010.

4. Acknowledgement

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