WWER Safety Investigations on LR-0 Reactor

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1. Introduction

The LR-0 reactor in Nuclear Research Institute Rez plc (NRI) is an experimental facility for the determination of the neutron – physical characteristics of the WWER and PWR type lattices and shielding with UO_2 or MOX fuel. The exploitation of this reactor is determined by the maximum power of 5 kW and maximum thermal flux of 10^{13} n·m^{2}s^{-1}, atmospheric pressure and room temperature (or heating up to 70°C). The fuel consists of the shortened WWER-1000 and WWER-440 type fuel assemblies (cassettes) containing the fuel elements (pins) with UO_2 pellets (O.D. 7.53 mm) having a Zr+1%Nb cladding (O.D. 9.15×0.72 mm) with the active length of 1250 mm and enrichment of 1.6-4.4% in ^{235}U. The fuel assemblies can be arranged in a reactor vessel of aluminium (diameter 3.5 m, height 6.5 m); the criticality is controlled by moderator level (boron acid with concentration up to 12 g/l) and control clusters (B_4C pellets).

2. Aim of the LR-0 Reactor Utilisation

The most important applications concern the nuclear safety and economy of the WWER type NPPs operation, as well as the subcriticality verification of the WWER type spent nuclear fuel storages.

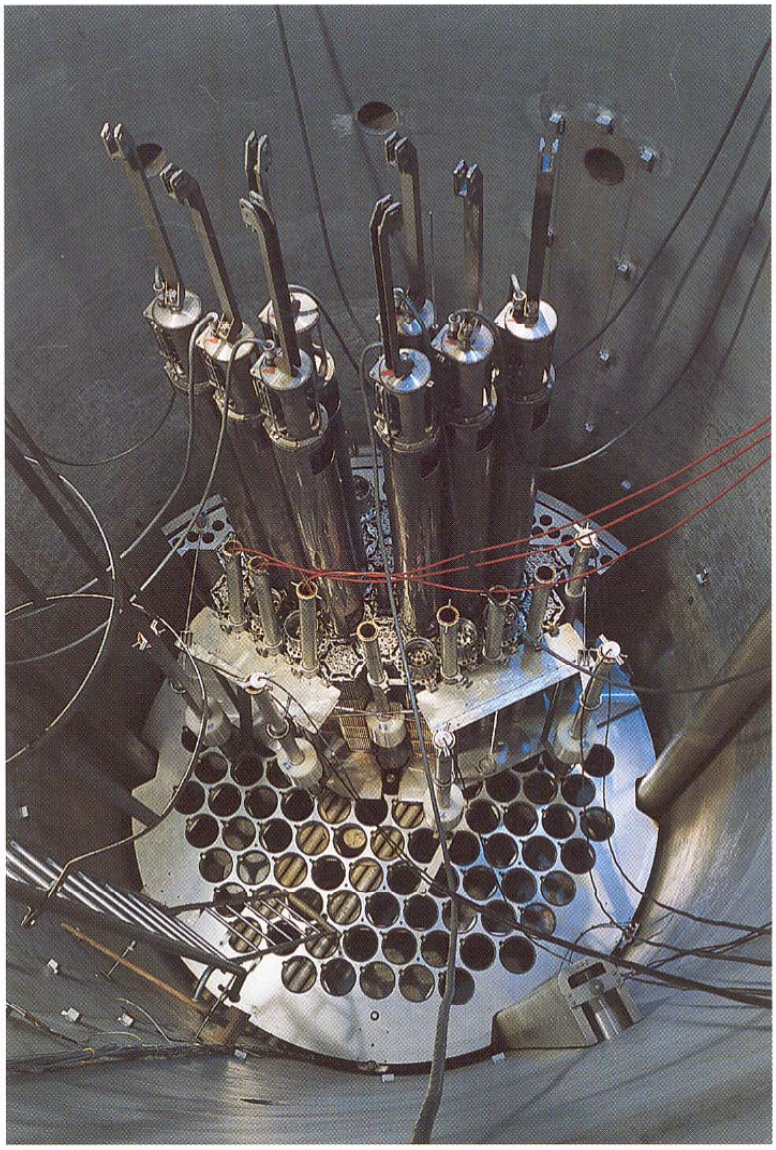
3. Experimental Programme on the Reactor LR-0

3.1. Reactor Pressure Vessel Dosimetry Experiments

A set of the measurements needed for the WWER-440 and WWER-1000 reactor lifetime assessment, verification of the methods, codes and input cross sections libraries for the WWER reactor pressure vessel exposure evaluation has been performed on the LR-0 experimental reactor.

The steel embrittlement is the most important damaging mechanism in assessment of the reactor pressure vessel (PV) lifetime. In spite of the fluence determination improvement (using better computational techniques and the corrected cross section values), significant discrepancies still exist between calculations and experiments.

To solve these problems, the WWER Mock-ups (engineering benchmarks) has been carried out on LR-0 experimental reactor (Figure 1), devoted to investigation of the differential neutron spectra for the reactor PV dosimetry purposes. The obtained



experimental results can be compared with calculations ones. The differential neutron energy spectra measured in the Mock-up provide a good test of the calculation models and data libraries with more information than a set of reaction rates usually measured in many benchmarks. Such experimental programme predominantly consists of the neutron spectra measurements with proton recoil spectrometer in the energy range 10 keV-10 MeV and of the core power distribution (pin to pin) measurement by means of the irradiated fuel pins using gamma scanning method. The low power of LR-0 limits the measurements with activation detectors, but the differential energy spectrum knowledge is a better test of calculation model and methodology than a set of reaction rates. The neutron spectrum is measured in the positions of the exposure monitors and the PV critical locations namely in WWER-440 and WWER-1000 engineering benchmarks.

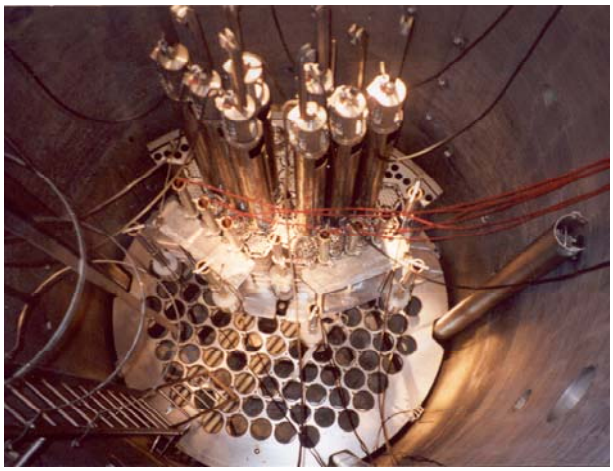


Figure 1. WWER-1000 mock-up arrangement on LR-0 reactor

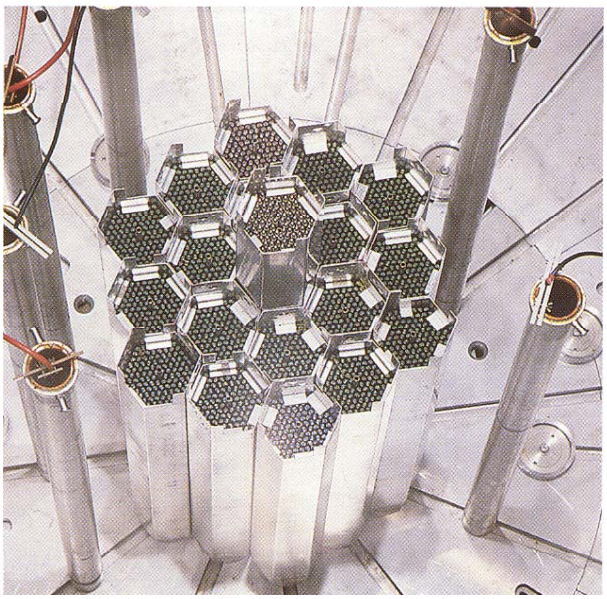


Figure 2. Core arrangement with WWER-440 control assembly model on LR-0 reactor

The applicability studies validate the similarity of the Mock-ups and NPP reactors and usefulness of experimental data as a WWER-440 reactor dosimetry benchmarks. The formulated benchmarks represent a good tool for the WWER-440 PV dosimetry methodology and calculation qualification. Moreover the Mock-up measured data can be directly applied to the power reactor dosimetry but with corresponding corrections in several cases. Especially in the power reactors without surveillance programmes (type V-230) and low leakage core, these results are very useful (Bohunice NPP, Slovakia, Kozloduy NPP, Bulgaria, and NPPs in Ukraine and Russia).

It can be recommended, the use of these benchmarks will be more effective if they are combined with the NPP ex-vessel dosimetry monitoring. Similar conclusions can be expected for the WWER-1000 engineering benchmarks. In both these cases, the corresponding neutron deep penetration benchmarks for “decommissioning calculations” can be arranged on LR-0 experimental reactor.

The WWER-440 and WWER-1000 Mock-up investigations, realized until now on LR-0 reactor, were done by NRI Rez, Skoda Nuclear Machinery, Plzen, Czech Republic, and Russian Research Centre “Kurchatov Institute” (RRC KI), Moscow and OKB Gidropress, Podolsk, Russia [1,2].

In the WWER-1000 Mock-up investigations supported by IAEA as the regional project RER/4/017, “The Data Base for WWER-1000 Reactor Pressure Vessel”, the NRI, RRC KI, Institute of Nuclear Research and Nuclear Energy, Sofia, Bulgaria and several Ukraine Institutes took part [3].

3.2. Measurements of the Control Assembly Influence

A set of critical experiments has been performed on the LR-0 reactor to determine the perturbation of the fission density distribution caused by the WWER-440 control assembly. This assembly, partially inserted in the core, has significant influence on the space power distribution, especially in the vicinity of this assembly. Because of its complicated geometry and material composition, the detailed calculation of this effect represents a substantial problem. Therefore it would be useful to have a possibility of carrying out the calculations using a code validated by means of experimental data. Since corresponding data of this type cannot be obtained in the NPPs, they should be determined on the basis of measurements performed in an experimental reactor with WWER-440 type core, containing an appropriate control assembly model. This way the desirable

information can be obtained with sufficient accuracy to validate the existing codes needed for such calculations.

Some measurements with a control assembly model were realized on LR-0 reactor in the past, e.g. the work [4] was partially covered by the contract concluded between NRI Rez and Hungarian Paks NPP (Figures 2 and 3). New experiments should be performed at more realistic conditions concerning e.g. the composition of the core containing the fuel assemblies having profiled enrichment, the various boron concentration (including zero-concentration, corresponding the end of the fuel cycle on the NPP), as well as taking into account modernization of the control assembly design described in [5] (plates of metal hafnium are provided to be arranged on the inner surface of jacketed tube in the region of the control assembly butt joint to suppress neutron flash-up).

3.3. Spent Nuclear Fuel Storage Subcriticality Verification

A wide research programme devoted to subcriticality investigation of the spent nuclear fuel storage has been realized on the LR-0 experimental reactor. Various critical experiments for this purpose has been prepared using the WWER-440 type fuel assemblies arranged in a corresponding geometry. The aim of these activities is a check of the corresponding storage type subcriticality, because of the nuclear safety requirements.

For this purpose, a core was arranged consisting two parts: the lower (subcritical - storage type) one, containing fuel assemblies placed in the tubes with absorbing material (borated steel tubes) and the upper core part as a driver. The detailed radial and axial measurements of the fission density distributions were performed, especially in the lower part of the core, to determine corresponding buckling values and the infinite reproduction constant of k_{inf}, needed for the verification of the required subcriticality.

For instance, an benchmark experiment of this type was realized on LR-0 reactor in corresponding geometry of CASTOR 440/84 type under contract between NRI, Rez and GNB Essen, Germany [6].

3.4. Experiments with New Fuel Assemblies

In the frame of NPPs modernization, a set of experiments has been performed on the LR-0 reactor with new type fuel assemblies with various burnable absorbers arranged in appropriate configurations and cores of the both WWER-440 and WWER-1000 types (e.g. experiments with fuel assemblies of WWER-1000 type containing fuel pins with Gadolinium [7]).

4. Conditions for the Experiment Realization

The activities mentioned above require corresponding material conditions and economical cooperation. Therefore, a permanent contact with potential customers and sponsors is necessary to discuss and to prepare the research projects and contracts to cover the investigation works. For this purpose, our important partners are the IAEA, EU (5-th FWP), Czech and foreign NPPs, research institutes and some other organisations.

The realization of each experiment on the reactor LR-0 consists of three main parts:

- 1-st part: preparation of the fuel assemblies, core arrangement, moderator (demineralized water or boron acid with required concentration), and the achieved critical height calculation of the moderator level (in the case of a “new” core);
- 2-nd part: realization of critical experiment, irradiations of detectors and measurements their activity;
- 3-rd part: dismounting the core and fuel assemblies, evaluation of measured data and final report preparation.

It could be mentioned, the experiments of different type (with different cores and “measurement programmes”) cannot be carry out at the same time. Each of them needs “own time”, depending on the volume and type of measurements. The last specific characteristic of the experiments on the LR-0 reactor is the fact, that their second part (mentioned above) need not be the longest one.

5. Experiments Performed in 2000

The azimuthal and axial distribution measurements of the fast neutron flux density were performed before and behind the LR-0 PV simulator in the WWER-1000 Mock-up using the stilbene proton recoil spectrometer. The works were supported by IAEA as the regional project mentioned above.

Further, a set of critical experiments was prepared using the fuel assemblies with enrichment of 3.6% and 4.4%, arranged in the WWER-440 type cores with various lattice pitch. The critical height of the moderator level and the moderator level coefficient of reactivity were measured as well as the effect of the fuel assembly, placed in a hexagonal tube of stainless steel containing boron absorber (ATABOR – STANDARD), was investigated. The obtained results are used for the validation of the codes (MCNP, KENO and SCALE) in the frame of the contract “Burn-up credit implementation for the storage and transport containers of the spent fuel from NPPs”.

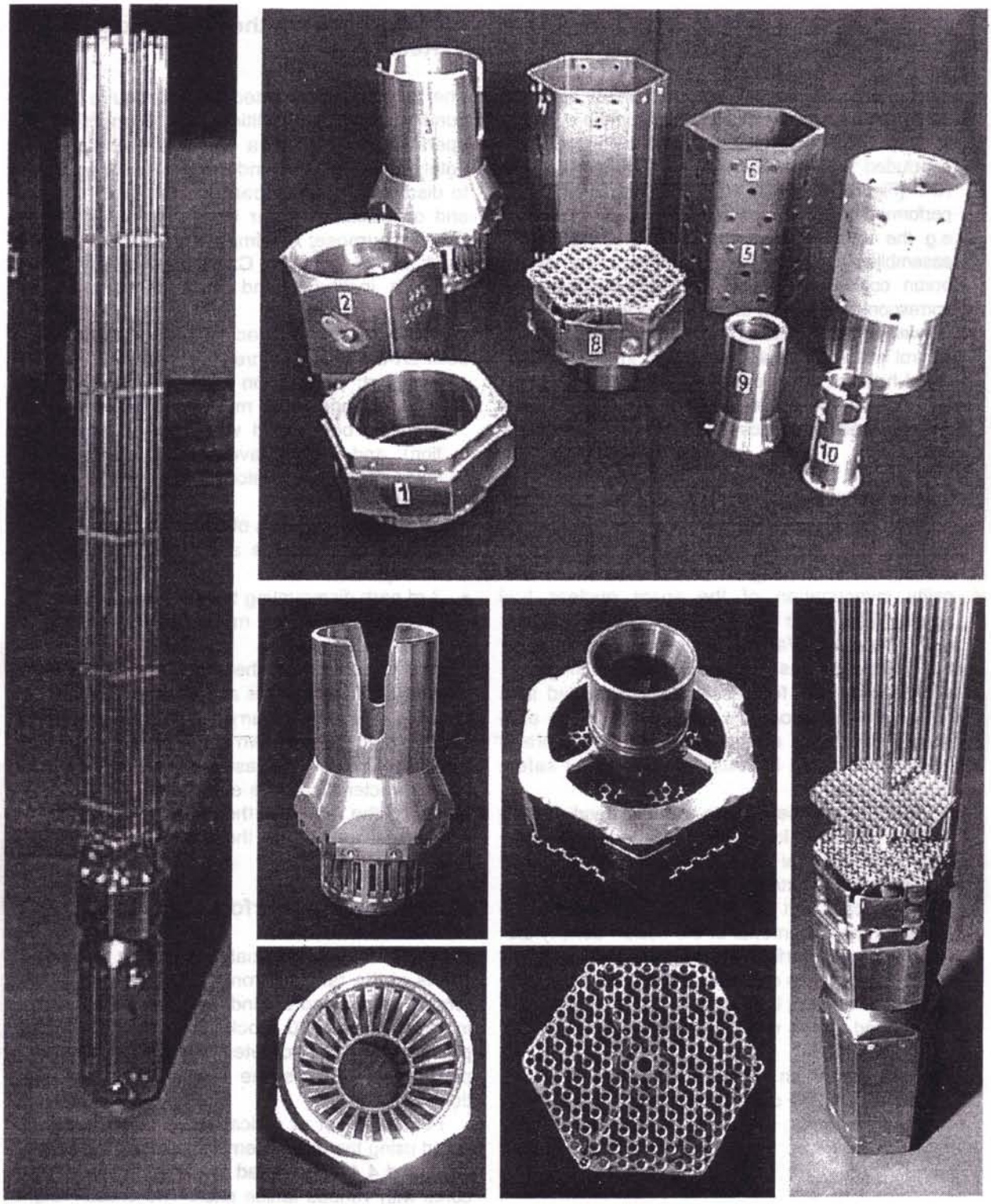


Figure 3. Separate parts of the WWER-440 control assembly model

6. Experimental Programme in 2001

The first experiment, started in this year, is covered by a “Contract” between NRI Rez and EU (5-th FWP). It concerns the combined neutron - gamma spectra measurements in the WWER-1000 Mock-up, namely at the reactor internals simulator and reactor PV model. This “Project” was prepared in co-operation with institutes from the Spain, France, Germany, Finland and Hungary, and with the Russia as a subcontractor. The next experiments will concern the control assembly influence measurement (as mentioned above), and the detailed fission rate distribution determination in a WWER-440 type core with the new-type fuel assemblies (profiled enrichment and fuel pins with Gadolinium).

Acknowledgement

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