AER BENCHMARK SITE

Mihály Makai
KFKI Atomic Energy Research Institute
H-1525 Budapest 114, POB 49
Hungary
makai@sunserv.kfki.hu

ABSTRACT

Atomic Energy Research (AER) is an international cooperation endeavoring to improve operation, design and inspection of VVER type reactors. AER has been maintaining a web site for VVER related benchmark problems and benchmark solutions. The benchmarks cover most of the computational tasks around a power plant. The benchmark collection includes homogenization problems, burnup credits and problems to test the accuracy of the few- group diffusion equation. The most complex problem set deals with reactor dynamics, it offers an inter-comparison for coupled thermal hydraulics- neutron physics at a variety of feedback situations. Efforts have been made to have reliable reference solutions where it is possible and to estimate the error of the reference solution.

1. INTRODUCTION

The increased interest in VVER type is explained by the following facts. According to a report [1] issued in 1994, 26 units of VVER-440 and 21 units of VVER-1000 have been operating in seven countries. In 1990, institutions of countries operating VVERs established the Atomic Energy Research (AER) cooperation to promote research leading to safer and more economic operation of VVER type nuclear reactors.

In 1998, the Scientific Council of AER decided on compiling a volume of VVER related benchmarks, in order to facilitate the validation and verification (V&V) process of VVER calculation programs and codes. The AER Scientific Council established a Benchmark Committee, which issued a Call for Benchmark. In response to the call, test problems were specified and submitted for review. The submitted tests were reviewed and collected. The AER Benchmark Site intends to collect the submitted test cases into a unified framework. All submitted cases have been utilized in V&V of VVER codes.

AER's collection is not the first benchmark collection. One of the best known collections is perhaps the Argonne Benchmark Problem Book [2], its volumes appeared between 1972 and 1985. The volumes of Argonne Benchmark Problem Book involve experimental and mathematical tests. That benchmark collection focuses on the V&V of basic nuclear library data and calculation methods, and has only a few tests devoted to such complex problems as, for example, the coarse-mesh calculation of a HTGR reactor. Since the late 70's, complex reactor physical calculations have been organized into large codes. Elements of such large codes as well as the full code should be tested, this gives rise to a broader range of tests in a benchmark collection. Since then, the calculation models underwent a considerable development, and further benchmarks have been used to verify the entire model. The benchmarks used in the present book, are so called mathematical benchmarks (see dynamics), or, operational measurements on a power plant.

Detailed experiments have been performed to learn neutron physical characteristics of lattices occurring in VVER cores. Experiments [3] performed on the ZR-6 critical facility have revealed several details concerning the spectral and spatial behavior of typical VVER lattices. Cores composed of real VVER-440 and VVER-1000 assemblies have been investigated on the LR-0 facility [4]. Measurements on simple periodic structures allowed us to verify nuclear libraries and to estimate the accuracy of the asymptotic codes. Those results are available elsewhere, including comparisons with a number of calculated results [5].

The AER Benchmark Site does not include all the tests being used in practice. The Benchmark Committee issued a Call for Benchmarks, and only tests submitted before 31 July 1999 are included. The tight deadline must hinder some authors to submit their tests in an electronic and reconsidered form. Later on the benchmark collection will be enlarged.

The tests included in the present benchmark problem collection do not claim an official acknowledgement from any national regulatory body or authority. At the same time, the tests included in the present volume do essentially contribute to the reliable V&V process of VVER calculation tools. The users of the tests should remember the following:

1. Good performance of a test does not guarantee good performance in practical applications. There are a number of other circumstances that the user should consider when selecting a code, e.g. its user friendly input and output, robustness, portability, speed.
2. Like the equations of physics in general, the equations of reactor physics are frequently continuous functions of the parameters. Thus, one may expect to get more or less the same accuracy if the parameters have been changed slightly. One should always ponder if the parameter change may bridge a drastic change in the model, or, if a large number of parameter changes.
3. The test set is not complete. It requires a considerable amount of work to document the performed measurement or calculation in such a manner that it is useful for others. There have been a number of tests to verify parts of the calculation models but the restricted resources have set a limit to the number of tests. At the same time if a test has been selected to be included it meets the requirements.

In naming the benchmarks, we have been applying naming conventions. From the point of view of the reference solution, tests have been classified as follows.

1, **Benchmark.** It is a problem to test a given algorithm. The input to the algorithm is provided. The required output of the algorithm is specified. There is a reference solution, its error is known. With a benchmark, we get a trustworthy estimation for the maximum error of the algorithm. The error may be even larger in other cases unless the test case is shown to be overly conservative.

2, **Standard exercise.** It is a problem to test a given algorithm. The input to the algorithm is provided. The required output of the algorithm is specified. There is a reference solution. With a standard exercise, we get an impression of the error of the algorithm. The comparison alone is inappropriate because the reference may fail, we have to analyze the nature of the differences.

3, **Intercomparison.** It is a problem to test a given algorithm. The input to the algorithm is provided. The required output of the algorithm is specified. An intercomparison is suitable to estimate the maximal effect of diverse approximations made in different algorithms. It is often impossible to declare which result is better.

Concerning the origin of test input data, cases are classified as mathematical, experimental or operational tests.

- A **mathematical** test provides all input data to solve a given equation. A good example is the solution of the diffusion equation without feed back.
- An **experimental test** is where the reference solution comes from measurements and the input fixes the experiment's situation. The recommended procedure is given in Ref. [6].
- An **operational test** describes the operational state of a working unit. The reference distribution is obtained from the plant measurements. The recommended procedure is given in Ref. [7].

In Section 2, we give a short description of VVER types in order to allow the possible user for judging if a given test is useful for him/her or not. This section provides the terminology utilized in the tests. The tests are enlisted in Section 3.

Although the test cases and the present work have been prepared with much care they may contain errors. The reviewers have verified that the given test can be performed but the text may be corrupted during subsequent steps of editing. The readers are encouraged to report bugs, typographic or other errors to the authors or to the AER Secretariat.

Finally, we remark that all the tests are available via Internet at location: http://www.kfki.hu/~aekihp/. Look up the Atomic Energy Research section there and follow the instructions.

2. BASIC DATA ON VVERS

The present section provides basic data of VVER-440 as well as VVER-1000 core and fuel assembly. There are different designs, the data in *Table I.* refer to VVER-440 model V213 and VVER-1000 model V320. Since a part of the possible readership may be unfamiliar with basic VVER features, some generally used terminology, concerning the characteristics of the power distribution, is also given. *Table I.* is a summary of block data, partly after Ref. [8]. In both VVER types, low enriched UO_2 fuel is used collected in hexagonal assemblies. Both types are controlled by boric acid and by control assemblies.

Reactor	VVER-440	VVER-1000
Thermal power	1375 MW	3000 MW
Number of loops, pumps and steam generators	6	4
Coolant pressure	122.5 bar	157 bar
Flow of coolant through the reactor	31 000-35000 t/h	63000 t/h
Average coolant temperature at in-let	267 ^oC	289.8 ^oC
Average coolant temperature increase	28.9 ^oC	30.3 ^oC
Fuel heat transmission area	3050 m^2	5175 m^2
Mass of Uranium	42 t	66 t
Number of fuel assemblies	349	163
Number of mechanical reactor control units	37 pc	61 pc
Vessel height (without upper plenum)	11.8 m	10.88 m
Vessel outer diameter	3.84-4.27 m *	4.57 m
Vessel mass	200.8 t	304 t
Outer diameter of main coolant pipeline	500 mm	850 mm
Steam generator		
Steam production	455 t/h	1470 t/h
Steam pressure	47 bar	64 bar
Heat transmission area	2500 m^2	5040 m^2
Generator		
Number of generators	2 pc	2 pc
Dry steam pressure before turbine	44 bar	60 bar
Output power	220 MW	500 MW
Unit		
Electric power	440 MW	1000 MW
Efficiency (gross)	32 %	33.3 %
Efficiency (net)	29.7 %	31.5 %

*3.84 m in the core region, 4.276 m at the vessel flange

Table I. Main Features of VVER-440 and VVER-1000 Units

2.1. VVER-440 REACTOR

VVER-440 is a water-cooled and water moderated thermal reactor. The core consists of 349 hexagonal assemblies. The fuel is low enriched UO_2. Criticality is controlled by the boric acid concentration and by the position of control rod banks. Control rods are sorted into groups. The most frequently referred group is numbered as 6^{th} and comprises 7 assemblies. Its elements are the central assembly, the other assemblies of the group are every 6^{th} assemblies along the 6 different directions starting out from the central assembly stepping to the next neighboring assembly along a given direction.

In mathematical benchmarks, a simplified geometry is specified only: The core is composed of assemblies of identical geometry but with different material properties unless otherwise stated. Assemblies are considered as homogeneous, their composition is described by two-group cross-sections, in diffusion approximation. If the internal structure of the assembly is relevant, it is also specified in a simplified way. The cells making up the assembly are homogeneous hexagonal cells of identical size. This is only an approximation because the assembly wall is poorly described this manner.

In operational benchmarks, however, details of the actual geometry may be relevant. Therefore, such tests should specify all relevant information (geometry, material composition, and coolant flow rate, inlet temperature) in an appropriately detailed manner. Below, we present certain general information concerning geometry of VVER-440 and VVER-1000 cores including also the in-core instrumentation.

In a VVER-440, 210 assemblies are equipped with outlet temperature measurements, 36 assemblies with self powered neutron detectors (SPNDs). In most test cases, the core height is taken as the nominal value: 250 cm, unless indicated otherwise. The lowermost spacer is placed at elevations z=16,3 cm from the bottom of the fuel, further spacers are placed equidistantly at 24 cm distance Spacers are made of stainless steel or zirconium niobium. If a test accounts for the spacers, it indicates clearly the nuclide densities and the geometry.

The clad material is zirconium-niobium with hafnium. The control assemblies slightly differ in structure, their active height is smaller and its hydraulic resistance also has been changed. The control assembly has three major axial parts. The lower part is the follower, it resides in the core when the control rod is fully withdrawn. The upper part is the absorber followed by a structure joining the absorber part to the fuel part. The fuel part is called the control rod follower. Usually control assemblies are fully withdrawn except control group 6, which is kept in the upper one third of the core. The control assembly contains borated steel absorber, structural material and water. The average fuel enrichment is 1.6, 2.4 or 3.6 w/w %.

A fuel cell has a fuel, a cladding and a moderator region. If an air gap is taken into account, it is indicated explicitly. Asymptotic codes (cell homogenization, generation of few group library, parametrization), such as burnup codes usually replace the hexagonal cell with a cylindrical cell of equal area.

In VVERs, the coolant and moderator is water. There are 6 loops in the primary circuit of VVER-440. The actual coolant flow rate through a given assembly depends on the flow rates of the individual loops. The assembly flow rates are not measured but estimated. The coolant entering temperature at a given assembly depends on the cold leg temperatures in the individual loops.

2.2. VVER-1000 REACTOR

VVER-1000 is a water-cooled and water moderated thermal reactor. The core consists of 163 hexagonal assemblies. The fuel is low enriched UO_2. Criticality is controlled by the boric acid concentration and by the position of control rod banks. Control rods are of cluster type and are sorted into 10 groups. The most frequently referred group is numbered as 10^{th} and comprises 6 assemblies.

In mathematical benchmarks, a simplified geometry is specified only: The core is composed of assemblies of identical geometry but with different material properties unless otherwise stated. Assemblies are considered as homogeneous, their composition is described by two-group cross-sections, in diffusion approximation. If the internal structure of the assembly is relevant, it is also specified in a simplified way. The cells making up the assembly are homogeneous hexagonal cells of identical size.

In operational benchmarks, however, details of the actual geometry may be relevant. Therefore, such tests should specify all relevant information (geometry, material composition, and coolant flow rate, inlet temperature) in an appropriately detailed manner. Below, we present certain general information concerning geometry of VVER-1000 cores including also the in-core instrumentation.

In most test cases, the core height is taken as the nominal value: 350 cm, unless indicated otherwise. Spacers are made of stainless steel or Zirconium Niobium. If a test accounts for the spacers, it indicates clearly the nuclide densities and the geometry. The VVER-1000 fuel assemblies are characterized by the following parameters [9,10]. The average enrichment of the assemblies is 2.0, 3.3, 3.6, 3.7, 4.0, 4.23, 4.3, 4.4 % (w/w). The structural and guide tube material is stainless steel or Zr alloy. In a VVER-1000, 95 assemblies are equipped with an outlet temperature measurement, 64 assemblies with self powered neutron detectors (SPNDs). We remark only here that following features should not be ignored:

- Type of burnable -poison rods (solid boron rods with natural boron concentration 0.036 g/cm^3; Gd_2O_3 and UO_2 mixture; no burnable poison at all)
- Number of burnable poison rods in an assembly (6 or 18).

2.3. TERMINOLOGY FOR CORE CALCULATIONS

In the test cases, we compare characteristics of the computed flux or power distributions. Below, the terms are defined for VVER-440 core, with 349 fuel assemblies and 10 axial layers of equal volume in the calculation. In this context, the following terms will be used:

- **Nuclear power release** is defined as the instant rate of thermal energy released from nuclear fissions and decay. Most of this energy is deposited in the fuel, but a small fraction (app. 2,5 %) is deposited directly into the coolant via neutron slowing down and gamma radiation.
- **Thermal power to coolant** is defined as the instant rate of thermal energy input to the coolant in the core. Most of this energy is transported to the coolant by heat transfer from the fuel, but a small fraction is deposited directly into the coolant via radiation. Note that the thermal power to coolant can also be influenced by changes in coolant inlet temperature. The difference between nuclear power release and thermal power to coolant results in a change of fuel temperature, including the cladding.
- The **position of a control assembly** is defined as the distance that the assembly is lifted from its fully inserted position. It is usually measured in cm. When fully withdrawn from the core, at position 250 cm, the bottom of the fuel pellet stack in the follower assembly is aligned with the rest of the core.
- **Core energy production** (sometimes referred to as **core burnup**) is defined as the total thermal energy production in the core since the beginning of an operating cycle. It is often measured using a customized unit of energy called a full power day (FPD). For VVER-440 reactors, full power (FP) is equivalent to 1375 MW and one FPD is hence equivalent to 1375 MWd of thermal energy.
- The **boron concentration** is defined as the mass fraction of natural boron in the coolant. It is usually measured in ppm (parts per million = 10^{-6}). Alternatively, the boric acid concentration is used. It is usually measured in g/kg (= 10^{-3}). To a good approximation, 1 g/kg of boric acid is equivalent to 175 ppm of boron.
- A volume element is called **node**. There are 3490 nodes in the core when the above given discretization is utilized.
- **Critical core state**: The following parameters are subjected to possible change in a core: boron concentration, control assembly positions, core input coolant temperature and coolant flow rate, load

pattern. A given core is called critical if these parameters are set so that the corresponding static eigenvalue k_{eff}=1. With the other parameters fixed, if one parameter (boron concentration or rod position) is set so that it makes the core critical then we speak of **critical boron concentration** or **critical rod position**.

- **Multiplication factor**: If the core is not a critical core state, the corresponding static eigenvalue k_{eff} that would make the core critical is called multiplication factor.
- **Power level**: the power released in the core is given either with absolute numbers (e.g. 343.75 MW) or in percent of the nominal power (1375 MW), e.g. 25%.
- **Fuel burnup** is defined as the release of thermal energy per unit mass of heavy metal (U, Pu) initially in the fuel. It is usually measured in units of MWd/kgU.
- **Power density**: W_{ij} -the power produced in node *j* of assembly *i* divided by the node volume. Its average value for an assembly is

$$\overline{W_i} = \frac{1}{10}\sum_{j=1}^{10} W_{ij} \ .$$

Its average value over the core is

$$\overline{W} = \frac{1}{349}\sum_{i=1}^{349} \overline{W}_i \ .$$

- **Assembly power**: W_i -the power released in an assembly due to fission. The thermal power is the power conveyed by the coolant, the nuclear power is the power calculated directly from fission.
- **Axial peaking factor** (k_z)

$$k_{zi} = \max_j \frac{W_{ij}}{\overline{W_i}}$$

- **Assemblywise peaking factor** (k_q) in assembly *i*:

$$k_{qi} = \frac{\overline{W_i}}{\overline{W}} \ .$$

- **Nodal volume peaking factor** (k_v) in assembly *i* node *j*:

$$k_{vij} = \frac{W_{ij}}{\overline{W}}$$

- **Intra-assembly peaking factor** (k_k) in assembly *i* node *j*: Let w_{ijm} be the pin power in assembly *i* node *j* and pin *m*. Factor k_k for assembly *i* and node *j* is given by

$$k_{kij} = \max_m \frac{w_{ijm}}{\overline{w_{ij}}} \ .$$

- **Radial peaking factor** (k_r) $k_r=k_q*k_k$
- **Local peaking factor** (k_o) $k_o=k_r*k_z$
- **Control group position** (H_6): position of the control assemblies in control group 6.

It may happen that not all of the above terms or features recurs in the first release of the Benchmark Book. If our endeavor is successful the scope of the benchmark activity will be gradually enlarged.

3. TEST CASES

This section is a short survey of the available tests listed in *Table II*. Each test has been assigned a mnemonic identification. The first invariable tag is AER. The second tag refers to the nature of the test. We used the following abbreviations:

DYN -dynamics
FCM -full core, mathematics
FCO -full core, operational
HOM -homogenization/dehomogenization
ASB -asymptotic burnup
BCR -burnup credit
KAB -assembly burnup
TRO -transient operational test.

The last tag is a three-digit number. Its first digit refers to the reactor type (0/1=VVER-440/VVER-1000), the last two digits make a sequential number.

Solutions to some test problems contain a large amount of numbers. Solutions to those test problems reside in separated files. The naming convention for solution files is as follows. We leave out AER in front of the test name and add the tag SXX, where XX is a serial number, S is a fixed character that refers to the word "solution".

4. TEST SPECIFICATIONS

The test specifications are available via internet at http://www.kfki.hu/~aekihp/ where you have to click on AER, there click on Benchmark Book. The file README.TXT gives a general explanation (text specification, input, required output, required format, etc.) and PREAMBLE.DOC gives detailed information on the tests. (Extension TXT refers to text files, DOC refers to WORD6 files.) Instead of assessing the test cases one by one, we make only a few comments on them.

1. The dynamics tests have been designed to rule out possible discrepancies of the codes gradually. Tests vary from pure neutronics to steam header break. In the meanwhile a new member has been added to the test series [11]. The new test models a double ended break of the main steam line.
2. Since nodal calculations form the base of several analyses, the accuracy of the nodal algorithms must be tested carefully. We have 60 deg and 180 deg mathematical tests and either test has a reliable reference solution.
3. Operational tests are rather expensive since they require a lot of work from the NPP personal. At present we have only one operational test which models load follow regime of a NPP. Further tests are planned.

If you wish your solution to be evaluated send an e-mail message to one of the addresses indicated on the web site. Solution evaluation and new benchmark inclusion is planned periodically.

4. FUTURE PLANS

A new solution [12] by N. Kolev to problem AER-DYN-002, raised the possibility of emerging large errors in control rod worth calculation by dynamic nodal codes. The problem should clarified and the new solution should be added to the available benchmark solutions.

The new member [11] of the dynamics test series should be included in the benchmark collection. Available solutions to that test also should be included.

In the last years, the problem of power density variations in a fuel assembly adjacent to a control assembly has been widely discussed. When a benchmark, such as proposed in Ref. [13], has been accepted by the affected community, it should also be included into the benchmark collection.

No.	Identification	Author	Company	Classification		Description	File
				Reference	Input		
1	AER-DYN-001	A. Kereszturi, M. Telbisz	AEKI	I	M	Neutronics	DYN001.doc
2	AER-DYN-002	U. Grundmann	FZR	I	M	Neutronics +Doppler feedback	DYN002.doc
3	AER-DYN-003	R. Kyrki-Rajamäki, E. Kaloinen	VTT	I	M	Neutronics +Thermal hydraulics	DYN003.doc
4	AER-DYN-004	R. Kyrki-Rajamäki	VTT	I	M	Boron dilution	DYN004.doc
5	AER-DYN-005	S. Kliem	FZR	I	M	Steam header break	DYN005.doc
6	AER-FCM-001	Cs. Maráczy et al.	AEKI	B	M	440 core, Seidel's test	FCM001.doc
7	AER-FCM-002	Cs. Maráczy	AEKI	B	M	180 deg 440 core	FCM002.doc
8	AER-FCM-101	N. P. Kolev	IAE	B	M	Schultz test	FCM101.doc
9	AER-FCM-102	G. Alekhova, M. Prodanova	KNPP-IAE	I	M	1000 core	FCM102.doc
10	AER-BCR-001	L. Markova	UJV	I	M	Burnup credit	BCR001.doc
11	AER-TRO-001	D. Burket	DNPP	B	O	Load follow	TRO001.doc
12	AER-KAB-001	P. Mikolaš	ŠKODA	I	M	Assembly burnup	KAB001.doc
13	AER-HOM-101	M. Makai	AEKI	B	M	Assembly homogenization	HOM101.doc

Table II. List of available tests
I-inter-comparison, B-benchmark
M-mathematical test; O-operational test

REFERENCES

1,*World Nuclear Industry Handbook* 1994, Nuclear Engineering International, 1994, pp. 22-49

2, Report ANL-7416, Supplement 1, (Revised 1972), Supplement 2. (Revised 1977), Suppl. 3 (Revised 1985)

3, *Final Report of TIC*, vol. 1 and 3, *Experimental Investigations of the Physical Properties of WWER-Type Uranium-Water Lattices*, Akadémiai Kiadó, Budapest, Hungary (1985-1991)

4, At the end of 1999 no open publication is available to introduce the measurements on the LR-0 facility.

5, *Final Report of TIC*, vol. 2, *Theoretical Investigations of the Physical Properties of WWER-Type Uranium-Water Lattices*, Akadémiai Kiadó, Budapest, Hungary(1994)

6. *Requirements for Reference Reactor Physics Measurements*, ANSI-ANS-19.5-1978 (reaffirmed 1984)

7. *A Guide for Acquisition and Documentation of Reference Power Reactor Measurements for Nuclear Analysis Verification,* ANS-194, ANSI N652-1976, (reaffirmed 1989)

8, F. Ya. Ovchinnikoff et al.: *Operational Modes of Water Cooled, Water Moderated Power Reactors*, Moscow (USSR), Atomizdat, 1977

9,V. Pavlov and A. Pavlovichev: *General Features of VVER-1000 Three- and Four Batch 12 Months Cycles with Improved Fuel Utilization*, in Proc. of the fourth Symposium of AER, p. 575, Sozopol, BG, 1994

10, *In-core fuel management code package validation for WWERs*, IAEA-TECDOC-874, Vienna, November 1995

11. S. Kliem, A. Seidel and U. Grundmann: *Definition of the Sixth Dynamic AER Benchmark Problem*, Proc. 10th AER Symp. on VVER Reactor Physics and Reactor Safety, vol**. II**. 749-759, Moscow, 2000

12. N. P. Kolev: *Finite-element Solution of the AER-2 Rod ejection Benchmark by CRONOS*, Proc. 11th Symp. of AER, Csopak (Hungary), pp. 395-399, 2001

13. E. Temevári, G. Hordósy, Cs. Maráczy and Gy. Hegyi*: A Proposal of a Benchmark for Calculation of the Power DIstribution Next to the Absorber*, Proc. 9th Symp. of AER, Demänovska Dolina, Slovakia, p. 117-130(1999)

ACKNOWLEDGEMENT

The present publication is based on the AER Benchmark Book available at the location http://www.kfki.hu/~aekihp. The test problems were collected and reviewed by a Benchmark Committee including:

P. Dařilek (VUJE)

L. Korpás	(PA Rt)
J. Kyncl	(UJV)
L. Maiorov	(KI)
M. Makai	(AEKI) - head
P. Siltanen	(IVO)

The present compilation is based on benchmark specifications and benchmark solutions prepared by the authors. The staff of Reviewers of the test cases and solutions included:

P. Dařilek (VUJE)
N. Kolev (IAE)
L. Korpás (PA Rt)
J. Kyncl (UJV)
M. Makai (AEKI)
I. Pós (PA Rt)
P. Siltanen (IVO)
J. Svarny (ŠKODA)

Abbreviations used for orghanizations:

AEKI	-KFKI Atomic Energy Research Institute, Budapest, Hungary
DNPP	-NPP Dukovany, Czech Republic
FZR	-Research Centre Rossendorf Inc., Germany
IAE	-Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
IBJ	-Institute of Atomic Energy, Swierk, Poland
IPPE	-Institute Obninsk, Russia
IVO	-Fortum Engineering Ltd, (formerly IVO Power Engineering Ltd), Finland
KAB	-Kraftwerkanlagenbau GmbH, Berlin, Germany
KI	-Russian Scientific Centre "Kurchatov Institute", Institute of Nuclear Reactors, Moscow, Russia
KNPP	-NPP Kozloduy, Bulgaria
NIS	-NIS Rheinsberg GmbH Ingenieurservice, Rheinsberg, Germany
PARt	-Paks Nuclear Power Plant Co., Paks, Hungary
SE	-Slovenské Elektrárne, Slovakia
ŠKODA	-ŠKODA JS a.s., Czech Republic
TUB	-Technical University Budapest, Hungary
TÜV	-TÜV Süddeutschland, Germany
UJV	-Nuclear Research Institute Řež plc., Czech Republic