SK00ST134

AER BENCHMARK ACTIVITY

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ABSTRACT

The test problems utilized in the validation and verification process of computer programs in Atomic Energy Research are collected into one bunch. This is the first step towards issuing a volume in which tests for VVERs are collected, along with reference solutions and a number of solutions. The benchmarks do not include the ZR-6 experiments because they have been published along with a number of comparisons in the Final reports of TIC. The present collection focuses on operational and mathematical benchmarks which cover almost the entire range of reactor calculation.

1. INTRODUCTION

The verification and validation (V&V) of a computer program developed for use by the nuclear industry involves a validation step. Validation consists of the testing of a computer program and the evaluation of the test results. Validation is based on a Test Plan, which according to Refs. [1,2] should answer the questions listed in Table 1.

Checklist Item	Question
5.a.	**Is the test case derived from a documented testing approach?**
5.b.	**Are the test cases consistent with the documented testing approach?**
5.c.	**Does the test case matrix clearly establish the relationship between test cases and requirements being tested?**
5.d.	**Is the specification for each test case complete?** **unique identification** **objective(s)**

	input **expected results** **evaluation criteria** **relation to other tests** **rationale for test setup** **hardware and software environment in which the test will be run**

Table 1. Part of Verification of a Test Plan

The testing approach should be given in the Requirement Specification, which is a part of the software documentation elaborated during the software life cycle.

Computer code validation needs a variety of test cases. The program requirements should be tested one by one, thus, we would need test cases permitting the validation of an individual program requirement item. Actually, it is hardly feasible to test individual requirement items. More frequently we test a bunch of requirements as a whole and endeavor to cover most requirements by tests. The present work summarizes the test cases elaborated and utilized in the AER.

2. AER BENCHMARK HISTORY

Besides the ZR-6 experiments, the test cases of Table 2. have been mentioned in the AER Proceedings. The ZR-6 experiments will not be mentioned because the experiments have been exhaustively described in Refs. [3,4].

Bench mark No	Type	Source	Author/User	Tested Algorithm
1	Infinite lattice	Ref. [7]	Szécsényi et al.	Intra assembly
2	Kinetics-1	Ref. [8]	A. Kereszturi, M. Telbisz	3D Kinetics
3	Kinetics-2	Ref. [9]	U. Grundmann, U. Rohde	3D Kinetics
4	Kinetics-3	Ref. [10]	R. K. Rajamäki, E. Kaloinen	3D Kinetics
5	Kinetics-4	Ref. [11]	R. K. Rajamäki	3D Kinetics
6	Kinetics-5	Ref. [12]	S. Kliem	Core-Primary Loop
7	Kinetics	Ref. [13]	R. K. Rajamäki	1D Kinetics
8	Kinetics Parameters	Ref. [14]	J. Švarný, V. Krýsl	Effective Kinetics Parameters
9	Operational (Load follow)	Ref. [15]	D. Burket	RF/TH

10	VVER-440-Math (SEIDEL)	Ref. [16]	Seidel	RF
11	VVER-1000 Math	Rostock, (1986)p. 388	H. (G) Schultz	RF
12	Gadolinium	Refs. [17,18, 27]	R. Becker	Asymptotic spectral
13	Control Rod	Ref. [19]	L. Korpás et al.	Coupled RF/TH
14	Burn-up	Ref. [20]	P. Mikoláš	Assembly burn-up
15	Burn-up	Ref. [21]	P. Mikoláš	Assembly burnup
16	Burn-up	Ref. [22]	L. Marková	Asymptotic cell
17	Operational (KOLA)	Ref. [23]	Gy. Hegyi	Global test
18	Operatonal (KALININ 1000)	Ref. [24]	P. Dařílek	Coupled RF/TH
19	Operational (Kozloduy 1000)	Ref. [24, 31]	T. Apostolov, G. Alekova	Coupled RF/TH
20	In-core	Ref. [25]	E. Jávor, I. Nemes	Surveillance
21	In-core	Ref. [26]	I. Hamvas, Z. Kálya	Surveillance
22	Shielding	Ref. [32]	G. Suschowk	Shielding code
23	VVER-440-Math	Ref. [33]	G. Hegyi et al.	RF

Table 2. List of Tests Mentioned in AER Proceedings

The abbreviations in Table 2 are as follows:
RF -global neutronics calculation without feed back (solution of the diffusion equation)
TH -global thermal hydraulics
RF/TH -coupled neutronics- thermal hydraulics global calculation

In Table 2., the original work is referred to, where possible. In a number of cases, however, the benchmark had been specified and a reference solution was provided only later on. The references have been selected to provide a compact resource wherever possible. The origin of some tests goes back to the time before 1990, those references may have been replaced by more recent ones. Some benchmarks have been defined beyond AER, sometimes we refer to the person advocating the given test.

We introduce a few technical terms. The goal of testing is to judge the error of a given algorithm. This is usually done by comparing the results obtained by the algorithm to a reference. Unfortunately, the reference is not "the eternal truth", rather it is derived from another algorithm or, from measurements. When the experimental error is known, or, the reference is obtained from a model with a less severe or with a more realistic approximation, the comparison with the reference may reveal the weak points of the algorithm.

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.

3. TEST SPECIFICATION

In this Section, we provide all the required information for each test case. We shall heavily rely on existing documents to cut the description short. The test cases are classified as mathematical, experimental or operational test.

- A **mathematical** test provides all input data to solve a given equation. A good example is the diffusion equation without feed back.
- An **experimental test** is where the reference solution comes from a measurements and the input fixes the experiment's situation. The recommended procedure is given in Ref. [5].
- 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. [6].

In the AER, the usual procedure for defining a test is as follows. People encounter a problem and communicate it with others interested. They specify a test case, first carry out an intercomparison. The first draft of the problem is distributed only then. In the course of the intercomparison, remarks concerning the test specification are incorporated into the test specification. Some of the participants may attempt to derive a reliable reference solution to promote the test to a standard exercise or even to a benchmark. All these activities take place in informal personal contacts and on work group meetings, which have no proceedings. Usually, one of the upcoming AER Symposiums sees the test in a more matured state, by then the participants are tired of the well known problem. As a consequence, the problem is reported shortly in the Symposium proceedings and often essential data of the test remain undocumented. It is needless to say that such a practice lessens the worth of the AER benchmark activity.

It would be desirable to restate every test in a Symposium proceeding so as to comply with the stringent but unavoidable requirements for operational benchmark reference solutions. If the AER intends to issue a benchmark volume, also the available solutions should be documented and revised.

3.1. Test No. 1

Identification: TEST-1
Type: Mathematical Test, Intercomparison
Testing Approach: Setting up an infinite periodical system from two assembly types, the spectral interaction between fuel pins can be studied. It is closely related with a number of ZR-6 experiments, where a large number of perturbation types have been investigated. Here the perturbation is a pin of different enrichment, in a hexagonal lattice every second pin represents the perturbation.
Requirement being tested: accuracy of burnup and FD algorithm
Objective: Judge the difference between finite difference power distributions in the test situation
Input: Geometry and composition are given in Ref. [7], but material composition is given only by enrichment and burnup, cell size is not given. 2D or 3D?
Expected results: pinwise power distributions
Evaluation criteria: Code dependent. Available results include power distributions by HELIOS (with self developing burnup),
Relation to other tests: In the ZR-6 experiments, the mildest perturbation is of type A. The tightest perturbed lattice is of type X3, where X varies from water hole to strong absorber, see Refs. [3, 4].
Rationale for test setup: An infinite lattice has been constructed with two cell types to investigate the pinwise power distribution calculation. This simple geometry allows for using high precision codes (Sn or Monte Carlo) to derive a reference solution.
Recommended activity: the provided data are insufficient to perform the test calculations. Nuclear data (number densities, compositions and material densities, temperatures) and cell geometry should be provided. A reference solution should be derived, its error estimated.

3.2. Test No. 2

Identification: KINETICS-1
Type: Mathematical test, Intercomparison
Testing Approach: A 3D core is given along with the 2 group cross-sections, including delayed neutron data. A control rod is ejected in a fully described manner, thus, the kinetics equations form a fully determined mathematical problem.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module.
Objective: Judge the difference between kinetics modules.

Input: geometry and cross-sections, see Ref. [8]
Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: The power maximum should be at the same position, its values determined by diverse codes should be close to each others. Available results include the expected results from KIKO3D, HEXDYN and HEXTRAN
Relation to other tests: First member of a test sequence to validate kinetics codes
Rationale for test setup: The test is based on a static benchmark, the first time dependent test for VVER type. One can study the impact of different solution techniques of the time dependent diffusion equation.

3.3. Test No. 3

Identification: KINETICS-2
Type: Mathematical, Intercomparison
Testing Approach: A well defined test in which strong effects (the worth of the ejected rod is 2β) and Doppler feedback should be accounted for.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module with Doppler's feedback.
Objective: Judge the difference between kinetics modules with Doppler's feedback
Input: geometry and cross-sections, see Ref. [9]
Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: The power maximum should be at the same position, its values determined by diverse codes should be close to each others. Available results include the expected results from KIKO3D, HEXDYN and HEXTRAN
Relation to other tests: A successor of test KINETICS-1
Rationale for test setup: KINETICS-1 served verification of the delayed neutron solver, KINETICS-2 involves the Doppler's feedback, too.

3.4. Test No. 4

Identification: KINETICS-3
Type: Mathematical, Intercomparison
Testing Approach: The coupled neutron physics-thermal hydraulics problem is a non-linear, time dependent problem, which is of vital importance from the point of view of safety. With the initial state and the time dependent cross-sections (due to rod ejection) given, the physical problem is properly described. Notwithstanding, the test specifies neither the thermal hydraulics model neither the feedback, thus, different engineering models can be implemented to describe the same physical situation.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module with Doppler's and thermal hydraulic feedback.
Objective: Judge the difference between kinetics modules with different feedback models
Input: Geometry and cross-sections, see Ref. [10]

Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: Code dependent. Available results include the expected results from KIKO3D, HEXDYN and HEXTRAN
Relation to other tests: A successor of test KINETICS-2, a member of a 5 element family to study the feed backs in the solution of neutron kinetics.
Rationale for test setup: KINETICS-1 served verification of the delayed neutron solver, KINETICS-2 involves the Doppler's feedback, KINETICS-3 accounts for the thermal hydraulic feed back.

3.5. Test No. 5

Identification: KINETICS-4
Type: Mathematical test, Intercomparison
Testing Approach: In VVERs, the boron slug may cause an important safety problem. It is an important feature of a dynamics model, how this phenomenon is accounted for. It is hopeless to derive a reference solution to such a complex nonlinear problem, hence only an intercomparison can pinpoint the influence of the individual approximations in diverse models. Detailed analysis of the results may reveal inadequate approximations.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module with Doppler's and thermal hydraulic feedback.
Objective: Judge the difference between kinetics modules with different feedback models for describing the boron slug effect
Input: Geometry and cross-sections, see Ref. [11]
Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: Code dependent. Available results include the expected results from KIKO3D, HEXDYN and HEXTRAN
Relation to other tests: A successor of test KINETICS-3
Rationale for test setup: The test may help in judging the ability of a code to describe the boron dilution and thermal shock effects. The effects due to the feed back models, or the kinetics solvers has been established by KINETICS-1, KINETICS-2 and KINETICS-3.

3.6. Test No. 6

Identification: KINETICS-5
Type: Mathematical, Intercomparison
Testing Approach: This is a dynamics test in which the initiating event is a break in the primary loop. This is the first dynamics test in which not only the core but also the primary loop should be accounted for.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module, due to a main steam header break
Objective: judge the difference between kinetics modules with different feedback models for describing the boron slug effect
Input: Geometry and cross-sections, see Ref. [12]

Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: Code dependent.
Relation to other tests: A successor of test KINETICS-3 and KINETICS-4
Rationale for test setup: The test may help in judging the ability of a code to describe the dynamics effects initiated by events in the primary loop. The effects due to the feed back models, or the kinetics solvers has been established by KINETICS-1, KINETICS-2 and KINETICS-3.

3.7. Test No. 7

Identification: KINETICS-1A
Type: Mathematical, Intercomparison
Testing Approach: 1D rod ejection problem, a one dimensional core is given along with the 2 group cross-sections, including delayed neutron data. A control rod is ejected in a fully described manner, thus, the kinetics equations form a fully determined mathematical problem.
Requirement being tested: accuracy of time dependent power distribution of a kinetics module.
Objective: Judge the difference between kinetics modules
Input: geometry and cross-sections, see Ref. [13]
Expected results: Integrated power as function of the time, nodewise power distributions at 0, 0.04, 0.08, 1 and 8 sec.
Evaluation criteria: Code dependent. Available results include results from TRAWA
Relation to other tests: First member of a test sequence to validate kinetics codes
Rationale for test setup: The test is based on a static benchmark, the first time dependent test for VVER type. It is considered as forerunner of KINETICS-1. Recently, 1D codes are scarcely used in VVER calculations.

3.8. Test No. 8

Identification: KINPAR
Type: Mathematical, Intercomparison
Testing Approach: With the assembly burnup and enrichment given, the kinetics parameters can be determined for each fuel assembly. Considering a standard fresh core, the effective kinetics parameters can be derived. Thus, we obtain an important orientation regarding the dynamic behavior of the core.
Requirement being tested: Effective kinetics parameters accuracy
Objective: To see the differences between effective parameters obtained by diverse codes.
Input: no explicit core and assembly geometry are given! Actually, the test includes a series of benchmark situations, see Ref. [14].
Expected results: β_{eff},-effective delayed neutron fraction; (β_{effj}, j=1,6)-effective delayed neutron fractions for the six delayed neutron groups, Λ_{eff},-effective neutron life time; (Λ_{effj}, j=1,6)-effective neutron life times for the six delayed neutron groups

Evaluation criteria: None

Relation to other tests: The output of the code tested, i.e. the effective kinetics parameters, are a part of input data for the codes tested in KINETICS-1, KINETICS-2, KINETICS-3 and KINETICS-4.

Rationale for test setup: βeff is an important kinetics parameter, this test helps verify it.

3.9. Test No. 9

Identification: LOADF-1

Type: Operational Benchmark

Testing Approach: Several typical load follow maneuvers have been performed at Dukovany NPP. Core features (Tin, Power, average temperature rise, control rod positions) have been recorded. A test of the coupled neutronics-thermal hydraulics code is to compare the calculated critical core state to the measured one at different moments of the transient process.

Requirement being tested: accuracy of the critical parameters in transient states

Objective: to verify the fission product build ups in different scenarios

Input: see Ref. [15]

Expected results: (T_{in}, Power, average temperature rise, control rod positions) and power distributions in given states, see Ref. [15].

Evaluation criteria: None

Relation to other tests: Tests No. 2-6 serve to test dynamics codes in normal operational states. Test No. 7 does the same in 1D.

Rationale for test setup: There are a number of relevant transient processes when a reactor works in load follow regime. The test aims at testing a code just under load follow conditions.

3.10. Test No. 10

Identification: SEIDEL

Type: Mathematical, Benchmark

Testing Approach: With geometry and cross-sections given, the solution of the diffusion equation becomes a mathematical problem which can be solved exactly. In order to economy with the time, a reference solution of finite accuracy is derived by means of fine discretization in a finite difference code. Thus, the accuracy of a coarse-mesh algorithm can be established.

Requirement being tested: accuracy of the 3D power distribution, accuracy of the 2D assembly power distribution

Objective: judge the accuracy of the power distribution of a coarse mesh program

Input: The problem was originally described on a TIC conference, the input is readily available in Ref. [16].

Expected results: assembly powers and node power using 10 axial nodes per assembly

Evaluation criteria: compare the calculated power to the reference and compare to your target accuracy

Relation to other tests: This test is the basis for a number of kinetics test problems.

Rationale for test setup: The very basic of a neutronics code is the solution of the diffusion equation. This is the first 3D benchmark for VVERs, the reference solution has become more accurate with the new cheap work stations.

3.11. Test No. 11

Identification: SCHULTZ
Type: Mathematical, Intercomparison
Testing Approach: The test specifies a VVER-1000 geometry, with given two energy group cross-sections. The resulting mathematical problem can be solved. The mesh size is 24.1 cm, which is too large for finite difference algorithms without refinement of mesh size. The boundary condition on external surfaces has not been specified.
Requirement being tested: Accuracy of the nodal algorithm
Objective: judge the accuracy of the assembly power distribution of a nodal algorithm
Input: See G. Schultz: Model Problem to calculate neutron field in VVER-1000, vol. I, p. 388, Proc. XV. Symposium of TIC, Rostock, 1987
Expected results: keff and assembly power distribution
Evaluation criteria: none
Relation to other tests: Analogous to SEIDEL, the major difference is the large mesh size.
Rationale for test setup: The test has made possible to verify the VVER-1000 neutronics algorithms. This is the first 3D benchmark for the VVER-1000 type.

3.12. Test No. 12

Identification:ARKUSWK
Type: Mathematical, Benchmark
Testing Approach: A Gadolinium cell is embedded into a fuel ambiance. From the spectral calculation of asymptotic lattices, we have learned the error of the spectral calculation. Further error may occur because of the Gadolinium cross sections and the spectral codes handling strong absorbers. Comparison with Monte-Carlo codes may reveal methodological errors.
Requirement being tested: Adequacy of spectral calculations
Objective: To verify the spectral code and cross-sections of Gadolinium isotopes.
Input: See Ref. [17, 18].
Expected results: kinf, absorption and fission rates by cells
Evaluation criteria: none
Relation to other tests: Similar experimental tests exist in the ZR-6 experiments, see Ref.[3, 4].
Rationale for test setup: The test has been used by R. Becker in Ref. [27]. Burnable poisons may play an important role in fuel management. One of the possible burnable poisons is Gadolinium, thus, it is important to study the Gadolinium cross-sections and the spectral codes. This test defines a Gadolinium cell surrounded by fuel cells. The test depicts a unit of 3x3 cells with reflective boundary condition.

3.13. Test No. 13

Identification: RODPAKS
Type: Operational, Benchmark
Testing Approach: An important feature of the calculational model is the calculated worth of the control rods. The test models a real core state, the measured control rod worth represent a challenge for the codes to be tested.
Requirement being tested: prescribed accuracy of the control rod worth
Objective: Verification of control rod worth calculation in the coupled neutronics-thermal hydraulics code.
Input: see Ref.[19]
Expected results: Integral worths of each control-rod group
Evaluation criteria: reasonable agreement of rod worths
Relation to other tests: none
Rationale for test setup: Both the evaluation of the control rod measurement and the control rod worth calculation have delicate points. An intercomparison between the calculated rod worths on the one hand, and the measured rod worths may pinpoint some model errors.

3.14. Test No. 14

Identification: MIKOLAS-1
Type: Mathematical, Intercomparison
Testing Approach: Fuel assembly parameters seem to be the key parameters in core design. Accuracy of the designed core parameters depends on the quality of cross-sections used in neutronics codes. In this test, the kinf and the power peaking factors are compared.
Requirement being tested: accuracy of assembly calculation
Objective: to verify the kinf and power peaking factors
Input: see Ref. [20].
Expected results: assembly k_{inf} and power distribution
Evaluation criteria: none
Relation to other tests: similar to MIKOLAS-2, see Test No. 15
Rationale for test setup: An attempt to compare assembly parameters in different burn up states

3.15. Test No. 15

Identification: MIKOLAS-2
Type: Mathematical, Intercomparison
Testing Approach: Fuel assembly parameters seem to be the key parameters in core design. Accuracy of the designed core parameters depends on the quality of cross-sections used in neutronics codes. In this test, the k_{inf} and the power peaking factors are compared.
Requirement being tested: accuracy of assembly calculation
Objective: to verify kinf and isotope compositions
Input: geometry, material composition, see Ref. [21]

Expected results: kinf and isotope concentrations
Evaluation criteria: none
Relation to other tests: similar to MIKOLAS-1, see Test No. 14
Rationale for test setup: An attempt to compare assembly parameters in different burn up states.

3.16. Test No. 16

Identification: MARKOVA
Type: Mathematical, Intercomparison
Testing Approach: The criticality evaluation of spent fuel storage or of transport casks usually assumes fresh fuel to be loaded instead of spent fuel. That assumption introduces an excessively large criticality safety margin for light water reactors when the burnup is typical. There are tendencies to increase further the burnup level, then the above assumption is even farther from the reality. The objective of the benchmark is to verify the safety margin for spent fuel systems e.g. against Monte Carlo codes.
Requirement being tested: reaction rates for selected nuclides
Objective: to verify burnup module
Input: geometry, material composition, see Ref. [22]
Expected results: see Ref. [22], where the format and data structure is specified. Briefly, reaction rates of specified nuclides is expected
Evaluation criteria: none
Relation to other tests: The test set up has been motivated by a series of OECD/NEA tests.
Rationale for test setup: The criticality evaluation of spent fuel storage usually assumes fresh fuel to be loaded instead of spent fuel. That assumption introduces an excessively large criticality safety margin for light water reactors when the burnup is typical. There are tendencies to increase further the burnup level, then the above assumption is even farther from the reality. To what extent, that can be studied by this test.

3.17. Test No. 17

Identification: KOLA-1
Type: Operational, Benchmark
Testing Approach: The use of 4.4% enriched assemblies allows the user for 4 year fuel cycle. The benchmark models an implementation of the associated reload scheme. The reference includes measured fields(?), boron let down curves.
Requirement being tested: Accuracy of parametrized assembly libraries in a 4 year fuel cycle
Objective: to verify the accuracy of power and temperature fields and boron let down curves
Input: Reload patters for 12 fuel cycles, see Ref. [23]
Expected results: boron curve, $\partial\rho/\partial c_B$, $\partial\rho/\partial T_{in}$
Evaluation criteria: none
Relation to other tests: A VVER-440 operational benchmark, the only one in the benchmark set. The four year fuel cycle makes it special.

Rationale for test setup: The KOLA Benchmark was initiated on the Fifth Symposium of AER, it was extended and corrected on the Sixth Symposium.

3.18. Test No. 18

Identification: KALININ-1
Type: Operational, Benchmark
Testing Approach: History of 6 fuel cycles modeling the operating state of Kalinin Unit-1 are given. Control rod positions, inlet temperatures, power levels are given for each cycle. Relative assembly powers and axial power profiles have been measured at specific burnup levels.
Requirement being tested: The calculational model in its entirety is tested.
Objective: to verify the accuracy of neutronics and thermal hydraulics codes
Input: see Ref. [24].
Expected results: boron curves, power distribuitions
Evaluation criteria: The accuracy of the operational measurements is unknown, the reference distribution hardly meets the criteria fixed in standards, therefore no evaluation criteria is given.
Relation to other tests: Another operational test is KOZLODUY-1, see test No. 19
Rationale for test setup: The test has been used in Ref. [28], [29] and [30]. The test gives the initial core and reload patterns for the first 6 fuel cycles of a VVER-1000. In core measurements are available.

3.19. Test No. 19

Identification: KOZLODUY-1
Type: Operational, Benchmark
Testing Approach: History of the first fuel cycle modeling the operating state of Kozloduy Unit-5 are given. Control rod positions, inlet temperatures, power levels are given for each cycle. Relative assembly powers and axial power profiles have been measured at specific burnup levels.
Requirement being tested: The calculational model in its entirety is tested.
Objective: to verify the accuracy of neutronics and thermal hydraulics codes
Input: see Ref. [24].
Expected results: boron curves, power distributions
Evaluation criteria: The accuracy of the operational measurements is unknown, the reference distribution hardly meets the criteria fixed in standards, therefore no evaluation criteria is given.
Relation to other tests: Another operational test is KALININ-1, see test No. 18
Rationale for test setup: The test describes a VVER-1000 core and reload patterns. There are in core operational measurements. After suitable preparation, the test has been successfully used at Westinghouse and in Ref. [31].

3.20. Test No. 20

Identification: FLUXREC-1

Type: Mathematical, Intercomparison
Testing Approach: In a VVER440, the fraction of metered assembly is 210 out of 349 (thermocouples) and 36 out of 349 (SPND). A major step in core surveillance is to estimate the power of non-metered assemblies. The test provides measured values for the metered assemblies and the goal is to reconstruct the missing values. The test is based on measured values obtained from the C-PORCA code, version unknown. Actually, it is a series of 5 test problems.
Requirement being tested: Accuracy of the reconstruction algorithm
Objective: To judge the accuracy of the estimation given for non-metered assemblies
Input: Core is given by fuel type and burnup values, see Ref. [25].
Expected results: Assembly out let temperatures
Evaluation criteria: To be as close to C-PORCA as possible
Relation to other tests: See test No. 21
Rationale for test setup: Some of the core states has been asymmetric, the accuracy of the reference solution is not known for such states. The cause of asymmetry has been given in terms of burnup of individual assemblies, which is of limited use.

3.21. Test No. 21

Identification: PAKSINC
Type: Operational, functionality test
Testing Approach: To verify the functionality of in-core signal processing codes, we need signals from normal and extreme core states as well. A wide range of core states have been recorded in a specific file format. The records include technological parameters (state of main circulating pumps), in-core detector signals (SPND and thermocouples), power, control rod position, coolant in let temperatures. The test has no reference solution.
Requirement being tested: The tested code should be capable of dealing with each recorded state.
Objective: To verify the functionality of in-core signal processing codes in unusual core states.
Input: No input is provided in Ref. [26].
Expected results: kq and kv fields
Evaluation criteria: the code should work
Relation to other tests: See test No. 20.
Rationale for test setup: The test set has made a good service because the functionality of a new algorithm can be tested in extreme conditions (e.g. 3 main circulating pumps switched off, a rod stacked).

3.22. Test No. 22

Identification: DSERATE
Type: Experimental, Standard exercise
Testing Approach: A CASTOR- 440/84 type cask was loaded with VVER-2 fuel. Neutron and γ rates were measured.
Requirement being tested: Accuracy of shielding codes is satisfactory

Objective: To verify shielding codes
Input: Fuel element data, geometry are provided in Ref. [27].
Expected results: neutron dose rates, γ dose rates
Evaluation criteria: None
Relation to other tests: None
Rationale for test setup: A practical case has served as background for verifying shielding codes.

3.23. Test No. 23

Identification: MAR
Type: Mathematical, Benchmark
Testing Approach: The core in the test models a core of 180 deg symmetry, thus permits to test the full core calculation. The reference solution has been derived by the DIFF3D finite difference code, the subdivision is fine enough to estimate the error of the reference solution.
Requirement being tested: accuracy of the eigenvalue keff and power distribution
Objective: to meet design criteria
Input: input is provided on this Symposium, see Ref.[]
Expected results: keff and 3D power distribution
Evaluation criteria: none
Relation to other tests: Similar to SEIDEL and the initial state of Test No. 2
Rationale for test setup: This is the first 3D neutronics test with less than 60 deg symmetry. The core models a VVER-440. The rod blackness has been increased to keep the eigenvalue reasonable so the test has larger gradients at places than usual.

3.24. Test No. 24

Identification: reserved
Type:
Testing Approach:
Requirement being tested:
Objective:
Input:
Expected results:
Evaluation criteria:
Relation to other tests:
Rationale for test setup:

3.25. Test No. 25

Identification: reserved
Type:
Testing Approach:
Requirement being tested:
Objective:

Input:
Expected results:
Evaluation criteria:
Relation to other tests:
Rationale for test setup:

4. Conclusions

The test cases published on AER Symposia and work group meetings represent a valuable contribution to the safe and economic operation of VVER type power plants. The tests cover almost the entire range of the reactor calculation. Similar collection of tests has been issued by the International Atomic Energy Agency, and some time ago by the American Nuclear Society. The VVER oriented experimental benchmarks, mostly the ZR-6 experiments, have been documented and the results are now available for the international community.

In order to achieve the same thing with the AER benchmarks, we need further coordinated work. In the author's opinion, the following actions should be taken to make the AER benchmark collection accessible for the international community:

- assess the test cases, and if the specification is incomplete or is unavailable in written form, the authors should provide a complete specification as a contribution to an upcoming AER Symposium. A test specification should answer all the questions addressed in Table 1.
- revise the operational tests and assure the compliance with Ref. [6].
- revise the reference solutions where possible. It is desirable to derive as accurate as possible reference solution and promote the tests towards the benchmark level.
- define a format for each test and put the available solutions into that format. Assess the available solutions.
- compile a benchmark volume which is gem for VVER users, designers and authorities.

Majority of the work has been done but without investing a little more we have something incomplete. We have got a good chance to achieve a great success in the benchmark area, too.

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