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BFS, a Legacy to the International Reactor Physics, Criticality Safety, and Nuclear Data Communities

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ABSTRACT

Two Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) programs, the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment Evaluation Project (IRPhEP) have been identifying existing integral experiment data, evaluating those data, and providing integral benchmark specifications for methods and data validation for nearly two decades. The Russian Federation, IPPE, and the BFS laboratories have made substantial contributions to those two projects. Contributions from the BFS facilities are highlighted in this paper.

1. INTRODUCTION

Interest in high-quality integral benchmark data is increasing as efforts to quantify and reduce calculational uncertainties associated with advanced modeling and simulation accelerate to meet the demands of next generation reactor and advanced fuel cycle concepts. Two Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) activities, the International Criticality Safety Benchmark Evaluation Project (ICSBEP), initiated in 1992, and the International Reactor Physics Experiment Evaluation Project (IRPhEP), initiated in 2003, have been identifying existing integral experiment data, evaluating those data, and providing integral benchmark specifications for methods and data validation for nearly two decades. Data provided by those two projects will be of use to the international reactor physics, criticality safety, and nuclear data communities for future decades.

The work of the ICSBEP and IRPhEP is documented in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (*ICSBEP Handbook*)[1] and the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (*IRPhEP Handbook*),[2] respectively. The Russian Federation, IPPE, and the BFS laboratories have made substantial contributions to those two projects since their participation began in 1994. Contributions from the BFS facilities are highlighted in Section 3.3.

2. THE LATEST EDITIONS OF THE *IRPhEP* AND *ICSBEP* *HANDBOOKS*

Over 400 scientists from 24 countries have combined their efforts to produce the *ICSBEP* and *IRPhEP Handbooks*. The contents of those handbooks are characterized in the following two subsections.

2.1. IRPhEP Handbook

The *IRPhEP Handbook* is published annually, generally in March, by the OECD NEA. The 2012 Edition of the *IRPhEP Handbook* (Fig. 1) contains data from 56 experimental series performed at 32 different reactor facilities. Included are benchmark specifications for criticality, buckling, spectral characteristics, reactivity effects, reactivity coefficients, kinetics, reaction-rate and power distributions, and a few miscellaneous types of measurements.

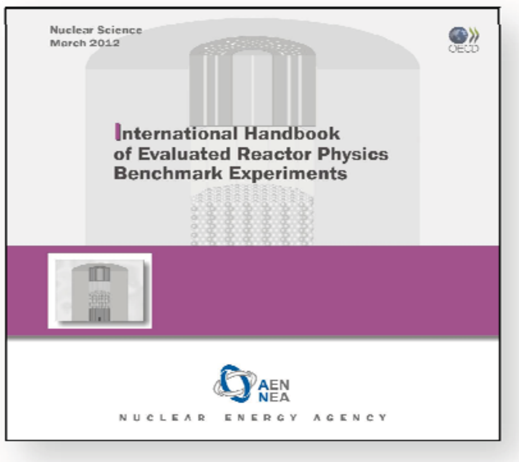

Figure 1. The 2012 Edition of the *IRPhEP Handbook*.

Contributions of data and expertise have been made from 16 countries including Argentina, Brazil, Belgium, Canada, China, Czech Republic, France, Germany, Hungary, Japan, Republic of Korea, Russian Federation, Slovenia, Switzerland, United Kingdom, and United States.

The 2012 Edition of the *IRPhEP Handbook* is available only on DVD. A copy of the DVD can be requested from the official IRPhEP Internet site at: http://www.oecd-nea.org/science/wprs/irphe/.

2.2. ICSBEP Handbook

The *ICSBEP Handbook* is published annually, generally in September, by the OECD NEA. The 2011 Edition of the *ICSBEP Handbook* (Figure 2) contains data from 532 experimental series and includes 4550 critical, subcritical, or k_∞ configurations, 24 criticality-alarm or shielding configurations with numerous dose points each, 155 fission rate and transmission measurements, and reaction rate ratios for 45 different materials.

Contributions of data and expertise have been made from 20 countries including Argentina, Brazil, Canada, China, Czech Republic, France, Hungary, India, Israel, Japan, Kazakhstan, Republic of Korea, Poland, Russian Federation, Slovenia, Serbia, Spain, Sweden, United Kingdom, and United States.

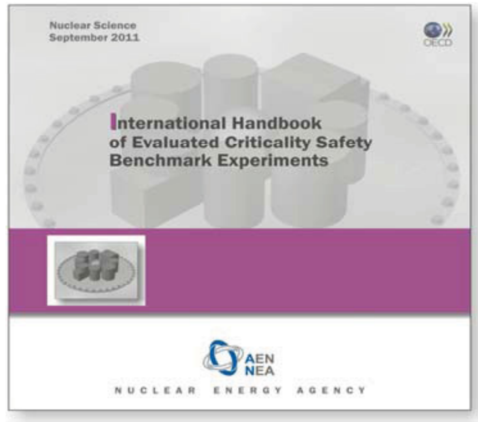

Figure 2. The 2011 Edition of the *ICSBEP Handbook.*

The 2011 Edition of the *ICSBEP Handbook* is available on DVD and on the Internet. The DVD and/or password access can be requested from the official ICSBEP Internet site at: http://www.oecd-nea.org/science/wpncs/icsbep /.

3. CONTRIBUTIONS TO THE *IRPhEP* AND *ICSBEP*

3.1. Contributions from the Russian Federation

The Russian Federation has been a major contributor to both the ICSBEP and IRPhEP. Contributions include: 568 critical configurations, 20 k_∞ configurations, 24 criticality-alarm or shielding configurations, 109 fission rate and transmission measurements, reaction rate ratios for 45 different materials, and numerous reactor physics measurements.

3.2. Contributions from the Institute of Physics and Power Engineering

The Institute of Physics and Power Engineering (IPPE) has been the major contributor from the Russian Federation. Contributions include: 231 critical configurations, 20 k_∞ configurations, 24 criticality-alarm or shielding configurations, 109 fission rate and transmission measurements, reaction rate ratios for 45 different materials, and numerous reactor physics measurements from BFS-1 and -2.

3.3. Contributions from the BFS Facility

Included in the benchmark specifications from the BFS Facility are: critical configurations from BFS-49, 61, 62, 73, 79, 81, 97, 99, and 101 (34 Configurations) ; k_∞ measurements from BFS-31, 33, 35, 38, and 42 (11 Configurations); spectral characteristics measurements from BFS-31, 42, 57, 59, 61, 62, 73, 97, 99, and 101; reactivity effects measurements from BFS-62-3A; reactivity coefficients measurements from BFS-73; kinetics measurements from BFS-73; and reaction rate measurements from BFS-42, 61, 62, 73, 97, 99, and 101. Highlights from several of those experimental series follow.

3.3.1. BFS-73: Sodium-Cooled Fast Reactor

BFS-73 experiments simulate a sodium cooled fast reactor with uranium metal fuel (average enrichment of 18.5%). The experiments were performed on BFS-1 in 1997. BFS-73-1 is published only in the *IRPhEP Handbook* and includes benchmark specifications for the critical configuration, spectral characteristics, reactivity coefficients, kinetics parameters, and reaction rates distributions.

3.3.2. BFS-61: Lead-Cooled Fast Reactor

BFS-61 experiments simulate a lead cooled fast reactor with plutonium metal and depleted uranium metal core. The experiments were performed on BFS-1 in 1990 and 1991. BFS-61experiments are published in both the *IRPhEP* and *ICSBEP Handbooks* and include benchmark specifications for three critical configurations, spectral characteristics, and reaction rates distributions.

3.3.3. BFS-31: K-infinity Measurements on BFS-2

BFS-31 experiments involve k_∞ measurements for a central test region of plutonium metal and depleted-uranium dioxide fuel. The experiments were performed on BFS-2 during 1974 and 1975. BFS-31 is published in both the *IRPhEP* and *ICSBEP Handbooks* and includes benchmark specifications for k_∞ and spectral characteristics measurements for ^{238}U in fast neutron spectra (two configurations). Similar Measurements were performed for BFS-33, -35, -38, -42.

3.3.4. BFS-79 and BFS-81: Geological Repository

During the second half of 1999 and early 2000, the BFS-1 Facility was transformed into a simulated geological repository for both highly enriched uranium (BFS-79) fuel and plutonium (BFS-81) fuel. Both types of fuels were intermixed with large quantities of very pure silicon dioxide pellets with high-purity SiO_2 sand as a reflector. Varying degrees of water ingress were simulated with polyethylene pellets and dowels. Configurations within those series of experiments had thermal spectra as high as 71%, intermediate spectra as high as 68%, and fast spectra as low as 11%, thus demonstrating the flexibility of the BFS Facility.

The neutron flux-per-unit-lethargy for selected configurations from the BFS-81 series is shown in Figure 3. Three-group neutron spectra (fission and capture) are given in Table 1.

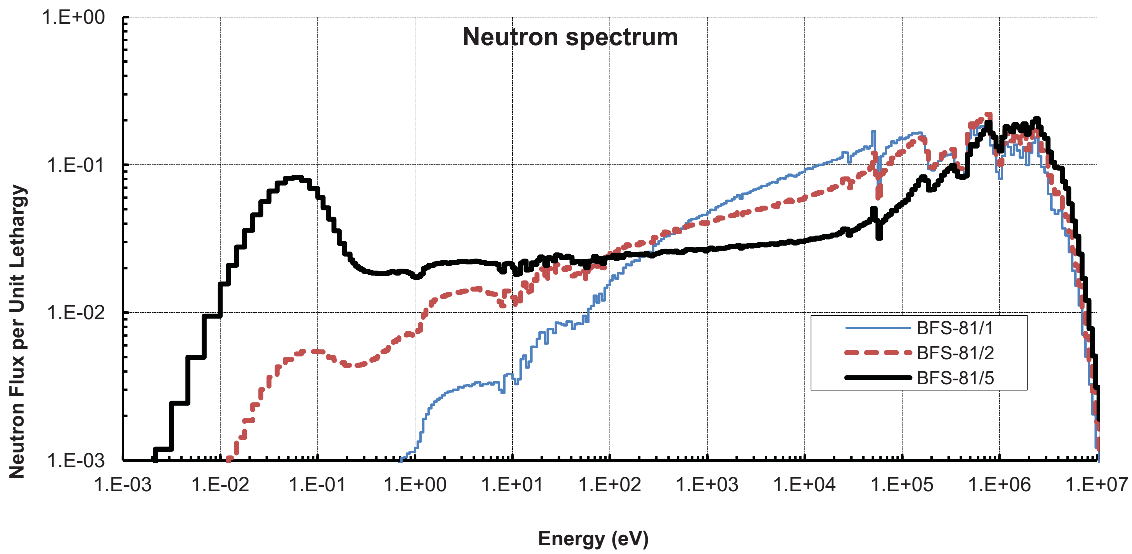

Figure 3. Neutron Flux per Unit Lethargy for the BFS-81 Series.

Table 1. Three-Group Neutron Spectra for the BFS-81 series.

Case Number	Fission, %			Capture, %		
	< 0.625 eV	0.625 eV - 100 keV	> 100 keV	< 0.625 eV	0.625 eV - 100 keV	> 100 keV
BFS-81/1	4.1	63.7	32.2	4.6	83.6	11.9
BFS-81/1A	6.7	61.4	31.9	8.4	79.9	11.6
BFS-81/2	22.0	53.0	25.0	24.2	67.2	8.6
BFS-81/3	34.8	43.8	21.4	37.9	54.8	7.3
BFS-81/4	70.3	18.2	11.5	78.3	18.1	3.6
BFS-81/5	70.6	18.1	11.4	78.5	17.9	3.6

BFS-79 includes 6 critical configurations and BFS-81 includes 5. The experiments were sponsored by the United States Spent Nuclear Fuel Program and were performed from August 1999 to February 2000. Both are published only in the *ICSBEP Handbook*.

3.3.5. BFS-97, -99, and -101: MOX Fuel Manufacturing

During 2004, 2005, and 2008 the BFS-1 facility was once again transformed and three series of experiments were designed and conducted in support of the MOX fuel manufacturing process, particularly for low-moderated MOX fissile media. The neutron flux-per-unit-lethargy for the selected configurations from the BFS-97 and -101 series is shown in Figure 4. Three-group neutron spectra (fission and capture) are given in Table 2. BFS-97, 99, and 101 are published in both the *IRPhEP* and *ICSBEP Handbooks* and include benchmark specifications for 16 critical configurations with spectral characteristics and reaction rate measurements for four of those configurations.

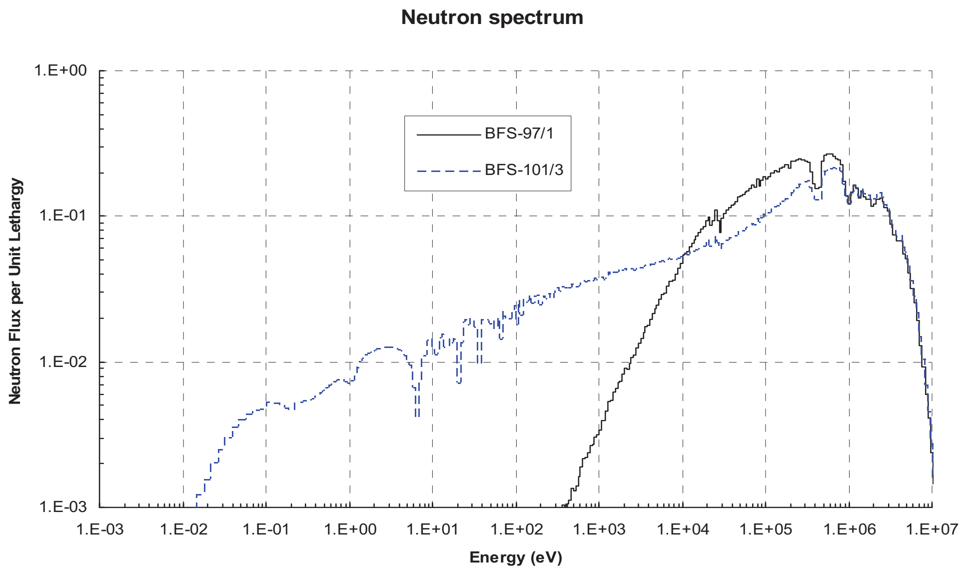

Figure 4. Neutron Flux per Unit Lethargy for the BFS-97/1 and -101/3.

Table 2. Neutron Spectra for BFS-97, -99, and -101.

Case Number	Fission, %			Capture, %		
	< 0.625 eV	0.625 eV - 100 keV	> 100 keV	< 0.625 eV	0.625 eV - 100 keV	> 100 keV
BFS-97/1	0.0	26.0	74.0	0.0	63.2	36.8
BFS-97/2	1.5	35.8	62.7	1.5	75.2	23.3
BFS-97/3	11.3	49.0	39.7	8.7	81.6	9.6
BFS-97/4	15.4	47.9	36.8	11.8	79.7	8.5
BFS-99/1	11.4	48.8	39.8	8.6	82.1	9.3
BFS-99/1A	11.8	47.6	40.6	9.0	81.6	9.5
BFS-99/2	15.7	47.5	36.8	11.8	80.1	8.1
BFS-101/1	4.3	44.4	51.3	2.6	80.7	16.7
BFS-101/2	11.6	45.0	43.5	6.8	80.8	12.4
BFS-101/2A	14.7	44.0	41.3	8.9	79.8	11.4
BFS-101/3	18.8	42.8	38.4	11.4	78.3	10.3

3.3.6. BFS-42, -49, -57 and -59: Earlier MOX Fuel Experiments

The BFS-42 critical configuration was assembled on BFS-1 in 1979 as part of a series of eleven k_∞ experiments performed on BFS-1 and BFS-2 during the 1970s. BFS-42 consisted of plutonium metal and depleted-uranium dioxide with a small amount of polyethylene for spectra modification.

BFS-49 was a series of experiments involving heterogeneous compositions of plutonium and depleted-uranium dioxide mixed with other materials like graphite, sodium, and polyethylene used for spectra modification. The experiments were performed on the BFS-1 critical facility in 1985. BFS-49/1A and -49/3G are particularly useful for the MOX fuel manufacturing process with low-moderated MOX fissile media, especially when considered together with the critical configurations from BFS-97, -99, and -101.

The BFS-57 and BFS-59 critical configurations were assembled on BFS-1 in October 1989 and May 1990. This experimental program was specifically performed to obtain integral benchmark data for perspective light-water reactors with traditional uranium or MOX fuel in lattices with decreased pitch.

BFS-42, -57, and -59 are published only in the *IRPhEP Handbook* and include benchmark specifications from spectral characteristics measurements.

BFS-49 is published only in the *ICSBEP Handbook* and includes benchmark specifications for two critical configurations.

4. SUMMARY AND CONCLUSIONS

Over 400 scientists from 24 different countries have combined their efforts to produce the *ICSBEP* and *IRPhEP Handbooks*. These two handbooks continue to grow and provide high-quality integral benchmark data that will be of use to the criticality safety, nuclear data, and reactor physics communities for future decades.

Russian Federation, IPPE, and BFS have contributed significantly to the success of the ICSBEP and IRPhEP. Although intended as a fast reactor test assemblies, the BFS assemblies offer unusual flexibility.

5. ACKNOWLEDGEMENTS

ICSBEP and IRPhEP are collaborative efforts that involve numerous scientists, engineers, administrative support personnel and program sponsors from 24 different countries and the OECD/NEA. The authors would like to acknowledge the efforts of all of those dedicated individuals without whom those two projects would not be possible.

The authors have made reference to numerous BFS benchmark reports that were authored and reviewed by various combinations of the following individuals:

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The reader is referred to the actual evaluations cited within the *ICSBEP* and *IRPhEP Handbooks* for complete identification of the respective authors of the BFS benchmark reports.

6. REFERENCES

1. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03/I-IX, Organization for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA), September 2011 Edition, ISBN 978-92-64-99163-7
2. *International Handbook of Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, Organization for Economic Co-operation and Development-Nuclear Energy Agency (OECD-NEA), March 2011 Edition, ISBN 978-92-64-99168-2