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ATTN: Document Control Desk
Director
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Louisiana Energy Services, L. P.
National Enrichment Facility
NRC Docket No. 70-3103

Subject: MONK 8A Validation and Verification

References: 1. Letter NEF#03-003 dated December 12, 2003, from E. J. Ferland (Louisiana Energy Services, L. P.) to Directors, Office of Nuclear Material Safety and Safeguards and the Division of Facilities and Security (NRC) regarding "Applications for a Material License Under 10 CFR 70, Domestic licensing of special nuclear material, 10 CFR 40, Domestic licensing of source material, and 10 CFR 30, Rules of general applicability to domestic licensing of byproduct material, and for a Facility Clearance Under 10 CFR 95, Facility security clearance and safeguarding of national security information and restricted data"

By letter dated December 12, 2003 (Reference 1), E. J. Ferland of Louisiana Energy Services (LES), L. P., submitted to the NRC applications for the licenses necessary to authorize construction and operation of a gas centrifuge uranium enrichment facility. Chapter 5, "Nuclear Criticality Safety," was included as part of the applications in the National Enrichment Facility (NEF) Safety Analysis Report (SAR). SAR Chapter 5 discusses the validation of the MONK 8A Monte Carlo computer code for the NEF specific criticality analyses.

During the March 9 and 10, 2004, in-office review of the LES Integrated Safety Analysis in the AREVA office in Marlborough, Massachusetts, the effort to validate the MONK 8A Monte Carlo computer code was discussed with U.S. Nuclear Regulatory Commission (NRC) representatives. In a subsequent conference call between LES and NRC representatives, it was requested that the MONK 8A Validation and Verification report be submitted to the NRC for review. This information is included in the Enclosure, "MONK 8A Validation and Verification, National Enrichment Facility."

NMSS01

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If you have any questions or need additional information, please contact me at 630-657-2813.

Respectfully,

Daniel G. Green for

R. M. Krich
Vice President – Licensing, Safety, and Nuclear Engineering

Enclosure:
MONK 8A Validation and Verification, National Enrichment Facility

cc: T.C. Johnson, NRC Project Manager

ENCLOSURE

MONK 8A Validation and Verification
National Enrichment Facility

MONK 8A
Validation and Verification

National Enrichment Facility

April 16, 2004

AREVA

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ABSTRACT

The objective of this report is the validation of the MONK 8A[5] Monte Carlo computer code package. The validated MONK 8A code is then used to verify the criticality calculations performed by Urenco for the National Enrichment Facility (NEF).

MONK 8A was validated against a set of 80 benchmark critical experiments. The average of the validation runs was 1.0017 ± 0.0005. This was in good agreement with the average of the corresponding MONK 8A benchmarks[6,8] of 1.0016 ± 0.0005 performed by the computer code vendor. Since the validation cases are models of actual criticality experiments, this also demonstrates that MONK 8A is conservative for calculating criticality.

Thirty one Urenco criticality calculations were selected for verification. The average of the Urenco results documented for the thirty one cases used in this report is 0.8755. The average of the verification runs is 0.8734 which is in good agreement with the Urenco results.

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1.0 Purpose and Objective

The objective of this report is the validation of the MONK 8A[5] Monte Carlo computer code and JEF 2.2 data library and the verification of criticality calculations performed for the National Enrichment Facility (NEF). A set of validation cases performed by the software vendor (Serco Assurance) were selected for validation and a set of criticality calculations performed by Urenco to support the NEF were selected for verification.

The validation process establishes method bias by comparing measured results from laboratory critical experiments to method-calculated results for the same systems. Critical experiments are selected to be representative of the systems to be evaluated in specific design applications. A selected set of benchmark experiments with a wide range of experimental conditions establishes the area of applicability over which the calculated method bias is applicable. Benchmark experiments are selected that resemble as closely as practical the systems being evaluated in the design application. The validation and verification processes are controlled and documented.

2.0 Identification of Computer Usage

The computer code MONK 8A[5,6], was installed in accordance with the applicable QA procedures for computer software installation.

MONK 8A validation and verification utilized the JEF 2.2 data library. Specifically, the following data library files were used for the MONK 8A validation and verification runs.

Table 1: Data Libraries for Validation and Verification

Library Types	Library Names
MATDB:	monk_matdbv2.dat
DICE:	dice96j2v5.dat
THERM:	therm96j2v2.dat

3.0 Analysis

3.1 Methodology

MONK 8A is a powerful Monte Carlo tool for nuclear criticality safety analysis. The advanced geometry modeling capability and detailed continuous energy collision modeling treatments provide realistic three-dimensional models for an accurate simulation of neutronics behavior to provide the best estimate neutron multiplication factor, k-effective. Complex models can be simply set up and verified. Additionally, MONK 8A has demonstrable accuracy over a wide range of applications and is distributed with a validation database comprising critical experiments covering uranium, plutonium and mixed systems over a wide range of moderation and reflection. The experiments selected are regarded as being representative of systems that are encountered in the nuclear industry, particularly with respect to chemical plant operations, transportation and storage. The validation database is subject to on-going review and enhancement by Serco Assurance. A categorization option is available in MONK 8A to assist the criticality analyst in determining the type of system being assessed and provides a quick check that a calculation is adequately covered by validation cases.

The extensive validation database contains a number of solution experiments applicable to the NEF application involving both low and high-enriched uranium. The MONK 8A code with the JEF2.2 data library was validated against these experiments which are provided in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[7]. From the extensive list of validation cases performed by Serco Assurance, thirteen case sets (80 experiments) were selected for this validation[8]. Since the NEF assumes the intrusion of water for accident scenarios, solution experiments containing both low and high enriched uranium provided the basis for the selection. The list of experiments is provided in Table 2.

Detailed descriptions, of the criticality experiments, were extracted from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[7] and are tabulated in Table 3.

The input files provided by Serco Assurance for the 80 validation cases were checked against the experimental data provided in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[7] for accuracy. Once satisfied with the accuracy of the data, the 80 validation cases were run using MONK 8A on a QA controlled computer.

Table 2: Uranium Solution Experiments Used for Validation

MONK 8A Case Set	Case Description	Number of Experiments	Handbook Reference[7]
13	High-enriched uranyl nitrate solutions at various H:U ratios (93.17 w/o U235)	12	HEU-SOL-THERM-002
23	Uranyl nitrate solution (~ 95 w/o enriched)	5	HEU-SOL-THERM-013
35	High-enriched uranyl nitrate solutions (U concentration from 20-700 g/L)	11	HEU-SOL-THERM-009 - HEU-SOL-THERM-012
43	Low-enriched uranyl nitrate solutions	3	LEU-SOL-THERM-002
51	Low-enriched uranium solutions (new STACY experiments)	7	LEU-SOL-THERM-004
63	Boron carbide absorber rods in uranyl nitrate (5.6 w/o enriched)	3	LEU-SOL-THERM-005
67	Highly enriched uranyl nitrate solution with a concentration range between 59.65 and 334.66 g U/L	10	HEU-SOL-THERM-001
68	Highly enriched uranyl fluoride/heavy water solution with a concentration range between 60 and 679 g U/L and a heavy water reflector	6	HEU-SOL-THERM-004
71	STACY: 28 cm thick slabs of 10 w/o enriched uranyl nitrate solutions, water reflected	7	LEU-SOL-THERM-016
80	STACY: Unreflected 10 w/o enriched uranyl nitrate solution in a 60 diameter cylindrical tank	5	LEU-SOL-THERM-007
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84	STACY: Borated concrete reflected 10 w/o enriched uranyl nitrate solution in a 60 cm diameter cylindrical tank	3	LEU-SOL-THERM-009
85	STACY: Polyethylene reflected 10 w/o enriched uranyl nitrate solution in a 60 cm diameter cylindrical tank	4	LEU-SOL-THERM-010

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
HEU-SOL-THERM-002	Concrete Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate	Fourteen critical experiments, each involving a single reflected tank of highly enriched uranyl nitrate, were performed at the Rocky Flats Plant, which was operated at that time by Rockwell International. The critical height for each experiment was determined by linear interpolation between slightly supercritical and slightly subcritical states. The tanks were cylindrical in shape and placed at different locations in a concrete reflector. Critical configurations had height-to-diameter ratios less than 1.2. Uranium concentrations varied between 59.65 and 334.77 grams of uranium per liter (93.172 wt.% ^{235}U). [See NOTE 1]
HEU-SOL-THERM-003	Plexiglas Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate	Nineteen critical experiments, each involving a single reflected tank of highly enriched uranyl nitrate, were performed at the Rocky Flats Plant, which was operated at that time by Rockwell International. The critical height for each experiment was determined by linear interpolation between slightly supercritical and slightly subcritical states. The tanks were cylindrical in shape and placed at different locations in a Plexiglas reflector. Critical configurations had height-to-diameter ratios less than 2.4. Uranium concentrations varied between 60.32 and 345.33 grams of uranium per liter (93.172 wt.% ^{235}U). [See NOTE 1]
HEU-SOL-THERM-013	Unreflected 174 Liter Spheres of Enriched Uranium Nitrate Solutions	The four measurements included in this evaluation are part of a series of experiments performed in the 1950's at the Oak Ridge National Laboratory with highly enriched (93.18 wt.% ^{235}U) uranium. Critical experiment measurements were made with uranyl nitrate solutions poisoned with boric acid in an unreflected 27.24-inch-diameter sphere (174 liters). The sphere was fabricated of 0.32-cm-thick 1100 aluminum. [See NOTE 2]
HEU-SOL-THERM-009	Water-Reflected 6.4-Liter Spheres of Enriched Uranium Oxyfluoride Solutions	The four water-reflected spheres included in this evaluation are part of a series of experiments performed in the 1950's at the Oak Ridge National Laboratory with highly enriched uranium. Critical experiment measurements were made with uranium oxyfluoride (UO_2F_2) solutions at various uranium concentrations (93.17-93.19 wt.% ^{235}U) in two water-reflected spheres nominally 9 inches in diameter (6.4 liters). Spherical reactors with nominal inner diameter of 9 inches were fabricated of aluminum and surrounded by an effectively infinite water reflector. The spheres were supported in the water reflector only by the top and bottom overflow and feed tubes, respectively.

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
HEU-SOL-THERM-010	Water-Reflected 9.7-Liter Spheres of Enriched Uranium Oxyfluoride Solutions	The four water-reflected spheres included in this evaluation are part of a series of experiments performed in the 1950's at the Oak Ridge National Laboratory with highly enriched uranium. Critical experiment measurements were made with uranium oxyfluoride solutions at temperatures and uranium concentrations (93.17-93.19 wt.% ^{235}U). A spherical reactor with nominal inner diameter of 26.4 cm (9.7 liters) was fabricated of aluminum and surrounded by an effectively infinite water reflector. The sphere was supported in the water reflector only by the top and bottom overflow and feed tubes, respectively.
HEU-SOL-THERM-011	Water-Reflected 17-Liter Spheres of Enriched Uranium Oxyfluoride Solutions	The two water-reflected spheres included in this evaluation are part of a series of measurements performed in the 1950's at the Oak Ridge National Laboratory with highly enriched uranium (93.2 wt.% ^{235}U). Critical experiment measurements were made with uranium oxyfluoride (UO_2F_2) solutions in a water-reflected 32-cm-inner-diameter (17-liter) sphere with an aluminum wall 1.27 mm thick. To provide 19 cm of water as an effectively infinite neutron reflector, the sphere was mounted in a cylinder of appropriate dimensions. The sphere was supported in the water reflector only by the top and bottom overflow and feed tubes, respectively.
HEU-SOL-THERM-012	Water-Reflected 91-Liter Sphere of Enriched Uranium Oxyfluoride Solution	This water-reflected sphere is part of a series of experiments performed in the 1950's at the Oak Ridge National Laboratory with highly enriched uranium (93.2 wt.% ^{235}U). This measurement was made with a uranium oxyfluoride (UO_2F_2) solution in a 27.9-cm inner radius (91 liters) water-reflected sphere. The sphere was fabricated of 0.20-cm-thick 1100 aluminum and surrounded by an effectively infinite water reflector.

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
LEU-SOL-THERM-002	174 Liter Spheres of Low Enriched (4.9%) Uranium Oxyfluoride Solutions	The three experiments included in this evaluation are part of a series of measurements performed in the 1950s at the Oak Ridge National Laboratory with low-enriched uranium (4.9 wt.% ^{235}U). Critical experiment measurements were made with uranium oxyfluoride (UO_2F_2) solutions in a 27.3-in-inner-diameter (174-liter) sphere with an aluminum wall 1/16 in. thick. The sphere was supported only by the top and bottom overflow and feed tubes, respectively. Three experiments are evaluated. One measurement was made in an unreflected sphere and two measurements were water reflected. To provide an effectively infinite neutron reflector for these two measurements, the sphere was mounted in a cylinder of appropriate dimensions.
LEU-SOL-THERM-004	STACY: Water-Reflected 10%-Enriched Uranyl Nitrate Solution in a 60-Cm-Diameter Cylindrical Tank	Seven critical experiments included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1995 at the Nuclear Fuel Cycle Safety Engineering Research Facility in the Tokai Research Establishment of the Japan Atomic Energy Research Institute. In the first series of experiments using the water-reflected 60-cm-diameter and 150-cm-high cylindrical tank, seven sets of critical data were obtained. The uranium concentration of the fuel solution ranged from 225 to 310 gU/liter and the uranium enrichment was 10 wt.% ^{235}U. On the bottom, side, and top of the core tank was a thick water reflector.

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
LEU-SOL-THERM-005	Boron Carbide Absorber Rods in Uranium (5.64% ^{235}U) Nitrate Solution	A large number of critical experiments with absorber elements of different types in uranium nitrate solution of different enrichments and concentrations were performed in 1961 - 1963 at the Solution Physical Facility of the Institute of Physics and Power Engineering (IPPE), Obninsk, Russia. The purpose of these experiments was to determine the effects of enrichment, concentration, geometry, neutron reflection, and type, diameter, number, and arrangement of absorber rods on the critical mass of light-water-moderated homogeneous uranyl nitrate solutions. The experiments included ones with a central boron carbide or cadmium rod, clusters of boron carbide rods, and triangular lattices of boron carbide rods in cylindrical tanks of different dimensions filled with solutions of uranyl nitrate. The three experiments included in this evaluation were performed with uranium enriched to 5.64 wt.% ^{235}U. Uranium nitrate solution with uranium concentration of 400.2 g/l was pumped into the core or inner tank, a stainless steel cylindrical tank with inner diameter 110 cm. One experiment was performed without absorber rods, another one with a central rod, and another one with a cluster of seven absorber rods arranged at the corners and center of a hexagon with a pitch of 31.8 cm, inserted in the center of the core tank. There was a thick side and bottom water reflector in these experiments.
HEU-SOL-THERM-001	Minimally Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate	Ten critical experiments, each involving a tank of highly enriched uranyl nitrate (93.172 wt.% ^{235}U), were performed at the Rocky Flats Plant, which was operated at that time by Rockwell International. The critical height for each experiment was determined by linear interpolation between reactor periods of slightly supercritical and slightly subcritical states. The tanks were cylindrical in shape and suspended in the approximate center of a large room. Critical configurations had height to diameter ratios less than 1.2. Uranium concentration varied between 50 and 360 grams of uranium per liter.
HEU-SOL-THERM-004	Reflected Uranyl-Fluoride Solutions in Heavy Water	In the early 1950's, a series of experiments was performed at the Los Alamos Scientific Laboratory to investigate critical parameters of enriched (93.65 wt.% ^{235}U) uranyl-fluoride (UO_2F_2) heavy-water solutions over a wide range of deuterium to ^{235}U atomic ratios. A total of 10 experiments were performed. Six experiments consisted of heavy-water reflected spheres of uranyl fluoride in which the atomic ratio of deuterium to ^{235}U ranged from 34 to 430. The remaining four assemblies were bare cylinders with deuterium to ^{235}U ratios ranging from 230 to 2080.

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
LEU-SOL-THERM-016	STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions, Water-Reflected	The seven critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed from 1997 to the summer of 1998 at the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) at the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Employing the 28-cm thick, 69-cm-wide slab core tank, a 10%-enriched uranyl nitrate solution was used in these experiments. The uranium concentration was adjusted, in stages, to values in the range of approximately 464 gU/l to 300 gU/l. The free nitric acid concentration ranged from 0.8 mol/l to 1.0 mol/l, approximately.
LEU-SOL-THERM-007	STACY: Unreflected 10%-Enriched Uranyl Nitrate Solution in a 60-cm-Diameter Cylindrical Tank	Five critical experiments included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1995 at the Nuclear Fuel Cycle Safety Engineering Research Facility in the Tokai Research Establishment of the Japan Atomic Energy Research Institute. In the first series of experiments using the unreflected 60-cm diameter and 150-cm-high cylindrical tank, five sets of critical data were obtained. The uranium concentration of the fuel solution ranged from 242 to 313 gU/liter and the uranium enrichment was 10 wt.%. The core tank was unreflected.
LEU-SOL-THERM-008	STACY: 60-cm-Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Concrete	Four critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1996 at the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) in the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Employing the 60-cm-diameter cylindrical core tank, a 10wt%-enriched uranyl nitrate solution was used in these experiments. The uranium concentration and the free nitric-acid concentration were adjusted to approximately 240 g/l and 2.1 mol/l, respectively. Four concrete reflectors of different thicknesses, packed in annular tube-shaped containers, were prepared and arranged against the outer wall of the core tank.

Table 3: Expanded Descriptions of the Criticality Experiments

Handbook Reference	Title	Short Description
LEU-SOL-THERM-009	STACY: 60-cm-Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Borated Concrete	Three critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1996 at the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) in the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Employing the 60-cm-diameter cylindrical core tank, a 10 wt%-enriched uranyl nitrate solution was used in these experiments. The uranium concentration and the free nitric-acid concentration were adjusted to approximately 240 g/l and 2.1 mol/l, respectively. Three borated-concrete reflectors of different boron content, packed in annular tube-shaped containers, were prepared and arranged against the outer wall of the core tank.
LEU-SOL-THERM-010	STACY: 60-cm-Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Polyethylene	Four critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1996 at the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) in the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Employing the 60-cm-diameter cylindrical core tank, a 10 wt%-enriched uranyl nitrate solution was used in these experiments. The uranium concentration and the free nitric-acid concentration were adjusted to approximately 240 g/l and 2.1 mol/l, respectively. Four thicknesses of reflectors, polyethylene blocks packed in annular tube-shaped containers, were prepared and arranged next to the outer wall of the core tank.

NOTE 1: The SAR[8] lists HEU-SOL-THERM-002 as the Handbook document for case 13. The twelve case 13 experiments are not all documented in HEU-SOL-THERM-002 in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[7]. Six of the experiments in case 13 use concrete reflectors and the other six use plastic reflectors. HEU-SOL-THERM-002 is for concrete reflectors and specifically documents experiments 2, 3, 7, 10, and 11. HEU-SOL-THERM-003 is for plastic reflectors and documents experiments 1, 4, 5, 8, 9, and 12. Experiment 6 has a concrete reflector but it is not in HEU-SOL-THERM-002. However, the configuration details for experiment 6 are documented in two source documents[2,3] used by HEU-SOL-THERM-002.

NOTE 2: HEU-SOL-THERM-013, from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[7], lists four experiments. A fifth experiment from the original Nuclear Science & Engineering Reference [1] was included by Serco Assurance.

3.2 Validation Input Files

A fundamental feature of all Monte Carlo computer codes is the requirement of a random number (seed) to initiate the calculation. By default, MONK 8A uses the date and time of execution to derive the seed values. To make the validation independent, the default feature was used for this analysis. Serco provided the MONK 8A input files for the 80 validation cases. Serco established that the data libraries in Table 1 were used with the validation cases. The MONK 8A input used a standard deviation on the STDV card of 0.0010 to match the Serco benchmark report[6].

3.3 Validation Outputs

The results of the validation runs are shown in Table 4, and are plotted in Figure 1. Table 4 has the following definitions.

- "H/U" is the hydrogen to fissile atom ratios for each experiment[6].
- "Serco Benchmark" is the k_{eff}[6] values from the Serco benchmark report.
- "AREVA Validation" are the k_{eff} values from the validation runs.
- "Count" is the total number of experiments.
- "Average" is the average of all the Serco benchmark and AREVA validation k_{eff} values calculated using the Excel AVERAGE function.
- "Standard Deviation" is the standard deviation of the k_{eff} values from the Serco benchmark and AREVA validation. The standard deviation used the Excel STDEV function which uses the equation:

$$\sigma = \sqrt{\frac{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)}};$$

where $x_i = k_{eff}$ of each experiment, n = number of experiments (80).

- "Standard Error" is the Standard Error of Measurement[4] of the k_{eff} values from the Serco benchmark and AREVA validation and uses the equation

$$\sigma_M = \frac{\sigma}{\sqrt{n}}.$$

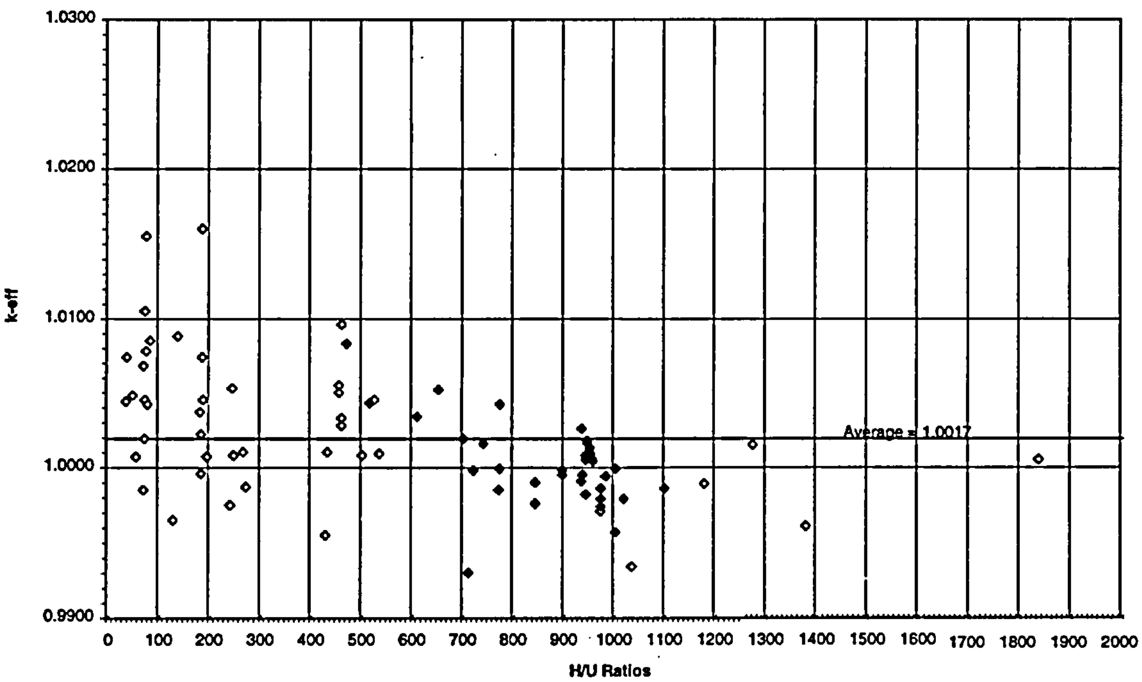
Because the random number generator seed values were based on the MONK 8A default feature, the date and time of execution, the results of each experiment would not be expected to exactly match the Serco benchmark results[6]. The average of the Serco benchmarks, for the 13 cases used in this project is 1.0016 ± 0.0005[6,8] and the average of the AREVA validation runs was 1.0017 ± 0.0005 as shown in Table 4. The agreement between the benchmark values and the validation runs is very good with the difference being attributed to the use of different seed values.

Table 4: Validation Results

Experiment	Case	H/U	Serco Benchmark	AREVA Validation
13	1	453.74	1.0046	1.0053
HEU	2	73.50	1.0075	1.0076
	3	73.50	1.0151	1.0153
	4	70.94	1.0050	1.0043
	5	70.94	1.0078	1.0103
	6	458.77	1.0048	1.0026
	7	458.77	1.0096	1.0094
	8	453.74	1.0053	1.0048
	9	453.74	1.0031	1.0053
	10	183.78	1.0063	1.0072
	11	183.78	1.0158	1.0158
	12	179.55	1.0029	1.0035
23	1	1377.86	0.9963	0.9959
HEU	2	1176.89	0.9979	0.9987
	3	1033.25	0.9941	0.9932
	4	971.59	0.9966	0.9969
	5	1834.85	0.9966	1.0003
35	1	35.84	1.0067	1.0072
HEU	2	47.23	1.0052	1.0046
	3	76.08	1.0044	1.0040
	4	126.47	0.9953	0.9963
	5	269.97	1.0021	0.9985
	6	264.24	1.0016	1.0008
	7	245.70	0.9990	1.0006
	8	239.02	0.9973	0.9973
	9	523.41	1.0028	1.0043
	10	533.12	1.0020	1.0007
	11	1272.25	1.0006	1.0013
43	1	1098.33	0.9950	0.9984
LEU	2	1001.28	0.9921	0.9955
	3	1001.28	0.9941	0.9997
51	1	719.02	1.0003	0.9996
LEU	2	771.30	1.0012	0.9997
	3	842.18	0.9958	0.9988
	4	895.83	1.0022	0.9996
	5	941.69	0.9996	1.0003
	6	982.52	1.0008	0.9992
	7	1017.55	0.9991	0.9977
63	1	972.18	0.9970	0.9984
LEU	2	972.18	0.9969	0.9977
	3	972.18	0.9972	0.9972

Experiment	Case	H/U	Serco Benchmark	AREVA Validation
67	1	181.79	1.0029	0.9994
HEU	2	70.60	1.0014	1.0017
	3	185.71	1.0027	1.0043
	4	68.15	1.0044	1.0066
	5	499.44	0.9993	1.0006
	6	458.76	1.0050	1.0031
	7	193.28	1.0007	1.0005
	8	181.79	1.0023	1.0020
	9	68.15	0.9999	0.9983
	10	427.40	0.9941	0.9953
68	1	34.20	1.0040	1.0042
HEU	2	53.70	1.0011	1.0005
	3	81.20	1.0060	1.0083
	4	135.30	1.0088	1.0086
	5	243.00	1.0059	1.0051
	6	430.99	1.0016	1.0008
71	1	468.73	1.0083	1.0081
LEU	2	514.15	1.0072	1.0041
	3	608.43	1.0024	1.0032
	4	650.21	1.0034	1.0050
	5	699.14	1.0044	1.0017
	6	738.93	1.0035	1.0014
	7	771.79	1.0040	1.0040
80	1	709.25	0.9997	0.9928
LEU	2	769.97	0.9991	0.9983
	3	842.18	0.9955	0.9974
	4	896.05	0.9980	0.9993
	5	942.24	0.9981	0.9980
81	1	954.82	1.0020	1.0004
LEU	2	952.22	1.0003	1.0007
	3	950.69	1.0008	1.0011
	4	956.36	0.9996	1.0002
84	1	935.78	1.0013	0.9993
LEU	2	934.06	1.0011	1.0024
	3	933.49	0.9995	0.9989
85	1	946.20	0.9998	1.0014
LEU	2	944.81	0.9995	1.0016
	3	943.63	1.0010	1.0005
	4	941.67	1.0010	1.0006
Count	80	**Average**	1.0016	1.0017
		Standard Error	0.0005	0.0005

Figure 1: Validation Results



◊ REPRESENTS HIGH ENRICHED URANIUM (HEU)
♦ REPRESENTS LOW ENRICHED URANIUM (LEU)

3.4 Repeatability

As mentioned earlier, a fundamental feature of all Monte Carlo computer codes is the requirement of a random number to initiate the calculation. By default, MONK 8A utilizes the date and time of execution to derive the seed values for each case. It is of interest to evaluate the effect of the random number seed values for MONK 8A. Therefore, one validation case is chosen for a brief sensitivity study of this effect. The first case of experiment 23 listed in Table 4 was run on different dates and times to test the repeatability and reliability of MONK 8A. The results are summarized in Table 5.

The average k_{eff} of the six runs was 0.9966 with a standard deviation of 0.0011. Since the convergence criterion for the runs was a standard deviation of 0.0010; this demonstrates that MONK 8A calculates consistent results.

Table 5: Results of Repeatability Sensitivity Study

Date	Time	Date/Time	Seed 1	Seed 2	keff
02/16/04	14:47:44	2/16/04 14:47	16033	29133	0.9959
02/19/04	10:49:28	2/19/04 10:49	108785	59133	0.9967
02/19/04	16:13:43	2/19/04 16:13	31421	59133	0.9955
02/20/04	13:44:37	2/20/04 13:44	6751	59133	0.9957
02/20/04	14:29:47	2/20/04 14:29	14975	69133	0.9983
02/23/04	9:47:56	2/23/04 9:47	97327	99133	0.9972
Count =	6			**Avg =**	0.9966
			Standard Deviation =		0.0011

4.0 VERIFICATION

Urenco ran an extensive set of MONK 8A criticality calculations in support of their existing facilities and NEF. Thirty one representative cases were selected for verification of the MONK 8A criticality analysis run by Urenco. As described in the validation section, the default seed values for the random number generator are used to make this verification independent of Urenco.

It is of interest to verify the reproducibility of the Monte Carlo solution. Therefore, the original random seed values were used in the first six cases in Table 6 to track the reproducibility of MONK 8A on the QA controlled computer. These six cases with the original seed values produced identical results to the Urenco cases.

The first six cases in Table 6 were also repeated with the default seed values. The results of all thirty one cases chosen for verification are shown in Table 6. The average of the Urenco results for the thirty one cases used in this report is 0.8755. The average of the verification runs is 0.8734 as shown on Table 6. The documented values and the verification runs are in good agreement.

Table 6: Verification Results

Case	Brief Case Description	Urenco	AREVA
1	5% Critical Value- Mass 37kgU H/U=27	0.9992	0.9974
2	5% Critical Value- Volume 28.9L	0.9979	0.9998
3	5% Critical Value- Cylinder Diameter 26.2cm	0.9977	0.9959
4	6% Critical Value- Mass 27kgU H/U=32	0.9971	0.9958
5	6% Critical Value- Volume 24L	0.9952	0.9951
6	6% Critical Value- Cylinder Diameter 24.4cm	0.9951	0.9965
7	Cold trap, center-to-center separation 110 cm with 2.5 cm reflector	0.7985	0.8012
8	Cold trap, same as case 7 with two additional components in interaction	0.8184	0.8194
9	Cold trap, pump in contact and a 2.5 cm water reflector	0.8628	0.8685
10	Product Vent in contact with pump with vacuum cleaner at side. Aluminum trap walls	0.9282	0.9276
11	Product UF6 Pumps in isolation – H/U=12	0.7434	0.7435
12	Product UF6 Pumps touching at gearbox ends – H/U=12	0.8232	0.8222
13	Product UF6 Pumps touching with vacuum cleaner along side H/U=12	0.8399	0.8399
14	Product UF6 Pumps same as case 13 but with 2.5 cm water reflector	0.8698	0.8693
15	UF6 Product Pipe work, 52cm-150mm pipe - 6% H/U=12	0.9404	0.9399
16	UF6 Product Pipe work, 52cm-150mm pipe - 6% H/U=13	0.9379	0.9451
17	UF6 Product Pipe work, 52cm-150mm pipe - 6% H/U=14	0.9405	0.9357
18	UF6 Product Pipe work, 13.5cm-100mm pipe - 6% H/U=12	0.9399	0.9420
19	UF6 Product Pipe work, 13.5cm-100mm pipe - 6% H/U=13	0.9432	0.9414
20	UF6 Product Pipe work, 13.5cm-100mm pipe - 6% H/U=14	0.9396	0.9397
21	Contingency Dump Trap in isolation with 2.5 cm of water reflection	0.6421	0.6479
22	Contingency Dump Trap linear array of 7 traps and three vessels at 60 cm	0.8492	0.8437
23	Vacuum Cleaners as isolated cylinder at optimum moderation with 2.5 cm reflector	0.7992	0.7924
24	TSB - isolated 12 liter containers at 60 cm containing contaminated charcoal	0.6980	0.6797
25	TSB – single isolated cylinder containing UF4/oil mixture	0.8495	0.8399
26	TSB – 5x5 array with a container in contact with a 2.5 cm water reflector	0.9236	0.9198
27	TSB Ventilation Room 7x7 array of chemical traps touching – H/U=12	0.9146	0.9124
28	TSB Ventilation Room 11x11 array of chemical traps 5 cm spacing – H/U=7	0.8620	0.8592
29	TSB Chemistry Laboratory 1S bottles in a 25x25 array with water flooding 1.5 cm spacing	0.6513	0.6397
30	TSB Decontamination Workshop – linear array of pairs of touching pumps 60 cm spacing	0.8507	0.8420
31	TSB Fomblin Oil Recovery System - optimum moderation H/U=14	0.7931	0.7842
	Average	0.8755	0.8734

5.0 RESULTS AND CONCLUSIONS

The average of the validation runs is 1.0017 ± 0.0005. This is in good agreement with the average of the corresponding MONK 8A benchmarks of 1.0016 ± 0.0005[6,8]. Because the runs are models of actual criticality experiments, this also demonstrates that MONK 8A is conservative for calculating criticality.

The average of the verification runs is 0.8735 which is in good agreement with the average of the corresponding documented MONK 8A results of 0.8755[8]. Therefore, it can be concluded that the verification of the criticality calculations is complete with satisfactory results.

6.0 References

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