Nuclear Reactor Laboratory
University of Wisconsin-Madison

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License R-74
Docket 50-156

August 22, 2006

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Dear Sir:

Enclosed is a copy of the 2005-2006 Annual Report for the University of Wisconsin Nuclear Reactor Laboratory as required by our Technical Specifications.

Sincerely,

Robert J. Agasie
Reactor Director

Enc. (Annual Report)

cc: Region III Administrator
Compliance Inspector, Region II, Craig Bassett
Facility Project Manager, Patrick Isaac
Reactor Safety Committee, RSC 899

A020

THE UNIVERSITY OF WISCONSIN

NUCLEAR REACTOR LABORATORY

FISCAL YEAR 2005-2006 ANNUAL OPERATING REPORT

Prepared to meet reporting requirements of:
U. S. Department of Energy
SPECIAL MASTER TASK RESEARCH SUBCONTRACT NO. C96-175937
and
U. S. Nuclear Regulatory Commission
(Docket 50-156, License R-74)

Prepared by:

Robert J. Agasie
Department of Engineering Physics

EXECUTIVE SUMMARY OF REACTOR UTILIZATION

Teaching: Teaching usage of the reactor during the year included:

- 89 Nuclear Engineering & Engineering Physics students in laboratory and lecture courses.
- 16 students and staff from other UW-Madison departments used the facilities for formal instruction.
- 47 students and staff from 2 additional college-level educational organizations used the facilities for formal instruction.
- 560 students and instructors from 8 non-college level educational organizations used the facilities for formal instruction as part of the UW Nuclear Reactor Outreach Program.

Research: Neutrons from the reactor were used primarily for neutron activation and analysis.

- 798 samples were irradiated for departments at UW-Madison.
- 37 samples were irradiated for other educational institution research programs.
- 362.6 hours of neutron beam time were attributed to the study of neutron radiolysis in water at supercritical pressures and temperatures.
- 12 hours of neutron beam time were attributed to the study of diesel nozzle spray patterns in the neutron radiography facility.

Industrial Use:

- Irradiation of 5 samples were performed for NAA.

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A. SUMMARY OF OPERATIONS

1. INSTRUCTIONAL USE -- UW-Madison Classes and Activities

Nuclear Engineering & Engineering Physics (NEEP) 231, "Survey of Nuclear Engineering" was offered in the spring semester with an enrollment of 26 students. The course is designed for freshmen students interested in nuclear engineering and consists of three lecture modules surveying fission, fusion and radiation science technologies. The fission module concludes with a reactor tour.

Fourteen students completed NEEP 234, "Principles and Practice of Nuclear Reactor Operation" during the fall semester. This course uses the reactor extensively, as each student performed at least 20 significant reactivity changes. Over 120 hours of exclusive reactor use specifically for training were required to provide this operating experience. Four of the students applied for and successfully obtained NRC Operator Licenses.

NEEP 427 was offered in the fall and spring semesters with a total enrollment of 31 students. Several NEEP 427 experiments use materials that are activated in the reactor. One experiment entitled "Radiation Survey" requires that students make measurements of radiation levels in and around the reactor laboratory.

Eighteen students were enrolled in NEEP 428 which was offered in the fall and spring semesters. Three experiments in NEEP 428 require exclusive use of the reactor. These experiments ("Critical Experiment", "Control Element Calibration", and "Pulsing") required a total of 18 hours of exclusive reactor use. Other NEEP 428 laboratory sessions use material that has been irradiated in the reactor ("Fast Neutron Flux Measurements by Threshold Foil Techniques" and "Resonance Absorption").

Individual class sessions for Engineering Professional Development 101, and Engineering Physics 468 were held in the Reactor Laboratory, with 16 students participating.

The Reactor Laboratory's continued commitment to its educational outreach program attracts large numbers of community organizations who visit the reactor. A listing of individual schools and educational programs who have visited is provided below in section A.2 of this report.

2. REACTOR SHARING PROGRAM

The University of Wisconsin Nuclear Reactor was again funded this year by the U.S. Department of Energy, Office of Nuclear Energy, Science and Technology to offer reactor services in accordance with the University Reactor Sharing Program. The purpose of the program is to make available university nuclear reactor facilities to non-reactor owning colleges, universities, and other educational institutions. User groups affiliated with the host institution (UW-Madison) are also eligible for assistance, up to 35% of the awarded funds. This year, the Reactor Laboratory provided $30,359 of reactor services free of charge to the user institutions under the University Reactor Sharing Program; of which, $18,100 was reimbursed by the U.S. Department of Energy. User institutions participation in this year's program are detailed below.

Participating Institution	Principal Investigator	Number of Faculty/ Students Involved
Beloit College	S. Ballou	1/0
Analyzed swipe tests to leak check radioactive sources and performed detector calibration.		
Engine Research Center	M. Anderson	1/1
Perform neutron radiography of diesel fuel injector nozzle to model spay patterns. See section A.4 of this report for more information.		
Notre Dame Radiation Laboratory	D. Bartels	3/5
Neutron beam irradiation in supercritical water test loop to measure neutron and beta/gamma radiolysis rates in supercritical water.		
University of Illinois - Champaign-Urbana	R. Uddin	1/11
Day long reactor operations demonstration and reactor physics measurements laboratory. Included real time demonstration of NAA capabilities.		

Participating Institution	Principal Investigator	Number of Faculty/ Students Involved

University of Wisconsin - Madison
Department of Anthropology
R. Law 1/0
NAA to characterize fragments of steatite manufacturing debris excavated from the archaeological site of Harappa, Pakistan.

University of Wisconsin - Madison
Department of Engineering Physics
M. Swandby 1/23
Reactor tour and demonstration of supercritical water test loop in support of graduate research recruitment program.

University of Wisconsin - Madison
Department of Engineering Physics
T. Allen 2/31
Production of various activation foils as gamma emitting sources for the Instrumentation Laboratory.

University of Wisconsin - Madison
Department of Engineering Physics
J. Blanchard 1/6
Safety training lecture provided to an introduction to engineering research seminar.

University of Wisconsin - Madison
Department of Engineering Physics
P. Wilson 1/1
Irradiation of activation foils for measuring the spacial flux distribution of beam ports number 1 and 2.

University of Wisconsin - Madison
Department of Engineering Professional Development
D. Woolston 1/10
Reactor tour with a discussion on applications of nuclear energy, uses of the UW nuclear reactor and opportunities in nuclear science and engineering.

University of Wisconsin - Madison
Ion Beam Laboratory
D. Whyte 1/1
Calibration equipment services provided to the Ion Beam Laboratory.

Participating Institution	Principal Investigator	Number of Faculty/ Students Involved

University of Wisconsin - Madison
Department of Medical Physics
B. Thomadsen 1/1
Neutron survey meter provided to department.

University of Wisconsin - Madison
Department of Physics
S. Oliva 1/1
Neutron calibration services provided to Madison Symmetric Torus Experiment.

University of Wisconsin - Madison
Police Department
J. Jansen 2/0
Reactor tour and lecture on radiation and radioactivity in the environment.

University of Wisconsin - Madison
Department of Soil Sciences
P. Helmke 2/1
NAA to determine Fe, K/Na ratios, and trace element concentrations of samples from a soil-stoneline-ironstone complex in Uganda.

University of Wisconsin - Milwaukee
Center for Byproduct Utilization
T. Naik 3/1
NAA to investigate the use of waste products in construction materials.

University of Wisconsin - Whitewater
S. Sayhun 1/0
Analyzed swipe tests to leak check radioactive sources and performed detector calibration.

Wisconsin Academy of Staff Development Initiative
J. Murphy 21/0
Reactor tour with a discussion on applications of nuclear energy, uses of the UW nuclear reactor and opportunities in nuclear science and engineering. WASDI is designed to assist Wisconsin teachers in leading students to increasingly higher achievement by to improving mathematics and science learning in their own classrooms, schools, districts, and the wider profession.

Non-College Groups:

Participating Institution	Number Instructor/Students Involved

Abundant Life Christian High School 1/14
Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor.

American Nuclear Society, UW-Madison Student Branch 1/15
Engineering Society sponsored tours of College of Engineering facilities for area high school students. The program was entitled "Shadow an Engineer for a Day". The tour included a discussion on nuclear energy in addition to a tour of the facility.

Boy Scouts of America 5/434
Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor. Program included hands on demonstrations of radiation detection and shielding. Program co-sponsored by the UW student branch of the American Nuclear Society in support of the Scouts Atomic Energy Badge program.

Discover World Museum 3/0
Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor. Part of a curriculum development session for future museum exhibits.

Engineering Summer Program 1/18
Reactor tour and nuclear energy discussion for minority high school student. Summer program to interest minority student in technical education.

Girl Scouts of the USA 3/33
Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor. Program included hands on demonstrations of radiation detection and shielding. Program co-sponsored by the UW student branch of the American Nuclear Society in support of the Girl Scout Atomic Merit Badge.

LaFollette High School 1/17
Advanced Science and Engineering Class. Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor. Provided real time gamma spectroscopy activation analysis laboratory demonstration.

Participating Institution Number Instructor/Students Involved

Waunakee High School 1/13
Reactor tour with a discussion on applications of nuclear energy and uses of the UW nuclear reactor.

USER SUMMARY:

Educational Institutions:	16
Students:	637
Faculty/Instructors:	61

3. SAMPLE IRRADIATIONS AND NEUTRON ACTIVATION ANALYSIS SERVICES

There were 840 individual samples irradiated during the year. Of these samples, 470 were irradiated for 15 minutes or less. Samples accumulated 205.7 irradiation space hours and 768.9 sample hours. Many samples were irradiated and then counted at the Reactor Laboratory as part of our neutron activation analysis service. In the listing below the notation (NAA) indicates that the samples were processed by our neutron activation analysis service.

Engineering Physics Department, UW-Madison
UW Nuclear Reactor Laboratory
18 samples, 5.55 sample hours
Production of calibration sources for required reactor measurements and development of methods for instrumental neutron activation analysis. UW support.

Engineering Physics Department, UW-Madison
Graduate Research Project
20 samples, 4.70 sample hours
Irradiation of CaF dosimeters for measuring the gamma flux around beam port number 1 and activation of aqueous salt solutions for measuring the spacial neutron flux distribution of beam port 2. UW Support.

Engineering Physics Department, UW-Madison
Undergraduate Research Project
31 samples, 7.75 sample hours
Irradiation of activation foils for measuring the spacial flux distribution of beam ports number 1 and 2. Supported by the DOE Reactor Sharing Program and the University of Wisconsin.

Engineering Physics Department, UW-Madison (NAA)
Capstone Design
8 samples, 0.80 sample hours
Neutron activation analysis of tungsten targets to determine if trace impurities a leading to early failure modes. Supported by the DOE Reactor Sharing Program and the University of Wisconsin.

Engineering Physics Department, UW-Madison
Instrumentation Laboratory
114 samples, 131.0 sample hours
Irradiation of foil sources for radiation detector experiments, including absolute counting for neutron flux measurements and activation of samples for neutron activation analysis experiment. Supported by the DOE Reactor Sharing Program and the University of Wisconsin.

Engineering Physics Department, UW-Madison
NEEP 428
88 samples, 106.9 sample hours
Irradiation of foils for resonance absorption measurements and fast neutron flux measurements. UW support.

Department of Soil Sciences, UW-Madison (NAA)
56 samples, 28 sample hours
Professor P. Helmke used NAA to determine Fe, K/Na ratios, and trace element concentrations of samples from a soil-stoneline-ironstone complex in Uganda. This information determines the degree and type of weathering, geochemistry and hydrology which control formation of these types of complexes throughout much of the tropics. Supported by the DOE Reactor Sharing Program and the University of Wisconsin.

Department of Anthropology, UW-Madison (NAA)

463 samples, 460.5 sample hours

Dr. R. Law used NAA to characterize fragments of steatite manufacturing debris excavated from the archaeological site of Harappa, Pakistan. Analyses of the rare earth element and transition metal concentrations in source samples indicated that source regions could be differentiated from one another with a high degree of confidence. Based on these characterizations, the archaeological steatite analyzed in this study appears to have originated from source regions in the Northwest Frontier Province and Baluchistan Province of Pakistan. Supported by the DOE Reactor Sharing Program and the University of Wisconsin.

University of Wisconsin- Milwaukee (NAA)
Center for Byproduct Utilization

32 samples, 17.6 sample hours

Professor T. Naik and one additional staff member used NAA to measure levels of various elements in concretes prepared using various byproduct materials, such as paper mill sludge, fly ash, and bottom ash. Supported by DOE Reactor Sharing Program.

University of Illinois - Champaign-Urbana (NAA)

5 samples, 1.10 sample hours

Activation foils provided for real time gamma spectroscopy activation analysis laboratory demonstration as part of a weekend session laboratory experience in reactor measurements. Supported by DOE Reactor Sharing Program.

Kraft Foods (NAA)

5 samples, 5.0 sample hours

Neutron activation analysis of tank sludge as part of a corrosion study analysis. Industrial Support

4. OTHER MAJOR EDUCATIONAL AND RESEARCH USE

The reactor Laboratory is continuing collaboration with the Notre Dame Radiation Laboratory on the study of neutron radiolysis in water at supercritical pressures and temperatures. At the UWNR, a supercritical water loop is used to determine yields of radiolysis products formed by reactions of radiation with water. The focus of the study is to determine the concentration of radical and molecule yields formed by radiolysis. These results, in combination with recombination rates (measured at the Notre Dame Radiation Laboratory) can be used to determine water

conditions using chemical simulation programs for supercritical water reactors (SCWRs), which will be essential in the choice and testing of new materials for SCWRs.

Both neutron and gamma energy deposition values have been evaluated using a combined approach of neutron activation analysis and a radiolysis reaction experiment at conditions where the reaction yields are known. The technique used will be developed as a new method of neutron and gamma dosimetry in very high fields of mixed radiation fields that can be difficult to measure with other methods. Recent data has been taken to determine the yields of aqueous electrons, hydrogen radicals, and hydrogen gas from 25 C up to 400 C at 3600 psi. Upgrades to the experiment including an additional heater have allowed data to be taken at higher temperatures than previously achievable.

The Neutron Radiography Facility at the UWNR was revitalized and reinstalled to support research in characterizing the spray in the near-nozzle region of typical diesel injectors. The neutron beam port and collimator were modified to increase the sensitivity of the neutron radiography facility for this diagnostic and a new shielding structure was constructed. A collaboration with Nova Scientific also allowed access to state of the art neutron microchannel plates for this study. Initial experiments were promising, however they pointed to several possible improvements that are necessary to enhance the diagnostic given the current neutron flux.

5. CHANGES IN PERSONNEL, FACILITY AND PROCEDURES

Any changes reportable under 10 CFR 50.59 are indicated in section E of this report. No other changes to the facility were completed during the year.

Personnel changes during the year were as follows:

The following reactor operators were removed from licensed status upon graduating and resigning their position with the university:

Todd N. Johnson	OP-70306	Effective 07/08/05
Paul W. Humrickhouse	OP-70305	Effective 12/23/05

Abdul Ben-Zikri, Acting Radiation Safety Officer, was appointed to the Reactor Safety Committee upon the retirement of Reactor Safety Committee Member Ronald R. Bressell effective March 2, 2006.

The following individuals were appointed as Reactor Operators effective April 21, 2006:

Corey S. Edwards	OP-70522
Aaron M. Lee	OP-70523
Daniel C. Ludwig	OP-70524
Joseph M. Prazak	OP-70525

The following individual was appointed as Senior Reactor Operator and Alternate Reactor Supervisor effective April 21, 2006:

Kevin T. Austin	SOP-70483

6. RESULTS OF SURVEILLANCE TESTS AND INSPECTIONS

The program of inspection and testing of reactor components continues, satisfactorily meeting procedural acceptance criteria. Inspection of underwater components during the annual maintenance showed no deterioration or wear.

The pool leak surveillance program continues to monitor the pool evaporation rate, the pool make-up volume, and pool water radioactivity. Analysis continues to show ^{3}H to be the only radionuclide present with an average concentration of $9.5 \times 10^{-5} \mu Ci/ml$, which is 9.5% of the 10 CFR Part 20, Appendix B, Table 2, column 2, maximum allowable water effluent release concentration. The pool leak surveillance program continues to show that no water effluent has been released to the environment.

B. OPERATING STATISTICS AND FUEL EXPOSURE

Operating Period	Critical Hrs	MW Hrs	Runs	Pulses
Fiscal Year 2005-2006	513.07	396.45	256	50
FLIP Core	17,233.93	14,358.86	5,027	1,050
TRIGA	24,498.92	19,347.04	7,017	2,361

Core I23-R10 was operated throughout the year. The excess reactivity of this core was determined to be 4.272%ρ.

C. EMERGENCY SHUTDOWNS AND INADVERTENT SCRAMS

There were seven automatic scrams or unintentional shutdowns during the year. Each is described below in chronological sequence.

July 20, 2005; Relay SCRAM from loss of power. During full power operations, the Mechanical Engineering Building suffered from a complete loss of electrical power resulting in a reactor SCRAM.

October 26, 2005; Rely and electronic SCRAM from picoammeter number 2. While attempting to increase reactor power from 1 W, a trainee failed to up range the picoammeter to the next higher range. As a result, a reactor scram from a neutron high flux trip at 125% occurred.

November 23, 2005; Relay and electronic SCRAM from picoammeter number 2. While performing a normal reactor shutdown, an operator trainee was down ranging the picoammeters in order to monitor the decrease in reactor power. The trainee inadvertently down ranged the picoammeter range switch two ranges and received a neutron high flux trip at 125%.

December 6, 2005; Rely and electronic SCRAM from picoammeter number 2. While attempting to increase reactor power from 120 W on the 300 W range, an operator trainee failed to anticipate a short reactor period following latching the transient rod while the reactor was exactly critical. The operator trainee was too distracted by the short period alarm that he failed to observe reactor power was rapidly increasing. As a result, a reactor scram from a neutron high flux trip at 125% occurred.

February 16, 2006; Manual SCRAM by reactor operator. Following an Area Radiation High alarm, the on shift reactor operator was unable to immediately determine the reason for the alarm. The operator initiated an emergency manual scram in accordance with UWNR 155. The source of the high radiation levels were determined to be due to ^{16}N activity at the pool top following failure of the ^{16}N Suppression Pump. It was later determined that the ^{16}N Suppression Pump failed because a wire connecting to the ON/OFF/AUTO switch broke. All wire connections were replaced.

March 6, 2006; Rely and electronic SCRAM from picoammeter number 2. While attempting to determine the transient rod withdrawn position in order to square wave to 1000 kW, an operator incorrectly estimated the required amount of reactivity to insert into the reactor. Sufficient reactivity was inserted to the reactor resulting in a reactor scram from a neutron high flux trip.

March 6, 2006; Rely and electronic SCRAM from picoammeter number 2. While attempting to again determine the transient rod withdrawn position in order to square wave to 1000 kW, an operator incorrectly estimated the required amount of reactivity to insert into the reactor. Sufficient reactivity was inserted to the reactor resulting in a reactor scram from a neutron high flux trip.

D. MAINTENANCE

The Preventive Maintenance Program continues to maintain equipment and systems in good condition. Routine regeneration of the demineralizer resins were performed on August 22, 2005 and April 19, 2006.

Corrective maintenance was performed on the following systems:

In December 2005, the reactor would scram when the mode switch was changed back to Square Wave after a pulse. Troubleshooting determined that the original 24VDC power supply to the High Voltage Monitor had failed to a high output (approximately 37VDC). A new 24VDC power supply was installed.

In December 2005, while performing the semi-annual checks, it was observed that picoammeter #2 trip set point was incorrect and that the trip could not be reset. It was

discovered that the trip circuit operational amplifier had failed. A new operational amplifier was installed.

On March 27, 2006, picoammeter #2 failed during the pre-startup checklist, when it was observed that the trip set point was approximately 150%. Upon inspection overheating resistors where observed on the power supply board. The resistors were replaced. It was suspected that the failing resistors lead to the premature failure of the operational amplfier which was replace in December 2005.

E. CHANGES IN THE FACILITY OR PROCEDURES REPORTABLE UNDER 10 CFR 50.59

There were no changes in the facility or procedures reportable pursuant to 10 CFR 50.59 completed during the year.

F. RADIOACTIVE WASTE DISPOSAL

1. SOLID WASTE

All solid waste was transferred to the University Broad Scope license for ultimate disposal in accordance with radioactive materials license number WI 25-1323-01. The amount and activity are detailed below.

Date	Isotope	Activity (μCi)
07/19/2005	Co-60	7.6E-8
	Co-58	4.3E-9
	Cr-51	6.4E-9
	In-114m	1.1E-9
	Mn-54	8.4E-8
	Zn-65	3.6E-8
	Total:	1.6E-7
Volume:	2.0 cubic feet	
Constituents:	contaminated steel pipe	

2. LIQUID WASTE RELEASED TO THE SANITARY SEWER

Liquid waste discharges from the facility during the year are detailed in Table 1.

3. PARTICULATE AND GASEOUS ACTIVITY RELEASED TO THE ATMOSPHERE

Table 2 presents information on stack discharges during the year.

4. LIQUID ACTIVITY RELEASED TO THE ENVIRONMENT

No liquid activity was released to the environment during the year.

G. SUMMARY OF RADIATION EXPOSURE OF PERSONNEL (01/01/05 - 12/31/06)

The personnel radiation monitoring program at the University of Wisconsin for the past calendar year used Global Dosimetry brand TLD monitors for whole body exposure while extremity dose was monitored using TLD ring badges processed by the University of Wisconsin Radiation Calibration Laboratory. No personnel received any significant radiation exposure for the above period. The highest annual doses recorded were 27 mrem to the whole body and 215 mrem to the extremities.

The highest dose received by a member of the public visiting the reactor lab was 5.487 mrem, as measured by Siemens brand Electronic Personal Dosimeters.

Monthly radiation surveys continue to demonstrate acceptable radiation dose rates within the reactor laboratory and no contamination.

H. RESULTS OF ENVIRONMENTAL SURVEYS (01/15/05 - 01/14/06)

The environmental monitoring program at the University of Wisconsin uses Landauer Luxel brand area monitors located in areas surrounding the reactor laboratory. Table 3 indicates the dose a person would have received if continuously present in the indicated area for the entire 2005 calendar year.

I. PUBLICATIONS

The following are theses, publications and presentations based on reactor use:

Anderson M.H., Bonazza, R., Sanders, S. Neutron Radiography of near nozzle diesel spray. Big 10 University Research and training reactors final report, 2005

Edwards, E., Sweet, A., Blanchard, M., Agasie, R., Jain, P., Rizwan-uddin. Distance Reactor Laboratory and Virtual Tours. 2006 ANS Annual Meeting. Reno, NV, June 7, 2006.

Edwards, E., Wilson, P.P.H., Anderson, M., Bartels, D.M., Pimblott, S., Schmitt, B., Ludwig, D., Prazak, J., Setter, T., "University of Wisconsin Supercritical Water Loop Radiation Energy Deposition Calibration", Transactions of the American Nuclear Society v. 94, 2006.

Edwards, E., Bartels, D., Olson, L., Wilson, P., Anderson, M., and Humrickhouse, P. "Radiation Chemical Yields of Water in Neutron and Gamma Radiation", Trans. Amer. Nuc. Soc. , 94, p. 533

Humrickhouse, P., and Wilson, P. "Operational Benchmarks for a Monte Carlo Model of the University of Wisconsin Nuclear Reactor", Trans. Amer. Nuc. Soc., 93, p. 871

Humrickhouse, P., "Development of a Monte Carlo Model of the University of Wisconsin Nuclear Reactor", M.S. Thesis, University of Wisconsin-Madison, Dec 2005.

Law, R.W. (2006) Moving Mountains: The trade and transport of rocks and minerals within the greater Indus Valley region. In Space and Spatial Analysis in Archaeology. Edited by E. C. Robertson, J. D. Seibert, D. C. Fernandez and M. U. Zender, pp. 301-313. University of New Mexico Press, Albuquerque.

Law, R.W. (2005) A Diachronic Examination of Lithic Exchange Networks During the Urban Transformation of Harappa. In South Asian Archaeology 2003. Edited by Ute Franke-Vogt and Hans-Joachim Weisshaar, pp. 111-121. Linden Soft, Aachen.

Law, R.W. (2005) Regional Interaction in the Prehistoric Indus Valley: Initial Results of Rock and Mineral Sourcing Studies at Harappa. In South Asian Archaeology 2001. Edited by C. Jarrige and V. Lefèvre, pp. 179-190. Éditions Recherche sur les Civilisations, Paris.

Law, R.W. (2006) Inter-Regional Interaction and Urbanism in the Ancient Indus Valley: A Geologic Provenance Study of Harappa's Rock and Mineral Assemblage. Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Anthropology), University of Wisconsin-Madison.

Law, R.W. (2005) Indus Rock and Mineral Trade Networks: The View from Harappa. 18th International Conference of the European Association of South Asian Archaeologist, London, England, July 4-8, 2005.

Rom, Craig, "Flow field and near nozzle fuel spray characterization for a cold flowing vortex" UW-Madison M.S. Thesis, 2006

Staum, C., BP#1 Shield Analysis using MCNP5, June 17, 2005

TABLE 1
LIQUID RADIOACTIVE WASTE DISCHARGED TO SEWER

Release Date:		08/16/2005	01/19/2006	04/17/2006	04/26/2006
Gallons Released:		1250	1200	1280	1350
Total µCi:		16.07	0.00	0.00	349.57
Sum of Fraction of MPC w/o dilution:		0.0840	-	-	0.6133
Sum of Fraction of MPC w/ daily dilution:		0.0042	-	-	0.0330
Isotope	MPC (µCi/ml)	Released	Released	Released	Released	
Co-58	2.00E-4	-	-	-	30.73	µCi
		-	-	-	6.02E-6	µCi/ml
		-	-	-	0.0300	Fraction of MPC
Co-60	3.00E-05	-	-	-	7.365	µCi
		-	-	-	1.44E-6	µCi/ml
		-	-	-	0.0480	Fraction of MPC
Cr-51	5.00E-3	-	-	-	152.5	µCi
		-	-	-	2.98E-5	µCi/ml
		-	-	-	0.0060	Fraction of MPC
K-40	4.00E-5	15.26	-	-	-	µCi
		3.23E-6	-	-	-	µCi/ml
		0.0806	-	-	-	Fraction of MPC
Mn-54	3.00E-04	-	-	-	28.55	µCi
		-	-	-	5.59E-6	µCi/ml
		-	-	-	0.0186	Fraction of MPC
In-114m	5.00E-05	0.8053	-	-	-	µCi
		1.70E-7	-	-	-	µCi/ml
		0.0034	-	-	-	Fraction of MPC
Zn-65	5.00E-05	-	-	-	130.5	µCi
		-	-	-	2.55E-5	µCi/ml
		-	-	-	0.5107	Fraction of MPC

Total volume of water released to the sanitary sewer (gallons)	=	5080
Total quantity of radioactive material released to the sanitary sewer (µCi)	=	365.6
Average daily sewage flow for dilution (gallons)	=	2.37E+04
Maximum fraction of MONTHLY release limit with DAILY dilution	=	0.0330
Maximum fraction of MONTHLY release limit with MONTHLY dilution	=	0.0021

TABLE 2
EFFLUENT FROM STACK

1. Particulate Activity

There was no discharge of particulate activity above background levels.

2. Gaseous Activity - All Argon-41

Month	Activity Discharged (Curies)	Maximum Concentration µCi/ml x 1E-6	Average Concentration µCi/ml x 1E-6*
July 2005	0.0519	1.40	0.0289
August	0.0257	1.50	0.0115
September	0.0302	1.40	0.0174
October	0.0217	1.20	0.0121
November	0.0274	1.00	0.0158
December	0.00001	1.60	5.577E-12
January 2006	0	0	0
February	0.0571	2.10	0.0358
March	0.0790	2.30	0.0440
April	0.0576	1.60	0.0332
May	0	0	0
June	0.00001	0.40	5.763E-12
	Total	Maximum	Average
	0.3506	2.30	0.0166

Using Gifford's model, as described in the appendix to the "Safety Analysis Report for the University of Wisconsin Nuclear Reactor", a concentration of 8E-6 µCi/ml at the stack discharge would result in a maximum air concentration of 1E-8 µCi/ml at any point downwind.

*Unless specifically noted.

TABLE 3
ANNUAL DOSE DATA -- Environmental Monitors
(01/15/05 - 01/14/06)

Location	Annual Dose mrem
Highest Dose Inside Reactor Laboratory	303.0
Dose Inside Reactor Laboratory Stack	38.0
Highest Dose Outside Reactor Laboratory (Reactor Lab roof ladder: monitor adjacent to stone surface)	60.0
Highest Dose in Occupied* Non-restricted Area (East wing hallway of Mechanical Engineering Building)	38.0
Average Dose in all Non-restricted Areas (28 Monitor Points)	16.6

*Occupied areas include classrooms, offices, and lobbies/meeting areas where an individual might reasonably spend in excess of 2 hours per day.