DOE/NV/10872--T30

November 15, 1995

Mr. Terry Vaeth
Mr. Dean Stucker
U.S. Department of Energy
Las Vegas, NV

Dear Mr. Vaeth and Mr. Stucker:

Enclosed please find our Waste Package Project Quarterly Report, covering the period of July 1, 1995 to September 30, 1995. The report summarizes our most recent research activities which are pertinent to the project.

Our project activities will end with the official expiration of the UNLV/DOE five year cooperative agreement January 1996, at which time a final report will be prepared.

We look forward to continued cooperation with the U.S. Department of Energy on various aspects of the long term storage of High Level Nuclear Waste.

Sincerely yours,

A handwritten signature in cursive script, reading "Samaan G. Ladkany".

Samaan G. Ladkany, Ph.D., P.E.
Professor of Civil Engineering
Director of DOE Waste Package Project

SGL/cs
Enclosures
cc: Office of Research and Grants, UNLV

Waste Package Project
Department of Civil and Environmental Engineering
4505 Maryland Parkway • Box 454041 • Las Vegas, Nevada 89154-4041
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MASTER

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PUBLICATIONS BY THE DOE NUCLEAR WASTE PACKAGE
PROJECT FACULTY, STAFF AND STUDENTS

1. Bergman, D., "A Study of a Container For Long Term Storage of High-Level Waste Using Finite Elements", M.S.E. Thesis, Department of Mechanical Engineering, University of Nevada, Las Vegas, Spring 1991, 72 pages.
2. Cardle, J., "Overview of Simplified Thermal Hydraulic Code", Performance Assessment Flow and Transport Modeling Workshop, May 5-6, 1992.
3. Cardle, J., "A Galerkin Method For The Convection - Diffusion Equation Using Asymmetric Weighting Functions", High-Level Radioactive Waste Management Conference & Exposition IV, April 1993.
4. Culbreth, W.G., Chagari, A., "Labeling of the Spent Fuel Waste Package", Proceedings of the 3rd International High-Level Nuclear Waste Conference, Las Vegas, March 1992.
5. Culbreth, W.G., Zielinski, P.R., "The Importance of Criticality in the Design of the Spent Fuel Waste Container", Scientific Basis for Nuclear Waste Management XVI, Materials Research Society, pp. 73-78, vol 294, 1993.
6. Culbreth, W. G., and Zielinski, P., "Analysis of the Criticality of a Spent Fuel Waste Package using Mathcad for Windows," Ninth ICMCM, Berkeley, CA, July 1993.
7. Culbreth, W. G., "Computational Heat Transfer Studies of the Proposed Nuclear Waste Repository," Ninth ICMCM, Berkeley, CA, July 1993.
8. Culbreth, W.G., and Zielinski, P.R., "The Effect of Fuel Burnup and Dispersed Water Intrusion on the Criticality of Spent High Level Nuclear Fuel in a Geologic Repository," 1993 Materials Research Society Fall Meeting, V, Boston, MA, November 30.
9. Culbreth, W.G., Bhagi, B.K., Kanjerla, A., "Review of Advanced Techniques For Waste Canister Labeling", High-Level Radioactive Waste Management Conference, May 1994.
10. Culbreth, W.G., Pattisam, S., "Experimental Heat Transfer and Fluid Flow Over Drift-Emplaced Canisters", High-Level Radioactive Waste Management Conference, May 1994.
11. Culbreth, W.G., Zielinski, P., "Long-Term Effects of Neutron Absorber and Fuel Matrix Corrosion on Criticality", High-Level Radioactive Waste Management Conference, May 1994.

12. Zielinski, P., and Culbreth, W. G, "Calculation of k_{eff} For Plutonium in High-Level Waste Packages", High-Level Radioactive Waste Management Conference, May 1994.
13. Culbreth, W.G., Ventresca, "Experimental Results: Drift Apex Wall Temperature Distribution", June 1995.
14. Culbreth, W.G., Ventresca, " Preliminary Results of Natural Convection Tests, June 1995.
15. James, D.E., Skaggs, R.L., Mohansingh, S., "Multi-Barrier Borehole Canister Designs For A Tuff Repository", High-Level Radioactive Waste Management, May 1994.
16. Joseph, M., "Heat Pipe Effect in Porous Medium", M.S. Thesis, Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, December 1992, 84 pages.
17. Kandalaft-Ladkany, N., "Design Management and Stress Analysis of a Circular Rock Tunnel For Storage of Spent Nuclear Fuel", M.S.E. Thesis, Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, Spring 1991.
18. Kandalaft-Ladkany, N., Wyman, R.V., "Design Management and Stress Analysis of a Circular Rock Tunnel For Storage of Spent Nuclear Fuel", Proceedings of High-Level Radioactive Waste Management, 1992, ANS and ASCE, pp. 2260-2266.
19. Kandalaft-Ladkany, N., Wyman, R.V., Ladkany, S.G., "Investigation in 3-D of Stress Distribution in a Circular Tunnel and Vertical Emplacement Holes Due to Thermal and Overburden Loading in Tuff", Proceedings of High-Level Radioactive Waste Management, 1993, ANS and ASCE, pp. 893-899.
20. Kandalaft-Ladkany, N., Wyman, R.V., "Investigation of Stress In a Circular Tunnel Due To Overburden and Thermal Loading of Horizontally Placed 21 PWR Multi Purpose Canisters", High-Level Radioactive Waste Management, 1994, ANS and ASCE.
21. Kandalaft-Ladkany, N., Wyman, R.V., "Thermal Stress in Backfilled Circular Tunnell Due to 21 PWR MPC's", High-Radioactive Waste Management, 1995.
22. Kniss, B., M.S.E. Thesis, "A Study of a Container For Long Term Storage of High-Level Nuclear Waste Using Finite Elements", Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, June 1991.
23. Ladkany, S.G., Kniss, B.R., "Critical Stresses in Pintle, Weldment, and Tophead of Nuclear Waste Container", Proceedings of High-Level Radioactive Waste Management, 1993, ANS and ASCE, pp. 1253-1260.

24. Ladkany, S.G., Gan, P., Rajagopalan, R., "Critical Stresses in Nuclear Waste Container Under Normal Handling Conditions", Proceedings of High-Level Radioactive Waste Management, 1993, ANS and ASCE, pp. 905-912.
25. Ladkany, S.G., Rajagopalan, R., "On the Structural Stability of Large Steel Nuclear Waste Containers", DOE Waste Package Project, University of Nevada, Las Vegas, Structural Stability Research Council, April 1993.
26. Ladkany, S.G., Rajagopalan, R., "Structural Performance of a Multipurpose Canister Shell For HLNW Under Normal Handling Conditions", High-Level Radioactive Waste Management, 1994, ANS and ASCE.
27. Ladkany, S.G., Huang, Y., "Investigation of Faulted Tunnel Models By Combined Photoelasticity and Finite Element Analysis", High-Level Radioactive Waste Management, 1994 ANS and ASCE.
28. Ladkany, S.G., Rajagopalan, R., "Effects of Potential drop on the structural stability of long thin nuclear pin and guide tube", Proceeding of the Structural Stability Research Council Annual Technical Session, June 1994, Bethlehem, PA
29. Ladkany, S.G., Huang, Y., "Stresses in Faulted Tunnel Models by Photoelasticity and Adaptive Finite Element", High-Level Radioactive Waste Management, 1995.
30. Ladkany, S.G., Rajagopalan, R., "Failure of MPC Overpack and Inner Container Under Corrosion and Mechanical Stresses in a Backfilled Drift", High-Level Radioactive Waste Management, 1995.
31. Ladkany, S.G., Channaraypatna, S.S., Trabia, M.T., "Experimental Verification of Hydraulic Robot for Remote Handling of HLNW" High-Level Radioactive Waste Management, 1995.
32. Moujaes, S., Lei, Y., "Heat Transfer in Vertical Concentric Cylinders in a High-Level Nuclear Waste Repository", High-Level Radioactive Waste Management Conference & Exposition IV, April 1993.
33. Moujaes, S., Bhargava, A., "Simulation of Heat Transfer Around a Canister Placed Horizontally In a Drift", High-Level Radioactive Waste Management Conference & Exposition, May 1994.
34. Moujaes, S., Lei, Y., "Heat Transfer Effects in Vertically Emplaced High-Level Nuclear Waste Container", High-Level Radioactive Waste Management Conference & Exposition, May 1994.

35. Musukula, V. R., M.S.E. Thesis, "Dynamic Analysis of an Overhead Crane Carrying a Canister by Finite Element Method", Department of Mechanical Engineering, University of Nevada, Las Vegas, May 1993.
36. Skaggs, R., Moujaes, S., Lei, Y., V.V. Gopal, "Thermal and Metallurgical Considerations of a Novel Design for the Nuclear Waste Container", Proceeding Nuclear Waste Packaging Focus 91, ANS, ASCE publication, July 1991, pp. 153-159 (1992).
37. Trabia, Mohamed B., Kiley, M., "ASME Pressure Vessel Code Application to Nuclear Waste Container Design", Proceedings of the Third International Conference on High-Level Radioactive Waste Management, Las Vegas, NV, April 12-16, 1992, American Nuclear Society, Inc. LaGrange Park, IL, pp. 1244-1252.
38. Trabia, M., "A Continuous Force Model For Elastic-Plastic Impact of Solids", 1993 ASME Advances in Design Automation Conference, pp. 687-692, DE-Vol. 65-1.
39. Veeramachaneni, V., M.S.E. Thesis, "Analysis and Evaluation of Three Promising Nuclear Waste Disposal Option", Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, May 1993.
40. Wyman, R., 1990, "Ventilation and Construction Considerations for a High Level Nuclear Waste Repository" in High-Level Radioactive Waste Management, Vol. 2, pp 1414-1417, ASCE Conference in Las Vegas, NV.
41. Zielinski, P., M.S. Thesis, "Parametric Studies on the Criticality of Radioactive Spent Fuel Canisters in a Tuff Repository", Department of Civil and Environmental Engineering, UNLV, April 1993, 125 pages.

DOE WASTE PACKAGE PROJECT
STAFF DIRECTORY

Project Office, TBE Room B120
Graduate Assistant's Office, TBE Room B107

Administration, Faculty and Staff

Samaan G. Ladkany	Director, Co-Project Investigator Professor of Civil Engineering TBE Room B-114; 895-3438/3701
William Culbreth	Associate Director, Co-Project Investigator Associate Professor of Civil Engineering TBE Room B-136; 895-3426/4153
Richard V. Wyman	Professor Emeritus of Civil Engineering TBE Room A-218; 895-3940/3701
Cynthia Shelly	Administrative Aide TBE Room B-120; 895-4328; FAX Number 895-3936

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Samir Moujaes	Associate Professor of Mechanical Engineering TBE Room B-134; 895-3265
Robert Skaggs	Professor of Mechanical Engineering TBE Room B-112; 895-3139
Mohamed Trabia	Associate Professor of Mechanical Engineering TBE Room B-124; 895-0957
Moses Karakouzian	Associate Professor of Civil Engineering TBE Room B-132; 895-0959

Project Associates

Nadia Ladkany, M.S.C.E. Project Associate
TBE B-164
(On leave since 07/01/95)
James Ventresca Ph. D Project Associate
TBE B-136; 895-3426

Graduate Students

Rajkumar Rajogopalan, GA Ph.D Candidate	Srividya Thirumali, TA (State Supported) Ph.D Candidate
Yuping Huang, GA	Qun Wang. GA
Paige Zelinski, US DOE Ph. D Candidate	

Recent Graduates of the Project

Sarath Abayaweera	Akshay Bhargava
Shashidhar Channarayapatna	

**EQUIPMENT PURCHASED, SUPPLIES,
REGISTRATION FEES, AND MISCELLANEOUS EXPENSES**

July 1, 1995 to September 30, 1995

Source	Price
Supplies, Software & Miscellaneous Expenses	
supplies	\$1,799.40
software	\$ 0.00
miscellnous	\$ 39.18
Total for Supplies, Software & Misc. Expenses	\$1,838.58
 Total for Conference Registration Fees	 \$ 0.00

TOTAL PURCHASES 07/01/95 to 09/30/95

QUARTERLY PROGRESS REPORT ON THE WASTE PACKAGE PROJECT

July 1, 1995 to September 30, 1995

SUBMITTED TO THE U.S. DEPARTMENT OF ENERGY UNDER THE UNLV/DOE

COOPERATIVE AGREEMENT

BY SAMAAAN G. LADKANY, PH.D., P.E.

PROFESSOR OF ENGINEERING AND PROJECT DIRECTOR

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**Task A.1 --- Overview and Progress of Waste Package Project and
Container Design**

Dr. Samaan G. Ladkany, Ph.D., P.E.

Project Director, DOE Waste Package Project

Quarterly Report

July 1, 1995 to September 30, 1995

A.1.1 Research Activities

Our Nuclear Waste Package Program recieved a fifth year grant of \$110,000 under the DOE/UNLV Cooperative Agreement, to carry the Nuclear Waste Package Project between August 18, 1994 to August 31, 1995, the deadline was extended by the DOE until January 31, 1996.

Considering that our project's research activities in the past five years have spanned all the near field aspects of High Level Nuclear Waste storage in geologic formations, and that eight faculty and over 20 graduate students have been trained in this area of research, we are hoping that parts of our project activities would be continued under the new format being negotiated between UNLV and the DOE.

Our normal research activities continued in some of the research areas as specified in our last proposal submitted under the DOE/UNLV cooperative agreement. A copy of our updated staff and student directory is enclosed in this report. Our research activities have spanned, multidisciplinary areas, which are:

- a) Structural and stress analysis of the container including nonlinear yield and damage assessment and structural stability studies of the multi purpose container (MPC).
- b) Nuclear fission criticality studies in the canisters.
- c) Heat transfer studies of the waste canisters and in the adjacent rock drifts.
- d) Characterization of a Faulted Rock Tunnel Model Using Photoelastic and Finite Element Studies.
- e) Experimental Investigation of a Three link Steel robot for potential remote handling of High Level Nuclear Waste

A.1.2.1 Conferences

Our project staff did not attend any conferences this quarter related to the Yucca Mountain project.

A.1.2.2 Meetings

Drs. Ladkany and Culbreth Held discussions with DOE/TRW/BWFC/LLNL Staff, for the exchange of data and research ideas between the two groups. Several preliminary proposal were delivered to Drs Bhattacharyia, Stanley and Liginin. Some of these proposals received preliminary approval and are awaiting the activation of the new fiscal YMP/ DOE budget.

A.1.3 Purchases

Supplies were purchased to support our ongoing research activities. Supplies, software, and miscellaneous expenses totaled \$1,799.40. A list of equipment purchases and other expenditures is included with this report.

A.1.4 Progress of Research

Our research activities continue in most of the areas specified in work statement covering the period of August 18, 1994 to August 31, 1995. Details of progress in the various research areas are included under the appropriate sections of this report.

A final project report with details of progress in the research area specified will be presented in January 1996.

A.1.5 Conclusions

Our project staff have been very active in their professional and research activities concerning the long term storage of spent high level nuclear fuel. Our research activities will continue until the end of the UNLV/DOE cooperative agreement in January 1996.

Task A.2.1---Nuclear Waste Container Design Considerations

Dr. William Culbreth

James Ventresca

Task A.2.1 -- Waste Container Design Considerations

Subtask: Experimental Drift Model

Faculty Researcher: Dr. William Culbreth

Title: Associate Professor of Civil Engineering
Associates: Dr. James Ventresca
Assistants: C. Lawson
L. Wong

During the last quarter of funding for this work, we continued a series of experiments in the experimental drift facility at UNLV. Several journal and conference papers are in progress, including:

- "Experimental Heat Transfer from Cylindrical Heat Sources in an Eccentric Annulus"
- "Local Heat Transfer and Fluid Flow near the Surface of Cylindrical Heat Sources in a Duct"
- "Distribution of Temperature along the Walls of a Long Cylindrical Drift with an Array of Cylindrical Heat Sources"
- "Laser-Induced Transient Heating of Rock Wall Surfaces to Assess Thermal Properties"
- "Average Heat Transfer Coefficients for Waste Packages"

Although the funding for this project is ending, a proposal titled: "Experimental Heat Transfer and Fluid Flow Over Drift-Emplaced Multipurpose Canisters," was submitted to the U.S. Department of Energy for continuation of the work in a more realistic geometry. The proposal was discussed with Suresh Lingenini at Intera, Inc. A copy of the proposal is attached to this research summary.

The work done by Laura Wong on this project will be presented in a master's thesis in January. A copy will be submitted to the project office. The results of her research will be included in the publications listed above.

Task A.2.1 -- Waste Container Design Considerations

Subtask: Criticality Analysis

Faculty Researcher: Dr. William Culbreth

Title: Associate Professor of Civil Engineering

Researcher: Dr. J. Ventresca

Student Assistants: L. Steeps

Criticality Analysis
of Proposed Spent Fuel Container Designs

Work in this area consisted of the preparation of articles for publication. The project is continuing under a new proposal funded by the U.S. Department of Energy titled: "Assessment of Nuclear Criticality in Waste Package Design".

PROPOSAL SUMMARY

Project Title: Experimental Heat Transfer and Fluid Flow Over
Drift-Emplaced Multipurpose Canisters

Submitted To: U.S. Department of Energy, Yucca Mountain Project Office
Attn: Bruce Stanley

Suresh Lingineni
Intera, Inc.

Submitted By: William Culbreth
James Ventresca
Department of Civil and Environmental Engineering
University of Nevada, Las Vegas

Project Duration: 1 October 1995 - 30 September 1996

Funds Requested: \$73,864

A. Summary

Proposed Research

In the proposed work, the UNLV Experimental Drift Model Facility will be used to obtain heat transfer and fluid flow data in support of the thermal studies required for the Yucca Mountain site. This data will be used to compute local heat transfer coefficients for model waste packages and the drift wall, to measure head losses in drifts due to the obstruction created by the waste packages and the pedestal, and to measure the temperature distributions and moisture levels in the near field surrounding the drift, in the invert, and about the waste package. These studies will include the effects of natural, mixed, and forced convection cooling of the repository drifts. The measured temperature distributions will also be used to verify computer predictions of the thermal performance of the repository.

Background of the Proposed Project

Natural and forced convection as well as radiation heat transfer will remove decay heat from

the spent fuel canisters used for the permanent storage of waste in an underground repository. While computational models are available to estimate the rate of heat loss from the packages and the resistance to flow presented by their obstruction to the flow, experimental data is necessary to provide accurate data and to verify numerical results. Experimental analyses are also needed to identify heat transfer problems that may not be observable in existing numerical models and to ensure a complete view of the heat transfer mechanisms.

Accurate data on heat removal rates from spent fuel packages are necessary to the proper design of the thermal loading scheme for the repository. The DOE has identified several key assumptions regarding thermal loading¹ and the proposed work will assist in validating these key assumptions.

Background of the Researchers

The University of Nevada, Las Vegas has accumulated five years of experience in the design of the proposed nuclear repository through the DOE/UNLV Waste Package Project. This project has received over \$1,200,000 in funding from the DOE over 5 years through a cooperative agreement.

During this time, Dr. Culbreth, Dr. Ventresca, and graduate students have experimentally and numerically studied the heat transfer and fluid flow over models of horizontally emplaced canisters inside drifts, and have obtained heat transfer coefficients, velocity profiles, pressure gradients and flow visualizations. The results of this work have been presented at technical conferences and published in their proceedings^{2,3,4}. Vitae for the two project principal investigators are included at the end of this proposal.

Available Facilities

Figure 1: Experimental Setup in the UNLV Experimental Drift Model Facility for Thermofluid Studies

The laboratory facilities will be used that have been developed over the past five years, including two experimental setups designed to study the heat transfer and fluid flow about drift-emplaced MPC's. These facilities were developed as a result of the DOE/UNLV Waste Package Project funded by the DOE. Figure 1 shows a side view of the **UNLV Experimental Drift Model Facility**. This device has a large fan attached to the drift model to simulate ventilated conditions. Figure 2 schematically shows a similar setup used to model natural convection about waste canisters using water as the medium. (Water allows higher Rayleigh numbers with lower temperature differences than air). Both facilities are fully instrumented and data obtained from their use have been published^{3,4}.

Additional equipment available to the project investigators include a hot wire anemometer, a 2-component laser Doppler velocimeter, a computer-based data acquisition system, NIST-calibrated temperature standards, a micromanometer, thermocouple calibration equipment, and a three-component traverse with computer controller.

Figure 2: Natural Convection Test Facility

B. Proposed Statement of Work

Goals and Objectives

The primary goal of the proposed work is to develop a body of experimental heat transfer and fluid flow data for the waste package and drift wall to be used in conjunction with numerical codes for thermal loading studies of the repository. Our past research has provided results on **overall** convective heat transfer rates from eccentrically-placed waste packages. Significant variations in drift wall and waste package temperature have been observed during our experiments. We would like to continue our work by measuring and documenting **local** heat transfer rates from the waste packages and to the drift wall. We also propose to use our test facilities to measure the effect of the drift invert on temperature distributions and head losses, the effect of pedestal placement and height, and waste package placement on the temperature distribution and flow within the drift. The results will be presented in the form of heat transfer coefficients and loss coefficients as functions of flowrate, heat output, and geometry.

The temperature distributions in the drift are very dependent upon the boundary conditions imposed by the temperature distribution in the drift wall. The drift wall is composed of porous tuff with entrained water. Thus, the second goal of the proposed work is to experimentally model the near field boundary conditions. This will be accomplished by constructing a new experimental facility to better match the boundary conditions expected in the near field of the repository. This **Nearfield Thermofluid Facility** will use a circular drift with model waste packages similar to the experimental setup currently in the laboratory. A porous media will be added to surround the drift to better model the boundary conditions expected in the repository. Our previous experiments have used either isothermal or insulated boundaries. An array of thermocouples and moisture sensors will be placed in the porous media to monitor the unsteady distribution of heat and water. Thermocouples will be placed on the drift wall and waste package surface as in our previous experiments to determine local Nusselt numbers and temperature

distributions. The drift will be ventilated using an existing fan, pitot tube traverse, and flow management section. Ventilation will allow data to be acquired for forced, mixed, and natural convection conditions. As in the previous experiments, conduction, convection, and radiation heat transfer rates will be monitored to account for heat removal from the system.

The final data analysis will result in Nusselt numbers from the waste package surface and the drift wall based on a boundary composed of a saturated porous media. Drift head losses due to waste package placement and invert height will be measured. Dynamic temperature and moisture data will be acquired within the porous media in the near field for comparison with the predicted results from TOUGH or V-TOUGH. Upon consultation with the contractors, the accumulated heat transfer and fluid flow results will be reported in a form useful to researchers conducting thermal loading studies of the proposed repository.

C. Tasks

The proposed studies will include the following tasks:

1. Update the current literature review of heat transfer and fluid flow near the waste package and drift wall surfaces.
2. Conduct a series of experiments to analyze local heat transfer coefficients and fluid flow about drift-emplaced MPC's using the current drift model facility as outlined in part B.
3. Compare the experimental measurements with numerical results of the heat transfer and fluid flow about drift-emplaced MPC's.
4. Design, construct, test, and acquire data from a new nearfield thermofluid facility.
5. Summarize past and current thermofluid work on similar waste package/drift geometries in a report to the DOE and contractors. This includes an assessment of Nusselt numbers where $Nu = Nu(Re, Ra, Pr, \text{geometry})$.

D. Deliverables

The project will generate technical assessments of proposed waste package and repository design. These will be reported in scholarly publications and in a technical report to the DOE at the end of the project year. The time schedule for the deliverables is as follows:

1. Quarterly report at three month intervals.
2. Annual technical report to include journal articles, research progress, computer models,

- graduate student thesis and dissertations, waste package and drift design assessments. The outcome of each assessment will be outlined in the annual report.
3. Reviews of documents related to thermal aspects of the repository design will be provided to the DOE.

E. Schedule

The proposed work will be completed during the period extending from 1 August 1995 to 31 July 1996.

F. Budget

	<u>months</u>	<u>\$/mo.</u>	<u>total</u>
A. Personnel			
1. Professional Staff			
a. Dr. William Culbreth	1	\$6,586	\$6,586
b. Dr. James Ventresca	4	\$4,500	\$18,000
Subtotal:	5		\$24,586
2. Graduate Students			
a. # of students:	1		
b. # acad. yr. mo	11	\$1,100	\$12,100
Subtotal:			\$12,100
Subtotal, Salaries:			\$36,686
B. Fringe Benefits			
1. Benefits, Faculty (2.87%):	\$24,586	=	\$706
2. Students (1.20%):	\$12,100	=	\$145
3. Group Ins.			
\$2,718/yr. for months:	5	=	\$1,133
Subtotal, Fringe Benefits:			\$1,983
C. Travel			
1. Basis of Estimate:			
a. Cost per out-of-state trip:		\$1,000	
b. Number of out-of-state trips:		2	\$2,000
c. Conference Registration			\$500
Subtotal, Travel:			\$2,500
D. Equipment	# units	\$/unit	
1. Experimental Facility for Near Field Thermofluid Measurements			\$4,500
2. Data Acquisition Board, 200kHz			\$1,100
3. Micromanometer			\$350
4. Hot Wire Probes and Signal Cond.			\$2,500
5. Switch Boxes, Thermocouples			\$320
6. Tubing, thermocouples, plexiglas, etc.			\$2,000
Subtotal, Equipment:			\$10,770
E. Supplies & Maintenance			
1. Computer supplies			\$250
2. Publishing costs			\$200
Subtotal, Supplies:			\$450
F. Other Direct Costs			
1. Software Licenses			\$1,000
2. Grad. Student Tuition			\$700
a. Cost per student:	\$700		
b. Number of students:	1		
Subtotal, Other Costs:			\$1,700
G. Total Direct Costs			
1. Total of Sections A-H:			\$54,089
H. Indirect Costs			
1. Total of all except equip, tuition			\$42,619
2. 46.4% of all except Equipment, Tuition:			\$19,775
I. Total Project Costs			\$73,864

G. References

1. DOE #B000000000-01717-4600-00032 Rev. 00A, "Controlled Design Assumption Document (CDA)", 1995.

Relevant Key Assumptions

- No. 7 -- No repackaging of the MPC's for purposes of heat load tailoring.
 - No. 10 -- Integrated rail transport will be used for subsurface transport of waste packages.
 - No. 11 -- Waste packages will be emplaced in-drift, in a horizontal mode.
 - No. 19 -- Develop a surface/subsurface configuration that will accommodate thermal loading operations for both a primary, high thermal load (80-100 MTU/acre, 91-114 kW/acre) and an alternative, low thermal load (25-35 MTU/acre, 28-40 kW/acre).
Develop waste package/EBS designs to accommodate both primary and alternative thermal ranges as specified above.
 - No. 20 -- A preliminary repository operational thermal load design will be made by 2008 license application update.
 - No. 21 -- Performance confirmation areas will be designed for both low and high thermal loads.
 - No. 46 -- No backfill (packing material) will be used in the emplacement drifts.
2. Culbreth, W. G., "Computational Heat Transfer Studies of the Proposed Nuclear Waste Repository," Ninth ICMCM, Berkeley, CA, July 1993.
 3. Culbreth, W. G., Pattisam, S., Jones, M. J., "Experimental Heat Transfer and Fluid Flow over Drift-Emplaced Canisters," Proc. of the Fifth Annual International High-Level Radioactive Waste Management Conference, pp. 772-779, 1994.
 4. Culbreth, W. G., and Wang, Q., "Experimental Investigation of Natural Convection about Drift-Emplaced Waste Canisters," Proceedings of the International High-Level Radioactive Waste Management Conference, 1995.

Vitae for the Proposal Co-Investigators

Dr. William Culbreth

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**Task B.1.1---Structural Investigation of Multi Purpose Nuclear
Waste Package Canister (MPC)**

Dr. Samaan G. Ladkany, P.E.

Rajkumar Rajagopalan

Task B.1.1. Structural Analysis and Design of Waste Package Canister

Faculty Researcher: Dr. Samaan Ladkany

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B.1.1.1. Assessment of Damage to the MPC in a Dented Region

Research on the damage assessment to the MPC due to a dent continued during the summer of 1995. Decisions were made regarding the size of the mild steel pipes to be used in the experimental investigations based on the results obtained from the Finite Element Analysis which were discussed in the last Quarterly Report to the DOE. Mild steel pipes having a diameter of 12" and 8" and thicknesses of 0.1875" and 0.125" respectively were purchased. The type of strain gages to be used in the experiments was also selected, based on the maximum strains obtained from the results of the finite element analysis (FEA). A wedge type indenter will be used to create the dents in the pipes. In the FEA, [REDACTED] the mild steel pipe will be modeled using shell elements while the gap between the wedge and the mild steel pipes will be modeled using contact elements. A theoretical approach, based on energy principles to compare the FEA and experimental results is also under consideration.

B.1.1.2. Description of Actual Work

B.1.1.2.a. Experiments

The dimensions of the pipes purchased, and the matrix of testing are tabulated below:

Material	D (inches)	t (inches)	L (ft)	Central Loading # of Pipes	Loading Near Ends # of Pipes	Loading mode	Total #
Mild Steel	12.0	0.1875	3.0	2	2	Perpen- dicular	4
Mild Steel	12.0	0.1875	3.0	2	N/A	Parallel	2
Mild Steel	8.0	0.125	2.0	2	2	Perpen- dicular	4
Mild Steel	8.0	0.125	2.0	2	N/A	Parallel	2
Mild Steel	8.0	0.25	2.0	2	2	Perpen- dicular	4
Mild Steel	8.0	0.25	2.0	2	N/A	Parallel	2

The pipes have been chosen such that a D/t aspect ratio of 64 is maintained, which is the aspect ratio of the Multipurpose Canister. Also an aspect ratio of L/D equal to 3 is maintained which again is the aspect ratio of the MPC. Since the experiments involve denting the pipes, thus the deformation of the pipe is large in the plastic zone, special strain gages which are capable of handling large strains in the order of 10% are necessary. Therefore high elongation strain gages have been purchased.

Specimens have been cut off from the pipe in the longitudinal direction (along the axis of the pipe). These specimens are used to establish the material properties of the mild steel. A tension test is performed in the MTS machine in our laboratory to determine the stress-strain characteristics of the mild steel. The material properties are used in the Finite Element Analysis to duplicate the properties in the finite element model. At least three specimens are tested in each category of the pipes. The material properties obtained from the tensile test in the MTS machine are compared to those furnished by the supplier. The performance of the high elongation strain gages are also evaluated in the process.

B.1.1.2.b. Finite Element Analysis

Studies have been going on in developing a model of the pipe and the wedge and in including contact elements to model the gap between the pipe and the wedge. Some of the preliminary finite element analysis results were summarized in the previous Quarterly Report. The analyses provided information on selecting the diameter of the pipes for laboratory testing. The initial study was based on analyzing a 16" diameter pipe with a scaling ratio of four with respect to the MPC. The analysis proved that in order to dent the pipe to a depth of 0.1D, ('D' is the diameter of the pipe) the load required would be more than the capacity of the MTS machine. This preliminary analysis dictated the use of a scaling ratio of five or less. In the literature survey, a scaling ratio of up to five has been acceptable. In order to create a desired dent depth using FEA, the load has to be increased gradually and then after denting, the loading has to be reduced to zero. A dent depth equal to 0.0025D is created in a 12" diameter pipe with 0.1875" thickness. The boundary conditions are shown in figure 1. The loading curve is shown in figure 2. A distributed load equivalent to 5520 lbf is applied at the center of the pipe. After a desired dent depth of 0.0025D is reached the load is taken back to zero as shown in the loading curve. A constant load is applied at the turning point to achieve stability in the analysis. The Von Mises stress plot for the peak load is shown in figure 3. The maximum Von Mises stress is 39600 psi which is slightly above yield and the material at the center has reached the plastic stage. The displacement at the central node is shown in figure 4. From the figure, it can be seen that the difference between the initial and final position of the central node is 0.0325" which is equivalent to 0.0025D.

REFERENCES

1. Cook, R.D., Malkus, D.S., and Plesha, M.E., "Concepts and Applications of Finite Element Analysis", Third Edition, John Wiley and Sons, New York, (1989).
2. COSMOS/M Finite Element Analysis System Manual, Structural Research and Analysis

Corporation, Los Angeles, (1994).

3. Timoshenko, S.P. and Krieger, S.W., "Theory of Plates and Shells", Second Edition, Mc-Graw Hill, New York, (1959).

Figure 1 Half model of the MPC showing the boundary conditions

Figure 2 The loading and unloading pattern input in the finite element analysis

NL1n STRESS Step:16 =0.7

Figure 3 Von Mises stress pattern in the half model of MPC corresponding to the peak load

Figure 4 Displacement at the central node at various time steps

**Task B.2.1---Investigation of Post Closure Stress in a Backfill
Circular Tunnel Due to Horizontally Placed 21PWR Multi-Purpose
Canisters**

Dr. Richard Wyman, P.E.

Nadia Kandalaft-Ladkany, MSCE

**Design Requirements of Rock Tunnel Drift for Long Term Storage of
High Level Waste**

Work in this task was not funded in the period of July 1 to September 30, 1995. Newly proposed work if funded by the U.S. DOE will investigate the stresses and displacement in the rock tunnel walls and the pressure exerted on the canisters by the proposed engineered backfill materials. Stresses at critical surfaces formed by the intersection of the drift, and access tunnels will be investigated using the finite element analysis. Temperature profile and geometry will be provided by the M & O, YMP staff.

**Task B.2.2 - Investigation of Faulted Tunnel Models by Combined
Photoelasticity and Finite Element Analysis**

Dr. Samaan G. Ladkany, P.E.

Yuping Huang

Task B.2.2. Investigation of Faulted Tunnel Models by Combined Photoelasticity and Finite Element Analysis

Faculty Researcher: Dr. Samaan Ladkany, Ph.D, PE,

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B.2.2.1. Scope of the Research

Research work on a Master's thesis titled, "Stress Study in Faulted Tunnel Models by Combined Photoelastic (PhE) Measurements and Finite Element (FE) Analysis" continued during July, August and September of 1995.

In the PhE measurements, a telemicroscope, combined with a monochromator were used. Principal stresses measured at the tip points of the crack by PhE method using monochromatic lense are much higher (about 50% higher) than those previously measured from an isochromatic fringe pattern. The principal stresses, $P1$ and $P2$, and the related stress concentration factor, K 's, when measured by both the PhE and the FE methods, are within 15% of each other.

B.2.2.2. Stress Study in Faulted Tunnel Models by Combined Photoelastic Measurements and Finite Element Analysis

The aim of this part of the Nuclear Waste Package Project research is to investigate the stress patterns due to a fault penetrating a tunnel system, such as the Ghost Dance¹ Fault at Yucca Mountain, and to study the effect of the fault on the stability of drifts in a proposed High Level Nuclear Waste Repository^{2,3}.

In our pervious paper^{4,5} presented at the HLNW Conferences held in Las Vegas in the springs of 1994 and 1995, stress concentration factors at specified locations in the models were obtained using the PhE measurements and by the FE method. The effect of short saw cuts representing minor failures in the tunnel along a fault line was analyzed. The adaptive mesh refinement technique (H-method) is being used in the FE modeling to achieve a close correlation between results from the PhE testing and the numerical FE Method.

In our experiments, both the plexiglass photoelastic model and the finite element model represent a plate having two adjacent parallel square openings (tunnels) with rounded corner and one circular opening (tunnel). The circular opening, with a diameter that equals to the side length of the square, is placed symmetrically under the two square openings, at a clear distance of about 80% of the square side length. The actual fault in the rock is depicted as a saw cut in the models, which has the same angle of incidence with the openings as that of the Ghost Dance Fault. The crack in the scaled tunnel model, which is produced by successive saw cuts, follows a line that crosses the corner of the right-hand side square opening and passes through the circular opening, close to its center.

In order to investigate the influence of the faults on the tunnel under different conditions, the saw cuts, beginning at the lower corner of the right-hand side square opening, are made to grow

progressively along the line. At each step, under each condition, the principal stress patterns are measured by both the PhE and the FE method, and the stress concentration factors, K , are calculated at predetermined points, such as at the corners and sides of the openings and at the tip of the progressing saw cut. Results from both the PhE models and the FE models are compared to each other at each step of the analysis.

The Adaptive H-method is used in the FE modeling. The H-method progressively improves the mesh by refining it, especially at the corners of the opening and at the tips of the crack. As the Adaptive H-method tends to refine the mesh, the sizes of elements around the tips become smaller than the size of the saw cut. P 's and K 's slowly increase with the decrease in the specified error tolerance. As the element size decreases, the mesh becomes somewhat insensitive to the flatness or roundness of the fault tip in the model.

Considering that the exact fringe order at the tip of the saw cut is difficult to measure, even with a telemicroscope when using a diffused light system and an isochromatic fringe pattern, a monochromatic adaptor is attached to the telemicroscope. Through the monochromator, a pattern of black fringes, instead of a diffused color pattern, clearly appear on the plexiglass model and a high fringe order can be counted.

By using a 20% error tolerance in the adaptive H-method, the iterative FE scheme gives results similar to those obtained from the PhE measurements.

The following table and figures illustrate the results obtained by the adaptive FE models and compares them to the monochromatic measurements using a monochromator and a telemicroscope.

REFERENCES

1. R.W. Elayer, "Private Communications," Morrison Knudsen Corp., Management and Operation Contractors to the US DOE, Las Vegas, Nevada, (1993).
2. N. Kandalaft-Ladkany and R.V. Wyman, "Design Management and Stress Analysis of a Circular Rock Tunnel and Emplacement Holes for Storage of Spent Nuclear Fuel," High Level Radioactive Waste Management, Proceedings of the 3rd International Conference, Las Vegas, Nevada, (1992).
3. N. Kandalaft-Ladkany, R.V. Wyman and S.G. Ladkany, "Investigation in 3-D of Stress Distribution in a Circular Tunnel and Vertical Emplacement Holes due to Thermal and Overburden Loading in Tuff," High Level Radioactive Waste Management, Proceedings of the 4th International Conference, Las Vegas, Nevada, (1993).
4. Samaan G. Ladkany and Yuping Huang, "Investigation of Faulted Tunnel Models by Combined Photoelasticity and Finite Element Analysis," High Level Radioactive Waste Management, Proceedings of the 5th International Conference, Las Vegas, Nevada, (1994).
5. Samaan G. Ladkany and Yuping Huang, "Stresses in Faulted Tunnel Models by Photoelasticity and Adaptive Finite Element," High Level Radioactive Waste Management, Proceedings of the 6th International Conference, Las Vegas, Nevada, (1995).

		Step Two	Step Three	Step Four	Step Five	Step Six
Photoelastic Method (PE)	P (psi)	-108.6	-110.5	-115.2	-120.0	-3429
	K	1.0	1.0	1.1	1.1	31.6
Finite Element Method (FE)	P (psi)	-102.5	-111.6	-112.2	-122.0	-3800
	K	1.0	1.1	1.1	1.2	37.1

Table 1 Comparison of the Principal Stresses, P , and the Calculated Relative Stress Concentration Factor, K , from both PE and FE Methods at Point 6.

Figure 1 Stress Concentration Factors, K , of Step Two to Step Six from both PE and FE Methods at Point 6.

Figure 2 **Dimension of the Photoelastic Plexiglass Model with a Thickness of 0.35 in..**

Figure 3 Adaptive Mesh Refinement Around the Lower Fault.

Figure 4 **Adaptive Mesh Refinement Around the Upper Fault.**

Figure 5 Principal Stress Pattern Around the Tip of the Upper Fault.