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DOE/NV/10872--T219

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July 20, 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 April 1, 1995 to June 30, 1995. The report summarizes our most recent research activities which are pertinent to the project.

Our project activities under the UNLV/DOE five year cooperative agreement will end September 1995, at which time a final report will be prepared.

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

Sincerely yours,

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

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LW

Waste Package Project
Department of Civil and Environmental Engineering
4505 Maryland Parkway • Box 454041 • Las Vegas, Nevada 89154-4041
(702) 895-4328 • FAX (702) 895-3936

MASTER

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Yuping Huang

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PROJECT FACULTY, STAFF AND STUDENTS

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2. Cardle, J., "Overview of Simplified Thermal Hydraulic Code", Performance Assessment Flow and Transport Modeling Workshop, May 5-6, 1992.
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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.
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13. Culbreth, W.G., Ventresca, "Experimental Results: Drift Apex Wall Temperature Distribution", June 1995.
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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

Adjunct Faculty

James Cardle	Associate Professor of Civil Engineering TBE Room B-128; 895-3941
David James	Assistant Professor of Civil Engineering TBE Room B-138; 895-1067
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

James Ventresca Ph. D Project Associate
TBE B-136; 895-3426

Graduate Assistants and Students

Rajkumar Rajagopalan (TA)
Ph.D Candidate

Srividya Thirumalai (TA)
Ph.D Candidate

Paige Zelinski, M.S.
Ph.D Candidate

Sarath Abayaweera

Akshay Bhargava

Shashidhar Channarayapatna

Yuping Huang

Qun Wang

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

April 1, 1995 to June 30, 1995

Source	Price
Supplies, Software & Miscellaneous Expenses	
supplies	\$ 432.00
software	\$ 981.89
miscellnous	\$ 0.00
Total for Supplies, Software & Misc. Expenses	\$ 1,417.24
 Total for Conference Registration Fees	 \$ 1,080.00

TOTAL PURCHASES 04/01/94 to 06/30/95

QUARTERLY PROGRESS REPORT ON THE WASTE PACKAGE PROJECT

April 1, 1995 to June 30, 1995

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

COOPERATIVE AGREEMENT

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

PROFESSOR OF ENGINEERING AND PROJECT DIRECTOR

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

April 1, 1995 to June 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.

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 our project funding would be restored to its previous level by the Fall of 1995.

Our normal research activities continued in most of the research areas specified and covered 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 dynamic behavior of the steel multi purpose container (MPC) under normal and accidental handling conditions.
- b) Nuclear fission criticality studies in the canisters.
- c) Investigation of novel canister design concepts and corrosion studies.
- d) Heat transfer studies of the waste canisters and in the adjacent rock drifts.

- e) Fluid flow in porous media and transport phenomena of radio nuclides in the near field rock.
- f) Studies of stresses and stability of the rock formations resulting from the thermal loading of the fuel elements and the multi tunnel concept being analyzed.
- g) Characterization of a Faulted Rock Tunnel Model Using Photoelastic and Finite Element Studies.
- h) Experimental Investigation of a Three link Steel robot for potential remote handling of High Level Nuclear Waste

A.1.2.1 Conferences

Dr. Ladkany attended the ASCE structures convention in Boston, MA in April, 1995. Drs. Culbreth and Ladkany along with our graduate students and staff attended the High Level Nuclear Waste Management Conference at the Mirage Hotel, in Las Vegas in May, 1995.

A.1.2.2 Meetings

Drs. Ladkany, Culbreth, and Project Associate, N. K. Ladkany, Held discussions with DOE/TRW/BWFC/LLNL Staff, for the exchange of data and research ideas between the two groups. Our project research is presently considering change assessment of MPC's and the stability of repository tunnels under conditions that emanate from post closure and backfill conditions.

A.1.3 Purchases

Hardware, software, and laboratory equipment were purchased to support our ongoing research activities. Office supplies, software, and miscellaneous expenses totaled \$1,417.24. A list of equipment purchases and other expenditures was enclosed earlier in this report

A.1.4 Progress of Research

Our research activities continue in all 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 in the appropriate sections of this report.

A final project report with details of progress in all the

research area specified will be presented in September 1995.

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 in all the areas covered in this report. Until the end of this five year project, in September, 1995.

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

Dr. William Culbreth

James Ventresca

The two attached reports document some of the results of the work completed by the team during the last quarter. An experimental facility constructed at UNLV has been extensively used to measure pressure drops and temperature distributions in and around waste canisters. The drift was ventilated and the velocity through the drift was monitored. A separate experimental setup was used to model natural convection flow over waste packages. The results include Nusselt numbers, temperature distributions, and pressure drops across individual waste packages. The attached reports include the variation of drift wall temperature and waste package surface temperature as a function of both circumferential and axial position. The results indicate that the highest temperature experienced on the drift wall is not over the center of the waste package, but near the two ends of the package. This is due to the natural convection flow that rises vertically along the flat ends of the package that rises towards the apex of the drift. Our measurements are being used to compute local heat transfer coefficients on the drift wall and waste package surfaces as functions of flowrate, package spacing, and package diameter. An existing finite difference program is under modification to report the expected axial and circumferential variation in temperature expected in the drift as a function of waste package heat output and ventilation conditions. The program will predict the drift wall apex temperature and the near field temperature some distance into the rock wall of the drift.

**Experimental Results:
Drift Apex Wall Temperature Distribution**

Dr. William G. Culbreth
Dr. James Ventresca

15 June 1995

UNLVWPP:61595.2

**Photograph of Natural Convective Flow
with Dye Injection about a Waste Package Model**

Experimental Results: Drift Apex Wall Temperature Distribution

Dr. William G. Culbreth
Dr. James Ventresca
University of Nevada, Las Vegas
Department of Civil and Environmental Engineering

15 June 1995

A. OVERVIEW

A series of experiments have been conducted in the **UNLV Repository Experimental Drift Model Facility** to conduct flow visualization studies and to measure heat transfer data over waste packages during natural, mixed, and forced air convection. The series of experiments were conducted during the spring of 1995 to determine the convection heat transfer rates from waste package models to the adjacent air and drift wall. This report summarizes some preliminary results where a dense matrix of thermocouples were located on the surface of the waste package and both the inner and outer surfaces of the drift wall. The results show a significant change in drift wall temperature in the axial direction due to the spacing between adjacent waste packages.

This report includes tables and graphs that document the change in drift wall temperature at the apex (uppermost portion) of the drift wall. Only natural convection data is included in this report for a total of 5 different Rayleigh numbers. Temperature distributions are presented as a function of drift axial position and Rayleigh number. Regression fits of the normalized temperature allow the results to be extrapolated from the laboratory model to the actual drift conditions.

B. EXPERIMENTAL SETUP

The experimental facility included a 10 meter long plexiglas model of a repository drift with scale-model waste packages. The system was instrumented with thermocouples, micromanometers, guard heaters, flow visualization equipment, and pitot tubes. A total of 64 thermocouples were used for these experiments. A more detailed description of the experimental setup and geometry is documented in UNLVWPP 61595.1.

B.1 Nondimensional Variables

The drift apex temperature is expressed in a non-dimensional form as:

$$u = \frac{T_{measured} - \bar{T}}{\bar{T}_{waste\ package} - \bar{T}_{drift\ wall}} \quad (1)$$

where,

$$\bar{T} = \frac{\bar{T}_{waste\ package} + \bar{T}_{drift\ wall}}{2} \quad (2)$$

The axial position in the drift is expressed in a nondimensional form as $x = x/S$ where S is the distance between the center of two adjacent waste packages. The center of a package corresponds to $x = 0$ and the point midway between two packages is at $x = 0.5$. The geometry is shown in figure 1.

Figure 1: Drift Geometry

C. RESULTS

C.1 Temperature Distributions

The apex of the drift wall was instrumented with 5 thermocouples. The measured temperatures are plotted in the figure on the following page as a function of the Rayleigh number of the flow. The normalized temperature is plotted versus the axial position, $x = x/S$, where $x = 0$ corresponds to the drift wall above the center of a waste package and $x = 0.5$ corresponds to the axial position midway between two adjacent waste packages. All data shows that the temperature above the edge of the waste package is significantly higher than the temperature midway between packages. The "hump" in the curve is due to the natural

Figure 2: Buoyant Jet Affect on Drift Wall

Apex Drift Wall Temperature

convection that occurs along the sidewall of the waste package as shown in figure 2. The axial variation along the drift apex is large. The difference between drift apex temperature and a weighted average varies by 45% when normalized by the difference in average waste package and drift wall temperatures.

C.1.1 Maximum Drift Wall Apex Temperature

The peak temperature on the drift wall occurred near the edge of the waste package, not over the middle as might be expected. For this experiment, this point corresponded to $x = 0.083$. The average value of the nondimensional temperature at this point was:

$$\bar{u}_{apex\ maximum} = -0.225 \pm 0.038 \quad (3)$$

More accurately, this value changed in a continuous fashion with the Rayleigh number of the flow:

$$u_{maximum}(Ra) = \frac{-0.387017 Ra}{191,066.6 + Ra} \quad (4)$$

This curve has a standard error (S.E.) of ± 0.011 , $R^2 = 0.933$, and the maximum error in u was 0.016.

C.1.2 Minimum Drift Wall Apex Temperature

This value occurred at the point midway between packages where $x = 0.5$. This minimum temperature did not vary in any predictable manner with temperature for our data.

$$\bar{u}_{apex\ minimum} = -0.6303 \pm 0.0219 \quad (5)$$

C.2 Curvefitted Equations

The apex temperature data was curvefitted by fitting data from each of the 5 runs with varying Rayleigh number. The graphical results of these individual curvefits are included in Appendix A. The resulting curvefits are accurate over the range of $0 \leq x = x/S \leq 0.5$, and, $154,000 \leq Ra \leq 420,000$. A contour plot of these individual curvefits is also included in the appendix.

The apex temperature varies with Rayleigh number and axial drift position according to:

$$u = u_0 + \beta(Ra) e^{-\gamma(Ra)[x - x_0]^2} \quad (6)$$

The coefficients are given by:

$$\beta(Ra) = \frac{0.3210836 Ra}{Ra - 4.108992 * 10^4} \quad (7)$$

$$\gamma(Ra) = 80.629332 - 9.5911513 * 10^{-5} Ra \quad (8)$$

The constants are: $u_0 = -0.6303$, $x_0 = 0.083$.

C.3 Accuracy of the Fit

The standard error in the nondimensional temperature, u , for the curvefit indicated in equation 6 was ± 0.0211 .

D. CONCLUSIONS

The experimental results cited in this report are preliminary. Further experiments are planned to attain higher Rayleigh numbers, to study the heat transfer and fluid flow in mixed convection over waste packages, and to more accurately match the geometry and boundary conditions expected in the repository.

This report documented the significant variation in drift wall apex temperature as a function of axial position and Rayleigh number.

Appendix A

Curvefits of Experimental Data

1. Ra = 154,000
2. Ra = 221,000
3. Ra = 225,000
4. Ra = 419,000
5. Ra = 420,000
6. Contour Plot of All Data

$r^2=0.975853843$ FitStdErr=0.0250152395 Fstat=2788.59763
 Rank 1 Eqn 8001 y=apex [UDF#1]
 $a=0.4417122$
 $b=-64.749276$

Jun 15, 1995 12:26 PM

71 Active X-Y Points

X: Mean: 0.25 SD: 0.1474282973

Y: Mean: -0.455797183 SD: 0.1598292213

File Source: RUN2TOP.DAT

Rank 1 Eqn 8001 y=apex [UDF#1]

r2	Coef Det	DF	Adj r2	Fit Std Err	F-value
0.9758538433	0.9751436623		0.0250152395	2788.5976276	

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.441712197	0.00676996	65.24590766	0.428207906	0.455216487
b	-64.7492759	2.905826112	-22.2825708	-70.5456349	-58.9529169

$r^2=0.975754984$ FitStdErr=0.0242858352 Fstat=2776.94572
 Rank 1 Eqn 8001 y=apex [UDF#1]
 $a=0.38996933$
 $b=-58.27552$

Jun 15, 1995 12:30 PM

71 Active X-Y Points

X: Mean: 0.25 SD: 0.1474282973
 Y: Mean: -0.483385915 SD: 0.1548521823

File Source: RUN6TOP.DAT

Rank 1 Eqn 8001 y=apex [UDF#1]

r2	Coef Det	DF	Adj r2	Fit Std Err	F-value
0.9757549838	0.9750418951		0.0242858352	2776.945715	

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.389969331	0.006405096	60.88422861	0.377192848	0.402745813
b	-58.2755196	2.817096046	-20.6863801	-63.8948855	-52.6561537

$r^2=0.985494173$ FitStdErr=0.0188525742 Fstat=4687.7092
 Rank 1 Eqn 8001 y=apex [UDF#1]
 $a=0.39072285$
 $b=-61.747627$

Jun 15,1995 12:30 PM

71 Active X-Y Points

X: Mean: 0.25 SD: 0.1474282973
 Y: Mean: -0.487532394 SD: 0.1554085609

File Source: RUN5TOP.DAT

Rank 1 Eqn 8001 y=apex [UDF#1]

r2	Coef Det	DF Adj	r2	Fit Std Err	F-value
0.9854941732	0.9850675312	0.0188525742		4687.709201	

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.390722849	0.005042895	77.47987518	0.3806636	0.400782098
b	-61.7476271	2.339549452	-26.3929566	-66.4144131	-57.0808412

Jun 15,1995 12:28 PM

71 Active X-Y Points

X: Mean: 0.25 SD: 0.1474282973

Y: Mean: -0.472443662 SD: 0.1297605583

File Source: RUN4TOP.DAT

Rank 1 Eqn 8001 y=apex [UDF#1]

r2	Coef Det	DF Adj r2	Fit Std Err	F-value
0.9819728496	0.9814426393	0.0175481251	3758.5600033	

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.346679579	0.004195918	82.62306501	0.338309826	0.355049331
b	-38.206679	1.36520913	-27.9859533	-40.9299123	-35.4834458

$r^2=0.983763017$ FitStdErr=0.0177392667 Fstat=4180.55784
 Rank 1 Eqn 8001 y=apex (UDF#1)
 $a=0.36826496$
 $b=-42.137445$

Jun 15, 1995 12:27 PM

71 Active X-Y Points

X: Mean: 0.25 SD: 0.1474282973
 Y: Mean: -0.46791831 SD: 0.138216062

File Source: RUN3TOP.DAT

Rank 1 Eqn 8001 y=apex [UDF#1]

r2	Coef Det	DF	Adj r2	Fit Std Err	F-value
0.9837630166	0.9832854583		0.0177392667	4180.5578375	

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.368264961	0.004335315	84.9453701	0.359617147	0.376912775
b	-42.1374449	1.466582181	-28.7317311	-45.0628907	-39.2119991

Normalized Temperature on Drift Apex

Preliminary Results of Natural Convection Tests

**Dr. William G. Culbreth
Dr. James Ventresca**

9 June 1995

UNLWPP:61595.1

**Photograph of Natural Convective Flow
with Dye Injection about a Waste Package Model**

Preliminary Results of Natural Convection Tests

June 9, 1995

1. **Prepared by:** William Culbreth
James Ventresca
University of Nevada, Las Vegas
Department of Civil and Environmental Engineering

2. **Summary:**

A series of experiments were conducted during the spring of 1995 to determine the convection heat transfer rates from waste package models to the adjacent air and drift wall. This report includes a summary of some preliminary results where a dense matrix of thermocouples were located on the surface of the waste package and both the inner and outer surfaces of the drift wall. The report shows the axial and circumferential variation of temperature along the surfaces. The results show a significant change in drift wall temperature in the axial direction due to the spacing between adjacent waste packages. The temperatures have been non-dimensionalized to allow the results to be extrapolated to actual repository drift conditions. The non-dimensionalized temperatures are given by:

$$\frac{T_{measured} - \bar{T}_{average}}{\bar{T}_{waste\ package\ surface} - \bar{T}_{drift\ wall\ surface}} \quad (1)$$

where,

$$\bar{T}_{average} = \frac{\bar{T}_{waste\ package\ surface} + \bar{T}_{drift\ wall\ surface}}{2} \quad (2)$$

The results are summarized in the Conclusions. Results include tabulated data, surface plots, and contour plots of the temperatures.

B. Background

The Repository Experimental Drift Model Facility at UNLV was used for these experiments. The facility includes a 10 meter long plexiglas model of a repository drift with scale-model waste packages. The system is instrumented with thermocouples, micromanometers, guard heaters, flow visualization equipment, and pitot tubes. A total of 64 thermocouples were used for these experiments as shown in figure 1. The facility is used to conduct flow visualization and heat transfer experiments over waste packages during natural, mixed, and forced air convection.

During the course of the natural convection experiments, the Rayleigh number was varied as shown in table 1.

Table 1

Run #	Rayleigh Number
2	154,000
3	420,000
4	419,000
5	225,000
6	221,000

The Rayleigh number represents the ratio of buoyant forces to thermal diffusivity within the fluid flow. The Rayleigh number gives an indication of the buoyancy-induced convection currents between the waste package and the drift wall. Higher Rayleigh numbers give rise to higher convective heat transfer within the repository drifts. In table 1, the Rayleigh number is defined as:

$$Ra = \frac{g\beta(T_{waste\ package} - T_{drift\ wall})\delta^3}{\nu\alpha} \quad (3)$$

The hydraulic diameter, δ , is defined as the drift diameter minus the waste package diameter.

Figure 1 gives a schematic representation of the experimental setup. A series of thermocouples (type-K) were attached to the drift wall and waste package surfaces. They were arranged by row, A through C on the waste package and I through M on the drift wall surface. The thermocouples were placed circumferentially at angles of 0 degrees (corresponding the top

of the drift wall), 45, 90, 135, and 180 degrees (bottom of the drift). Additional thermocouples were located at one end of the waste package and in the air midway between the top of the package and the drift wall. The following non-dimensionalized distances were used:

1. x/l axial position over waste package length.
2. $L/l = 10/4 = 2.5$ waste package separation distance over waste package length.
3. $D/d = 6/2.5 = 2.4$ drift diameter over waste package diameter.
4. $l/d = 4/2.5 = 1.6$ waste package length over waste package diameter.
5. $S/d = 14/2.5 = 5.6$ waste package midpoint spacing.

B. Experimental Results

The computer analysis of the heat transfer accounted for radiation, conduction, and convection losses from the waste package. Three sets of results are included with this report: Laboratory Summaries (original data sheets), Processed Data Sheets, and Normalized Temperature Data Sheets.

C. Conclusions

All experiments indicated that there is a variation in surface temperature on the waste package. A set of figures were prepared for experimental run #3 ($Ra = 420,000$). Figure 2 shows the temperature versus the axial position measured from the center of the waste package and versus the drift wall angle (0 degrees corresponds to the top of the drift). As seen in the 3D plot, the temperature is relatively high at the top of the drift and extremely high at the bottom of the drift due to the proximity of the waste package. Figure 3 provides a contour plot of the same data. Note that there is a significant decrease in drift wall temperature in the axial direction away from the center of the waste package. Unfortunately, our current data extends only to $x/l = 1.0$. The axial position midway between two waste packages is at $x/l = 1.75$. We are extending our thermocouple array to include this entire region. The contour plot also indicates that the temperature at the top of the drift wall centered above the waste package is hotter than the rest of the drift wall (with the exception of the area near the bottom in close proximity to the waste package). This may lead to higher compressive forces in the drift wall at this location than would be expected if the drift wall were at a uniform temperature.

Figure 4 shows a 3D plot of the temperature on the waste package surface as a function of axial position and circumferential angle. Natural convection patterns lead to lower temperatures at the top of the waste package with the ends of the top surface being cooler than the rest of the package surface. Stagnation zones in the flow give rise to higher temperatures at the bottom of the package surface.

Figure 1
Location of Thermocouples on the
Waste Package and Drift Inner Wall

Laboratory Summaries: Experimental Data Sheets

Experimental Data Sheet

A. Experiment Overview

A.A1	Run	-----	2
A.A2	Date	-----	4/10/95
A.A3	Time	-----	3:45
A.A4	Waste Package Diameter (in)	-----	2.5
A.A5	Waste Package Length (in)	-----	4.0
A.A6	Waste Package Spacing (in)	-----	10
A.A7	Waste Package Thermal Contact Width (in)	-----	0.25
A.A8	Flowrate (%)	-----	0

B. Ambient Values

B.B1	Temperature (C)	-----	23.6
B.B2	Pressure (mm Hg)	-----	740.0

C. Core Heater Values

C.C1	Voltage, Source (VAC)	-----	57.3
C.C2	Voltage, Reference Resistor (VAC)	-----	0.155
C.C3	Resistance, Leads (ohms)	-----	0.0
C.C4	Resistance, Reference Resistor (ohms)	-----	0.82
C.C5	Resistance, Core Heater (ohms)	-----	93.8

D. Temperatures, Steady State, Stagnant Conditions

ON CYLINDER, GROUP A

A.01	T1 (C)	-----	41.9
A.02	T2 (C)	-----	43.9
A.03	T3 (C)	-----	44.3
A.04	T4 (C)	-----	43.9
A.05	T5 (C)	-----	43.9

ON CYLINDER, GROUP B

B.01	T6 (C)	-----	43.7
B.02	T7 (C)	-----	44.5
B.03	T8 (C)	-----	44.1
B.04	T9 (C)	-----	44.6
B.05	T10 (C)	-----	43.9

ON CYLINDER, GROUP C

C.01	T11 (C)	-----	44.0
C.02	T12 (C)	-----	44.4
C.03	T13 (C)	-----	42.4
C.04	T14 (C)	-----	44.8
C.05	T15 (C)	-----	43.9

INSIDE DRIFT, GROUP I

I.01	T16 (C)	-----	34.1
I.02	T17 (C)	-----	33.2
I.03	T18 (C)	-----	31.8
I.04	T19 (C)	-----	32.6

INSIDE DRIFT, GROUP J

J.01	T20 (C)	-----	35.8
J.02	T21 (C)	-----	32.5
J.03	T22 (C)	-----	31.6
J.04	T23 (C)	-----	32.3

INSIDE DRIFT, GROUP K

K.01	T24 (C)	-----	34.4
K.02	T25 (C)	-----	31.8
K.03	T26 (C)	-----	31.4

CENTER OF END FACE

K.04	T27 (C)	-----	44.0
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INSIDE DRIFT, GROUP L

L.01	T28	(C)	-----	31.9
L.02	T29	(C)	-----	31.3
L.03	T30	(C)	-----	30.9
L.04	T31	(C)	-----	30.4
L.05	T32	(C)	-----	31.4

INSIDE DRIFT, GROUP M

M.01	T33	(C)	-----	31.1
M.02	T34	(C)	-----	31.2
M.03	T35	(C)	-----	30.6
M.04	T36	(C)	-----	29.9
M.05	T37	(C)	-----	30.1

OUTSIDE DRIFT, GROUP O

O.01	T38	(C)	-----	32.6
O.02	T39	(C)	-----	32.2
O.03	T40	(C)	-----	31.4
O.04	T41	(C)	-----	32.6
O.05	T42	(C)	-----	39.4

OUTSIDE DRIFT, GROUP P

P.01	T43	(C)	-----	32.8
P.02	T44	(C)	-----	32.0
P.03	T45	(C)	-----	31.1
P.04	T46	(C)	-----	32.6
P.05	T47	(C)	-----	40.7

INSIDE AIR TEMPERATURE

Q.01	T48	(C)	-----	36.0
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OUTSIDE DRIFT, GROUP Q

Q.02	T49	(C)	-----	31.4
Q.03	T50	(C)	-----	30.9
Q.04	T51	(C)	-----	31.9
Q.05	T52	(C)	-----	38.0

OUTSIDE DRIFT, GROUP R

R.01	T53	(C)	-----	31.8
R.02	T54	(C)	-----	31.1
R.03	T55	(C)	-----	30.5
R.04	T56	(C)	-----	31.1
R.05	T57	(C)	-----	34.3

OUTSIDE DRIFT, GROUP S

S.01	T58	(C)	-----	31.1
S.02	T59	(C)	-----	30.6
S.03	T60	(C)	-----	30.5
S.04	T61	(C)	-----	30.1
S.05	T62	(C)	-----	30.9

INSULATION, GROUP T
BETWEEN

T.01	T63	(C)	-----	**
OUTSIDE				
T.02	T64	(C)	-----	27.2

END

Experimental Data Sheet

A. Experiment Overview

A.A1	Run	-----	3
A.A2	Date	-----	4/13/95
A.A3	Time	-----	4:10
A.A4	Waste Package Diameter (in)	-----	2.5
A.A5	Waste Package Length (in)	-----	4.0
A.A6	Waste Package Spacing (in)	-----	10
A.A7	Waste Package Thermal Contact Width (in)	-----	0.25
A.A8	Flowrate (%)	-----	0

B. Ambient Values

B.B1	Temperature (C)	-----	24.4
B.B2	Pressure (mm Hg)	-----	760

C. Core Heater Values

C.C1	Voltage, Source (VAC)	-----	100.6
C.C2	Voltage, Reference Resistor (VAC)	-----	.272
C.C3	Resistance, Leads (ohms)	-----	0
C.C4	Resistance, Reference Resistor (ohms)	-----	.82
C.C5	Resistance, Core Heater (ohms)	-----	93.8

D. Temperatures, Steady State, Stagnant Conditions

ON CYLINDER, GROUP A

A.01	T1 (C)	-----	69.6
A.02	T2 (C)	-----	73.2
A.03	T3 (C)	-----	74.4
A.04	T4 (C)	-----	73.0
A.05	T5 (C)	-----	74.1

ON CYLINDER, GROUP B

B.01	T6 (C)	-----	72.2
B.02	T7 (C)	-----	75.1
B.03	T8 (C)	-----	73.8
B.04	T9 (C)	-----	75.3
B.05	T10 (C)	-----	74.1

ON CYLINDER, GROUP C

C.01	T11 (C)	-----	74.0
C.02	T12 (C)	-----	74.6
C.03	T13 (C)	-----	73.8
C.04	T14 (C)	-----	75.8
C.05	T15 (C)	-----	74.1

INSIDE DRIFT, GROUP I

I.01	T16 (C)	-----	48.1
I.02	T17 (C)	-----	47.1
I.03	T18 (C)	-----	43.9
I.04	T19 (C)	-----	45.7

INSIDE DRIFT, GROUP J

J.01	T20 (C)	-----	50.9
J.02	T21 (C)	-----	44.8
J.03	T22 (C)	-----	43.8
J.04	T23 (C)	-----	44.6

INSIDE DRIFT, GROUP K

K.01	T24 (C)	-----	49.9
K.02	T25 (C)	-----	44.0
K.03	T26 (C)	-----	42.5

CENTER OF END FACE

K.04	T27 (C)	-----	73
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INSIDE DRIFT, GROUP L

L.01	T28 (C)	-----	44.5
L.02	T29 (C)	-----	42.8

L.03	T30	(C)	-----	41.4
L.04	T31	(C)	-----	39.8
L.05	T32	(C)	-----	42.2
INSIDE DRIFT, GROUP M				
M.01	T33	(C)	-----	42.1
M.02	T34	(C)	-----	42.6
M.03	T35	(C)	-----	40.8
M.04	T36	(C)	-----	38.4
M.05	T37	(C)	-----	38.7
OUTSIDE DRIFT, GROUP O				
O.01	T38	(C)	-----	45.3
O.02	T39	(C)	-----	44.0
O.03	T40	(C)	-----	42.6
O.04	T41	(C)	-----	45.8
O.05	T42	(C)	-----	61.7
OUTSIDE DRIFT, GROUP P				
P.01	T43	(C)	-----	45.4
P.02	T44	(C)	-----	43.6
P.03	T45	(C)	-----	42.4
P.04	T46	(C)	-----	45.7
P.05	T47	(C)	-----	65.3
INSIDE AIR TEMPERATURE				
Q.01	T48	(C)	-----	45.2
OUTSIDE DRIFT, GROUP Q				
Q.02	T49	(C)	-----	42.7
Q.03	T50	(C)	-----	41.6
Q.04	T51	(C)	-----	43.4
Q.05	T52	(C)	-----	57.7
OUTSIDE DRIFT, GROUP R				
R.01	T53	(C)	-----	43.5
R.02	T54	(C)	-----	41.7
R.03	T55	(C)	-----	40.4
R.04	T56	(C)	-----	37.1
R.05	T57	(C)	-----	48.9
OUTSIDE DRIFT, GROUP S				
S.01	T58	(C)	-----	41.7
S.02	T59	(C)	-----	40.8
S.03	T60	(C)	-----	39.4
S.04	T61	(C)	-----	39.1
S.05	T62	(C)	-----	41.1
INSULATION, GROUP T				
BETWEEN				
T.01	T63	(C)	-----	**
OUTSIDE				
T.02	T64	(C)	-----	31.2
END				

Experimental Data Sheet

A. Experiment Overview

A.A1	Run	-----	4
A.A2	Date	-----	4/19/95
A.A3	Time	-----	4:00pm
A.A4	Waste Package Diameter (in)	-----	2.5
A.A5	Waste Package Length (in)	-----	4.0
A.A6	Waste Package Spacing (in)	-----	10
A.A7	Waste Package Thermal Contact Width (in)	-----	0.125
A.A8	Flowrate (%)	-----	0

B. Ambient Values

B.B1	Temperature (C)	-----	24.2
B.B2	Pressure (mm Hg)	-----	780

C. Core Heater Values

C.C1	Voltage, Source (VAC)	-----	100.5
C.C2	Voltage, Reference Resistor (VAC)	-----	.273
C.C3	Resistance, Leads (ohms)	-----	0
C.C4	Resistance, Reference Resistor (ohms)	-----	.82
C.C5	Resistance, Core Heater (ohms)	-----	93.8

D. Temperatures, Steady State, Stagnant Conditions

ON CYLINDER, GROUP A

A.01	T1 (C)	-----	70.2
A.02	T2 (C)	-----	73.0
A.03	T3 (C)	-----	74.3
A.04	T4 (C)	-----	73.0
A.05	T5 (C)	-----	73.6

ON CYLINDER, GROUP B

B.01	T6 (C)	-----	72.0
B.02	T7 (C)	-----	74.8
B.03	T8 (C)	-----	73.8
B.04	T9 (C)	-----	75.4
B.05	T10 (C)	-----	73.6

ON CYLINDER, GROUP C

C.01	T11 (C)	-----	74.4
C.02	T12 (C)	-----	74.9
C.03	T13 (C)	-----	73.8
C.04	T14 (C)	-----	75.9
C.05	T15 (C)	-----	73.6

INSIDE DRIFT, GROUP I

I.01	T16 (C)	-----	49.2
I.02	T17 (C)	-----	46.9
I.03	T18 (C)	-----	44.0
I.04	T19 (C)	-----	46.1

INSIDE DRIFT, GROUP J

J.01	T20 (C)	-----	50.2
J.02	T21 (C)	-----	45.0
J.03	T22 (C)	-----	44.0
J.04	T23 (C)	-----	44.2

INSIDE DRIFT, GROUP K

K.01	T24 (C)	-----	48.8
K.02	T25 (C)	-----	44.0
K.03	T26 (C)	-----	42.7

CENTER OF END FACE

K.04	T27 (C)	-----	72.8
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INSIDE DRIFT, GROUP L

L.01	T28 (C)	-----	44.4
L.02	T29 (C)	-----	42.9

L.03	T30	(C)	-----	41.5
L.04	T31	(C)	-----	39.8
L.05	T32	(C)	-----	42.0
INSIDE DRIFT, GROUP M				
M.01	T33	(C)	-----	42.2
M.02	T34	(C)	-----	42.7
M.03	T35	(C)	-----	40.9
M.04	T36	(C)	-----	38.3
M.05	T37	(C)	-----	38.6
OUTSIDE DRIFT, GROUP O				
O.01	T38	(C)	-----	45.6
O.02	T39	(C)	-----	44.1
O.03	T40	(C)	-----	42.6
O.04	T41	(C)	-----	46.1
O.05	T42	(C)	-----	62.2
OUTSIDE DRIFT, GROUP P				
P.01	T43	(C)	-----	45.8
P.02	T44	(C)	-----	43.8
P.03	T45	(C)	-----	42.4
P.04	T46	(C)	-----	45.8
P.05	T47	(C)	-----	65.4
INSIDE AIR TEMPERATURE				
Q.01	T48	(C)	-----	45.2
OUTSIDE DRIFT, GROUP Q				
Q.02	T49	(C)	-----	42.7
Q.03	T50	(C)	-----	41.4
Q.04	T51	(C)	-----	43.1
Q.05	T52	(C)	-----	58.3
OUTSIDE DRIFT, GROUP R				
R.01	T53	(C)	-----	43.7
R.02	T54	(C)	-----	41.9
R.03	T55	(C)	-----	40.4
R.04	T56	(C)	-----	41.2
R.05	T57	(C)	-----	48.9
OUTSIDE DRIFT, GROUP S				
S.01	T58	(C)	-----	42.0
S.02	T59	(C)	-----	40.9
S.03	T60	(C)	-----	39.6
S.04	T61	(C)	-----	39.1
S.05	T62	(C)	-----	41.1
INSULATION, GROUP T				
BETWEEN				
T.01	T63	(C)	-----	
OUTSIDE				
T.02	T64	(C)	-----	31.5
END				

Experimental Data Sheet

A. Experiment Overview

A.A1	Run	-----	5
A.A2	Date	-----	4/21/95
A.A3	Time	-----	4:00
A.A4	Waste Package Diameter (in)	-----	2.5
A.A5	Waste Package Length (in)	-----	4.0
A.A6	Waste Package Spacing (in)	-----	10
A.A7	Waste Package Thermal Contact Width (in)	-----	0.125
A.A8	Flowrate (%)	-----	0

B. Ambient Values

B.B1	Temperature (C)	-----	24
B.B2	Pressure (mm Hg)	-----	780

C. Core Heater Values

C.C1	Voltage, Source (VAC)	-----	57.3
C.C2	Voltage, Reference Resistor (VAC)	-----	.155
C.C3	Resistance, Leads (ohms)	-----	0
C.C4	Resistance, Reference Resistor (ohms)	-----	.82
C.C5	Resistance, Core Heater (ohms)	-----	93.8

D. Temperatures, Steady State, Stagnant Conditions

ON CYLINDER, GROUP A

A.01	T1 (C)	-----	41.8
A.02	T2 (C)	-----	43.3
A.03	T3 (C)	-----	43.8
A.04	T4 (C)	-----	43.5
A.05	T5 (C)	-----	43.5

ON CYLINDER, GROUP B

B.01	T6 (C)	-----	43.1
B.02	T7 (C)	-----	43.8
B.03	T8 (C)	-----	43.7
B.04	T9 (C)	-----	44.2
B.05	T10 (C)	-----	43.5

ON CYLINDER, GROUP C

C.01	T11 (C)	-----	43.9
C.02	T12 (C)	-----	44.0
C.03	T13 (C)	-----	41.2
C.04	T14 (C)	-----	44.4
C.05	T15 (C)	-----	43.5

INSIDE DRIFT, GROUP I

I.01	T16 (C)	-----	33.4
I.02	T17 (C)	-----	32.9
I.03	T18 (C)	-----	31.5
I.04	T19 (C)	-----	32.6

INSIDE DRIFT, GROUP J

J.01	T20 (C)	-----	35.0
J.02	T21 (C)	-----	32.0
J.03	T22 (C)	-----	31.5
J.04	T23 (C)	-----	32.4

INSIDE DRIFT, GROUP K

K.01	T24 (C)	-----	33.5
K.02	T25 (C)	-----	31.9
K.03	T26 (C)	-----	31.1

CENTER OF END FACE

K.04	T27 (C)	-----	43.5
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INSIDE DRIFT, GROUP L

L.01	T28 (C)	-----	31.7
L.02	T29 (C)	-----	31.1

L.03	T30	(C)	-----	30.7
L.04	T31	(C)	-----	30.4
L.05	T32	(C)	-----	31.3

INSIDE DRIFT, GROUP M

M.01	T33	(C)	-----	30.8
M.02	T34	(C)	-----	31.1
M.03	T35	(C)	-----	30.6
M.04	T36	(C)	-----	29.8
M.05	T37	(C)	-----	29.9

OUTSIDE DRIFT, GROUP O

O.01	T38	(C)	-----	32.3
O.02	T39	(C)	-----	31.8
O.03	T40	(C)	-----	31.0
O.04	T41	(C)	-----	32.8
O.05	T42	(C)	-----	39.4

OUTSIDE DRIFT, GROUP P

P.01	T43	(C)	-----	32.3
P.02	T44	(C)	-----	31.6
P.03	T45	(C)	-----	31.0
P.04	T46	(C)	-----	32.9
P.05	T47	(C)	-----	40.7

INSIDE AIR TEMPERATURE

Q.01	T48	(C)	-----	32.3
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OUTSIDE DRIFT, GROUP Q

Q.02	T49	(C)	-----	31.0
Q.03	T50	(C)	-----	30.6
Q.04	T51	(C)	-----	32.0
Q.05	T52	(C)	-----	37.8

OUTSIDE DRIFT, GROUP R

R.01	T53	(C)	-----	31.4
R.02	T54	(C)	-----	30.7
R.03	T55	(C)	-----	30.2
R.04	T56	(C)	-----	31.2
R.05	T57	(C)	-----	34.1

OUTSIDE DRIFT, GROUP S

S.01	T58	(C)	-----	30.8
S.02	T59	(C)	-----	30.3
S.03	T60	(C)	-----	30.0
S.04	T61	(C)	-----	30.2
S.05	T62	(C)	-----	30.8

INSULATION, GROUP T

BETWEEN

T.01	T63	(C)	-----	
T.02	T64	(C)	-----	26.7

END

Experimental Data Sheet

A. Experiment Overview

A.A1	Run	-----	6
A.A2	Date	-----	4/24/95
A.A3	Time	-----	4:00
A.A4	Waste Package Diameter (in)	-----	2.5
A.A5	Waste Package Length (in)	-----	4.0
A.A6	Waste Package Spacing (in)	-----	10
A.A7	Waste Package Thermal Contact Width (in)	-----	0.125
A.A8	Flowrate (%)	-----	0

B. Ambient Values

B.B1	Temperature (C)	-----	24
B.B2	Pressure (mm Hg)	-----	780

C. Core Heater Values

C.C1	Voltage, Source (VAC)	-----	57.6
C.C2	Voltage, Reference Resistor (VAC)	-----	.156
C.C3	Resistance, Leads (ohms)	-----	0
C.C4	Resistance, Reference Resistor (ohms)	-----	.82
C.C5	Resistance, Core Heater (ohms)	-----	93.8

D. Temperatures, Steady State, Stagnant Conditions

ON CYLINDER, GROUP A

A.01	T1 (C)	-----	42.1
A.02	T2 (C)	-----	43.5
A.03	T3 (C)	-----	43.9
A.04	T4 (C)	-----	43.5
A.05	T5 (C)	-----	43.5

ON CYLINDER, GROUP B

B.01	T6 (C)	-----	43.3
B.02	T7 (C)	-----	44.0
B.03	T8 (C)	-----	43.7
B.04	T9 (C)	-----	44.4
B.05	T10 (C)	-----	43.5

ON CYLINDER, GROUP C

C.01	T11 (C)	-----	44.0
C.02	T12 (C)	-----	44.2
C.03	T13 (C)	-----	41.5
C.04	T14 (C)	-----	44.5
C.05	T15 (C)	-----	43.5

INSIDE DRIFT, GROUP I

I.01	T16 (C)	-----	33.5
I.02	T17 (C)	-----	32.8
I.03	T18 (C)	-----	31.5
I.04	T19 (C)	-----	32.4

INSIDE DRIFT, GROUP J

J.01	T20 (C)	-----	35.0
J.02	T21 (C)	-----	32.0
J.03	T22 (C)	-----	31.5
J.04	T23 (C)	-----	31.9

INSIDE DRIFT, GROUP K

K.01	T24 (C)	-----	33.2
K.02	T25 (C)	-----	31.4
K.03	T26 (C)	-----	31.0

CENTER OF END FACE

K.04	T27 (C)	-----	43.5
------	---------	-------	------

INSIDE DRIFT, GROUP L

L.01	T28 (C)	-----	31.6
L.02	T29 (C)	-----	31.0

L.03	T30	(C)	-----	30.5
L.04	T31	(C)	-----	30.0
L.05	T32	(C)	-----	31.0

INSIDE DRIFT, GROUP M

M.01	T33	(C)	-----	30.7
M.02	T34	(C)	-----	31.0
M.03	T35	(C)	-----	30.2
M.04	T36	(C)	-----	29.5
M.05	T37	(C)	-----	29.8

OUTSIDE DRIFT, GROUP O

O.01	T38	(C)	-----	32.4
O.02	T39	(C)	-----	31.8
O.03	T40	(C)	-----	30.9
O.04	T41	(C)	-----	32.4
O.05	T42	(C)	-----	40.3

OUTSIDE DRIFT, GROUP P

P.01	T43	(C)	-----	32.3
P.02	T44	(C)	-----	31.6
P.03	T45	(C)	-----	30.9
P.04	T46	(C)	-----	32.0
P.05	T47	(C)	-----	40.3

INSIDE AIR TEMPERATURE

Q.01	T48	(C)	-----	32.6
------	-----	-----	-------	------

OUTSIDE DRIFT, GROUP Q

Q.02	T49	(C)	-----	31.2
Q.03	T50	(C)	-----	30.8
Q.04	T51	(C)	-----	31.3
Q.05	T52	(C)	-----	37.5

OUTSIDE DRIFT, GROUP R

R.01	T53	(C)	-----	31.5
R.02	T54	(C)	-----	30.8
R.03	T55	(C)	-----	30.3
R.04	T56	(C)	-----	30.6
R.05	T57	(C)	-----	33.8

OUTSIDE DRIFT, GROUP S

S.01	T58	(C)	-----	30.8
S.02	T59	(C)	-----	30.4
S.03	T60	(C)	-----	30.0
S.04	T61	(C)	-----	29.9
S.05	T62	(C)	-----	30.6

INSULATION, GROUP T

BETWEEN				
T.01	T63	(C)	-----	
OUTSIDE				
T.02	T64	(C)	-----	27.1

END

Processed Data: Thermal Output Data Sheets

 * THERMAL OUTPUT *

***** RUN # 2 *****

A. Experiment Overview

1. Current Date -----	06-05-1995
2. Experiment Date -----	4/10/95
3. Experiment Time -----	3:45
4. Ambient Temperature (K) -----	296.76
5. Ambient Pressure (Pa) -----	98658.55
6. Flowrate (% of full) from Variac -----	0

B. Geometry

1. Waste Package Diameter (m) -----	.0635
2. Waste Package Diameter (d/D) -----	.4166667
3. Waste Package Spacing (l/d) -----	4

D. Thermal Values

1. Core Power (W) -----	3.351495
3. Drift (Plexiglas) Cond. Loss (W) -----	3.814619
3. Drift Insulation Loss (W) -----	2.380865
4. Drift Convection Into Wall (W) -----	3.280334
5. Drift Radiation Into Wall (W) -----	0
2. WP Conduction Heat Loss (W) -----	7.116051E-02
6. WP Convection Heat Loss (W) -----	3.280334
7. WP Radiation Heat Loss (W) -----	0
8. WP Radiation Heat Loss (%) -----	0
9. Nusselt Number (waste package) -----	0
10. Nusselt Number (drift wall) -----	1.699249E-05
11. Grashof Number -----	218937.2
12. Rayleigh Number -----	154312.8

E. Air Properties (T = 296.76 K)

1. Kinematic Viscosity (m ² /s) -----	1.537727E-05
2. Prandtl Number -----	.7088151
3. Density (kg/m ³) -----	0
4. Thermal Conductivity (W/m-K) -----	2.598689E-02
5. Flow Velocity (m/s) -----	0
6. Reynolds No. (bsd. on hydr. diam.) -----	0
7. Hydraulic Diameter (m) -----	.0889

F. Temperatures

1. Ambient Temperature (K) -----	296.76
2. Inner Air Temperature (K) -----	309.16
3. Plexiglas, top, outside (K) -----	305.1
4. Plexiglas, bottom, outside (K) -----	312.5267
5. Plexiglas Wall (inside) (K) -----	306.5767
6. Plexiglas Wall (outside) (K) -----	305.7267
7. Insulation, second layer (K) -----	300.36
8. WP, average (K) -----	317.04
9. Film temperature, waste package (K) -----	313.1
10. WP, end, center (K) -----	317.16
12. WP, top, end (K) -----	315.06
13. WP, top, 1/4 (K) -----	316.86
14. WP, top, center (K) -----	317.16
16. WP, side, end (K) -----	317.46
17. WP, side, center (K) -----	315.56
18. WP, bottom, end (K) -----	317.06
19. WP, bottom, center (K) -----	317.06

H. Relative Heat Flux on WP Surface

1. WP, end, center -----	1.015228
2. WP, top, end -----	.7487297
3. WP, top, 1/4 -----	.9771583
4. WP, top, center -----	1.015228
5. WP, side, center -----	.8121815
6. WP, bottom, end -----	1.002537
7. WP, bottom, center -----	1.002537

 * THERMAL OUTPUT *

***** RUN # 3 *****

A. Experiment Overview

1. Current Date -----	06-01-1995
2. Experiment Date -----	4/13/95
3. Experiment Time -----	4:10
4. Ambient Temperature (K) -----	297.56
5. Ambient Pressure (Pa) -----	101325
6. Flowrate (% of full) from Variac -----	0

B. Geometry

1. Waste Package Diameter (m) -----	.0635
2. Waste Package Diameter {d/D} -----	.4166667
3. Waste Package Spacing (l/d) -----	4

D. Thermal Values

1. Core Power (W) -----	10.32079
2. Drift (Plexiglas) Cond. Loss (W) -----	11.21857
3. Drift Insulation Loss (W) -----	10.32019
4. Drift Convection Into Wall (W) -----	-5.383461
5. Drift Radiation Into Wall (W) -----	5.835111
6. WP Conduction Heat Loss (W) -----	.1967381
7. WP Convection Heat Loss (W) -----	4.288942
8. WP Radiation Heat Loss (W) -----	5.835111
9. WP Radiation Heat Loss (%) -----	56.53743
10. Nusselt Number (waste package) -----	12.45394
11. Nusselt Number (drift wall) -----	-43.35209
12. Grashof Number -----	599149.6
13. Rayleigh Number -----	419688.1

E. Air Properties (T = 297.56 K)

1. Kinematic Viscosity (m ² /s) -----	1.545465E-05
2. Prandtl Number -----	.7086124
3. Density (kg/m ³) -----	1.184919
4. Thermal Conductivity (W/m-K) -----	2.604914E-02
5. Flow Velocity (m/s) -----	0
6. Flow Rate (m ³ /s) -----	0
7. Reynolds No. (bsd. on hydr. diam.) -----	0
8. Reynolds No. (bsd. on drft. diam.) -----	0
9. Hydraulic Diameter (m) -----	.0889
10. Pressure Coefficient -----	0

F. Temperatures

1. Ambient Temperature (K) -----	297.56
2. Inner Air Temperature (K) -----	318.36
3. Plexiglas, top, outside (K) -----	316.88
4. Plexiglas, bottom, outside (K) -----	334.7267
5. Plexiglas Wall (inside) (K) -----	320.6974
6. Plexiglas Wall (outside) (K) -----	318.1975
7. Insulation, second layer (K) -----	304.36
8. WP, average (K) -----	346.9667
9. Film temperature, waste package (K) -----	332.6633
10. WP, end, center (K) -----	346.16
11. WP, top, end (K) -----	342.76
12. WP, top, 1/4 (K) -----	345.36
13. WP, top, center (K) -----	347.16
14. WP, side, end (K) -----	347.56
15. WP, side, center (K) -----	346.96
16. WP, bottom, end (K) -----	347.26
17. WP, bottom, center (K) -----	347.26

H. Relative Heat Flux on WP Surface

1. WP, end, center -----	.9718013
2. WP, top, end -----	.8529481
3. WP, top, 1/4 -----	.9438351
4. WP, top, center -----	1.006758
5. WP, side, center -----	.9997674
6. WP, bottom, end -----	1.010254
7. WP, bottom, center -----	1.010254

 * THERMAL OUTPUT *

***** RUN # 4 *****

A. Experiment Overview

1. Current Date -----	06-05-1995
2. Experiment Date -----	4/19/95
3. Experiment Time -----	4:00pm
4. Ambient Temperature (K) -----	297.36
5. Ambient Pressure (Pa) -----	103991.4
6. Flowrate (% of full) from Variac -----	0

B. Geometry

1. Waste Package Diameter (m) -----	.0635
2. Waste Package Diameter (d/D) -----	.4166667
3. Waste Package Spacing (l/d) -----	4

D. Thermal Values

1. Core Power (W) -----	10.39682
3. Drift (Plexiglas) Cond. Loss (W) -----	9.554761
3. Drift Insulation Loss (W) -----	6.291476
4. Drift Convection Into Wall (W) -----	10.30551
5. Drift Radiation Into Wall (W) -----	0
2. WP Conduction Heat Loss (W) -----	9.130536E-02
6. WP Convection Heat Loss (W) -----	10.30551
7. WP Radiation Heat Loss (W) -----	0
8. WP Radiation Heat Loss (%) -----	0
9. Nusselt Number (waste package) -----	0
10. Nusselt Number (drift wall) -----	1.898436E-05
11. Grashof Number -----	598253.2
12. Rayleigh Number -----	419063.5

E. Air Properties (T = 297.36 K)

1. Kinematic Viscosity (m ² /s) -----	1.543529E-05
2. Prandtl Number -----	.708663
3. Density (kg/m ³) -----	0
4. Thermal Conductivity (W/m-K) -----	2.603358E-02
5. Flow Velocity (m/s) -----	0
6. Reynolds No. (bsd. on hydr. diam.) -----	0
7. Hydraulic Diameter (m) -----	.0889

F. Temperatures

1. Ambient Temperature (K) -----	297.36
2. Inner Air Temperature (K) -----	318.36
3. Plexiglas, top, outside (K) -----	317.12
4. Plexiglas, bottom, outside (K) -----	335.1267
5. Plexiglas Wall (inside) (K) -----	320.6266
6. Plexiglas Wall (outside) (K) -----	318.4975
7. Insulation, second layer (K) -----	304.66
8. WP, average (K) -----	346.9134
9. Film temperature, waste package (K) -----	332.6367
10. WP, end, center (K) -----	345.96
12. WP, top, end (K) -----	343.36
13. WP, top, 1/4 (K) -----	345.16
14. WP, top, center (K) -----	347.56
16. WP, side, end (K) -----	347.46
17. WP, side, center (K) -----	346.96
18. WP, bottom, end (K) -----	346.76
19. WP, bottom, center (K) -----	346.76

H. Relative Heat Flux on WP Surface

1. WP, end, center -----	.966612
2. WP, top, end -----	.8755531
3. WP, top, 1/4 -----	.9385936
4. WP, top, center -----	1.022647
5. WP, side, center -----	1.001634
6. WP, bottom, end -----	.9946293
7. WP, bottom, center -----	.9946293

 * THERMAL OUTPUT *

***** RUN # 5 *****

A. Experiment Overview

1. Current Date -----	06-05-1995
2. Experiment Date -----	4/21/95
3. Experiment Time -----	4:00
4. Ambient Temperature (K) -----	297.16
5. Ambient Pressure (Pa) -----	103991.4
6. Flowrate (% of full) from Variac -----	0

B. Geometry

1. Waste Package Diameter (m) -----	.0635
2. Waste Package Diameter (d/D) -----	.4166667
3. Waste Package Spacing (l/d) -----	4

D. Thermal Values

1. Core Power (W) -----	3.351495
3. Drift (Plexiglas) Cond. Loss (W) -----	3.515382
3. Drift Insulation Loss (W) -----	2.513248
4. Drift Convection Into Wall (W) -----	3.318531
5. Drift Radiation Into Wall (W) -----	0
2. WP Conduction Heat Loss (W) -----	3.296421E-02
6. WP Convection Heat Loss (W) -----	3.318531
7. WP Radiation Heat Loss (W) -----	0
8. WP Radiation Heat Loss (%) -----	0
9. Nusselt Number (waste package) -----	0
10. Nusselt Number (drift wall) -----	1.678304E-05
11. Grashof Number -----	318648.1
12. Rayleigh Number -----	224748

E. Air Properties (T = 297.16 K)

1. Kinematic Viscosity (m ² /s) -----	1.541594E-05
2. Prandtl Number -----	.7087137
3. Density (kg/m ³) -----	0
4. Thermal Conductivity (W/m-K) -----	2.601802E-02
5. Flow Velocity (m/s) -----	0
6. Reynolds No. (bsd. on hydr. diam.) -----	0
7. Hydraulic Diameter (m) -----	.0889

F. Temperatures

1. Ambient Temperature (K) -----	297.16
2. Inner Air Temperature (K) -----	305.46
3. Plexiglas, top, outside (K) -----	304.72
4. Plexiglas, bottom, outside (K) -----	312.46
5. Plexiglas Wall (inside) (K) -----	306.3142
6. Plexiglas Wall (outside) (K) -----	305.5308
7. Insulation, second layer (K) -----	299.86
8. WP, average (K) -----	316.5734
9. Film temperature, waste package (K) -----	311.0167
10. WP, end, center (K) -----	316.66
12. WP, top, end (K) -----	314.96
13. WP, top, 1/4 (K) -----	316.26
14. WP, top, center (K) -----	317.06
16. WP, side, end (K) -----	316.96
17. WP, side, center (K) -----	314.36
18. WP, bottom, end (K) -----	316.66
19. WP, bottom, center (K) -----	316.66

H. Relative Heat Flux on WP Surface

1. WP, end, center -----	1.007796
2. WP, top, end -----	.854826
3. WP, top, 1/4 -----	.9718038
4. WP, top, center -----	1.043788
5. WP, side, center -----	.8008392
6. WP, bottom, end -----	1.007796
7. WP, bottom, center -----	1.007796

 * THERMAL OUTPUT *

***** RUN # 6 *****

A. Experiment Overview

1. Current Date -----	06-05-1995
2. Experiment Date -----	4/24/95
3. Experiment Time -----	4:00
4. Ambient Temperature (K) -----	297.16
5. Ambient Pressure (Pa) -----	103991.4
6. Flowrate (% of full) from Variac -----	0

B. Geometry

1. Waste Package Diameter (m) -----	.0635
2. Waste Package Diameter {d/D} -----	.4166667
3. Waste Package Spacing (l/d) -----	4

D. Thermal Values

1. Core Power (W) -----	3.39488
3. Drift (Plexiglas) Cond. Loss (W) -----	3.291057
3. Drift Insulation Loss (W) -----	2.290805
4. Drift Convection Into Wall (W) -----	3.362439
5. Drift Radiation Into Wall (W) -----	0
2. WP Conduction Heat Loss (W) -----	3.244086E-02
6. WP Convection Heat Loss (W) -----	3.362439
7. WP Radiation Heat Loss (W) -----	0
8. WP Radiation Heat Loss (%) -----	0
9. Nusselt Number (waste package) -----	0
10. Nusselt Number (drift wall) -----	1.680445E-05
11. Grashof Number -----	312664.6
12. Rayleigh Number -----	220512

E. Air Properties (T = 297.16 K)

1. Kinematic Viscosity (m ² /s) -----	1.541594E-05
2. Prandtl Number -----	.7087137
3. Density (kg/m ³) -----	0
4. Thermal Conductivity (W/m-K) -----	2.601802E-02
5. Flow Velocity (m/s) -----	0
6. Reynolds No. (bsd. on hydr. diam.) -----	0
7. Hydraulic Diameter (m) -----	.0889

F. Temperatures

1. Ambient Temperature (K) -----	297.16
2. Inner Air Temperature (K) -----	305.76
3. Plexiglas, top, outside (K) -----	304.8
4. Plexiglas, bottom, outside (K) -----	312.5267
5. Plexiglas Wall (inside) (K) -----	306.16
6. Plexiglas Wall (outside) (K) -----	305.4267
7. Insulation, second layer (K) -----	300.26
8. WP, average (K) -----	316.7
9. Film temperature, waste package (K) -----	311.23
10. WP, end, center (K) -----	316.66
12. WP, top, end (K) -----	315.26
13. WP, top, 1/4 (K) -----	316.46
14. WP, top, center (K) -----	317.16
16. WP, side, end (K) -----	317.06
17. WP, side, center (K) -----	314.66
18. WP, bottom, end (K) -----	316.66
19. WP, bottom, center (K) -----	316.66

H. Relative Heat Flux on WP Surface

1. WP, end, center -----	.9963402
2. WP, top, end -----	.8683704
3. WP, top, 1/4 -----	.9780576
4. WP, top, center -----	1.042044
5. WP, side, center -----	.8135253
6. WP, bottom, end -----	.9963402
7. WP, bottom, center -----	.9963402

**Normalized Data:
Data Sheets with Normalized
Temperatures**

Run Number: 2

(Normalized Temperature followed by T in Celsius)

Waste Package:

A (1-5):

.3339359	41.89999
.5010416	44.89999
.53444622	44.29999
.5010416	43.89999
.5010416	43.89999

B (1-5):

.4843326	43.70001
.5511738	44.5
.5177532	44.10001
.5595296	44.60001
.5010416	43.89999

C (1-5):

.5093974	44
.342818	44.39999
.3757124	42.39999
.5762386	44.79999
.5010416	43.89999

End Face:

.5093974	44
----------	----

Drift Wall:
I (1-4):

-.3177751	34.10001
-.3929722	33.20001
-.5099481	31.79999
-.4431044	32.60001

J (1-4):

-.1757368	35.79999
-.4514602	32.5
-.5266572	31.60001
-.4681717	32.29999

K (1-3):

-.2927103	34.39999
-.5099481	31.79999
-.5433688	31.39999

L (1-5):

-.5015924	31.89999
-.5517246	31.29999
-.5851452	30.89999
-.6269216	30.39999
-.5433688	31.39999

M (1-5):

-.5684336	31.10001
-.5600778	31.20001
-.61021	30.60001
-.668698	29.89999
-.6519864	30.10001

Air Temperature (C):
Normalized Air Temperature:
Average WP Temperature (C):
Average Drift Wall Temperature (C):
Average Temperature of WP/DW (C):

36
-1590253
43.88751
31.91904
37.90329

Run Number: 3

(Normalized Temperature followed by T in Celsius)

Waste Package:

A (1-5):
.36152 69.60001
.4814653 73.19998
.5214478 74.39999
.4748023 73
.5114527 74.10001

B (1-5):
.4481469 72.19998
.5447711 75.10001
.5014576 73.80002
.5514352 75.30002
.5114527 74.10001

C (1-5):
.5081207 74
.5281119 74.60001
.5014576 73.80002
.5680944 75.80002
.5114527 74.10001

End Face:
.4748023 73

Drift Wall:

I (1-4):
-.3548253 48.10001
-.3881437 47.10001
-.494763 43.89999
-.4347893 45.70001

J (1-4):
-.2615343 50.89999
-.4647766 44.79999
-.498095 43.79999
-.4714397 44.60001

K (1-3):
-.2948527 49.89999
-.4914309 44
-.5414085 42.5

L (1-5):
-.4747718 44.5
-.5314134 42.79999
-.578059 41.39999
-.6313686 39.79999
-.5514036 42.20001

M (1-5):
-.5547357 42.10001
-.5380765 42.60001
-.5980502 40.79999
-.6780141 38.39999
-.668018 38.70001

Air Temperature (C): 45.20001
Normalized Air Temperature: -.4514485
Average WP Temperature (C): 73.75626
Average Drift Wall Temperature (C): 43.7428
Average Temperature of WP/DW (C): 58.74954

Run Number: 4

(Normalized Temperature followed by T in Celsius)

Waste Package:

A (1-5):
.3833871 70.19998
.4768443 73
.5202354 74.30002
.4768443 73
.4968709 73.60001

B (1-5):
.4434669 72
.5369241 74.80002
.5035468 73.80002
.5569497 75.39999
.4968709 73.60001

C (1-5):
.5235723 74.39999
.540261 74.89999
.5035468 73.80002
.5736383 75.89999
.4968709 73.60001

End Face:
.4701694 72.80002

Drift Wall:

I (1-4):
-.3175359 49.20001
-.3943044 46.89999
-.4910985 44
-.4210059 46.10001

J (1-4):
-.2841586 50.20001
-.4577211 45
-.4910985 44
-.4844226 44.20001

K (1-3):
-.3308877 48.79999
-.4910985 44
-.5344886 42.70001

L (1-5):
-.4777478 44.39999
-.5278138 42.89999
-.5745418 41.5
-.6312837 39.79999
-.5578532 42

M (1-5):
-.5511773 42.20001
-.5344886 42.70001
-.5945684 40.89999
-.6813497 38.29999
-.6713359 38.60001

Air Temperature (C): 45.20001
Normalized Air Temperature: -45.10453
Average WP Temperature (C): 73.69376
Average Drift Wall Temperature (C): 43.73331
Average Temperature of WP/DW (C): 58.71353

Run Number: 5

(Normalized Temperature followed by T in Celsius)

Waste Package:

A (1-5):
.3621427 41.79999
.4898826 43.29999
.5324625 43.79999
.5069156 43.5
.5069156 43.5

B (1-5):
.4728522 43.10001
.5324625 43.79999
.5239486 43.70001
.5665286 44.20001
.5069156 43.5

C (1-5):
.540979 43.89999
.5494956 44
.3110489 41.20001
.583559 44.39999
.5069156 43.5

End Face:
.5069156 43.5

Drift Wall:

I (1-4):
-.3532 33.39999
-.3957799 32.89999
-.5150033 31.5
-.4213269 32.60001

J (1-4):
-.2169436 35
-.4724233 32
-.5150033 31.5
-.4383599 32.39999

K (1-3):
-.3446835 33.5
-.4809399 31.89999
-.5490667 31.10001

L (1-5):
-.4979703 31.70001
-.5490667 31.10001
-.5831302 30.70001
-.6086797 30.39999
-.5320363 31.29999

M (1-5):
-.5746163 30.79999
-.5490667 31.10001
-.5916467 30.60001
-.6597762 29.79999
-.6512597 29.89999

Air Temperature (C):

Normalized Air Temperature:

Average WP Temperature (C):

Average Drift Wall Temperature (C):

Average Temperature of WP/DW (C):

32.29999
-.4468764
43.41879
31.67618
37.54749

Run Number: 6

(Normalized Temperature followed by T in Celsius)

Waste Package:

A (1-5):
 .3805794 42.10001
 .4968817 43.5
 .5301106 43.89999
 .4968817 43.5
 .4968817 43.5

B (1-5):
 .480266 43.29999
 .5384184 44
 .5134974 43.70001
 .5716473 44.39999
 .4968817 43.5

C (1-5):
 .5384184 44
 .5550342 44.20001
 .3307348 41.5
 .5799552 44.5
 .4968817 43.5

End Face:
 .4968817 43.5

Drift Wall:

I (1-4):
 -.333853 33.5
 -.3920055 32.79999
 -.5 31.5
 -.4252344 32.39999

J (1-4):
 -.2092428 35
 -.4584633 32
 -.5 31.5
 -.4667711 31.89999

K (1-3):
 -.3587741 33.20001
 -.5083079 31.39999
 -.5415367 31

L (1-5):
 -.4916922 31.60001
 -.5415367 31
 -.5830735 30.5
 -.6246102 30
 -.5415367 31

M (1-5):
 -.5664577 30.70001
 -.5415367 31
 -.6079945 30.20001
 -.6661469 29.5
 -.6412259 29.79999

Air Temperature (C): 32.60001
Normalized Air Temperature: -.4086187
Average WP Temperature (C): 43.53754
Average Drift Wall Temperature (C): 31.5
Average Temperature of WP/DW (C): 37.51877

**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

Title: Professor of Civil Engineering and Director, DOE Waste Package Project,
University of Nevada, Las Vegas

Student Assistant: Rajkumar Rajagopalan

B.1.1.1. Presentation of paper at HLNW Conference

A paper titled, "Failure of MPC Overpack and Inner Container Under Corrosion and Mechanical Stresses in a Backfilled Drift", was prepared and presented in the HLNW Conference held in May '95 at Las Vegas. The final thickness and time at failure of the proposed 100mm thick overpack and 9.5mm thick inner container of a Multipurpose canister have been assessed due to loads resulting from temperature, overburden, backfill pressure and seismic loads. Critical stresses at various reduced thicknesses resulting from pitting corrosion over the years of emplacement, have been evaluated using Finite Element Analysis. Both simple and continuous support conditions of the overpack have been considered in the analysis. The anticipated failure time of the canister due to corrosion of overpack and inner container, is further reduced due to overburden, self-weight and seismic loads.

B.1.1.2. Damage Assessment of the MPC in a Dented Region

The purpose of this research is to establish a relationship between the size of a dent and the maximum stresses and strains developed in the dented region that may develop in an MPC, due to an accidental impact that does not cause an extensive failure of the container, thus obviating its rejection. The research will help us in establishing a method which is easy to understand and apply, for damage assessment.

Numerical simulations using FEA will be used to study the damage due to a slow and steady applied load on pipe sections modeling the MPC. We will attempt to establish some criteria to determine the extent of damage sustained by an MPC, in an accident resulting from normal handling conditions, by measuring the size and shape of the dent and by relating the aspect ratios of the dent to the maximum stresses and strains in the dented region. Consequently, a potential local failure of the container may be determined by measuring the geometry of the dent.

The knowledge gained from this research may be used to determine whether to continue using the canister or to reject it and opt for another canister.

The size of a permanent dent and the potential damage that may result from the dent can be studied by relating the size of the dent to the energy absorbed by the dented region. The maximum stresses and strains in the dent will also be related to the size and the aspect ratio of the dent as well as to the aspect ratio of the container.

B.1.1.2.1. Preliminary Finite Element Analysis Results

A nonlinear step by step static analysis was performed on a 16 inch diameter shell model having a thickness of 1/4 inch and a length of 48 inches. This ensures the diameter to thickness ratio of 64, which is approximately the same as a full size MPC, using a scaling ratio of four, the length of the MPC being approximately 193 inches. Only one quarter of the container is modeled due to symmetry. Based on previous research, an aspect ratio of 1 x 1 x 1 is chosen until a distance of 18 inches and the model was meshed with increasing size of elements there on, maintaining an aspect ratio below 5. The model consisted of approximately 4500 elements and 4500 nodes. A yield strength of 36000 psi and an ultimate strength of 80000 psi for the material was used in the analysis. Results from the nonlinear analysis are shown in Figures 7 to 17. The nonlinear analysis was performed by applying a linear increase in pressure until a maximum of 3250 psi over a square inch area on the quadrant. This is equivalent to an applied load of approximately 13000 lbs. The maximum displacement at the center was 0.16 inch which is 1/100 of the diameter as shown in Figure 17. The axial and circumferential stresses are plotted at various applied pressures for node 1, 8 and 442 in Figures 9 to 16. Node 1 is the central node on the shell while node 8 and node 442 lie on the circumference and axial direction respectively, where the shell changes its curvature due to the applied load. Figure 7 shows the stress plot in the circumferential direction for an applied pressure of 3250 psi. Figure 8 shows the deformed shape of the container shell for an applied pressure of 3250 psi. The location of the plastic hinge in the circumferential direction is clearly seen from these figures. Figures 13 and 14 show the Principal and Von Mises stresses for node 1 and node 8. From these figures, it can be seen that the material had yielded and reached a Principal stress of approximately 60000 psi. The analysis will be further continued until a desired dent depth of approximately 0.1D is obtained. The material is expected to fail beyond this point. Figure 15 and 16 show the stresses for node 442. As seen from the plots, the stresses are still below yield in the axial direction where the shell changes its curvature due to the applied pressure.

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Figure 7 Stresses in the Circumferential Direction for an Applied Pressure of 3250 psi

Figure 8 Deformed Shape of the Cross-section of the Container Shell for an Applied Pressure of 3250 psi

Figure 9 Axial Stress Corresponding to Various Applied Pressures for Node 1

Figure 10 Axial Stress Corresponding to Various Applied Pressures for Node 8

Figure 11 Circumferential Stress at Various Applied Pressures for Node 1

Figure 12 Circumferential Stress at Various Applied Pressures for Node 8

Principal Stress (P1)

Figure 13 Principal Stress at Various Applied Pressures for Node 1 and Node 8

Von Mises Stress

Figure 14 Von Mises Stress at Various Applied Pressures for Node 1 and Node 8

Figure 15 Axial Stress at Various Applied Pressures for Node 442

Figure 16 Circumferential Stress at Various Applied Pressures for Node 442

Figure 17 Displacement Profile Along the Axis of the Shell

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

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

TASK B.2- Design requirement of Various Rock Tunnel Shapes for Long Term Storage for High Level Nuclear Waste

Richard V. WYMAN, PhD. PE, Professor Emeritus of Civil Engineering

Nadia KANDALAFT- LADKANY, MSCE. Associate, Nuclear Waste Package Project

Investigation of Stress in a Circular Backfilled Tunnel Due to Overburden and Thermal Loading of Horizontally Placed 21PWR Multi-purpose Canisters

B.2.1. Actual work

Introduction

In our previous study we used thermal loading data due to the horizontally placed MPC's in the drifts. The data is from an M & O Group report by T. Doering & B. Bahney regarding the thermal analysis for two thermal loading cases of 114 Kw/acre and 57 KW/acre. The study was a 2 dimensional analysis for a horizontally emplaced canister in the drift without backfill.

Table 1 shows the temperature values at X=0 which is at the rock wall and X= 1, 3, 5, &13 m in the rock at different years after horizontal emplacement of the MPC's for the thermal load case of 114 KW/acre and a drift spacing of 26 m and waste package spacing of 14 m..

0 (m)	1 (m)	3 (m)	5(m)	13 (m)	
86.16	72.36	52.12	47.964	31.34	AT 1 YEAR
143.48	131.25	112.45	106.986	85.13	AT 10 YEARS
173.02	166.78	156.93	153.13	137.93	AT 60 YEARS
170.9	166.5	159.52	156.756	145.7	AT 100 YEARS
166.91	164.18	159.85	158.092	151.06	AT 200 YEARS
151.31	150.37	148.89	148.29	145.89	AT 1000 YEARS

Table 1. Temperature values for 114 KW/acre used in drift stress and displacement computations

Table 2 is the temperature values for the thermal load case of 57 KW/acre with drift spacing of 26 m and waste package spacing of 14 m with no backfill.

0 (m)	1 (m)	3 (m)	5 (m)	13 (m)	
85.57	71.15	52.36	46.842	24.77	AT 1 YEAR
125.26	112.67	95.38	86.634	51.65	AT 10 YEARS
131.6	125.46	116.85	112.444	94.82	AT 60 YEARS
125.5	121.2	115.2	112.08	99.6	AT 100 YEARS
118.95	116.32	112.63	110.732	103.14	AT 200 YEARS
106.78	105.89	104.65	104.02	101.5	AT 1000 YEARS

Table 2. Temperature values for 57 KW/acre used in drift stress and displacement computations.

The thermal studies for a backfilled tunnel of the same diameter of 7.6 m (25 ft) were done by S. Lingineni from the M&O Group according to Mishra's model of flux equivalent horizontal concentric rings.

Lingineni's temperature data in the container, backfill and rock walls for different thermal loading conditions : 28 kW/acre, 57 kW/acre and 114 kW/acre were obtained also at different years after horizontal emplacement of the MPC's. The highest temperature profile values in the drift was caused by a waste package spacing of 8 m. To insure the constant value of the waste package spacing there was different drift spacing (DS) for different thermal loading. Tables 3, 4, and 5 shows those values. Tables 6, 7, and 8 shows the temperature values for the same thermal loading cases and for a backfilled drift but for a drift spacing (DS) of 26 m and for various waste package spacing(WPS).

0 (m)	1 (m)	3 (m)	5 (m)	
187.24	168.55	140.65	120	AT 10 YEARS
203.6	193.1	177.5	166	AT 60 YEARS
202.4	196.3	187.3	180.7	AT 120 YEARS
195.6	190.8	183.75	178.5	AT 200 YEARS
161.85	160.53	158.56	157.1	AT 1000 YEARS

Table 3. Temperature values for 114 KW/acre and DS 45 m.

0 (m)	1 (m)	3 (m)	5 (m)	
148.3	129.6	101.7	81.1	AT 10 YEARS
139.1	128.6	113	101.5	AT 60 YEARS
129.2	123.1	114.1	107.5	AT 120 YEARS
124.2	119.4	112.4	107.1	AT 200 YEARS
104.5	103.1	101.2	99.7	AT 1000 YEARS

Table 4. Temperature values for 57 KW/acre and DS 90 m.

0 (m)	1 (m)	3 (m)	5 (m)	
115.3	96.5	68.6	48	AT 10 YEAR.
106.7	96.2	80.6	69.1	AT 60 YEARS
92.8	86.7	77.8	71.1	AT 120 YEARS
85.8	81.1	73.9	68.7	AT 200 YEARS
68.2	66.9	65	63.5	AT 1000 YEARS

Table 5. Temperature values for 28 KW/acre and DS 181 m.

0 (m)	1 (m)	3 (m)	5 (m)	
158.5	147.8	131.8	120	AT 10 YEARS
187.5	181.6	172.6	166	AT 60 YEARS
193.1	189.7	184.5	180.7	AT 120 YEARS
188.3	185.6	181.5	178.5	AT 200 YEARS
159.8	159	157.9	157.1	AT 1000 YEARS

Table 6. Temperature values for 114 KW/acre and WPS 14 m.

0 (m)	1 (m)	3 (m)	5 (m)	
100.4	95	87	81.1	AT 10 YEARS
112.3	109.3	104.8	101.5	AT 60 YEARS
113.7	112	109.4	107.5	AT 120 YEARS
112	110.6	108.6	107.1	AT 200 YEARS
101	100.7	100.1	99.7	AT 1000 YEARS

Table 7. Temperature values for 57 KW/acre and WPS 28 m.

0 (m)	1(m)	3 (m)	5 (m)	
57.6	55	51	48	AT 10 YEARS
74.5	73	70.8	69.1	AT 60 YEARS
74.2	73.3	72	71.1	AT 120 YEARS
71.1	70.5	69.5	68.7	AT 200 YEARS
64.2	64	63.7	63.5	AT 1000 YEARS

Table 8. Temperature values for 28 KW/acre and WPS 56 m.

Temperature profiles were used as input to a 2-D finite element model. All three loading cases were studied (28 KW/acre, 57 KW/acre and 114 KW/acre) at 10, 60 200, and 1000 years after emplacement of the MPC and the backfill.

Analysis

The geometry in figure 1 is a schematic figure which shows the MPC horizontally emplaced in a drift of 7.6 m diameter and resting on an invert material of 1.8 m thickness and later in time the drift will be backfilled with a gravel material of a thickness of 5 m.

In this study the container is considered to be continuously supported along its length so the weight of the canister is uniformly distributed on the invert material. Also the backfill material will exert pressure on the rock wall as well as the canister and this will be calculated in the finite element analysis.

Figure 1. Schematic view of the MPC and the drift

Half drift models were used due to symmetry of drift and loading. Finite element mesh uses triangular elements in the rock, backfill and the engineered invert material. It is a plane strain condition where triangular elements have two displacements at each node. Gap elements were used to separate rock, backfill, invert material and canister surfaces from each other. Gap elements accept compressive stress only which provide us with amount of pressure applied on the rock wall and on the canister.

When the temperature values in the rock increase the compressive stresses in the rock wall increase too which in return may cause crushing in the rock. Studying the temperature values available to us worst case scenario is at 60 yrs for most thermal loadings.

Cosmosm, a finite element analysis system, version 1.71 of May 1994 was used for this analysis. Material property data provided by the Reference Information Base of August 1990. Table 9 shows the mechanical properties for the TSW2 rock mass. Only one value for the compressive strength of the TSW2 was available and it is at ambient temperature. There is a pressing need for more data concerning the crushing stress for the TSW2 rock mass with elevated temperature. Therefore in this study we were not able to make conclusive judgement whether failure can occur in certain places or at any certain time for any thermal loading. The study was of a comparative nature between all the cases.

Table 10 shows the thermal expansion coefficient of the rock mass for the repository level and the very near field close to the drift opening according to the temperature. We considered the thermal expansion coefficient for the rock to be temperature dependant. Therefore the finite element model was divided to 52 surfaces each surface will have constant temperature value and different material properties. To accommodate the rapid change in temperature in the first 3 m close to the opening of the tunnel, the surfaces are very dense. Figure 2.

	Unconfined Compressive Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio
TSW2 Intact Rock from wells USWG-1, USW GU-3, USW G-4	155 +/- 59	32.7 +/- 4.6	.22 +/- .03
ROCK MASS (TSW2)	75	15.2	.22

Table 9. TSW₂ rock, Mechanical Properties, YMP/RIB & OCRWM.

Linear Thermal Expansion Coef..	25° - 50°	50° - 100°	100° -150°	150° -200°	200°-250°
TSW ₂ for Very Near Field	5.40E-6	8.0E-6	9.8 E-6	17.0 E-6	25.0 E-6
TSW2 Rock Mass Environment	9.1 E-6	8.2 E-6	6.8 E-6	9.7 E-6	No data

Figure 10. Linear Thermal Expansion Coefficients for TSW₂ Rock @ Temperature Ranging from 25°C to 250°C, From Reference, YMP/RIB

The very near field was assumed to be in the range of 1.2 to 1.5 m and the stresses will be considered as unconfined compressive stress.

The overpack of the canister has a Young's modulus of 200 G Pa and the coefficient of linear thermal expansion¹ is 18xE-6 and a density of 7.849 g/cm³ (490 pcf). The invert material was considered to be of the same material as the crushed rock due to the tunnel boring machine and compacted and cemented together with some additive and the Young's modulus is about 6890 Mpa and the coefficient of linear thermal expansion³ 12.6xE-6 and a density of 2.32 g/cm³. The backfill material was assumed to be of sand and gravel and since the more dense the mixture the higher Poisson's ratio and the range is between of 0.2 - 0.35, we assumed to have a dense mixture with a Poisson's ratio of 0.35. Young's modulus is 50-150 MPa (1000-3000 ksf) from the cone penetration resistance² and a density of 1.9 g/cm³.

Boundary conditions are defined for two different load case.

Load case I. In this case where gravity and overburden are the loads applied, no horizontal

translations in the X direction were allowed on the YZ plane boundaries and no vertical translations on the XZ plane at the bottom of the model and vertical displacement on the XZ plane on top of the model were allowed to accept the distributed load due to the rock weight above the model and the gravity loading of the model was accounted for directly in the finite element model.

Load case II. In this case where temperature on the node is the only load applied, no horizontal translations in the X direction were allowed on YZ plane boundaries and no vertical translations were allowed on the XZ plane at the top and bottom of the model.

RESULTS

0	1	3	5	Through the crown	
-18.5	-13	-6.6	-3.9	sx	28kw/acre
-35	-24.4	-14.5	-11.8	sx	57kw/acre
-70.4	-50.8	-20.8	-18.3	sx	114kw/acre

0	1	3	5	Through the waist of the drift	
-24.5	-15.8	-7.5	-4.2	sy	28kw/acre
-50.4	-26.3	-15.3	-12.3	sy	57kw/acre
-96.4	-54.9	-22.9	-18.4	sy	114kw/acre

Table 11. Comparison of stresses at 10 years after emplacement with backfill material and for different thermal loading cases.

0	1	3	5	x	Thermal Load	crown
-24.6	-19.5	-12.9	-10.3	Sx	28kw/acre	
-37.3	-28.5	-18.3	-16.9	Sx	57kw/acre	
-122.1	-69.1	-42.97	-35.9	Sx	114kw/acre	

Table 12. Comparison of stresses at 60 years after emplacement with backfill material and for different thermal loading cases along the vertical symmetry line .

0 (m)	1 (m)	3 (m)	5 (m)		Thermal load	Waist
-28	-21	-13.5	-10.6	Sy	28 Kw/acre	60 yrs
-49.8	-30	-18.8	-17	Sy	57 KW /acre	
-168.8	-99.6	-51.5	-47.8	Sy	114 KW/acre	

Table 13. Comparison of stresses at 60 years after emplacement with backfill material and for different thermal loading cases along the horizontal line across the rib (waist) of the tunnel.

Tables 11, 12 and 13 show stress results for backfilled drifts at 10 years after emplacement (Table 11) and at 60 years after emplacement (Table 12& 13).

The tables show horizontal stresses, Sigma X, at the crown and vertical stresses, Sigma y, at the waist of the tunnel.

Four conclusions are apparent from the results shown :

1. That the stress in the rock decrease rapidly from maximum at the surface of the tunnel to about 30% or less of the maximum values at a distance of 5 meter into the rock.
2. Stresses at the inner surface of the tunnel exceed in the case of 114 kw/acre loading condition of 75 Mpa for the rock mass strength of TSW2 (shown in the table 9 at ambient temperature), which may be lower than 75 Mpa at elevated temperature.
3. Stresses remain above the 75 Mpa level for the 114 Kw/acre loading condition within approximately half a meter inside the rock for 10 years after emplacement. Sixty years after emplacement. stresses above the 75 Mpa penetrate to within 1.5 meter inside the rock.
4. Stresses remain below the 75 Mpa level for all other loading conditions.

Figures 3 to 9 show details of the stress distribution for the various thermal loading cases shown in the tables and discussed above.

Results from various thermal loading conditions and time after emplacement along with the comparison between backfill and no backfill conditions will be shown and discussed in our final project report.

Figure 2.

Figure 3.

Figure 4.

Sigma_X

HORIZONTAL STRESSES

THERMAL LOAD 28 KW/ACRE

060 YRS AFTER EMPLACEMENT

HORZ. STRESSES ALONG THE VERT. LINE
THROUGH THE BOTTOM OF DRIFT 0-5 M IN THE ROCK

Figure 5.

Sigma_X

16.200

11.200

6.2400

1.2800

-3.690

-8.650

-13.60

-18.60

-23.50

-28.50

-33.50

HORIZONTAL STRESSES

THERMAL LOAD 28 KW/ACRE

@60 YRS AFTER EMPLACEMENT

HORZ. STRESSES ALONG THE VERT. LINE
THROUGH THE CROWN @-5 M IN THE ROCK

Figure 6.

Figure 7.

Figure 8.

Figure 9.

**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

Title: Professor of Civil Engineering and Director, DOE Waste Package Project,
University of Nevada, Las Vegas

Student Assistant: Yuping Huang

B.2.2.1. Presentation at HLNW Conference

A paper titled, "Stresses in Faulted Tunnel Models by Photoelasticity and Adaptive Finite Element" was prepared and presented in the HLNW Conference held in May 1995 at Las Vegas. So far, stress concentration factors at specified locations in the model have been found by Photoelastic (PE) experiment and Finite Element (FE) method due to short saw cuts representing minor failures in the tunnel. Fault studies continue to determine the overall behavior of tunnels and stress concentration factors due to a spread in the length of the fault crossing the tunnel. Adaptive mesh refinement technique (H method) is used in the FE modeling to achieve a close correlation between results from the PE testing and numerical FE Method.

B.2.2.2. Stresses in Faulted Tunnel Models by Photoelasticity and Adaptive Finite Element

The aim of this part of the Nuclear Waste Package Project research is to investigate the stresses in a faulted mountain, such as the Ghost Dance¹ Fault at Yucca Mountain, and the effect of the fault on the stability of drifts in a proposed High Level Nuclear Waste Repository.

In our previous work^{2,3}, we investigated the stress patterns in the rock tunnel walls of a proposed High Level Nuclear Waste (HLNW) repository. Two dimensional studies² and 3-D studies³, using FE models of the rock tunnels, were evaluated due to overburden loads and due to the thermal loading, 10 years after the emplacement, of the HLNW Canisters in vertical emplacement holes. Depending on the formal results, we tried to investigate the stress effect of an existing rock fault that cuts through the tunnels in last year's research⁴. Results from last year's research were not much correlated to each other from Photoelastic (PE) measurement and Finite Element (FE) Analysis at the tips of the crack, because of the much smaller size of the crack compared to the element size around it. Meshing must be refined in the vicinity of the crack tips. An Adaptive H method is used in this year's research.

In our experiments, the plexiglass photoelastic and the numerical finite element models represent two parallel square openings (tunnels) having rounded corners and one adjacent circular opening (tunnel). The circular opening, with a diameter that equals to the side length of the square,

is placed directly under the square openings, at a clear distance of about 80% of the square side length. The fault in the rock is depicted as a crack in the models, and having the same angle of an incidence with the tunnels. 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 stresses, P , are measured by both the PE 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. At the final step, in order to investigate the size influence of the tip, the width of the saw cut is reduced from 0.021 in. to 0.007 in.. The Adaptive H method is used in the FE modeling. The H method progressively improves the mesh by refining it, especially at the opening corners and 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 and K slowly increase with the decrease in the tolerance, and thus the element size, becomes somewhat insensitive to the flatness or roundness of the fault tip in the model. The investigation shows that, except at the tip of the fault, the principal stresses and the calculated K from both techniques are within 15% from each other at the predetermined points. It is also shown that, the principal stresses are very sensitive to the size of the tip (average about 130% increasing). Since plastic material behavior shows up in the vicinity of the crack tips, the measured values of principal stress from PE method are generally lower than those obtained by the FEA method in the region of the crack tip.

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Figure 1. Model of Two Square and One Adjacent Circular Tunnel with Partially Extended Faults Showing Vertical Stress Distribution.

Figure 2. Adaptive Mesh Around the Lower Fault Region at Various Tolerance Errors and Showing Flat and Rounded Faulted Tips.

d) Flat Fault Tip

e) Round Fault Tip

Figure 2. Adaptive Mesh Around the Lower Fault Region at Various Tolerance Errors and Showing Flat and Rounded Faulted Tips.

FINITE ELEMENT ANALYSIS, ADAPTIVE H METHOD									PHOTOELASTIC MEASUREMENTS		
			4% Tolerance Error		10% Tolerance Error		20% Tolerance Error				
			P(MPa)	K	P(MPa)	K	P(MPa)	K			P(MPa)
Tip Point of Fault	Flat Top Model	Upper Point	9.03	13.8	6.99	10.7	5.22	8.00	Upper Point		
										11.7	17.9
		Lower Point	-29.9	20.9	-25.8	18.1	-17.5	12.3	Lower Point		
										-12.6	8.80
	Rounded Top Model	Upper Point	9.00	13.8	6.97	10.7	5.25	8.04	Background Principal Stresses: P1=0.653 P2=-1.43		
		Lower Point	-28.4	19.9	-23.0	16.1	-16.3	11.4			
Corner Point of Rectangular Tunnel				-8.76	2.72	-8.35	2.59	-7.17	2.23	-8.37	2.60
										Background Principal Stresses: P1=0.0, P2=-3.22	

Table 1. Principal Stresses, P, and Stress Concentration Factors, K, at the Tip of a Fault and at a Corner Point in a Faulted Tunnel Model. Upper and Lower Points Refer to the Top & Bottom Fillets at the Tip of the Cut.

Width of the Fault		0.533 mm	0.178 mm	Increasing (%)
P (MPa)	Upper Point	11.7	31.6	170
	Lower Point	-12.6	-24.4	94
K	Upper Point	17.9	48.4	170
	Lower Point	8.8	17.1	94

Table 2. Principal Stresses, P, and Stress Concentration Factors, K, at the Tip of the Fault in Photoelastic Measurement with Different Size of the Width.