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**Project Title/Work Order**

105 K East Isolation Barrier Acceptance Analysis Report / L1175

**From**
K. J. McCracken
Mechanical Engineering

**Date** 5/26/95

**EDT No.** 612137

**ECN No.** N/A
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K-Basin Field Engineering

3. From: (Originating Organization)  
K. J. McCracken  
Mechanical Engineering

4. Related EDT No.:  
N/A

5. Proj./Prog./Dept./Div.:  
51400 / LI/75

6. Cog. Engr.:  
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7. Purchase Order No.:  
N/A

8. Originator Remarks:  
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11. Receiver Remarks:

16. Approval Designator (F)  
Reason for Transmittal (G)  
Disposition (H) & (I)

E, S, G, D or N/A  
(see WHC-CM-3-5, Sec. 12.7)

1. Approval  
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BD-7400-172-2 (04/94) GEF097
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105 K EAST ISOLATION BARRIER ACCEPTANCE ANALYSIS REPORT

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INDEPENDENT REVIEW

Document Reviewed 105-K5 Isolation Barrier Leak Rate Acceptance Test Report

Author K. J. McCracken Report No. WHC-SD-SNF-TRP-006 EDT No. 612137

The subject document has been reviewed by the undersigned. The reviewer reviewed and verified the following items as applicable [EP.4.1].

- Engineering Specification
- Design Input
- Basic Assumption
- Approach/Design Methodology
- Related Information
- Conclusion/Result Interpretation

D. A. Wallace  
Reviewer  

5/30/95  
Date
## CHECKLIST FOR INDEPENDENT REVIEW

**Document Reviewed**: 105-KE Isolation Barrier Leak Rate Acceptance Test Report  
**Author**: K. J. McCracken

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TABLE OF CONTENTS

1.0 INTRODUCTION ................................................................. 1
2.0 DEFINITIONS ................................................................. 1
3.0 TEST SPECIFICATION REVIEW .............................................. 2
4.0 ACCEPTANCE TEST PROCEDURE/ACCEPTANCE TEST REPORT .......... 3
5.0 ACCEPTANCE TEST RESULTS ................................................ 3
   6.1 RESULTS DISCUSSION ..................................................... 4
      6.1.1 Field Isolation Barrier Leakage Estimate .................. 5
      6.1.2 Discharge Chute Leakage and Additions, Evaporation, and
           Instrumentation Effects ........................................ 9
      6.1.3 Adjusted Isolation Barrier Leakage Computation .......... 12
   6.2 CONCLUSION ............................................................. 12
7.0 ACCEPTANCE TEST REPORT ................................................ 13
8.0 QUALITY ASSURANCE ..................................................... 13
9.0 REFERENCES ................................................................. 14

APPENDICES

APPENDIX A. KE-BASIN BASELINE LEAK TEST FINAL OBSERVATIONS ....... A-i
APPENDIX B. KE-BASIN ISOLATION BARRIER LEAK TEST PROGRAM LEAK.EXE .. B-i
APPENDIX C. KE-BASIN ISOLATION BARRIER LEAK TEST #2 DATA ANALYSIS
               UTILIZING LEAK.EXE ........................................ C-i
APPENDIX D. KE-BASIN ISOLATION BARRIER LEAK TEST #2 TK SOLVER
               ANALYSIS ..................................................... D-i
APPENDIX E. KE-BASIN ISOLATION BARRIER TEST EQUIPMENT
               AND INSTRUMENTATION ........................................ E-i
FIGURES

Figure 1. Revised Isolation Barrier Acceptance Criteria ..................................... 3
Figure 2. Acceptance Test Basin and Discharge Chute Level Data ......................... 4
Figure 3. Level Differential vs. Time (4/10/95) .................................................. 6
Figure 4. Isolation Barrier Leak Rate vs. Time (4/18/95) ...................................... 8
Figure 5. Final Extrapolated Leak Rate with Acceptance Criteria Comparison ........ 12

TABLE

Table 1. Error Analysis Table ............................................................................... 12
1.0 INTRODUCTION

The objective of this document is to report and interpret the findings of the isolation barrier acceptance tests performed in 105KE/100K. The tests were performed in accordance with the test plan (McCacken 1995c) and acceptance test procedure (McCacken 1995a). The test report (McCacken 1995b) contains the test data. This document compares the test data (McCacken 1995b) against the criteria (McCacken 1995a, c). A discussion of the leak rate analytical characterization (Irwin 1995) describes how the flow characteristics and the flow rate will be determined using the test data from the test report (McCacken 1995b).

The barriers must adequately control the leakage from the main basin to the discharge chute to less than the 1,500 gph (5,680 lph) Safety Analysis Report (SAR 1994) limit.

Two modes of water loss were considered; basin and/or discharge chute leakage, and evaporation. An initial test (Test 1, 3/22/95) established baseline leakage data and instrumentation performance. For the initial test the results of test 1 are reported in Appendix A.

Test 2 evaluated the sealing performance of the isolation barrier by inducing an 11 in. (27.9 cm) level differential across the barrier. The leak rate at this 11 in. (27.9 cm) level is extrapolated to the 16 ft. (4.9 m) level differential postulated in the DBE post seismic event. If the leak rate, adjusted for evaporation and basin leakage (determined from Test 1), is less than the SAR limit of 1,500 gph (5,680 lph) at a 16 ft (4.9 m) level differential, the barriers pass the acceptance test.

2.0 DEFINITIONS

BASIN - That portion of 100KE used for irradiated fuel storage; is hydraulically connected to the Weasel Pit, Filter/Viewing Pits, Dummy Elevator Pit, and South Loadout Pit; and is hydraulically separated from the Discharge Chute, by the isolation barrier and the North Loadout Pit (Sand Filter Backwash Pit) by a separate barrier.

DISCHARGE CHUTE - That portion of 100KE that contains no irradiated fuel; is hydraulically separated from the basin by the isolation barriers; and is hydraulically connected to the Reactor Fuel Discharge Pit.

ISOLATION BARRIER - The two steel barriers and (McCacken 1995) the mounting brackets that were installed in the discharge chute openings, isolating the basin from the discharge chute.
TEST 1 - The initial baseline test for basin leakage and instrumentation set-up. The basin and discharge chute levels were equal to measure evaporation and construction joint losses.

TEST 2 - The isolation barrier leak test where a level differential was induced across the isolation barrier to determine leak tightness.

3.0 TEST SPECIFICATION REVIEW

As discussed in McCracken 1995c, the acceptance criteria of 1,500 gallons (5,680) per hour at a 16 ft. (4.9 m) corresponded to 358 gallons (1,360 l) per hour for a turbulent criteria and 86 gallons (326 l) per hour for a laminar criteria at an 11 in. (27.9 cm) level differential between the basin and discharge chute. These leak rate values corresponded to a turbulent 0.64 in. (16.2 mm) or a laminar 0.16 in. (4.1 mm) rise in the discharge chute in one hour provided no construction joint leakage.

McCracken 1995c and Irwin 1995 discussed the turbulent relationship between flow (Q) through the isolation barrier and differential water level (ΔH) across the isolation barrier as being:

\[ Q = \sqrt{\Delta H} \]  

(1)

and the laminar flow relationship as being:

\[ Q = \Delta H. \]  

(2)

Figure 1 depicts the acceptance criteria for the laminar and turbulent flow regimes relationship.
4.0 ACCEPTANCE TEST PROCEDURE/ACCEPTANCE TEST REPORT

The leak test procedure was conducted in accordance with the acceptance test procedure (ATP) (McCracken 1995a). The acceptance test report (ATR) (McCracken 1995b), documents completion of all ATP steps.

5.0 ACCEPTANCE TEST RESULTS

Figure 2 shows the basin and discharge chute level data prior to and during the acceptance test. The ultra-sonic level detectors (USLDs) were set on different ranges to monitor the entire drawdown. With the basin and discharge chute levels equal, the USLDs were calibrated to read 2.0 in. (5.0 cm) and 12.0 (30.5 cm) in. respectively. Once the drawdown was initiated, observations indicated that as the discharge chute level was decreasing and the basin level was increasing as seen in Figure 2. The entire drawdown was monitored but the initial data was not stored until 15 minutes after the pump start. The entire drawdown was monitored but the initial data was not stored until 15 minutes after the pump start. Test 2 began at $T_s$, when the 11-in. (27.9 cm) level differential was obtained (discharge chute level down 10 in. (25.0 cm) and the basin level up 1 in. (2.5 cm)).
There were no basin water additions during the 24 hour test, but less than 1 gallon (3.8 l) of water was sprayed on the discharge chute walls every four hours. This was performed to minimize airborne contamination from the exposed discharge chute walls.

6.1 RESULTS DISCUSSION

The discussion of the test results is in the following format.

- Field Isolation Barrier Leakage Estimate
- Discharge Chute Leakage and Additions, Evaporation, and Instrumentation Effects
- Adjusted Isolation Barrier Leakage Computation
6.1.1 Field Isolation Barrier Leakage Estimate

Based on the 24 hour USLD test data, the flow through the isolation barrier at the 11 in. (27.9 cm) level differential was fully turbulent at a rate of 4.89 gpm (18.5 lpm). The following describes how these numbers were calculated.

The test data needed manipulation in accordance with Irwin 1995 to determine the leak rate and the flow exponent (0.5 for turbulent and 1 for laminar). The data was manipulated to obtain a leak rate in units of feet per hour. The leak rate is the difference between the basin and discharge chute water levels as it changed over time. Figure 3 displays the converted data. NOTE: The level differential did not exceed the expected 11 in. (29.7 cm).

Using these data conversions, the initial isolation barrier leakage was calculated from the counted data using three separate calculation methods: Grapher for Windows software; LEAK.EXE software; and TK!Solver software. The three separate methods and field calculations allowed a check to be performed verifying the results of each software package.

Grapher for Windows software (Golden Software) was used to establish the flow exponent and initial leak rate using differential level, time, and regression analysis discussed in Irwin 1995. The graphs displayed in this report were developed using the Grapher software.

LEAK.EXE is an independent software routine developed by Frank Schmittroth of Radiation Physics and Shielding. It uses using level differential and hourly time data to establish an initial leak rate, a flow exponent, and an uncertainty analysis. LEAK.EXE is a closed form solution of hand calculations verified by Grapher and TK Solver which are validated through the WHC purchasing requirements. A listing of the computer program and a sample on the final KW leak test are provided in Appendices B and C, respectively. The program was developed on the Hanford Site Sun Unix system and recompiled for use on a MS-DOS PC by the use of Microsoft Fortran.

From Irwin 1995, (105-K Basin Isolation Barrier Leak Rate Test Analytical Development), the initial leak rate is determined from the polynomial regression curve fit of the data in Figure 3.

---

1Grapher is a registered trademark of Golden Software, Inc., Boulder, Colorado.
2Windows is a registered trademark of Microsoft Corporation, Redmond, Washington.
3TK Solver is a registered trademark of Universal Technical Systems, Inc., Rockford, Illinois.
4MS-DOS is a registered trademark of Microsoft Corporation, Redmond, Washington.
5Microsoft Fortran is a registered trademark of Microsoft Corporation, Redmond, Washington.
A second order polynomial regression curve is fit to the differential height measurement, $h$, versus time data (Irwin 1995). The polynomial regression curve fitting is obtained by writing:

$$h(t) = x_1 + x_2 t + x_3 t^2$$  \hspace{1cm} (3)

where

- $h(t)$: differential w/respect to time (L)
- $x_1$, $x_2$, $x_3$: regression curve coefficient
- $t$: time (t).
\[ x_1 = h_{ti} \]
\[ x_2 = h_{ti}^{\alpha} b \]
\[ x_3 = \frac{\alpha}{2} b^2 h_{ti}^{2\alpha-1} \]

where

\[ h_{ti} \] initial level differential at time zero (L)
\[ \alpha \] flow regime exponent (dimensionless)
\[ b \] flow coefficient (1/t).

The quantities, \( h_{ti}, b, \) and \( \alpha, \) are readily found by inverting these equations:

The flow rate as a function of time can then be calculated from the following:

\[ Q_j = \left( \frac{-x_2}{x_1^\alpha} \right)^\alpha \left( x_1 + x_2 t_j + x_3 t_j^2 \right) \frac{L_3}{t} \]

where

\[ Q_j \] barrier flow rate at time \( t_j \left( \frac{L_3}{t} \right) \)
\[ A^* \] surface area parameter for basin and discharge chute (L²).

\( Q_j \) is the instantaneous flow rate at any given time, \( t_j, \) less than a critical time, i.e., the time at which the differential height is zero. The values for \( x_1, x_2, \) and \( x_3, \) are determined from the regression curve fit. The flow parameter, \( \alpha, \) is determined in terms of \( x_1, x_2, \) and \( x_3, \) from the equation noted above. At the initial time, \( t_j = 0, \) the flow rate, \( Q_j \) is at the initial differential height (specified to be 11 inches) is then determined by the following equation.

\[ Q_j = -x_2 A^*. \]

The equation for \( A^* \) is repeated as follows (Irwin 1995).

\[ \frac{1}{A^*} = \frac{1}{A_B} \frac{1}{A_{DC}}. \]

where

\( A_B \) is surface area of basin
\( A_{DC} \) is surface area of discharge chute
The data from Alward 1991 for area of the basin, $A_B$, and area of the discharge chute, $A_{DC}$. Calculates the value of $A^*$ to be 850.0 sq. ft. The value of $x_2$, noted in Figure 3 is in units of inches per hour, therefore to convert to gallons per minute, the initial leak rate can be calculated from;

$$Q_j = -x_2 A^* = -x_2 \left( \frac{850 \cdot 7.48}{12 \cdot 60} \right) \times 60 = -8.83 x_2 \times 60.$$  \hfill (9)

Figure 4 contains the values of the second order polynomial regression exponents, the calculation of the flow parameter, $a$, and the initial leak rate. Figure 4 depicts the isolation barrier leak rate as a function of time. This figure was determined utilizing equation 6 above.

**Figure 4.** Isolation Barrier Leak Rate vs. Time (4/18/95).

LEAK.EXE utilized the same methodology as noted above. The results from this program agree with the method utilized above and as noted on Figure 3.

The TK!Solver analysis consisted of: a polynomial regression on basin and discharge chute levels; conversion of fitted basin levels to gallons per hour leak rate using basin surface area.
The TK! Solver analysis consisted of: a polynomial regression on basin and discharge chute levels; conversion of fitted basin levels to gallons per hour leak rate using basin surface area (Alward 1991) and time differentials; and use of a power curve fit to establish the flow exponent and extrapolate the flow to the 16 ft (4.9 m) level difference using the fitted test level differentials and calculated basin leak rate. A sample run of this analysis is provided in Appendix D.

The initial barrier leakage, \( Q_i \), was determined from the field calculations and LEAK.EXE software and field calculations to be 4.89 gpm (18.5 lpm) at the 11.1 in. (28.2 cm) level differential with a fully turbulent flow (\( \alpha = 0.5 \)). This corresponds to a flow of 1,170 gph (4,430 lph) at a 16 ft (4.9 m) level differential.

Additional analysis with Grapher and LEAK.EXE account for data scatter to obtain 95% upper confidence limit (UCL) show a nominal \( Q_i = 4.89 \pm 0.004 \) gpm (18.5 \pm 0.023 lpm) and \( \alpha = 0.52 \pm 0.001 \). Utilizing this

\[
Q_i^{\text{extrapolated}} = Q_i \left( \frac{\Delta H_{16}}{\Delta H_{11}} \right)^{\alpha} \times 60
\]

\[
Q_i^{\text{extrapolated}} = 4.89 \text{ gpm} \left( \frac{16 \times 12}{11.05} \right)^{0.524} \times 60 = 1,304 \pm 1 \text{ gph}
\]

where

- \( Q_i^{\text{extrapolated}} \): Leak rate extrapolated to the 16 ft (4.9 m) level differential
- \( \Delta H_{16} \): 16 ft (4.9 m) level differential
- \( \Delta H_{11} \): 11.126 in. (28.26 cm) level differential.

This leakage does not account for evaporation, discharge chute leakage and additions, or instrumentation effects. These effects are discussed below. Instrumentation affects are addressed in the test plan (McCracken 1995c).

### 6.1.2 Discharge Chute Leakage and Additions, Evaporation, and Instrumentation Effects

#### 6.1.2.1 Discharge Chute Leakage and Additions

Test 1 was conducted both prior to and after the final leak test to validate the instrumentation network, and to establish baseline data for K East. These test observations are in Appendix A, 105 K East Test 1 Observation Report. The data obtained from this shows there was no apparent leakage from the basin or discharge chute during the test.

The water that was sprayed during the test to minimize basin airborne contamination is considered negligible since the total water addition was under 6 gallons (22.7 l) over the 24 hours. This amount of water would have raised the discharge chute level a nominal 8.2E-4 in. (20.8 \( \mu \)m) or change the leak rate by 0.25 gph (0.95 lph).
6.1.2.2 Evaporation Effects

Evaporation is included for the flow analysis because evaporation from the basin contributes to the basin level decrease and the discharge chute level increase. The level changes in the basin and discharge chute due to evaporation would cancel each other, but due to the basin and discharge chute surface area differences, the volumetric rates are different. The volumetric calculations for the discharge chute assumed that the evaporation rate was approximately equal on the basin and reactor sides of the banana wall. (A more conservative approach than McCracken 1995c.)

The vernier evaporation detector (VED) detected a 0.028 in. (0.07 cm) level change over the 24 hour test period. This level change corresponds to an average VED, basin, and discharge chute evaporation rate of 1.9E-3 gph (7.2E-3 lph), 6.35 gph (24 lph), and 0.7 gph (2.7 lph) respectively. Though this may appear high, it can be stated that the evaporation rate for the final leak test is bounded by these numbers.

The VED water temperature was maintained within ±2 °F (1.1 °C) of the basin water temperature throughout the test. Vent and Balance team performed air flow checks to verify that there was no parallel airflow above the VED and basin water surfaces (Vent and Balance air flow data is available in Appendix A, Table A-1). With these conditions met, the VED water level difference is the equivalent basin and discharge chute water level difference due to evaporation.

6.1.2.3 Instrumentation Sensitivity

The instrument sensitivity is defined as the sum of the squares of the instrument uncertainty. This effect was computed using the LEAK.EXE software and computed as ± 0.28 gph (0.98 lpm) at the 11 in (27.9 cm) level. The LEAK.EXE calculated a data uncertainty data reference as one standard deviation (1 σ) at ± 0.005 gpm.

6.1.2.4 Instrument Calibration

The instrument calibration was verified from post-test calibration checks in the WHC Standards Lab. They show no apparent instrumentation corruption that could invalidate or bias the test results. The post-test calibrations are located in Appendix V of the 105 K East Isolation Barrier Test Report (McCracken 1995b).

6.1.3 Adjusted Isolation Barrier Leakage Computation

The final isolation barrier leakage is described from the following equation.

\[ Q_{\text{corrected}} = Q_{\text{nominal}} + \Delta Q_{\text{evap}} + \Delta Q_{\text{data}} + \Delta Q_{\text{DC add}} \]  \hspace{1cm} (11)

(extrapolated with \( \alpha \) at 95% UCL and \( h_i \) at 95% UCL).
The final leak rate at the 11 in. (27.9 cm) level differential is 5.00 gpm (18.9 lpm) as computed in Table 1.

### Table 1. Error Analysis Table

<table>
<thead>
<tr>
<th>Initial Barrier Leakage $Q_{\text{nom}}$</th>
<th>Discharge Chute Leakage and Additions $\Delta Q_{\text{DC ADD}}$ (+/-)</th>
<th>Basin Evap $\Delta Q_{\text{EVAP}}$ (+/-)</th>
<th>Data Uncertainty at 95% UCL $\Delta Q_{\text{Dav E}}$</th>
<th>Total Effects (+/-)</th>
<th>Final Barrier Leakage at 95% UCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.89</td>
<td>+0.004</td>
<td>+0.106/-0.012</td>
<td>0.008</td>
<td>0.107</td>
<td>5.00</td>
</tr>
</tbody>
</table>

All values are in gpm at the 11 in. (27.9 cm) differential. Multiply by 3.79 to obtain lpm

The final isolation barrier leak rate at 95% UCL with an $a = 0.527 (0.525 \pm 0.002)$ given by Equation 10 is

$$Q_{\text{extrapolated}} = 5.00 \times \left( \frac{16 \times 12}{11.1142} \right)^{0.527} \times 60$$

$$= 1,344.8 \text{ gph.}$$

### 6.2 CONCLUSION

The K East isolation barriers pass the 1,500 gph (5,680 lph) acceptance criteria. After the evaporation and instrumentation effects are accounted for the adjusted leak rate is 1,350 gph (5,110 lph) with a 95% UCL as shown in Figure 5.

The results of this acceptance test can be used for future in-place testing as a baseline to examine the isolation barrier seals and epoxy degradation. The posulated laminar flow condition in the Test Specification and Test Plan (McCracken 1995c), can be disregarded for future isolation barrier inplace testing because flow through the isolation barrier was characterized as fully turbulent. The evaporation effects can also be dismissed because the rate is insignificant to the barrier leak rate over the 24 hour test duration.
7.0 ACCEPTANCE TEST REPORT

The Acceptance Test Report (McCracken 1995b) will contain a copy of the signed ATP steps, the raw data generated from the baseline and final leak tests, all test logs, J-7 ATP revisions, and all instrumentation post-test calibrations.

8.0 QUALITY ASSURANCE

The Acceptance Test Report and the Test Results will be Quality Assurance reviewed and approved by post-test instrument calibrations.
9.0 REFERENCES


APPENDIX A

KE-BASIN BASELINE LEAK TEST FINAL OBSERVATIONS
A1.0 PURPOSE

The purpose of the initial test was two-fold: instrument operation check and basin or discharge chute leak detection. The instrumentation check consisted of the following items: establishing air flow patterns above and below the grating; installing the instrumentation; verifying communication from the remote data logger to the computer base station located outside the basin; checking the ultra-sonic level detectors (USLDs) for accurate basin level and discharge chute measurement; and observing any evaporation from the vernier evaporation detector (VED).

The leak detection was accomplished by observing the data from the USLDs and the VED. If the basin level remained constant over the duration of the test, with no water being added and subtracting evaporation, there would be no detectable leak.

A2.0 PROCEDURE

Vent and Balance established air flow patterns per WHC-SD-SNF-ATP-005 Section 8.2.3 and 8.2.4. By using hot wire anemometers manually positioned above and below the grating at certain points in the 105-KE building (see Figure A-1) and by verifying which ventilation fans were operating, the airflow patterns across the basin water surface was established.

Figure A-1. Air Flow Measurement Locations

The instrument installation was performed in accordance with the 105-KW Isolation Barrier Leak Test Procedure (WHC-SD-SNF-ATP-004) Sections 8, 9, and 10. Once the equipment was installed and powered, the communications link was established and data collection began.

A-1
A3.0 RESULTS AND DISCUSSION

A3.1 AIR FLOW MAPPING

The results of the air flow tests are presented in Table A-1.

Table A-1. Basin Air Velocities at Air/Water Interface

<table>
<thead>
<tr>
<th>Map Point</th>
<th>N fpm</th>
<th>NE fpm</th>
<th>E fpm</th>
<th>SE fpm</th>
<th>S fpm</th>
<th>SW fpm</th>
<th>W fpm</th>
<th>NW fpm</th>
</tr>
</thead>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 level</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 above</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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</tr>
<tr>
<td>3 level</td>
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<td>0</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>4 below</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
The results of the air flow readings show that the air flow below the grating in all areas are negligible and the air flow readings above the VED are also negligible. This means that the evaporation due to air flow over the VED is the same as over the basin.

**A3.2 COMMUNICATIONS LINK**

All starting conditions matched the initial baseline test.

The wireless data logger remote and base station communications link was successful from the inside of the basin zone to the outer clean zone. A data sample is shown in Table A-2. The test was started at 4:00 p.m., April 1, 1995 and ended at 8:00 a.m., April 19, 1994, approximate duration: 16 hours.
Table A-2. Data Sample Baseline Test (4/18/95 - 4/19/95)

<table>
<thead>
<tr>
<th>TIME (s)</th>
<th>dc (in.)</th>
<th>bsn (in.)</th>
<th>dewpt (°F)</th>
<th>AirTp (°F)</th>
<th>airved (°F)</th>
<th>B1 (°F)</th>
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<td>64.8522</td>
<td>48.2009</td>
</tr>
</tbody>
</table>
A3.3 USLD DATA

Figure A-2 shows the data gathered from the basin, discharge chute and VED USLD’s during the final baseline test, which displays data within the calibration parameters. The specifications for each of the USLDs were ±0.02 in. for a 4 in. (0.051 @ 10.22 cm) span and ±0.06 in. for a 12 in. (0.15 @ 30.5 cm) span.
A3.4 EVAPORATION OBSERVATIONS

When the initial KE test was conducted the fan conditions did not match the conditions noted during the vent and balance airflow measurements. Vent and balance was rescheduled to retake the measurements after the final barrier test but when KE Test 2 was performed the fan conditions were the same as the vent and balance noting. KE Test 1 was rerun directly following KE Test 2 to eliminate any evaporation errors.
A3.4.1 Water Temperature

To determine the evaporation from the basin, the VED conditions needed to match the basin conditions as close as possible. It has already been established that the air flow across the VED matches that across the basin, so all that remains is to duplicate the water temperatures. Table A-3 shows some data for VED and average basin water temperature tracking while Figures A-3 and A-4 display the VED and basin temperature traces over the entire test duration (Baseline Test of 4/18/95 - 4/19/95).

Table A-3. VED Vs Basin Water Temperature Tracking Record Baseline Test 1

<table>
<thead>
<tr>
<th>Time</th>
<th>Basin Temp °F</th>
<th>VED Temp °F</th>
<th>Adjust Set Point Δ °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/18 4:53pm</td>
<td>47.9</td>
<td>46.9</td>
<td>--</td>
</tr>
<tr>
<td>7:53pm</td>
<td>48.0</td>
<td>47.0</td>
<td>--</td>
</tr>
<tr>
<td>10:53pm</td>
<td>48.2</td>
<td>47.2</td>
<td>--</td>
</tr>
<tr>
<td>11:50pm</td>
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<td>47.0</td>
<td>--</td>
</tr>
<tr>
<td>4/19 1:58pm</td>
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<td>47.0</td>
<td>--</td>
</tr>
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<td>47.0</td>
<td>--</td>
</tr>
<tr>
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<tr>
<td>9:00am</td>
<td>48.0</td>
<td>47.2</td>
<td>--</td>
</tr>
</tbody>
</table>

The VED detected 0.0028 in. (0.070 cm) drop in level which correlates to 152.5 gal (580 l) lost in the basin over the 16 hour initial baseline test duration due to evaporation which is 9.5 gph (36 lph) loss rate and 0.11 gph (4 lph) for the discharge chute.
Figure A-3. VED Temperature Trace (4/18/95-4/19/95).

Figure A-4. Basin Water Average Temperature Trace (4/17/95 - 4/19/95).
A3.4.2 Dew Point

The dew point sensor and thermocouple worked successfully throughout both the initial and final baseline tests. Figure A-6 displays the final baseline test data for dew point.

The dew point is needed, along with the total evaporation and basin water temperature, to calculate an evaporation constant for the basin. This can be provided if needed for future reference after the barrier leak test is performed.

The dew point correlates closely to the average Pacific Northwest Laboratory (PNL) weather data which means that no humidification is being added to the basin outside air inlet. The dew point can be obtained from PNL and no additional instruments are needed for future evaporation calculations, given the water temperature and the experimentally determined evaporation constant referred to above.

A3.4.3 Air Temperature

The air temperature definitely shows a slight diurnal trend as it slowly decreases at night and begins to rebound in the morning as shown in Figure A-7. Given any dew point temperature and corresponding air temperature, a relative humidity can be obtained to check with the K-Basin Operation's relative humidity.

Figure A-5. Dew Point Temperature Trace (4/17/95 - 4/19/95).
A4.0 SUMMARY

Some trouble was encountered with the initial baseline test run. Data analysis displayed erroneous spikes in the level data but the remaining thermocouple and dew point sensor data were unaffected. The problem was a ground fault in the USLDs, it was repaired and another baseline test was conducted several months later. After the final baseline test, data analysis revealed an apparent chiller malfunction through the rising basin water temperature that was not accounted for in the VED water temperature. Therefore the VED evaporation rate would be slightly different than the basin evaporation rate. This error would have an effect on the basin leakage observations, but by combining the initial and final baseline tests data, an accurate baseline basin leak rate can be defined.

It was shown in Appendix E. that due to instrument accuracy there was a negative leak rate in the basin, since water does not enter the basin without Operations support. Therefore, it is safe to conclude that there is approximately zero leakage through the construction joint to the ground at K-West.
Program kbleak

Parameter (n0 = 5000, nx = 3)
Dimension h(n0), hc(n0), tm(n0)
Dimension b(n0, nx), bth(3), btbi(nx,nx)
Dimension x(nx), sigx(nx), covx(nx,nx)
Dimension fld(2), wka(nx)
Character*60 title
Data lun, lout / 5, 6/

Read np measured times, heights, tm(k), h(k)

Read(lun, 'a') title
Write(lout, '1x, a') title

np = 0
15 Read(lun, *, end=16) fld
   np = np + 1
   tm(np) = fld(1)
   h(np) = fld(2)
   Goto 15
16 Continue
   Write(lout, '
   No. of data points =', i4)') np

Set up B-matrix
Do 1 k = 1, np
   tk = tm(k)
   b(k,1) = 1.0
   b(k,2) = tk
   b(k,3) = tk*tk
1 Continue

Write(lout, '
   h(t), 1st 5 pts. + last pt. --')
Do 20 k = 1, 5
20 Write(lout, 200) k, b(k,2), h(k)
Write(lout, 200) np, b(np,2), h(np)
200 Format(1x, i5, 1P2E12.4)

Calculate btbi = BBt'(-1)
Do 2 i = 1, nx
   Do 2 j = 1, nx
      sm = 0.0
      Do 3 k = 1, np
         sm = sm + b(k,i) * b(k,j)
      btbi(i,j) = sm
   2 Continue

Call Invert(nx, nx, btbi, wka)
Calculate x = BBt'(-1) Bt H
Do 4 i = 1, nx
sm = 0.0
Do 5 k = 1, np
5 sm = sm + b(k,i) * h(k)
4 bth(i) = sm
c
Do 6 i = 1, nx
sm = 0.0
Do 7 j = 1, nx
7 sm = sm + btbi(i,j) * bth(j)
6 x(i) = sm
c Calculate sum of squared resid.
hsig2 = 0.0
Do 8 k = 1, np
sm = 0.0
Do 9 i = 1, nx
9 sm = sm + b(k,i) * x(i)
hc(k) = sm
sm = h(k) - sm
hsig2 = hsig2 + sm * sm
8 Continue
Write(*, '(" hsigt2 = ", 1PE10.3)') hsig2
c Calculate Cov(x,x)
f = hsig2/(np-nx)
Do 10 i = 1, nx
Do 10 j = 1, nx
10 covx(ij) = f * btbi(i,j)
c Output x(i), std-dev
Write(lout, (" x(i) std-dev.") )
Do 11 i = 1, nx
11 write(*, '(2x,i5, lP2E13.3)') i, x(i), sigx(i)
c
ca = 2.0 * x(1) / x(2)**2
alf = ca * x(3)
alfsigt = ca * sigx(3)
Write(*, '(/" alpha ", 2F10.3)') alf, alfsigt
c astr = 850.0
c Conversion from in/ft and gal/ft3
cq = astr * (7.48/12.0)
ql = -cq * x(2)
qlsig = cq * sigx(2)
Write(*, '(/" q0, gal/hr", 2F10.2)') ql, qlsig
c Write h(t), hc(t) to file for plotting
Open(10, FILE="lk.plt")
Do 13 k = 1, np
13 Write(10, 201) tm(k), h(k), hc(k)
201 Format(1x, 1PE15.5,';',E15.5,';',E15.5,';')

End

Subroutine Invert(n, n0, a, wka)
Dimension a(n0,*), wka(*), det(2)
Data lunerr /6/

Call Spoco(a, n0, n, rcond, wka, ierr)

if (ierr .ne. 0) then
  write(lunerr,300) ierr
300 format(///'*** inversion error ierr=',i5,' ***///)
else
  job = 1
  call Spodi(a, n0, n, det, job)
endif

Fill out the matrix
Do 1 i = 1, n0
Do 1 j = i, n0
1   a(j,i) = a(i,j)

Return
End

Subroutine P3mtr(x, a)
Character*(*) a
Dimension x(3,3)
write(*,'(a," matrix")') a
write(*, 200) x(1,1), x(1,2), x(1,3)
write(*, 200) x(2,1), x(2,2), x(2,3)
write(*, 200) x(3,1), x(3,2), x(3,3)
200 format(1x,1P3e12.3)
Return
End
APPENDIX C

KE-BASIN ISOLATION BARRIER LEAK TEST #2
DATA ANALYSIS UTILIZING LEAK.EXE
The following calculation is from the LEAK.EXE PC program:

No. of data points = 1502  KETEST2  @ 4/17/95
-- h(t), 1st 5 pts. + last pt. --

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<th>Time (hrs)</th>
<th>Measured Ht (in)</th>
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<tr>
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<tr>
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<td>5</td>
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<tr>
<td>1502</td>
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\[ h_{sig2} = 2.090E+00 \]

\[ x(i) \quad \text{std-dev.} \]
- \( X1: 1.109E+01 \quad 2.887E-03 \)
- \( X2: -5.523E-01 \quad 5.333E-04 \)
- \( X3: 7.220E-03 \quad 2.065E-05 \)

\[ \alpha = 0.525 +/- 0.002 \]

\[ Q_i, \text{gal/hr} = 292.65 +/- 0.28 \]
\[ Q_i, \text{gal/min} = 4.88 +/- 0.005 \]
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Figure D-1. TK Solver Basin Regression (ft/time).

Figure D-2 TK Solver Discharge Chute Regression (ft/time).
The following are the variable sheets for TK solver power curve fit. They display the number of data points, a and b factors for $Y = aX^b$ equation, and the flow value (y) for the level differential (x) of 16 ft.

### TK obtaining exponent

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<th>Name</th>
<th>Output</th>
<th>Unit</th>
<th>Comment</th>
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<td></td>
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<td>283.22453 coefficient</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>16 x</td>
<td>y 1108.6812 dependant variable</td>
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### 0.5 exponent

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<th>Name</th>
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<th>Unit</th>
<th>Comment</th>
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</thead>
<tbody>
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<td></td>
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### 0.528 exponent

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</table>
This program is used for a power curve fitting routine.
A power curve takes the form of $y = ax^b$.
By inputing positive variable pairs, the program will give the
coefficient and exponent to the equation. This can, in turn,
be used to estimate a point, given one variable, along the
curve using limited data.

PROCEDURE FUNCTION: expon

Comment: a and b
Parameter Variables: n
Input Variables:
Output Variables: a, b, rsqrd

S Statement

```
sumlnx:= 0
sumlny:= 0
sumlnxxy:= 0
sumlnxsqrd:= 0
sumlnysqrd:= 0
for i = 1 to n
  x:= 'x0[i]
  y:= 'y0[i]
  Lnx:= ln(x)
  Lny:= ln(y)
  sumlnx:= sumlnx + Lnx
  sumlny:= sumlny + Lny
  sumlnxxy:= sumlnxxy + Lnx * Lny
  sumlnxsqrd:= sumlnxsqrd + Lnx^2
  sumlnysqrd:= sumlnysqrd + Lny^2
next i
b = (sumlnxxy - ((sumlnx * sumlny) / n)) / (sumlnxsqrd - (sumlnx^2 / n))
"b = 0.5 
  "Allows for exponent input
coeff = sumlny / n - b*(sumlnx / n)
a = exp(coeff)
```
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<td>int. basin level</td>
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<td>ft</td>
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D-6
APPENDIX E

K-BASIN ISOLATION BARRIER TEST EQUIPMENT AND INSTRUMENTATION
E1.0 INTRODUCTION

This document describes the equipment that needed to be manufactured and purchased for the K-Basin Isolation Barrier Leak Test. It characterizes purchases of Ultra-sonic Level Detectors (USLDs), thermocouples (TCs), dew point sensors, Vernier Evaporation Detector (VED), and data loggers. It also gives a description of the mounting brackets and the instrumentation stand that needed to be manufactured for each one of these instruments.

E2.0 INSTRUMENTATION DESCRIPTION

E2.1 LEVEL DETECTION AND MOUNTING

Level indication is needed because given the surface area of the basin and discharge chutes, leakage can be observed and the amount can be calculated from the level changes.

E2.1.1 USLDs

Many level indication devises were considered from many companies such as Omega Engineering Inc., Hewlett Packard, Fischer and Porter, and Kistler Morse dealing with resistance and capacitance measuring, RF transmitters, Ultra-sonic, and laser technology. The Fischer and Porter ultra-sonic flow meter was chosen over the others because of affordable accuracy and repeatability, availability, NIST traceability, and reliability. The Fischer and Porter model 50US3115 flow/level indicator (see Figure E-1) uses a transducer to generate a signal and receive the signal echo and the microcomputer in the transmitter unit averages the pulses per second from the transducer and temperature compensates for differing temperatures using a reference reflector a known distance from the transducer.
The USLD accuracy (±0.02 in. (0.051 cm) over a 4 in. (10.2 cm) span) was stated by the vendor and verified by WHC Standards Lab calibration. Instrument accuracy determined by the manufacturer as follows: the span (operator set) is broken into 8 bits of data or 256 increments (200 span increments and 28 over-span and under-span increments). Accuracy across a 4 in. (10.2 cm) span equals 4 in./200 (10.2 cm/200) increments which equals ± 0.020 in. (0.051 cm). The standards lab used a laser calibration system, NIST traceable, to calibrate the USLD. (Calibration papers are available in the K West Basin Isolation Barrier Leak Rate Test Procedure, WHC-SD-SNF-ATP-004.)

**E2.1.2 USLD MOUNTING**

Dampening the waves out of the basin water caused from the IXM pump operation and mounting the USLD transducer presented small hurdles. The water needed to be calm for the USLDs to have good and repeatable results; and the transducer needed to be within 24-30 in. of the water surface for maximum accuracy. The solution was to hang the USLD transducers and a stilling wells from the solid grating supports in the concrete basin walls (see Figure E-2).
The USLD transmitter units and the remaining instruments (dew point sensor, VED, and data logger) were mounted on a moveable table (see Figure E-3). The table needed to be easily movable because all instruments except the thermocouples would be removed from the basin after a baseline test to reduce the chance of damage during barrier installation and then reinstalled after the isolation barriers were completed.
E2.2 TEMPERATURE DETECTION AND MOUNTING

Water temperature and dew point indication are needed to obtain the water surface vapor pressure and the room vapor pressure for evaporation calculation (ASHRAE 1982). By knowing the vapor pressures and total evaporation determined from the VED, an evaporation constant can be calculated.

E2.2.1 THERMOCOUPLES

Type K (chromel-alumel) TCs were chosen because of their lower cost over RTDs, accuracy, and compatibility with a preliminary data logger without additional costs. The TCs are manufactured by Omega Engineering Inc. with 304 stainless steel 1/16 in. (0.16 cm) diameter sheaths for corrosion resistance and quick response.
E2.2.2 THERMOCOUPLE MOUNTING

The typical water temperature TC would need to be mounted where the TC tip would be submerged but near the water surface. A simple mount was constructed by strapping the TC to a 1/2" piece of conduit, lowering the conduit through the grating to the proper level and hose clamping it to the basin grating suspension system (see Figure E-4). The rigidity of basin grating suspension system was no concern since movement has little effect on the TC temperature indication.

One thousand feet of type K thermocouple extension wire was needed to transfer the TC mV signal from the TCs to the data logger located nearly half way across the basin from several of the temperature locations (see Figure E-5). The longest run of TC extension wire is only 140' ft (43 m) which is routed up and over the building support structure. The TC signal losses are negligible due to the relatively short extension wire length and only one junction from the TC to the data logger.

Figure E-4. Typical Thermocouple Mounting
E2.2.3 DEW POINT TEMPERATURE DETECTION

Dew point chilled mirror technology was chosen because it has low errors, quick response times, and is easily maintained. Chilled mirror technology is the Standard in dew point indication. The dew point has a direct relationship to vapor pressure which is directly related to the evaporation rate. The General Eastern chilled mirror dew point sensor model DEW-10 is powered by 120 VAC input, returns a 4-20 mA signal for 0-100 °F (-17.8 - 37.8 °C) dew point, and accurate to ± 2 °F (1.1 °C) is perfect for room vapor pressure indication.

Errors that arise in vapor pressure determination through relative humidity using dry bulb and wet bulb has many error possibilities. An estimated dry bulb error ranges between 0.05% of absolute temperature minimum and 2% of absolute temperature maximum while the estimated wet bulb temperature depression is 5 °F to 10 °F (-15 to -12 °C). Dew point is also not as susceptible to room air temperature gradients as would relative humidity.
E2.3 EVAPORATION DETECTION

To determine an accurate leak rate through the isolation barriers, evaporation must be taken into consideration over the test duration. Methods discussed to obtain evaporation rates were HVAC mass balances, past water level indications, or evaporation model.

The mass balance on the existing ventilation system to observe the amount of moisture entering and exiting the basin facility would have been costly and pointless without a truly air-tight facility. The existing data obtained over the years is not only observing evaporation but also a suspected basin leak that could be occurring all year round. A final suggestion was made by simulating the basin conditions (air temperature, water temperature, and air velocity across the water surface) in a known leak-free vessel, the evaporation off the vessel would be the evaporation off the basin, hence the VED came into existence.

E2.3.1 VED

The VED consists of a acrylic bath, an immersion heater/circulator/temperature controller, an immersion chiller, and a vernier hook gauge assembly capable of level measurement to the nearest 0.002 in. (0.005cm) (see Figure E-6).

Figure E-6. Vernier Evaporation Detector (VED)

The VED is placed in the basin for air temperature and air velocity compatibility. The immersion heater/circulator/temperature controller and the immersion chiller maintain the VED water temperature at the average basin water temperature. The vernier/hook gauge is used because the level change due to evaporation may be less than the USLD sensitivity. The hook gauge operates by adjusting
the vernier until the points of the hook gauge point and its mirror image touch. The mirror image is formed by observing from a position below the bath water line and observing the hook point and the water surface. The vernier reading is recorded and, after the test is completed, the hook gauge is reset and the reading recorded-again. The level differences in VED multiplied by the basin surface area can give the evaporation of the entire basin in cubic feet. A subsequent evaporation rate may be determined in units of cubic feet per hour or gallons per hour.

E2.4 DATA ACQUISITION

The output signals (mV or mA) from all the instruments has to be sent to a computer to perform the necessary data analysis. This can be accomplished by a data logger either internal or external to that computer.

E2.4.1 DATA LOGGER

Many manufacturers and distributors of data acquisition systems (DAS) were researched including Omega Engineering Inc., Cole Pramer, Fluke, and Hewlett Packard. With most (DASs), the data logger needed to be physically wired to the computer or the instruments were directly wired to a computer expansion card. Neither choice was desirable because the computer was to be located outside of the fuel storage basin zone for monitoring and ALARA purposes. In these cases the instrumentation wires or RS-232 cables would have to be routed through the basin walls. Fluke is the only DAS on the market that has a wireless data logger. This meant the information may be gathered at a remote site and radio transmitted to a computer base station through walls.

The Fluke model 2625 wireless data logger is capable of reading 20 channels of instruments and transmitting the information, at 900 MHz, to the computer base station. The instruments are hard wired to the remote station inside the basin and transmits the data to the computer base station outside. The base station can store the information in an ASCII file, and display the data graphically or numerically as it is received. Figure E-7 shows a wiring diagram of the instrumentation set-up.
The most vital instruments to this test were the USLDs and the data logger. An additional USLD (the VED USLD) and data logger were purchased and calibrated as backups.

**E3.0 SUMMARY**

The accuracy and dependability of this state of the art instrumentation is not surpassed in the field. This equipment can be used in future tests or in daily monitoring. The data obtained from recent operations was received via a strong signal, with little or no transmission or data errors.