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Study of the Unit 2 Spent Fuel Pit Permeability

Prepared for

Entergy Nuclear Northeast
Indian Point Unit 2

Report No. 1464385-R-004
Revision: Draft B

DRAFT

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TABLE OF REVISIONS

Revision No.	Description of Revision	Date
DRAFT - A	Original Issue	09/16/05
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APPROVAL COVER SHEET

TITLE: Study of the Unit 2 Spent Fuel Pit Permeability

REPORT NUMBER 1464385-R-004

CLIENT: Entergy Nuclear Northeast – Indian Point Energy Center

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REVISION RECORD				
REV. NO.	DATE	PREPARED	REVIEWED	APPROVED
A	09/16/05	G. Zysk	S. Yim	P. Bruck
B	09/19/05	G. Zysk	S. Yim	P. Bruck

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1.0 INTRODUCTION

This report is prepared as a study to investigate the limit of potential steady state transfer of spent fuel pool water through the concrete wall of the spent fuel pit. This report is prepared in support of an on-going investigation of observed moist concrete at an identified indication in the concrete wall on the south side of the Indian Point Energy Center (IPEC) Unit 2 spent fuel pit (SFP). This indication was found during excavation of soil in a location to the south of the south wall in support of activities associated with the IPEC Independent Spent Fuel Storage Installation (ISFSI) project.

1.1. Scope & Objective

The scope and objective of this study is to quantify the steady state leakage rate through the spent fuel pit wall, and determine the transfer time for water traveling through the wall.

1.2. Background

The Spent Fuel Pit is a reinforced concrete structure located in the Fuel Storage Building (FSB) consisting of a concrete spent fuel pit and covering of structural steel and metal siding. The pit, which is stainless steel lined with ¼" thick plate and filled with borated water, contains spent fuel in racks, which are supported on the floor and walls of the pit.

The pit has walls of 4'0" and 6'-3" thick with a 3'-0" thick base mat. The structure is founded on rock at elevation (El.) 50'-0" beneath the spent fuel pit, see Figure 1 and Figure 2.

A crack like indication has been identified on the SFP south wall, located at El. 64 ft, approximately 10 feet up from the base slab. The south wall of the SFP at this location is 4 ft thick. At one location along this horizontal indication a moist region of concrete has been identified with dimensions of approximately 20" wide by 20" high, Figure 3. This region has been observed for approximately two weeks, and the moist location of the wall is drying and disappearing. Further excavation to a depth approximately two feet below the first indication identified a similar indication, which is now currently moist.

A prior leak was identified in the liner in approximately the 1992 timeframe and was repaired. As part of investigative work on the pool structure as a result of this leak, concrete samples were removed from the pool walls and were evaluated, Ref. 1. The Reference 1 report provides fundamental observations of the condition and strength of the SFP concrete walls, which are utilized to support information herein.

For the purposes of this study, it is assumed pool water is trapped between the inside concrete surface of the wall and the ¼" thick stainless steel interstitial space, either from a former or current leak in the liner.

2.0 DISCUSSION

The south wall of the SFP was originally covered by the back-filled soil and rock material in the space between the outside of the wall, and the excavated rock to its south, see Figure 2. The back-filled material (soil) provided an overburden pressure against the wall. During excavation of this soil it was noted that the composition contained large rock with voids being present. With the soil in place, the concrete of the wall and a portion of the soil adjacent to the wall will with time approach the temperature inside the pool, approximately 100 degrees F. With the soil removed adjacent to the wall, the exterior of the wall is exposed to ambient air conditions.

The transfer of water through the concrete wall is a function of the transfer of liquid water, water vapor, and of the removal process at the exterior wall (Ref. 2). A diagram showing the penetration of water into the concrete wall, from right to left, is presented in Figure 4. In this diagram, the liquid is driven to some depth in the wall by the head of water in the interstitial space between the inner exposed concrete surface and the liner. At a mid-wall point, vapor diffusion and liquid flow are combined, and at the final section of the wall, vapor diffusion carries the flow to the outside surface. If liquid water does not continue to the outside wall, the surface appears dry. If liquid does reach the outside wall, the surface appears wet, and evaporation or drainage carries away the surface moisture.

2.1. Concrete Petrographic Discussion

Movement of water and other elements in concrete occurs through capillary pores, micro-cracks and transition zones, and through macro scale cracks.

At the smallest scale, water may move into concrete through interconnected capillary porosity. Capillary pores are essentially a residue of the originally water filled spaces in fresh concrete. Capillary pore scale is important with respect to durability of concrete as it is the path by which water and other aggressive ions penetrate into the concrete matrix. A depiction of this is shown in Figure 5 (A).

Somewhat larger but of similar magnitude to capillary pores are micro-cracks and transition zones. Micro-cracks may be formed due to internal thermal and shrinkage forces or stress due to external loads. The transition zone is a weak permeable layer that occurs around aggregate particles. This scale is also of importance with respect to movement of water and other aggressive chemicals within the concrete matrix and thus is important from a durability standpoint as well. A depiction of micro-cracks and transition zone is shown in Figure 5 (B) and Figure 5 (C), respectively.

On the macro scale, water or chemicals may move through cracks or construction joints in the concrete.

Concrete petrographic examination of the cores removed during the 1992 investigation, Ref. 1, identified cores with uniform aggregate distribution. Many of the cores were reported to contain micro-cracks with widths less than 0.004 in., which most likely occurred during curing or as a result of differential thermal cycles. The water-to-cement ratio, based on cement paste properties, were in the range of 0.38 to 0.45, a normal and satisfactory range corresponding to a water permeability in concrete of approximately 2×10^{-12} in/sec (5×10^{-12} cm/sec) (Ref. 1, Ref. 5).

3.0 EVALUATION

3.1. Transfer Mechanics

The ability of liquid water, under pressure, to flow through a porous material is referred to as the material's permeability and is quantified by a permeability coefficient. The transfer of liquid water through the wall is generally the limiting flow process. Estimates of vapor diffusion and exterior evaporation are typically higher than liquid flow. Liquid transfer through a porous medium can be quantified using a linear solution to the Darcy equation (Ref. 2, Ref. 6):

$$Q = K \times A \times dH / L$$

where:
Q = flow rate (vol/time)
K = permeability constant (length/time)
A = area (length squared)
dH = differential pressure (length)
L = wall thickness (length)

For uncracked concrete, the permeability constant K is on the order of 2×10^{-12} in/sec or 5×10^{-12} cm/sec, as determined for the SFP concrete by the core bore testing performed in 1992 (Section 2.1). For an uncracked wall, the leakage rate based on the permeability constant and driving pressure would be very small, and leakage would not be expected to noticeably penetrate the 4ft.. If a micro or macro crack were to occur within the wall of the SPF, the permeability constant would increase. A study performed by Wang and Jansen (Ref. 3) determined values of permeability versus crack size, Figure 6. Observations of the wall indication, Figure 3 identified a hairline crack at the surface. Based on the field observations the width of this crack through the wall is impossible to determine at this time. A concrete crack of 150 micron (0.006 in) would increase the permeability constant to approximately 7×10^{-5} cm/sec (Figure 6, Ref. 3).

The differential pressure driving flow through the crack is the difference between the interior liquid head (approximately 30' of water or 13 psi at the crack indication elevation) and the exterior vapor pressure. With the wall now exposed, the exterior pressure will be a function of air temperature and relative humidity. When the wall was covered by soil, the exterior vapor pressure in the soil or pore pressure would be determined by the elevation of the moisture in the ground. This ground moisture elevation is due to both ground water level and capillary action of the soil to draw moisture above the ground water level. If the elevation of the moisture in the ground is above the crack, there will be an external head equal to this elevation difference above the crack, and this would decrease the leak rate.

3.2. Leakage Rate Assessment

As part of water sample collection, an area of the exterior wall at the second (lower) crack like indication, approximately 3 ft. x 3 ft. was encapsulated with plastic. A sample of approximately 200 mL over a 24-hour period was collected (Ref. 4). This sample collection can be equated to a leakage rate of 8.3 mL/hr.

The leak rate of the second identified crack indication was assessed, using the increased permeability values for cracked concrete as shown in Figure 6. Considering the indication as through wall with a crack width of 200 micron, the leakage was determined to be on the order of 0.08 gal per day (12.6 mL/hr) for the 3 foot long section, Attachment A. A total leak rate can then be projected as 4.2 mL/hr per linear foot of indication, or 126 mL/hr for the 30' long crack. Based on these leakage rates, pool water would penetrate the 4 ft. wall in approximately 18 hours.

The calculated 200 micron crack leak rate is in reasonable agreement with the measured data. While exact crack dimensions are not known, the agreement with the measured data provides a justification of the crack size assumed at this time.

It should be noted that the leakage rates in areas adjacent to the test are not known, although they are likely to be lower than the rate in areas that were observed to be wet on the surface. Additional testing is recommended to quantify leakage rates over the remainder of the crack.

The methodology for obtaining the leak rate sample by encapsulating a portion of the wall with plastic is conservative relative to the soil cover against the wall condition, unless the soil is completely dry. Under the test conditions, the exterior pressure was approximately 1 psi at 100 degrees F and 100% relative humidity, which are conservatively bounding conditions within the plastic bag. If the soil were completely dry in the region of the crack, there will be no (0 psi) external pressure. This would increase the flow rate through the wall by 8% (13/(13-1) = 1.08) compared to the tested condition. To bound the dry soil case, the leak rate is increased 8% due to the negligible pore pressure for the soil under dry conditions.

The condition without soil or test plastic on the wall exterior surface exposes the wall to evaporation and diffusion within the wall. These increased transfer mechanisms move the fluid boundary into the wall interior, thereby causing the wall surface to appear dry over time. These mechanisms would also provide initially higher moisture transfer rates until the wall reaches a steady state.

4.0 CONCLUSIONS

During excavation work adjacent to the south wall of the IPEC Unit 2 spent fuel pit (SFP), a crack like indication was observed in the wall at El. 64 ft., approximately 10 feet above the SFP base slab. This crack like indication appears to be relatively tight, hairline in nature, and is likely associated with shrinkage cracking. A portion of the indication near the southwest corner was found to be moist. This region has been observed for a period of approximately two weeks and the surface appears to be drying. A portion of the soil below this region of the indication was subsequently excavated an additional two feet, identifying a similar indication, which also was initially moist.

A sample of the water was extracted from this area by bonding a plastic bag to the wall and collecting water condensing on the bag. A sample of approximately 200 mL was obtained over a 24-hour period. A study has been performed to quantify this leakage rate and compare the leakage rate to that which would be expected from a hairline crack in the wall, of a width comparable to the observed moist region of the indication. Assuming a hairline crack of 200 microns produced a leakage rate comparable to that of the obtained sample. The resulting leakage through such a crack was calculated as 0.08 gal/day (12.6 mL/hr) for the 3 foot test section or approximately 126 mL/hr for the 30' long crack length. With consideration of this leakage rate, it would take approximately 18 hours for the water to migrate through the 4 ft. thick concrete wall at this location. The leakage rate provided is believed to be conservative, but additional testing is recommended to quantify leakage rates over the remainder of the crack.

The calculated leakage rate is based on observable leakage at the presently identified indication only, and based on the assumption of steady state leakage. Initial leakage rates due to vapor diffusion and evaporation could be higher than steady state but are transient in nature as the wall dries out. Additional leakage over and above this value could also be occurring at lower elevations of the wall, which are presently not visible.

5.0 REFERENCES

1. Lucius Pitkin, Inc. (LPI) Report No. ME-3802, "Evaluation of Spent Fuel Pool Walls – Indian Point Unit 2 Nuclear Power Plant", March 26, 1993.

2. McGrath, P.F. "Water Permeability vs. Waterproofing". ASCE Met. Section Construction Group, Cooper Union May 25, 2000.

3. Wang, K, D.C. Jansen, & S.P. Shah, "Permeability Study of Cracked Concrete", Cement & Concrete Research, Vol. 27, No. 3, pp 381-393, 1997.

4. Telecon, J. Skonieczny to P. Bruck, 9/19/05. (included in Attachment A)

5. Grasberger, S. and Meschke, G. "A Hygro-Thermal-Poroplastic Damage Model for Durability Analyses of Concrete Structures". European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2000, 9/2000.

6. Blevins, "Applied Fluid Dynamics Handbook", Kreiger Publishing, 1992.

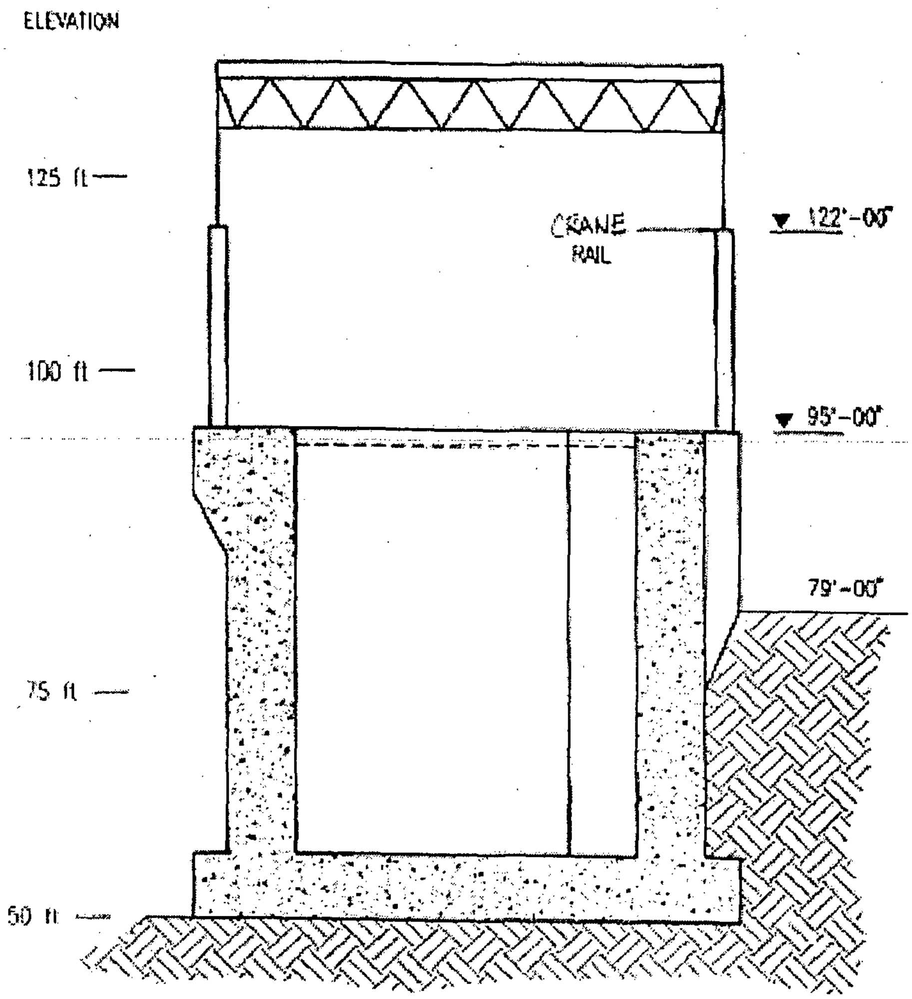


Figure 1: FHB Looking North

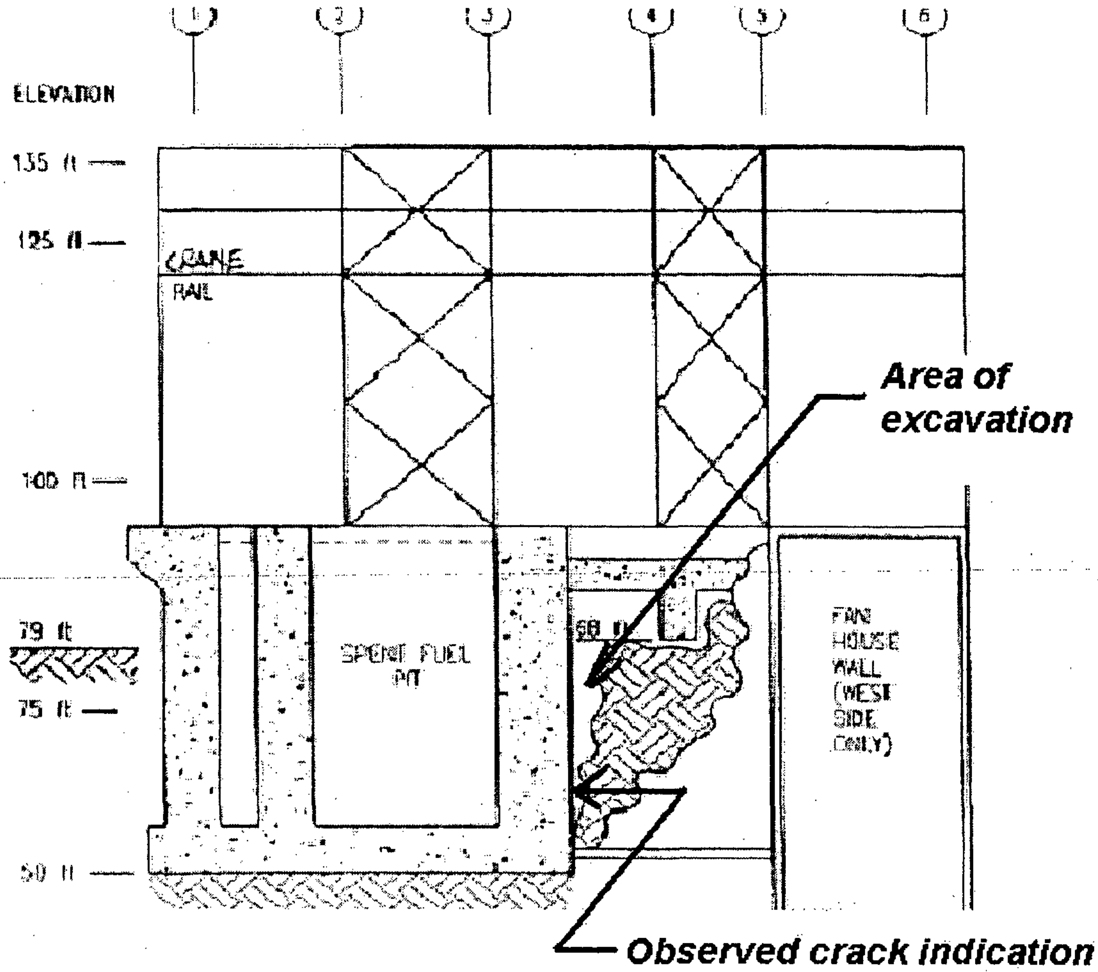


Figure 2: FHB Looking East

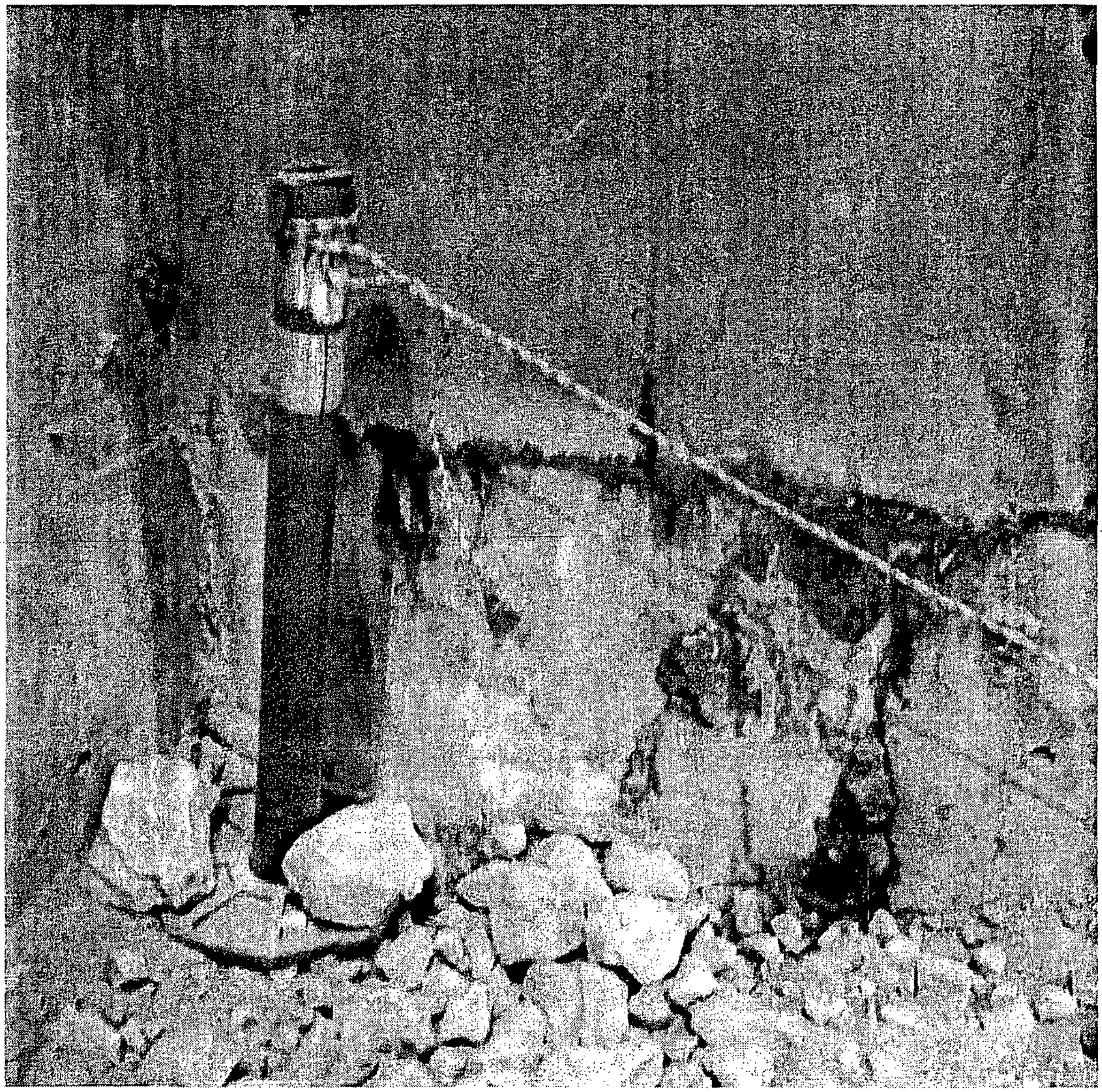


Figure 3: Crack Like Indication & Moist Region – Approx. El. 64 ft.

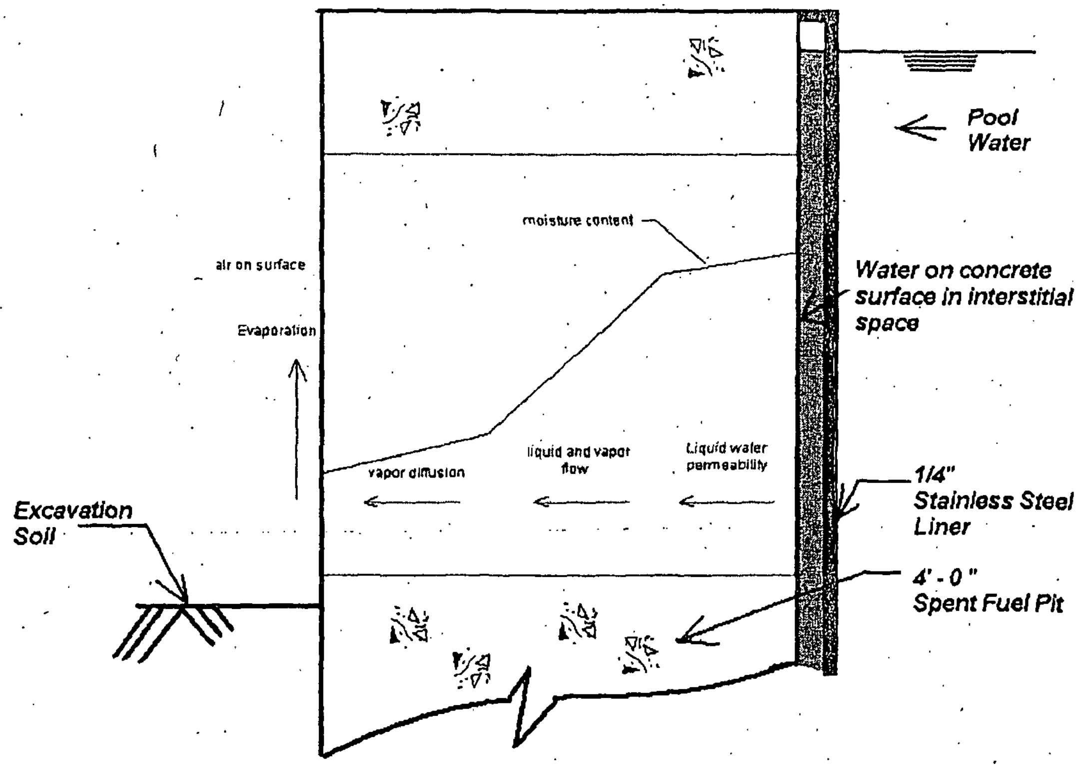
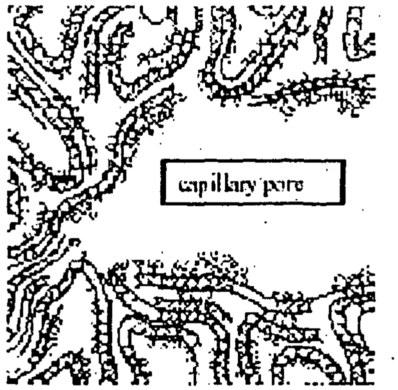
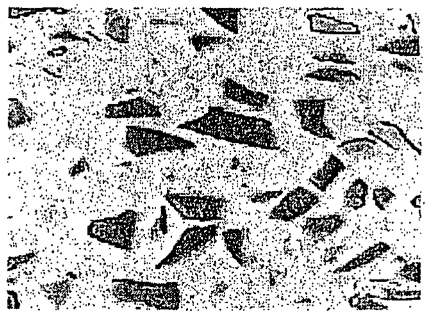


Figure 4: Unsaturated Flow Through SFP Wall



A – Capillary Pore in Hydrated Cement Paste



B - Micro Crack around Aggregate Particles

C – Illustration of the Transition Zone

Figure 5: Concrete Size Scale Relative to Water Movement

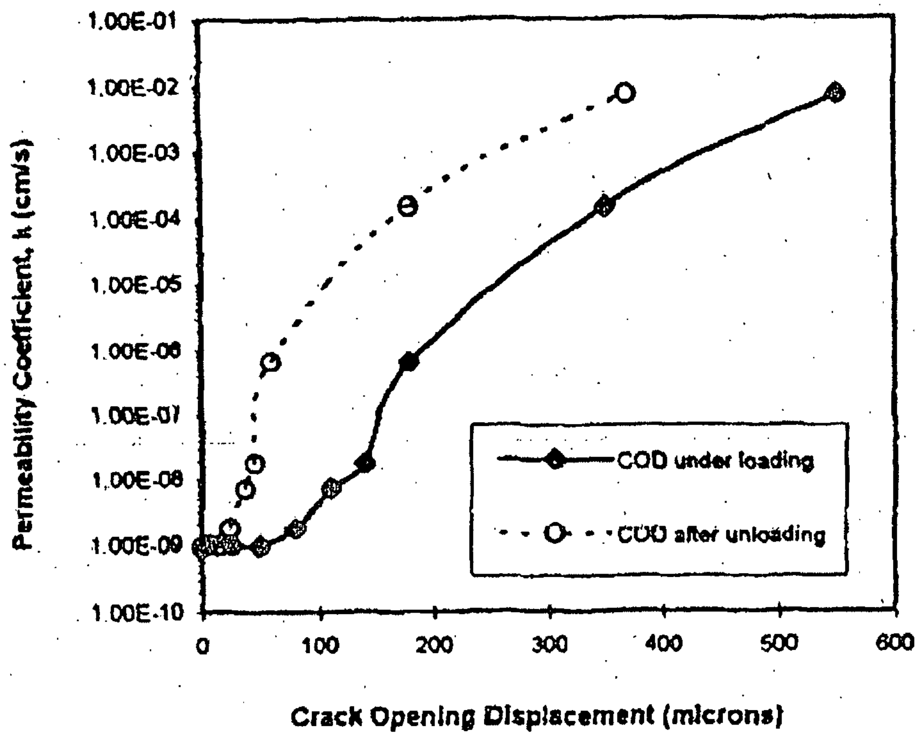


Figure 6: Crack Opening vs. Permeability Coefficient (Ref. 3)

ATTACHMENT A

Seepage Assessment Through Wall

Introduction:

Seepage from IP2 fuel pool is observed on the outside surface of the pool wall as the overburden is being uncovered. This calculation will approximate the amount of seepage.

$mil := \frac{1}{1000} in$

$i := 0..12$

Methodology

Quantifying the leak rate through cracks in a concrete wall via Darcy Equation

$micron := 1 \cdot 10^{-6} m$

$gpm := 1 \frac{gal}{min}$

$j := 0..2$

$EL_{water} := 93ft + 6in$

$EL_{crack\_sample} := 63ft$

$H_{water} := EL_{water} - EL_{crack\_sample}$ Head location of crack

$t_{wall} := 4ft$ wall thickness

$H_{water} = 30.5\ ft$

$t_{crack} := 0.2mm$ thickness of crack

$L_{crack} := 3ft$ Crack Length

Sample Area

$H_{sample} := 3ft$

$W_{sample} := 3ft$

$t_{crack} = 200\ micron$

$t_{crack} = 7.874\ mil$

$CA_{crack} := L_{crack} \cdot t_{crack}$ Area of Crack

$A_{sample} := H_{sample} \cdot W_{sample}$

$V_{crack} := CA_{crack} \cdot t_{wall}$

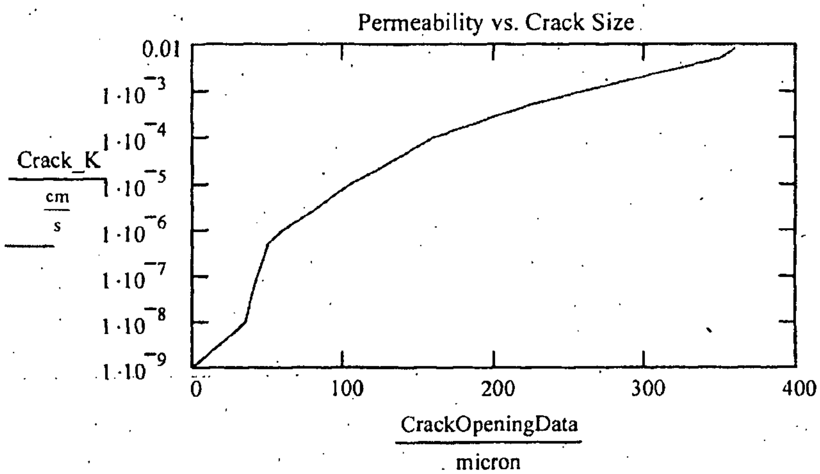
$CrackOpeningData_i :=$

0micron
25micron
35micron
40micron
50micron
60micron
75micron
105micron
160micron
225micron
260micron
350micron
360micron

$Crack\_K_i :=$

$1 \cdot 10^{-9} \cdot \frac{cm}{s}$
$5 \cdot 10^{-9} \cdot \frac{cm}{s}$
$1 \cdot 10^{-8} \cdot \frac{cm}{s}$
$5 \cdot 10^{-8} \cdot \frac{cm}{s}$
$5 \cdot 10^{-7} \cdot \frac{cm}{s}$
$1 \cdot 10^{-6} \cdot \frac{cm}{s}$
$2 \cdot 10^{-6} \cdot \frac{cm}{s}$
$1 \cdot 10^{-5} \cdot \frac{cm}{s}$
$1 \cdot 10^{-4} \cdot \frac{cm}{s}$
$5 \cdot 10^{-4} \cdot \frac{cm}{s}$
$1 \cdot 10^{-3} \cdot \frac{cm}{s}$
$5 \cdot 10^{-3} \cdot \frac{cm}{s}$
$8 \cdot 10^{-3} \cdot \frac{cm}{s}$

Ref. 3
Permeability Coefficient vs Crack Opening Data per Cement and Concrete Research, "Permeability Study of Cracked Concrete", Vol 27, No. 3, pp. 381-393, 1997



$K_{crack} := 2.5 \cdot 10^{-4} \cdot \frac{cm}{s}$ Permeability of crack concrete from above data based on crack thickness

$K_{uncrack} := 5 \cdot 10^{-12} \frac{cm}{s}$ Permeability of Uncrack concrete from Lucius Pitkin Report ME-3802-TR8281 (Ref. 1)

$$Q_{estimate} := \frac{K_{crack} \cdot CA_{crack} \cdot H_{water}}{t_{wall}} + \frac{K_{uncrack} \cdot A_{sample} \cdot H_{water}}{t_{wall}}$$

$Q_{estimate} = 12.551 \frac{mL}{hr}$

$Q_{estimate} = 0.08 \frac{gal}{day}$

$Q\_collected := 200 \frac{mL}{24hr}$ Sample collected from 9/17 to 9/18 (Ref 4)

$Q\_collected = 8.333 \frac{mL}{hr}$

$$K_{collected} := \frac{t_{wall} \cdot Q\_collected}{H_{water} \cdot CA_{crack}}$$

Therefore permeability value correlates with collected data.

$K_{collected} = 1.66 \times 10^{-4} \frac{cm}{s}$

From the samples collected the time to traverse the wall is:

$$t_{col} := \frac{V_{crack}}{Q\_collected}$$

$t_{col} = 1.11 \text{ day}$

For the estimated flow rate, the time to traverse the wall is:

$$time_{est} := \frac{V_{crack}}{Q_{estimate}}$$

$time_{est} = 17.764 \text{ hr}$

Telecon:
9/19/05

Participants:
John Skonieczny
Entergy

Paul Bruck
ABS Consulting

John called to discuss leakage rate of collected water from the 2nd (lower indication) during the weekend (9/17 through 9/18/05). A sample of 200 mL was collected in 24 hours.

Paul M. Bruck 9/19/05

ATTACHMENT B

NQP-02 Exhibit 1 Review Guidelines (1 sheet attached)

Criterion	Design Attributes	Status (S, U, N/A)
1.	Were the inputs correctly selected and incorporated into design?	
2.	Are assumptions necessary to perform the design activity adequately described and reasonable? Where necessary, are the assumptions identified for subsequent re-verifications when the detailed design activities are completed?	
3.	Are the appropriate quality and quality assurance requirements specified?	
4.	Are the applicable codes, standards and regulatory requirements including issue and addenda properly identified and are their requirements for design met?	
5.	Have applicable construction and operating experience been considered?	
6.	Have the design interface requirements been satisfied?	
7.	Was an appropriate design method used?	
8.	Is the output reasonable compared to inputs?	
9.	Are the specified parts, equipment, and processes suitable for the required application?	
10.	Are the specified materials compatible with each other and the design environmental conditions to which the material will be exposed?	
11.	Have adequate maintenance features and requirements been specified?	
12.	Are accessibility and other design provisions adequate for performance of needed maintenance and repair?	
13.	Has adequate accessibility been provided to perform the in-service inspection expected to be required during the plant life?	
14.	Has the design properly considered radiation exposure to the public and plant personnel?	
15.	Are the acceptance criteria incorporated in the design documents sufficient to allow verification that design requirements have been satisfactorily accomplished?	
16.	Have adequate pre-operational and subsequent periodic test requirements been appropriately specified?	
17.	Are adequate handling, storage, cleaning and shipping requirements specified?	
18.	Are adequate identification requirements specified?	
19.	Are requirements for record preparation review, approval, retention, etc., adequately specified?	

Design Reviewer:__________________ Date:____________

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