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2. To: (Receiving Organization) Spent Nuclear Fuel Project	3. From: (Originating Organization) Nuclear Fuel Evaluations	4. Related EDT No.:
5. Proj./Prog./Dept./Div.: K-Basin	6. Cog. Engr.: George L. Fox	7. Purchase Order No.: N/A
8. Originator Remarks: This document examines the consequences if the isolation barrier plate is dropped and falls over on the fuel stored in the water-filled K-East basin.		9. Equip./Component No.: N/A
11. Receiver Remarks: N/A		10. System/Bldg./Facility: K-East Basin
		12. Major Assm. Dwg. No.: N/A
		13. Permit/Permit Application No.: N/A
		14. Required Response Date: N/A

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-SNF-SARR-004		0	Results of Falling Barrier Analyses	ESQ	1	1	1

16. KEY			
Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged	

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Document Number: WHC-SD-SNF-SARR-004, Revision 0

Document Title: Results of Falling Barrier Analyses

Release Date: November 29, 1994

**This document was reviewed following the
procedures described in WHC-CM-3-4 and is:**

APPROVED FOR PUBLIC RELEASE

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11/29/94

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SUPPORTING DOCUMENT		1. Total Pages 13
2. Title Results of Falling Barrier Analyses	3. Number WHC-SD-SNF-SARR-004	4. Rev No. 0
5. Key Words K-Basin, Spent Nuclear Fuel, Safety Analyses	6. Author Name: George L. Fox <i>George L. Fox</i> Signature 8D510/L2140 Organization/Charge Code	
7. Abstract <p>This document assesses the consequences if the isolation barrier plate is dropped and falls over on the fuel stored in the water-filled K-East basin. The water slows the rate of fall and some canister bending is expected but only a few rods, if any, would get crushed. The basin criticality calculations will not be affected.</p>		
8. RELEASE STAMP <div style="border: 1px solid black; padding: 5px; margin: 10px auto; width: fit-content;"> OFFICIAL RELEASE 38 ENV BY WHC DATE NOV 30 1994 <i>Sta #21</i> </div>		

REV. 0

Document Title: Results of Falling Barrier Analyses
Spent Nuclear Fuel Program

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11-2-94
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13/11/3/94

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MASTER

RESULTS OF FALLING BARRIER ANALYSES

1.0 BACKGROUND

A plate, 5.5 m high and 1.1 m wide, is to be used as an isolation barrier in the water filled K-East basin. The plate is nominally 1.3 cm thick, but with various seals and attachments, weighs 1091 kg under water. This is equivalent to a solid steel plate which is 2.7 cm thick. This memo examines the consequences if this plate were to fall over on the N-reactor fuel storage canisters which are located in racks at the bottom of the basin. The assessment considers the water drag forces and calculates the velocities and energy of the plate when it collides with the fuel canisters. The details of the collision event are examined and the amount of damage to the canisters is estimated.

2.0 SUMMARY

The plate falls by rotating about its bottom edge and the velocity becomes quasi-steady where the gravity forces are in equilibrium with those from water drag. The analyses shows the presence of water reduces the plate kinetic energy by a factor of 20. The plate first impacts the fuel canisters while at an angle of 27° with the basin floor, losing 20% of its kinetic energy in the collision. The energy dissipation is expected to occur by flattening the outside edge of the canisters, and bending the wall inward. The fuel is expected to be pushed forward but few rods, if any, would get crushed. The plate rotational speed is increased 50% by the collision because of the new pivot point although the kinetic energy is decreased. The plate's second impact is flat across the top of the canisters but does not cause crushing because the loadings are distributed.

An edgewise falling event is considered to be incredible but was analyzed anyway as a worst case. Water drag does not slow the plate which is assumed to fall in a diagonal direction and impact some canisters with its outer edge. Fuel crushing could occur in as many as four canisters but this is still not expected to affect basin criticality calculations. No significant environmental release is expected to occur.

3.0 SMALL SCALE EXPERIMENTS

Small scale experiments using plates in water with the correct height to width (aspect ratio) show that if the standing plate is released from a vertical position, it will hinge along the bottom edge. If the bottom edge is initially at a horizontal corner, the plate will flop down in a simple and direct manner. If the plate bottom edge is not firmly in the corner, there may be some sideways rotation (i.e. shifting side to side) during the downward travel. It is very small and the bottom corners of the plate provide a restoring moment which prevents significant sideways rotation. If the plate is released while standing away from the basin sides, midway through the downward motion, the bottom edge slides backward and a sideways rotation may

develop, sometimes as much as 180° or more. However, it is significant that the plate always falls by hinging about the bottom edge. Any tendency to tip sideways is overcome by the plate bottom corners on the pool bottom which provide a restoring moment. Also, the plate always lands flat on the tank bottom. (However if the plate is released as falling on a sideways edge, it will continue like that all the way to the bottom).

Another observation is that the plate falling velocity is controlled by the drag resistance of the water. A heavy steel plate falls much faster than a lighter aluminum plate with the same height and width. This is expected of course and, as will be shown later, the terminal velocity causes drag forces which are in equilibrium with the weight.

4.0 MODELING

There is some uncertainty in the drag coefficient. A flat plate of infinite length is estimated to have a value near 2. However, for finite lengths, Reference 1 shows values which range from 1.1 to 1.5. Since a smaller drag coefficient means higher plate velocities, a conservative value of 1.0 was selected for this study.

A computer model was constructed for the falling plate with the bottom edge as the hinge. Gravitation forces accelerate the plate during its rotation and drag forces by the water retard this motion. It was observed that the plate was soon in equilibrium with the drag forces and the predicted terminal velocity could be calculated by considering the plate to be horizontal and summing moments about the bottom edge. The accelerating moment is caused by the plate weight acting at the center of gravity. The resisting moment is obtained by integrating the drag forces along the plate. The inertia of the plate is included in the model but does not play a role.

These concepts are shown in Equation 1;

$$\Sigma M = 0$$

$$\frac{WL}{2} - \frac{1}{2} \rho_w C_D \frac{S}{L^2} V_{\max}^2 \int_0^L r^3 dr = 0 \quad (1)$$

where W = Plate weight under water
 L = Plate length
 ρ_w = Density of water
 C_D = Drag coefficient
 S = Plate width
 $V_{\max}$ = Velocity at plate tip

Solving Equation 1 for $V_{\max}$ yields a velocity of 2.7 m/s (8.8 ft/sec) with a kinetic energy of 1540 J. (The falling time is over 5 seconds). This may be contrasted with a case without water drag. Here the falling time is about 2.7 seconds, final tip velocity is 11.3 m/s, and the kinetic energy is 3×10^4 J. The presence of water reduces the plate kinetic energy by a factor of 20. However the case without water drag is similar to an unlikely edge drop case which is used as a bounding accident.

5.0 IMPACT PROCESS

The preceding discussion maximizes the plate kinetic energy by allowing it to fall from a vertical to a horizontal position. This does not consider the fuel stored in the basin and a more complex sequence of events will be developed in the following sections.

The fuel storage racks and canisters are located 1.5 m from the basin sides and are 0.76 m high. As the plate falls toward the canisters, the front row is impacted first when the plate has rotated 63° and is at an angle of 27° with the basin floor. The impact dissipates some kinetic energy, kicks the lower end upward, and the plate now pivots about the new point of contact. Major differences are that the moment of inertia and the accelerating moment from the weight are reduced because the pivot point has moved closer to the center of gravity. Also, drag forces from the water act at both top and bottom ends.

The collision process is quantified by applying conservation of the moment of momentum about the impact point before and after collision. The equation for angular velocity of the plate after impact is developed in Reference (2) and given by Equation 2.

$$\omega_1 = \frac{a^2 + k^2 - ab}{(a-b)^2 + k^2} \omega_0 \quad (2)$$

where

- ω_0 = angular velocity before impact
- a = distance from bottom to center of gravity
- b = distance from bottom to impact point
- k = radius of gyration about center of gravity

The new plate rotational velocity and kinetic energy are calculated and the results summarized below.

6.0 ENERGY ABSORPTION

Data has been developed for canister compression to support the design of equipment to dispose of canisters by crushing them. The equipment must be designed to withstand the maximum forces needed. The crush data were collected for empty aluminum and steel canisters. The crushing begins by local indentations of the wall by the compression force on the canister. (usually symmetrically located on opposing sides.) The resistance remains high until the initial buckling occurs (the first set of indentations.) Then it drops for a period until the first set of dents are fully collapsed. Then the resistance rises until another set of indentations appear and the process is repeated.

The crushing data has not been formally reported but has been summarized by J. C. Wiborg, WHC, based on data logs, discussion with the PNL lead engineer (J. M. Alzheimer) and review of video footage of the tests. The crushing results for two coupled canisters are shown in Figure 1.

These results indicate each canister (note "canister" here refers to a single 21 cm diameter barrel) has a crush strength of 15,000 to 40,000 lb (6.7×10^4 to 1.8×10^5 N). Classical buckling formulas³ with correction for experimental results appear to overestimate the crushing force as much as a factor of two for steel but are ok for aluminum. The crushing results in Figure 1 are also consistent with those which assume initial buckling occurs at the onset of wall yielding.

Figure 1. Force to Compress Two Canisters

At the time of impact, the plate has 1340 J of kinetic energy, and application of Equation 2 shows that 20% is lost by an inelastic collision with the edge canisters. (i.e. $0.20 \times 1340 \text{ J} = 268 \text{ J}$). The plate spans four canisters which distributes the loading. Using the minimum strength value

which corresponds to ongoing buckling, a crush distance for flat loading is calculated to be 1 mm, which is very small.

$$\begin{aligned}
 \text{Distance} &= \frac{\text{Energy}}{4 \times \text{Force}} \\
 &= \frac{268 \text{ J}}{4 (6.7 \times 10^4 \text{ N})} \\
 &= 1 \times 10^{-3} \text{ m (1 mm)}
 \end{aligned}$$

Since the plate will not land flat on the front row, the canisters will deform more on the nearest side, perhaps collapsing the edge. The longest fuel elements may be within 1.25 cm of the top but it is likely the fuel rods near the collapsed edge would be pushed forward against their neighbors. The impact velocity is slow, about 0.8 m/s, and the angle of plate impact requires friction coefficients of 0.5 or greater to trap and compact the fuel. Dry metal-to-metal friction is typically 0.1 to 0.2. Our underwater conditions would decrease the friction even more. This leads to the conclusion that some fuel could be deformed but it should be very localized and involve only a few rods. This amount of fuel deformations and distortions will not affect the basin criticality calculations.

Following the impact with the first row, the plate retains 1066 J of energy. Interestingly, the collision increases the rotational speed about 50% but since the center of rotation is now closer to the plate centroid, the moment of inertia and energy are both reduced. However, the plate tip velocity is too high and the drag moment exceeds the weight forcing moment. This causes the plate to rapidly slow and return to an equilibrium rotation rate. The second impact across the top of the fuel canisters dissipates the remaining 880 J. Now the plate will cover fifty or more canisters, distributing the forces so that further canister deformation is neglectable.

There is another damage mechanism, which should be discussed, that is associated with this type of plate accident. When the plate impacts the first row of canisters, the bottom edge is assumed to be at the basin edge and against a vertical wall. This maximizes the crushing energy of the first impact. During the rotation following the collision, the basin side wall causes the plate to push forward about 18 cm toward the canisters. If anything on the door snags a canister, there could be gross distortions of the upper edge and perhaps loss of covers. The vertical force at the pivot point prior to the second impact is estimated to be 8000 N (1800 lb) and, because of the plate sliding motion, results in a horizontal friction force about 900 N. (200 lb) That friction force is balanced by a horizontal wall reaction causing a vertical friction drag force of 630 N on the rotating plate bottom. This drag decreases the plate rotational speed only about 5% and has minimal effects.

The foregoing discussion completes the description of mechanisms that could occur if the plate falls over on the first row of canisters. The 900 N friction force, depending on how it is distributed, could cause deformations on the tops of canisters if they are not constrained by covers. But there is nothing to indicate any major relocation would occur of the stored fuel

elements. There may be some gas released if the covers are displaced but any particulates would become trapped in the water. The released gas is expected to be hydrogen with perhaps some of the original nitrogen cover gas. The quantity of hydrogen in a canister is small and has been addressed previously in Reference (4). No significant environmental release is expected to occur.

7.0 INCREDIBLE EVENTS

Suppose the plate were dropped just before arriving in position and before hitting the bottom of the basin, hits a submerged obstruction with the outside corner, and tips over sideways toward the fuel. In this case, water drag would be small and will be ignored. The maximum kinetic energy is simply submerged weight times falling distance and is 2.4×10^4 J.

For the incredible event analysis, we will use a more appropriate average canister crushing strength estimated from Figure 1 as 8.9×10^4 N (20,000 lb). The total canister crushing distance is calculated to be 27 cm as follows:

$$\begin{aligned} \text{Distance} &= \frac{\text{Energy}}{\text{Force}} \\ &= \frac{2.4 \times 10^4 \text{ J}}{8.9 \times 10^4 \text{ N}} = 0.27 \text{ m} \end{aligned}$$

At this point it is necessary to define inconsequential canister damage. The canister extends above the longest fuel elements about 1.25 cm. If the canister were crushed more than this, fuel element compaction could occur. If compaction occurs in a large number of canisters, the changed geometry could invalidate criticality calculations. We will assume canister crushing up to 1 cm does not compact the fuel.

Next we will consider how the plate might land on the stored fuel. The worst description would be if the plate falls in a diagonal direction and only the end impacts the canisters. The canister density is selected as one canister per foot of plate edge. The plate end is assumed to crush its canister 1.5 cm and is beginning to compact that fuel. At this time, the plate angle is 8° from the basin floor which is a variation of 4.39 cm per canister row. For example, if the last canister at the plate end is crushed 1.5 cm, the next inboard canister must be crushed 5.89 cm, the third must be crushed 10.28 cm and the fourth inboard canister must be crushed 14.67 cm. The sum of these four canisters is 32.34 cm which exceeds the 27 cm crushing distance that dissipated the total kinetic energy. This example indicates that no more than four canisters would have fuel compaction, even with incredible events.

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- (3) Roark, R. J., "Formulas for Stress and Strain," McGraw-Hill, dated 1943.
- (4) Weber, J. W., "*Review of Consequences of Uranium Hydride Formation in N-Reactor Fuel Elements Stored in the K-Basins*" WHC-SD-SNF-SARR-001, Rev. 0, Westinghouse Hanford Company, Richland, WA., September 1994.

**Westinghouse
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**Internal
Memo**

From: Facility Stress Analysis
Phone: 376-3330 H5-57
Date: October 20, 1994
Subject: IMPACT ANALYSIS OF FALLING BARRIER

WWC-8D420-94-002

To: G. L. Fox, Jr. L5-01

cc: M. R. Lindquist H5-57 *MR*
WWC File/LB

Review of the impact analysis for the falling barrier in the water filled K East Basin has been completed. Comments have been resolved. Mathematical calculations have been checked and found to be conservative and accurate.

Attached please find the review check list. If you have any question, please call me at 376-3330.

W. W. Chen, Principal Engineer
Facility Stress Analysis

rw

Attachment

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed Impact Analysis of Falling BarrierAuthor George FoxYes No N/A

☒	☐	☐	Problem completely defined.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors.
☒	☐	☐	Code run streams correct and consistent with analysis documentation.
☒	☐	☐	Code output consistent with input and with results reported in analysis documentation.
☒	☐	☐	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.

MANDATORY

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W. W. Chen
ReviewerW. W. Chen10-20-94
Date

09/22/93

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