983

RELATED CORRESPONDENCE

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

DOCKETED
USNRC

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

'86 OCT -6 P5:16

OFFICE OF SECRETARY
DOCKETING & SERVICE
BRANCH

In the Matter of:	)	Docket Nos. 50-275-OLA and 50-323-OLA
PACIFIC GAS AND ELECTRIC COMPANY	)	
	)	ASLBP No. 86-523-03-LA
(Diablo Canyon Nuclear Power Plant, Units 1 and 2)	)	

SIERRA CLUB RESPONSE TO FIRST SET OF INTERROGATORIES
AND REQUEST FOR PRODUCTION OF DOCUMENTS
FROM PG&E AND THE NRC

* * * * * * * *

The Sierra Club objects to the following interrogatories from PG&E for reasons indicated:

PG&E #35: "Please set forth what you believe to be the appropriate coefficients of friction for analysis of rack response." In the work done by Dr. Ferguson of the Sierra Club the coefficients of friction used have been those used PG&E's own analysis, 0.8 and 0.2. Dr. Ferguson has received a copy of the experimental work which served as the basis for this choice of coefficients (Ref. 21). At the present time, the choice of coefficients is not being contested by Dr. Ferguson, but he has made no attempt to ascertain the validity of these values. Future developments may bring these choices into question, in which case PG&E would be notified.

PG&E # 36: "Is it your belief or position that there is a standard engineering practice for the proposed reracking? Provide the basis for the response." This question seems overly vague. There are certainly many design criteria governing the design of spent fuel facilities. In addition, good engineering practice demands that theoretical work be verified experimentally before being used in design and that uncertainties be identified and evaluated conservatively.

DS03

PG&E #45: "Is it your belief or position that the higher density racks will not preclude criticality due to the closer spacing? Provide the basis for the response." We do not understand what information this question is asking for.

The Sierra Club objects to the following requests for production of documents from PG&E for the reasons indicated:

PG&E #2: "You are requested to produce all documents you intend to use or rely on in written testimony or oral argument."

PG&E #3: "You are requested to provide all documents you intend to have marked for identification at the hearing of this matter or which you will attach to any testimony." According to the ASLB order of August 28, 1986, prefiled testimony is not required to be filed until March 11, 1987. The Sierra Club has requested additional information in its interrogatories which it has yet to receive. An enormous amount of technical analysis remains to be done. It is unreasonable that documents to be used much later be identified now since new information and study can be expected to change arguments to be presented by the Club and could even cause some or all of the contentions to be withdrawn.

The Sierra Club objects to the following interrogatories from the NRC for the reasons indicated:

NRC #1-1a: "Upon what person or persons do you rely to substantiate in whole or in part your position on Contentions I and II?"

NRC #1-1c: "Identify which of the above persons or any other person you amy call as witnesses on this contention."

NRC #1-2: "Provide summaries of the views, positions or proposed testimony on Contentions I and II of all persons named in response to Interrogatory 1-1, that you intend to present as witnesses during this proceeding."

NRC #1-3: "State the specific bases and references to any documnets upon which the persons named in response to Interrogatory No. 1-1 rely to substantiate their views regarding contentions I and II."

NRC #1-4 "With regard to Contentions I and II identify all documentary or other material that you intend to use during this proceeding to support these contentions and that you may offer during your cross-examination of witmesses presented by the Licensee and/or the NRC staff." These interrogatories are premature for exactly the same reasons listed above in response to PG&E's request for documents #2 and 3.

* * * * * * * * * *

INTRODUCTION

The following report is submitted in response to the wide range of interrogatories presented to the Club by PG&E and the NRC. It has been prepared by Dr. Richard B. Ferguson who is solely responsible for its content. He has had discussions with other experts on many occassions, most of whom are engineers and scientists at the California State University, San Luis Obispo. However, professional etiquette prohibits identification of these individuals until they have agreed to support positions expressed in this report in their professional capacity. Given the preliminary state of the work reported herein, the professional support of any of these experts for any position has not been requested. As final testimony is prepared, notice will be given as to the individuals responsible.

Because of the large range of questions, the material has been presented in report form. Every effort has been made to provide references to documents in support of claims made. At the end of the report is a list of citations to sections of the report which respond to the various interrogatories. It is felt that this procedure provides technical experts with a thorough understanding of Dr. Ferguson's work. It should be noted, however, that this work is on-going in an attempt to understand both the problems posed by the reracking and the analytical work previously done by others. All claims regarding the problem are therefore subject to change as new information and insight becomes available.

All references in this report refer either to documents previously referenced and/or distributed by PG&E and the NRC and presumably in the posession of all persons on the service list or to unpublished work of Dr. Ferguson. The Sierra Club does not intend to redistribute more copies of the former. Printouts of computer programs used by Dr. Ferguson are provided as appendices to the present report. These programs will be made available on magnetic diskette upon request.

TECHNICAL DETAILS OF THE PROPOSED HIGH DENSITY RERACKING AT DIABLO CANYON

THE SEISMIC PROBLEM

There are several potential technical concerns related to the reracking proposal including possible cooling problems arising from the increase in radioactive material, structural questions related to increased loads on the pool, etc. However, the problem on which we have focussed our attention is the behaviour of the rack system in response to the design seismic event for the facility, the so-called "postulated Hosgri event" (PHE). The magnitudes of the seismic accelerations associated with the PHE are large enough to generate problems unique to Diablo. The response of the racks in the spent fuel pools must be known if safety issues relating to the reracking license amendment are to be resolved.

The general questions are therefore:

a) In response to the PHE, what is the expected motion of the spent fuel racks and fuel which may be contained in the racks?

b) What is the nature of the interactions between the racks, between the racks and the walls of the pool and between spent fuel and the racks in response to seismic excitation? What role does the surrounding water play in these interactions?

c) In particular, what are the forces on the racks and the fuel as a result of these interactions? Can the racks and fuel withstand these forces without damage?

THE PG&E ANALYSIS

The analysis of rack behavior discussed in the "Reracking Report" (Ref. 1) makes use of a simplified rack model which is investigated by means of a time history analysis. The approach used by PG&E shall be referred to herein as the STH. In this model, the rack itself is assumed to be rigid except during collisions with other racks or with fuel elements. It moves with three translational and three rotational degrees of freedom. The fuel assemblies are assumed to move in unison and are modeled by two lumped masses, one fixed to the rack and one moving with two degrees of freedom. The entire rack motion is therefore modelled by an 8 DOF model. Various loading patterns were used and two different coefficients of friction between the floor and the rack, 0.8 and 0.2, were used to study the behavior of the racks in response to the PHE.

Interactions between the fuel and the rack are modelled by elastic collisions between fuel assemblies and the cell walls with spring constants determined by the manufacturer. 4% structural damping is assumed. There exists a gap between the fuel assemblies and the cell walls through which the (lumped) fuel mass moves before contacting cell walls. Fluid coupling is also assumed between the fuel mass and the cell with two fluid coupling parameters used. (see below)

Interactions between the racks are also modelled as impacts and fluid coupling. On each face of each rack is assumed to be four springs which are used to represent the elasticity of the rack itself. Fluid coupling coefficients are used to account for forces exerted on the rack by the surrounding water. No material or fluid damping is assumed. Fluid virtual mass is included in the vertical equations of motion but is expected to be accounted for by the fluid coupling coefficients in the other dimensions.

The accelerations of the spent fuel pools in three dimensions assumed to represent the PHE are given by a seismic time history with time steps of 0.01 seconds having a maximum horizontal acceleration in both directions of 0.75g (Ref. 2) With this input the equations of motion are integrated to find the resulting motion of the racks.

If interactions with other racks are ignored. the displacement of a rack was found by the STH to be approximately 3 inches relative to the pool floor.

(Ref. 3) Collisions between racks are therefore expected to occur, since the racks have a spacing much less than this. The report submitted to the NRC by PG&E makes no mention of collisions between racks and the walls of the pool, although some later material indicates some collisions are expected to occur. (Ref. 4) At the present time we have no information as to how such collisions were analyzed.

Although there is some doubt about the exact details of the collision modelling, it appears that impact is assumed to occur whenever a rack has moved half the initial spacing between racks from its initial position. (Ref. 5) The collision is assumed to occur with an identical rack having velocities, displacements, etc., which are the negatives of those of the first rack. The STH refers to the second rack as being "out of phase".

The time history analysis proceeds with this constraint, and the maximum compression of the impact springs is used to compute the maximum impact force on the rack during the 24 second seismic event. Maximum values for several stresses are also computed. Maximum velocities, fluid coupling forces, or other parameters are evidently not recorded. (Ref. 6)

The Reracking Report lists the maximum allowable impact force to be 175,000 lb. It claims that the largest value obtained from the STH is 71,400 lb and that therefore impacts between racks can be accommodated without violating rack integrity. They also claim that the maximum impact force on the fuel assemblies is 251,000 lb which they compare to a limiting load of 883,000 lb.

FERGUSON ANALYTICAL MODEL

The analyses done by Dr. Ferguson make some further simplifications to the model in order to make the problem tractable to smaller computers. Rotations have been ignored altogether, so that problems arising from tipping or turning of the racks are not dealt with. All collisions are thereby assumed to occur head-on, whereas contact between racks could be initiated at rack corners. The 4% structural damping has been ignored. Only the smaller of the two friction coefficients has been used since this gives the larger sliding displacements.

Before receiving the seismic acceleration time histories from PG&E the one dimensional problem of an elastic object striking an infinitely massive accelerating wall was investigated, in which the acceleration is assumed constant and the collision perfectly elastic. (Ref. 7) The maximum force can be computed analytically in terms of the initial relative velocity of the object, its mass, spring constant and the acceleration of the wall. The result should be approximately correct and applicable to the head-on collisions of the fuel racks with the pool walls so long as the impact time is not too long compared with fluctuations in the actual expected acceleration of the pool walls.

This model yields conservatively small values for the force on the rack in if actual rack mass is used for computations rather than an appropriately larger effective mass which would give larger forces. As a first approximation, frictional forces were neglected. This is reasonable so long as collision times are short and frictional forces small compared to impact forces. As will be seen below, these assumptions are verified by later results. The entire fuel mass is also assumed to be fixed to the rack. Later work removes this restriction. Fluid coupling is also ignored, since the model begins after impact has occurred and since the behavior of the fluid between a rack and a wall during a collision would be difficult to model.

The results of this model give the impact force as :

1a) $$F = V \sqrt{kM} \qquad \text{if } A = 0$$

1b) $$F = M A \left(1 + \sqrt{1 + k V^2 / M A^2}\right) \quad \text{if } A > 0$$

where M is the mass of the rack, k the net spring constant, V the relative velocity of the rack with respect to the wall, A the acceleration of the wall.

This analytical approach yields the interesting result that for a collision with zero initial relative velocity, the maximum impact force on the rack is 2MA, which for M = 200,000/g and A = 0.75g (peak Hosgri horizontal acceleration) results in an impact force of 300,000 lbs, well above the limiting value given by the manufacturer. Thus we see that collisions with accelerating walls are of considerable interest in the safety problem, if such collisions are possible. If one assumes rack velocities of the order of those attained by the pool, and further assumes that "out of phase" collisions with pool walls ocur, the impact forces become quite large (see Table 1), far in excess of the maximum allowable.

While it is true that several simplifying assumptions regarding the nature of the collisions were made in order to make the problem analytically tractable, the analytical solution is useful. From this solution the dependence of the impact force on the system parameters (mass, elasticity, relative velocity, etc.,) is transparent. The STH treatment of rack-rack collisions fails to record impact velocities and does not show how the impact forces depend on system parameters. The reviewer therefore has no way of knowing how sensitive the time history results are to assumptions which might change impact velocities or other important variables.

It may be argued that the head-on collision modelled in the one dimensional analytical result is unlikely to occur, since the rack may be turned or tipped when it contacts a wall. However, although these more complex collisions may well occur, the requirement that a rack be able to withstand a

TABLE 1

MAXIMUM IMPACT FORCE AS FUNCTION OF VELOCITY AND ACCELERATION FOR SIMPLE RACK-WALL COLLISION

$k = 4.8 \times 10^7$ (lb/ft)
$M = 200{,}000/g$ (slug)
$g = 32.15$ (ft/sec/sec)

ACCELERATION = 0.00 (FT/SEC/SEC)

VEL (FT/SEC)	FORCE (LBS)
0	0.00
1	5.46 E+5
2	1.09 E+6
3	1.64 E+6
4	2.19 E+6
5	2.73 E+6

ACCELERATION = 8.04 (FT/SEC/SEC)

VEL (FT/SEC)	FORCE (LBS)
0	1.00 E+5
1	5.99 E+5
2	1.14 E+6
3	1.69 E+6
4	2.24 E+6
5	2.78 E+6

ACCELERATION = 16.08 (FT/SEC/SEC)

VEL (FT/SEC)	FORCE (LBS)
0	2.00 E+5
1	6.56 E+5
2	1.20 E+6
3	1.74 E+6
4	2.29 E+6
5	2.83 E+6

ACCELERATION = 24.11 (FT/SEC/SEC)

VEL (FT/SEC)	FORCE (LBS)
0	3.00 E+5
1	7.17 E+5
2	1.25 E+6
3	1.80 E+6
4	2.34 E+6
5	2.89 E+6

simple head-on collision seems reasonable.

The analytical result is valuable in understanding the time history results computed by the rack designer for rack-rack collisions, as well. As mentioned above, the STH assumes that such collisions occur between racks "out of phase". Under such a constraint the collision is identical to a collision with an infinitely massive wall having zero velocity and acceleration. In other words, the analytical result for A = 0 should give results for head-on collisions between racks having velocity V and -V respectively at time of impact which are substantially the same as those obtained by the STH the same conditions. The analytical result of equation 1a shows us therefore how the rack-rack impact forces might reasonably be expected to vary with changes in rack elasticity, mass and velocity. From this equation we see that an impact force of 7.14E4 as computed by the STH corresponds to a rack velocity of approximately 4 inches/sec, approximately 1/10 the expected maximum pool velocity.

FERGUSON TIME HISTORY ANALYSIS

After receiving the PHE acceleration time histories from PG&E it was possible to construct a model for rack-wall collisions which avoided some of the assumptions used in the analytical model. In this time history model (THM) the accelerations of the PHE are used for the wall, although constant acceleration can also be assumed in order to benchmark the THM against the analytical result if desired. Friction between the rack and the pool floor is included, with the vertical acceleration of the pool and its effect on the friction force fully accounted for, although vertical effective mass effects are still ignored. The motion of the moving fuel mass is also taken into account, with the position of the fuel at the instant of impact as an adjustable parameter. A single multiplier to adjust the effective mass of the rack is included. A listing of the computer program "COLL4050" used for the

THM is attached as Appendix A.

The THM does retain several assumptions, however. Rotations are still not included, so that the results are most applicable to head-on collisions, as before. Fluid coupling effects between the fuel elements and the cells is ignored, the 4% damping term is omitted, and no fluid coupling between the rack and the wall is used. The implications of these assumptions are discussed below.

As was mentioned in the discussion of the analytical solution, the THM is also applicable to rack-rack collisions. The impact velocity, which is entered as a parameter in the model, represents the relative velocity between the rack and the wall for that situation, and represents the velocity of one of the racks for rack-rack collisions. The other rack is assumed to have an exactly opposite velocity according to the STH assumptions.

The THM was checked for convergence and found satisfactory. In the results quoted below, an integration step of 0.0002 seconds was used. Results are expected to be within a few percent of the asymtotic solutions. The THM was benchmarked against the analytical solution by using a rigid rack, zero friction and constant acceleration. Agreement was within one percent, less than the expected convergence errors. The other THM results quoted here for rack-wall collisions assume that the wall faces east-west and is moving according to the PHE and that impact occurs at 4.050 seconds into the event.

Whereas the analytical result discussed above assumed that the entire mass moved as a unit, the THM assumes that half the mass of the fuel moves separately. The spring constant between the rack and the wall is taken to be 4.8E+07 lbs/ft, the spring constant between the fuel and the cell walls is taken to be 1.68E+6 lbs/ft. We can see that the fuel is acted upon by a softer spring than is the rack. As a result, when the rack has reached zero velocity during the collision, the fuel has not. The maximum impact force is therefore less than for the analytical result. In addition, after the rack bounces off the wall, the fuel and the center of mass of the loaded rack is still moving toward the wall, so that the rack may return to strike the wall again. This leads to the double impact clearly shown in many of the graphs discussed below.

The THM can be used, for example, to examine the effect of the coefficient of friction upon the collision. Calculations were made for the maximum impact force for various values of the coefficient with an impact velocity of 1.0 ft/sec, with the following results:

coefficient	max force (lbs)
0.0	509909
0.1	495349
0.2	481181
0.3	467360

As can be seen, the choice of friction has little effect on the maximum computed impact force. By treating all motion as one dimensional, we assure that the entire frictional force will be in the direction of motion. In fact, we expect some of the force to act in the north-south direction. As can be seen above, this will change the results only slightly.

In our work we have assumed that all fuel elements move in unison. The STH makes the same assumption in order to reduce the problem to manageable size. In analyzing collisions, the THM assumes also that at impact the fuel mass has the same velocity as the rack. There is, however, room for a fuel element to move within a cell, the fuel having an equilibrium "gap" of 0.302 inches on either side. The THM can analyze a collision with various initial positions of the fuel, with the following results:

position (in)	max force (lbs)
-.302	481181
0.0	479447
+.302	479447

We see that the initial position of the fuel has little effect on the maximum impact force. The initial velocity of the fuel would be expected to strongly influence the results, of course.

If we compare the analytical results from Table 1 to the THM results for comparable collisions as read from Figure 2, we find the latter approximately 33% smaller than the initial result. Thus it is clearly seen that the inclusion of effects relating to friction, non-constant wall acceleration, independently moving fuel, etc., while lowering the expected maximum impact force somewhat, do not change the qualitative results of the analytical model. Contrary to the claims of certain reviewers of the earlier work, (Ref. 8) the analytical model is quite useful in understanding the collision process.

The THM can be used to examine the effect of effective mass on the maximum impact force, as well. As the rack moves through the water of the spent fuel pool, the motion of some of the water will be coupled to the motion of the rack, a phenomenon to be discussed later. For some applications, this coupling can be simply accounted for by using an "effective mass" in place of the mass of the rack. PG&E's analysis has used this technique for the vertical motion of the racks. The THM can be used with an "effective mass multiplier", EFF, so that the effective mass used in the THM is EFF times the mass of the rack. No multiplier is used for the mass of the fuel.

The results of this analysis are shown in Figure 1 where the impact force on the rack is plotted as a function of time for varoius values of EFF. We make no claim at this time as to what a reasonable choice of EFF should be. We note only that any value larger than 1.0 will serve to increase the maximum impact force on the rack for collisions having the same impact velocity.

Figure 2 shows the results of the THM plotting impact force as a function of time for various values of impact velocity with EFF = 1.0. The results show that a collision of a rack with a wall at a relative velocity of approximately 3 inches/sec would result in an impact force which exceeded the manufacturer's specifications.

In order to use the THM to analyse rack-rack impacts, a family of curves has been generated for A = 0. These curves are shown in Figure 3. The impact forces shown would represent the forces exerted during a head-on rack-rack collision between two racks "out of phase" where the velocity represents the speed of one of the racks. EFF is assumed equal to 1.0. As can be seen from the figure, a speed of about 6 inches per second results in an impact force equal to the limit set by the manufacturer. It can also be seen that if the maximum impact force is 71,400 lbs as claimed by PG&E, the impact speed would correspond to about 3 inches/second.

Further refinements in the model could change these values, of course. Giving the rack an effective mass with EFF > 1 would lower the value still farther, for example, as would a two dimensional friction force. On the basis of all the foregoing, it seems reasonable to believe that the impact speeds for rack-rack collisions analyzed by PG&E are no greater than a few inches per second, and that speeds larger than that would result in collisions expected to damage the racks according to manufacturer's specifications. It is unfortunate that the impact velocities were not recorded when the analysis was performed by PG&E so that comparisons with the above predictions could be made.

EXPECTED RACK SPEED

The seismic model used by PG&E for the postulated Hosgri event results in postulated accelerations in three dimensions with a time step of 0.01 seconds. These accelerations can be directly integrated to find the postulated speed of the spent fuel pools at any time during the event, since the pools are assumed to move with the earth in which they are imbedded. Thus it is found that the postulated maximum speed of the pools is approximately 30 inches/second in both the east-west and north-south directions.

There has been considerable discussion of what can be inferred from the PHE seismic data. (Ref. 9) An expert from PG&E claims that the data "was not intended to represent any physical situation (i.e., displacement) of the pools." (Ref. 10) The same expert claims that the maximum ground velocity resulting from the PHE is 24 inches/second. We fail to understand how this statement can be reconciled with the mathematical consequences of the PHE data. There is no need to revive this discussion here, however, since both the 24 in/sec and 30 in/sec values are an order of magnitude larger than the speed needed to damage the racks in a collision.

The expected maximum rack speed is not simply related to the maximum pool speed, of course. Again, it is unfortunate that the elaborate model used in the STH left no record of the maximum speed attained by a rack. This model does report a maximum displacement for a rack of approximately 3 inches. We have constructed a simpler model which also results in rack displacements of several inches and which predicts the maximum speed for a free rack to be of the order of 24 inches/second. Thus we believe that speeds attained by a single rack would in fact be approximately equal to the maximum speed attained by the pool itself for smaller values of the coefficient of friction.

The question which needs to be answered in order to understand the PG&E analysis is the question of why the maximum speed of the racks at impact, as judged from the small impact forces, is only a few inches per second. Calculations on single racks indicate maximum speeds approximately ten times as large.

STH COLLISION ASSUMPTIONS

According to the STH, collision is assumed to occur <u>whenever</u> the rack has moved half the distance toward the neighboring rack, a displacement of 0.125

inches. Under this assumption the maximum distance through which a rack may be accelerated is limited to 0.25 inches. It is possible that this constraint prevents the rack from attaining large velocities and therefore insures small impact forces. It is difficult to test the effect of his assumption that a rack is permanently confined during the PHE. The assumption is deeply embedded in the computer program used for the STH and neither the speeds attained by a rack, nor impact forces which might occur if the racks were to spread apart even slightly during the seismic event are reported.

Work is continuing to predict the maximum speed of racks confined in a limited space during the PHE. Results to date seem to indicate that even under the assumptions used in the STH the expected speeds are larger than a few inches per second. It should be noted that the assumptions were used to make the problem tractable, not because it accurately reflected what is expected to happen during the seismic event. Although there is some controversy as to what the bahavior of the racks will in fact be, (Ref. 11) it seem unreasonable to expect that <u>every time</u> a rack has moved a certain amount it will be turned around by a collision. As will be discussed later, there is reason to expect that there is instead a large degree of correlation between the motions of the racks.

Since the results of the STH rely heavily on the assumptions regarding the movement of the spent fuel racks, the validity of these assumptions need to be looked at in much greater detail than has been done so far. It is our impression, however, that even with this assumption the maximum speed expected to be attained by a rack would be large enough to result in damaging collisions in the absence of fluid coupling forces.

FLUID COUPLING

It therefore appears that the assumtions made by the STH regarding fluid coupling are essential to the model's safety predictions. During the motion of an object immersed in a fluid, fluid near the object participates in the motion to some extent. As mentioned above, this effect is sometimes handled theoretically by treating the inertial mass of the object to be larger than it actually is, to account for the water which must be accelerated with the rack. As described above, this larger "effective mass" would be expected to lead to larger impact forces for collisions of equal impact velocities.

There is another hydrodymanical effect which needs to be considered for colliding objects immersed in water. As two objects approach each other, the fluid between must be pushed out of the way. Newton's third law indicates that the fluid must exert a force back on the objects. If this is all that occurs, the fluid being expelled from between colliding racks might be expected to slow the racks like a kind of "shock absorber", chusioning the impact by reducing the speed of the racks before impact occurs. This description is overly simplified and ignores a wide range of phenomena but does describe a mechanism which could explain the small impact forces computed by the STH.

The details of the fluid coupling mechanism assumed by the STH are not included in public documents available at this time. The Sierra Club has requested that they be made available. The following discussion is based on currently available material and is therefore tentative.

Rather than assume an effective mass for horizontal motion and a force to describe the effects of the expelled water during a collision, the STH has evidently used a new theory to account for all the forces exerted on a rack by the surrounding water. (Ref. 12) This theory supplies two parameters which relate the forces to the accelerations of each of the two racks. Neither parameter is discussed in available documents, nor is there any reference given to experimental work which could validate his theory.

Reference is made to work done by R.J.Fritz in 1972, (Ref.13) but we have no indication as to how the parameters used relate to those described by Fritz. It should be noted that Fritz' work is based on the assumption that all motions be small compared to fluid channel thicknesses and other dimensions on the system. The Technical Report (Ref. 14) mentions this problem in the following way:

> "Fritz's work, as applied to the rack modules, is limited in that his experimental work, which compared well with his theory, was accomplished for infinitesimal vibratory displacements and for relatively large fluid spaces between the vibrating body and the fluid boundary wall. While this is opposite to the conditions that prevail for spent fuel rack modules, the technique is based upon well established principles in fluid mechanics and serves to provide a lower bounding estimate of the fluid coupling for rack module analysis."

In other words, the STH has extrapolated the work of Fritz into a region in which Fritz' assumptions are no longer valid. At present we do not know how this extrapolation was performed. While one would hope that the extrapolation was, in fact, based on "established principles" this alone does not assure its validity. Nor has any evidence been presented that the results do "provide a lower bounding estimate of the fluid coupling for rack module analysis" as is claimed. The use of a theory derived under certain conditions for a very different problem without substantial experimental evidence seems unwarrented.

A different expression for predicting fluid coupling forces between racks is currently being investigated. This computes the force on a rack in terms of rack dimensions, velocity and separation between the rack and the wall or other rack. The derivation is based on familiar Bernoulli's law arguments and does not depend on the acceleration of the second object as the STH appears to. The derivation of the fluid coupling force expression is recent and is being checked against published work. Although earlier indications were that the forces expected were not large enough to reduce impact forces to the values reported by PG&E, the Bernoulli expression may predict fluid coupling forces similar to the STH results. Work on the fluid coupling problem is continuing and details will be released as soon as possible.

It seems reasonable to believe that the low impact forces reported by PG&E may be the result of large fluid coupling forces acting on the racks. As a result of these forces, the velocities of the racks at impact may be reduced to a few inches per second, perhaps an order of magnitude less that the velocity attained by a free rack. The accuracy of the fluid coupling predictions is essential to the prediction of rack impact forces. If the theory or its application are incorrect, the impact velocities and hence the impact forces could well be too large to guarantee rack safety.

However, even if the fluid coupling theories are correct, other serious problems related to fluid coupling remain. For if the these forces are indeed large enough to reduce impact velocities to a few inches per second, the forces must be quite large. For example, to stop a fully loaded rack initially moving 24 in/sec in a distance of 0.25 inches requires a force of approximately 600,000 pounds. The STH fails to report the magnitude of the fluid coupling forces and does not discuss possible damage to the racks resulting from these large forces. The magnitude of the fluid coupling forces and their effect on the spent fuel racks are essential to understand in order to assure safety of the system in response to a serious earthquake.

MULTIPLE RACK COLLISIONS

The reader is invited to perform the following experiment: place a sheet of paper on a table; place dissimilar objects on the paper; shake the paper back and forth; observe the behavior of the objects. If the reader shakes the paper hard enough so that the objects slide, he will observe that the objects tend to slide back and forth more or less in unison. The explanation is that in spite of different masses, coefficients of friction, etc., the motion of the objects is driven by the motion of the paper which is the same for all the objects.

The same explanation is valid for the expected motion of the fuel racks in response to seismic excitation of the spent fuel pools. Everyone working on the problem assumes that the movement of the pool is identical for each rack. This is because the wavelength of the seismic excitation is much longer than the dimensions of the pools. Indeed, if this were not the case, the differential motion of different segments of the pools could well result in damage to the pools themselves.

In addition to the similarity of the seismic accelerations of each of the racks, fluid coupling forces tend to oppose differential motion of the racks. As discussed above, the fluid coupling forces resist the motion of racks approaching each other since fluid between the racks must be expelled. In exactly the same way, the fluid opposes the motion of racks moving away from each other since fluid must flow into the widening gap. We cannot be sure how the STH treats this phenomenon since no information has been provided. The tentative Bernoulli expression currently being examined treats the two motions in exactly the same way. Thus there is some expectation that fluid coupling forces act to tend to keep the racks moving in unison.

Some reviewers have expressed the opinion that the nature of the interactions between is random and the possibility that two or more racks could be positioned tightly together and move in unison is remote. (Ref. 11) In light of the discussion above, it would seem that this opinion requires some evidence to gain credence. We are aware of no experimental evidence in support of this opinion.

Indeed, the racks are positioned tightly together initially, being separated by only 1/4 inch. It does seem plausible that owing to interactions between racks during the seismic event this spacing will increase and the spacing between the outer racks and the wall will decrease (see below regarding potential collisions between the racks and the pool walls). However, even if the racks were to separate by the maximum possible ammount, the racks would be separated by an average of only a few inches. Given the size of the racks, a spacing of a few inches must still be considered tightly packed.

As can be seen from the collision graphs in Figures 2 and 3, racks involved in collisions are expected to be in contact for several hundredths of a second. During this time, a rack moving at a speed of one foot per second covers a distance of approximately 1/2 inch. In other words, given reasonable spacings between racks and expected velocities, it is probable that two racks involved in a collision will be struck by a third during the time of contact. It is important to note that even if contact by a third does not occur, fluid coupling forces from a third rack may well be acting on one of the original racks during the collision. As we have seen, these fluid coupling forces are expected to be significant and thereby increase the forces and consequences of the original collision.

It should be noted here that the interactions between all the racks in the pools are expected to be quite complex. Although it is reasonable to focus attention on the interactions of two racks for analytical purposes, the behavior of other racks cannot be ignored. The complete description of all racks and their interactions is not probably not possible by currently available techniques. One could assume that a row of racks might slide together and investigate the impact forces if the row collided with a wall or another rack. While this problem would not be simple, a solution may be attempted.

The solution of this problem would depend on the coupling forces between racks, masses, and so forth. A first approximation, however, could be obtained by assuming all the mass to be rigidly connected, thereby ignoring the impact springs and the water assumed to exist between the racks. In such an approximation, the force would increase proportionately with the mass, as indicated by the analytical result, equations 1. A second approximation which includes the elasticity of the racks, the movement of the fuel, etc., could be made. The predicted impact forces would be less than in the original approximation, but larger than for a single rack.

We have argued that collisions with the pool walls by loaded racks can result in impact forces larger than the maximum specified by the manufacturer. If a rack involved in such a collision were to have a force exerted on it by another rack while impact with the wall was occurring, the impact force from the wall would be greater. This is true whether or not the second rack makes contact. As a result, such multi-rack collisions pose additional hazards to the spent fuel storage system.

LIKELIHOOD OF RACK-WALL COLLISIONS

According to PG&E, at least one of the racks is predicted to move a distance of 2.79 inches from its equilibrium position. (Ref. 3) It is not known what assumptions were involved in this prediction or how other racks might behave in this regard. We note that at least one of the racks is located approximately 2.0 inches from a wall, and other racks are also located within a few inches of the walls of the pools. (Ref. 15) One is forced to conclude that collisions between the racks and the walls of the pools are possible, although the discussion of such collisions does not appear in reports from the NRC or from PG&E to date. In a summary of a meeting between PG&E and the NRC there is an indication that PG&E reported the expected collision of five racks in each pool with a wall. (Ref. 4) No report is given as to how these collisions were analyzed.

Our work with a simple model also results in a prediction of sliding displacement of a single rack of several inches. Work with more sophisticated models is continuing. There seems to be widespread agreement that collisions between racks and the pool walls are possible even disregarding arguments by the NRC that interactions between the racks would spread the racks out and move some closer to the walls during the seismic event. If the racks were to spread out, one would expect the likelihood of collisions between the racks and the walls of the pools to increase still farther.

SUMMARY OF RERACKING ANALYSIS PROBLEMS

The resolution of problems relating to fluid coupling effects on impact forces must await further information. However, it seems clear from the above that several potentially damaging phenomena exist. Collisions between a rack and an accelerating pool wall can result in large impact forces regardless of speed at impact. Multi-rack collisions seem likely to occur resulting in forces larger than those from simple collisions. The effect of fluid coupling forces on racks has not been examined. Until and unless these phenomena are understood and rack safety can be assured, it is unreasonable to permit the racks to be used.

IMPLICATIONS OF RACK DAMAGE

The implications of rack damage will be better understood upon receipt of information regarding the manufacturer's analysis of failure modes. At the present time we note that a reduction of the lattice spacing by decreasing the outer (flux-trap) water thickness increases the reactivity of the stored spent fuel. (Ref. 16) Impact or fluid coupling forces large enough to damage the rack could conceivably reduce this water thickness by bending the spacers, cell walls, and other components of the rack. Failure of various welds upon impact could produce the same effect.

The fuel elements themselves have stress limits which may be exceeded during collisions. In extreme cases one might expect the cells to rupture, reducing the effectiveness of the flux-traps. Fuel elements spaced as closely as those in the proposed high-density racks are dependent on the flux-traps to maintain the reactivity to safe levels. Fuel spaced this closely and separated only by water is highly reactive, and would be expected to exceed criticality. (Ref. 17)

The racks in region A also depend on the integrity of the boraflex neutorn absorbing material to maintain reactivity at acceptable levels. If, as a result of seismic motion this material were to become displaced and/or broken, the effectiveness of this absorber could no longer be assured.

There exists, therefore, the potential for a criticality accident as a result of rack damage during a large seismic event. In view of the recent accident at Chernobyl, the potential effects of such accidents are well known.

ALTERNATIVES

As the reader is no doubt already aware, the concerns discussed above all relate to effects associated with the postulated Hosgri event. The accelerations associated with the PHE are significantly larger than the more usual design criteria. (Ref. 18) The possibility of a 7.5M earthquake is unique to Diablo Canyon and does not exist at other reactors, to the best of our knowledge.

The Nuclear Waste Policy Act prohibits storage of spent fuel at facilities at which such storage is deemed "unreasonable". Given the difficulties associated with the proposed reracking, this procedure cannot be considered "reasonable" without a comparison of alternatives. The NRC's acceptance criterial also require a consideration of alternatives. (Ref. 19) NEPA also requires discussion of alternatives as part of the environmental impact assessment which the US Ninth Circuit of Appeals has recommended for the reracking proposal. (Ref. 20) We might add that common sense dictates consideration of alternatives to the proposed reracking. The adequacy of such consideration can be determined by the provisions of NEPA, for example.

The addition of structural members to the spent fuel storage system to prevent gross sliding and tilting according to the Standard Review Plan would seem like an alternative worth consideration. Shipment to another facility, shipment to a federal interim storage facility, dry cask storage and the construction of additional facilities at Diablo Canyon appear to be alternatives which might provide better solutions than the proposed reracking.

October 3, 1986
San Luis Obispo, California

Richard B. Ferguson

Dr. Richard B. Ferguson
Vice-Chairman
Sierra Club, Santa Lucia Chapter

REFERENCES

1) Reracking of Spent Fuel Pools Diablo Canyon Units 1 and 2, Pacific Gas and Electric Company, September, 1985, (Reracking Report), Chapter 6.

2) Reracking Report, pp 6-33 ff.
This data was kindly supplied to Dr. Ferguson on computer diskette. The Sierra Club appreciates the assistance of George Wu and his colleagues of the PG&E engineering staff.

3) Reracking Report, p 6-25.

4) Letter of Hans Schierling, NRC, to J.D. Shiffer, PG&E, dated February 28, 1986, subject "Reracking of Spent Fuel Pools".

5) Reracking Report, p 6-5, 6-15.

6) George Wu et al, private communication, May 22, 1986.

7) Affidavit of R.B.Ferguson, Petitioners' Opening Brief, San Luis Obispo Mothers for Peace and the Sierra Club vs USNRC, US Ninth Circuit Court of Appeals, June 15, 1986, Appendix A.

8) Affidavit of R.C.Herrick, NRC Staff Response to Request for a Stay by Sierra Club and Mothers for Peace, June 24, 1986.

9) R.B.Ferguson, Report to NRC on Efforts to Resolve Sierra Club Contention IA, August 15, 1986.

10) Affidavit of S. Bhattacharya, Respondent-Intervenor's Brief, SLOMFP et al. vs. NRC, US Ninth Circuit Court of Appeals, July 29, 1986.

11) Herrick affidavit, p 4.

12) Reracking Report, p 6-7.

13) R.J.Fritz, "The Effects of Liquids on the Dynamic Motions of Immersed Solids", Journal of Engineering for Industry, Trans. of ASME, February, 1972, pp 167-172.

14) "Evaluation of Spent Fuel Racks Structural Analysis", Franklin Research Center, Technical Report, April 30, 1986, TER-C5506-625, p 23.

15) Reracking Report pp 2-4,5.

16) Reracking Report, p 4-20.

17) Reracking Report, p 4-24, 4-35

18) Reracking Report pp 6-33 ff

19) OT Position for Review and Acceptance of Sp ent Fuel Storage and Handling Applications, NRC, January 18, 1979.

20) SLOMFP et al. vs USNRC, Opinion, September 11, 1986.

21) "Friction Coefficients of Water-Lubricated Stainless Steels for a Spent Fuel Rack Facility", E.Rabinowitz, Report to Boston Edison Do., November 5, 1976.

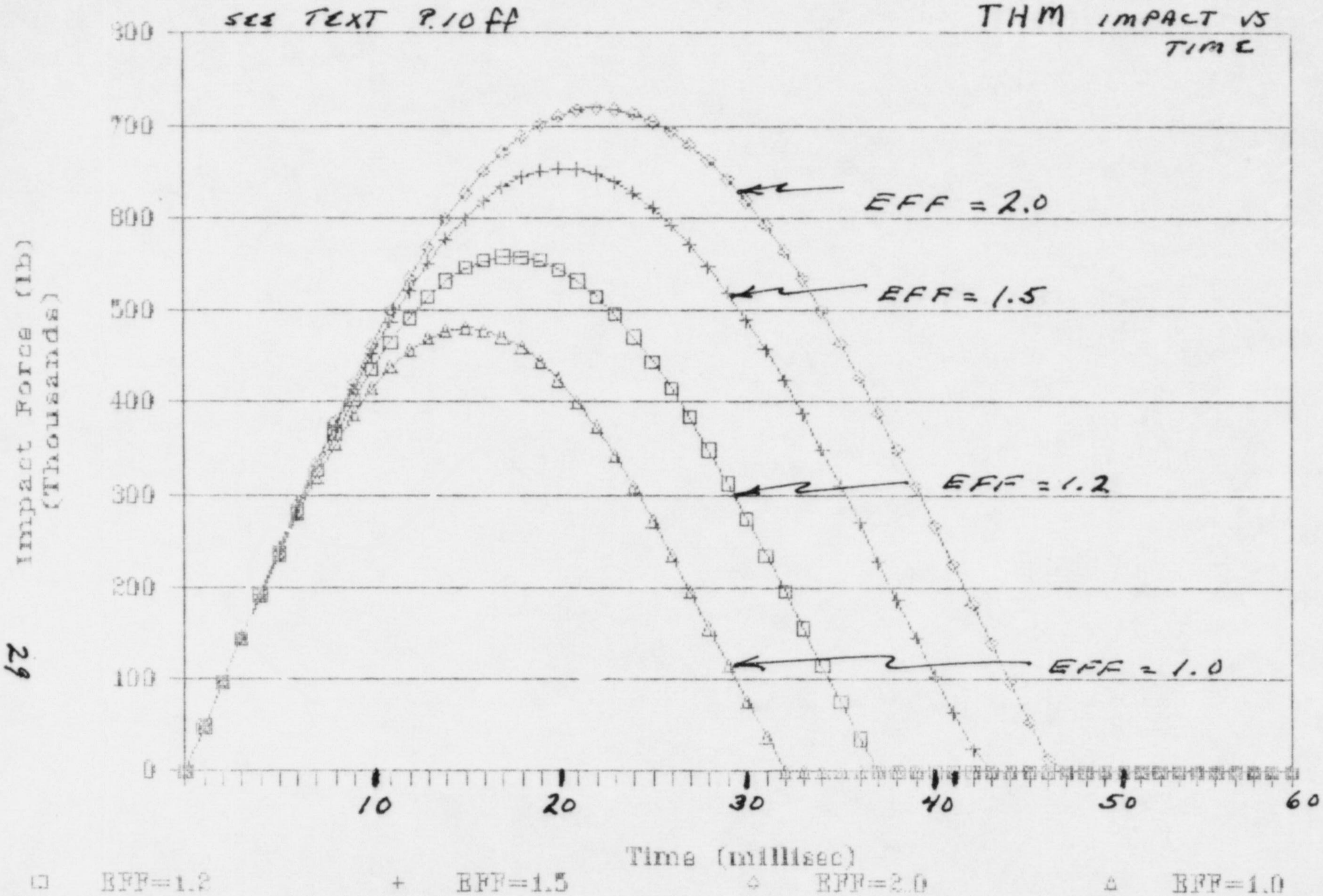
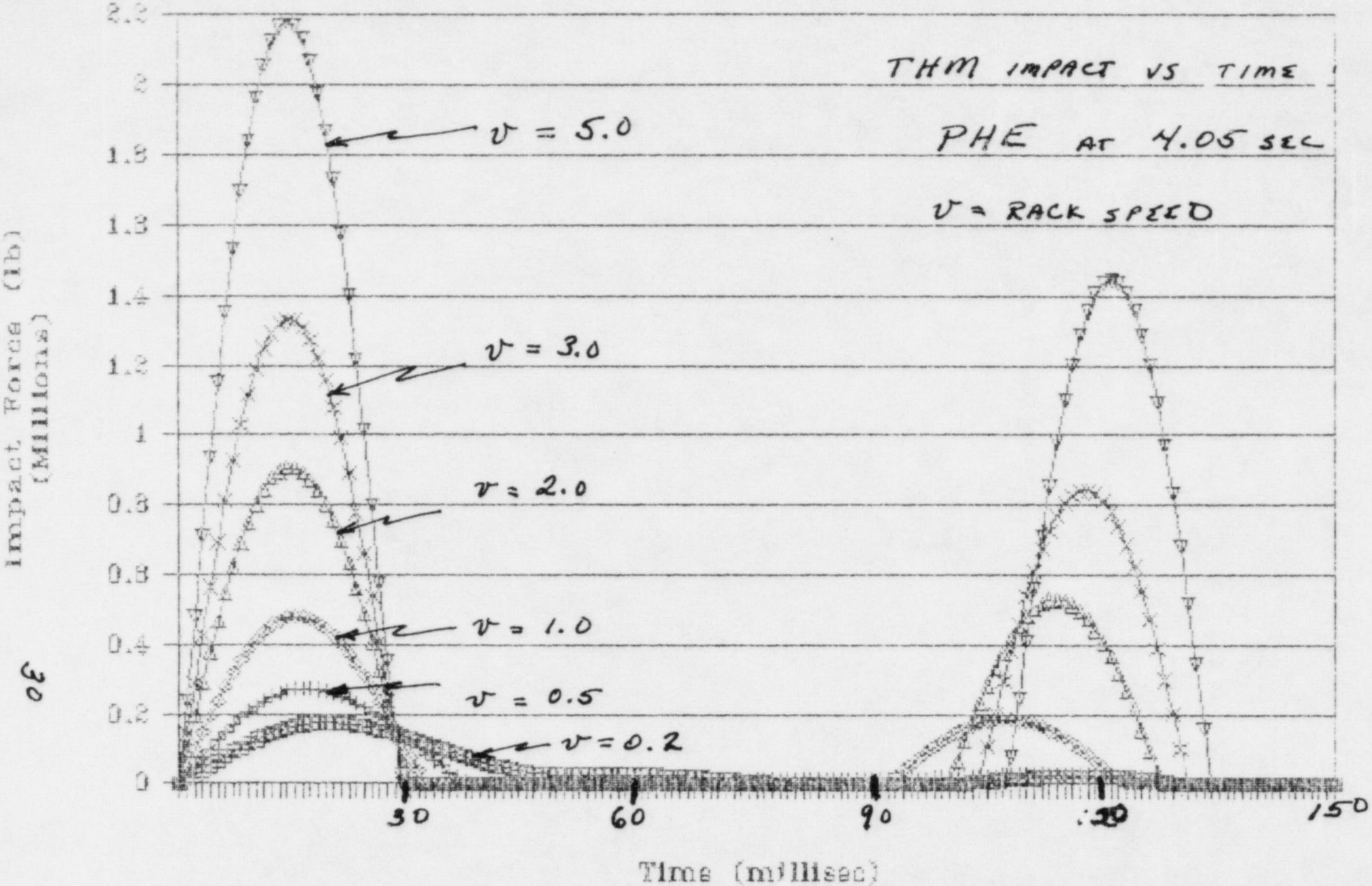

SEE TEXT P.10 ff
THM IMPACT VS TIME
Impact Force (lb)
(Thousands)
0
100
200
300
400
500
600
700
800
10
20
30
40
50
60
Time (millisec)
EFF = 2.0
EFF = 1.5
EFF = 1.2
EFF = 1.0
EFF=1.2
EFF=1.5
EFF=2.0
EFF=1.0

FIGURE 1



THM IMPACT VS TIME
PHE AT 4.05 SEC
v = RACK SPEED
v = 5.0
v = 3.0
v = 2.0
v = 1.0
v = 0.5
v = 0.2
Impact Force (lb)
(Millions)
2
1.4
1
0.4
0
30
60
90
150
Time (millisec)

FIGURE 2

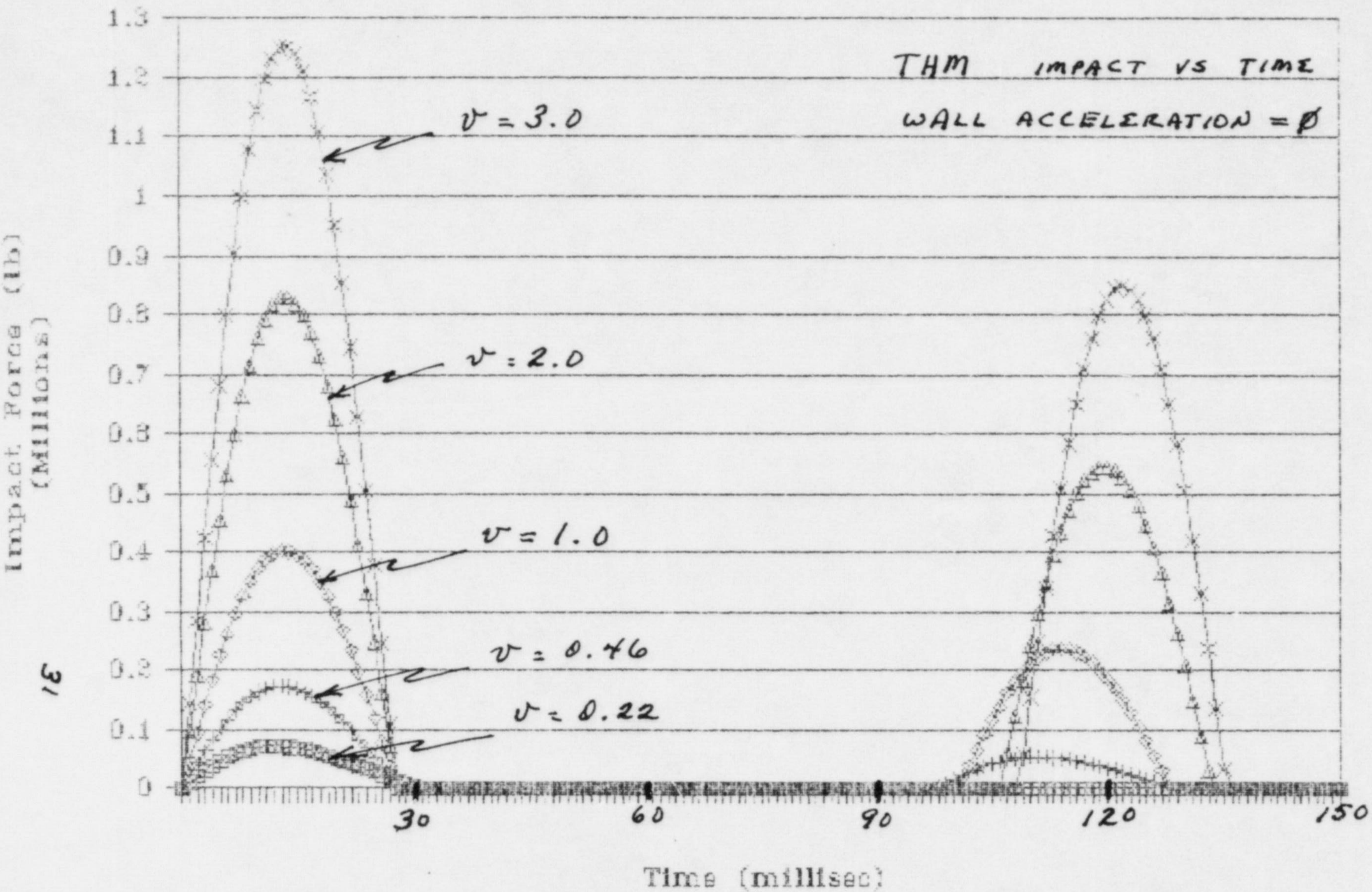

THM IMPACT VS TIME
WALL ACCELERATION = Ø
v = 3.0
v = 2.0
v = 1.0
v = 0.46
v = 0.22
Impact Force (lb) (Millions)
Time (millisec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
30
60
90
120
150

FIGURE 3

```
10 REM /* "COLL4050" */
20 REM /* IMPACT FORCES CALCULATED USING 2-D TIME HISTORY INTEGRATION */
30 ' /* ONE HORIZ DIM BEGINNING AT 4.050 SEC */
40 ' /* INCLUDES FUEL MOTION AND FRICTION */
50 ' /* INPUTS RVEL (DOES NOT USE PREVIOUS INTEGRATIONS) */
60 ' /* SAVES OUTPUT TO DISK FOR USE WITH PLOTTER IF DESIRED */
70 REM /* USED TO EXAMINE COLLISION USING THA FOR VARIOUS INPUTS */
100 OPEN "I", #1, "EWA4050"
110 OPEN "I", #2, "VZA4050"
120 OPEN "O", #3, "PHEVEL/5": REM /* CHANGE THIS AS PARAMETERS CHANGE */
200 KW = 4.8E+07
210 KI = 1.68E+06
211 MU = .2
212 GAP = 0 : REM /* CHOOSE 0 TO .05 */
213 EFF = 1 : REM /* EFFECTIVE MASS MULTIPLIER */
214 VRF = -.5 : REM /* RACK VEL AT IMPACT IN FT/SEC */
215 NOTE$ = "ZERO ACCELERATION "
216 FLNM$ = "PHEVEL/5": REM /* OUTPUT DATA FILE NAME */
220 D = 1: REM /* DUMMY VARIABLE */
230 DELT = .0002: REM /* INTEGRATION VARIABLE */
240 INTTIME = 15: REM /* INTEGRATION LENGTH HUNDREDTHS OF SECONDS */
250 NUMSTEPS =  .01 / DELT
270 GEE = 32.15
280 MF = 55 * 1616/GEE: MR = MF + 26000/GEE: REM 110 ELEMENTS, HALF FIXED
300 MR = MR * EFF
305 REM  GOTO 320
310 LPRINT TAB(20) "FILENAME : ";FLNM$
311 LPRINT TAB(20) "COMMENTS : ";NOTE$
312 LPRINT TAB(20) "KW = "; KW ; "LBS/FT"
313 LPRINT TAB(20) "COEFFICIENT OF FRICTION = "; MU
314 LPRINT TAB(20) "INITIAL FUEL GAP = "; GAP ; "FEET"
315 LPRINT TAB(20) "EFFECTIVE MASS MULTIPLIER = "; EFF
316 LPRINT TAB(20) "INTEGRATION STEP = "; DELT ;"SECONDS"
317 LPRINT TAB(20) "RACK VEL AT IMPACT = "; VRF ; "FT/SEC"
320 LPRINT TAB(20) "RACK MASS = "; MR ; "SLUG"
330 LPRINT TAB(20) "FUEL MASS = "; MF ; "SLUG"
340 '
350 '
400 I = INTTIME
410 DIM AWF(I)
420 DIM AZF(I)
2000 REM /* CALCULATES AND GRAPHS COLLISION DATA BEGINNING AT COLLTIME */
2100 REM /* LOAD ACC & TIME DATA INTO CALC ARRAYS */
2110 FOR I = 1 TO INTTIME
2115 REM  AWF(I) = 0: GOTO 2130 /* USE THIS LINE FOR CONST ACC */
2120 INPUT #1, A: AWF(I) = GEE * A
2130 INPUT #2, B: AZF(I) = GEE * B
2140 NEXT I
2150 '
2160 REM
2170 REM
2180 REM
2190 REM
2230 REM
2240 REM
2250 REM
2260 REM
2270 REM
2280 REM
2290 GOTO 2500
```

APPENDIX A

```
2300 FOR I = 0 TO (INTTIME - NUMSTEPS) STEP NUMSTEPS
2310 FOR J = 1 TO NUMSTEPS -1
2320 AWF(I + J) = AWF(I) + (J/NUMSTEPS) * (AWF(I + NUMSTEPS) - AWF(I))
2330 AZF(I + J) = AZF(I) + (J/NUMSTEPS) * (AZF(I + NUMSTEPS) - AZF(I))
2340 NEXT J
2350 NEXT I
2360 REM
2370 REM
2380 REM
2390 REM
2470 REM
2480 REM
2490 REM
2500 REM /* INIT STARTING VALUES */
2510 XWF = 0
2520 IF VRF <0 THEN XRF = D ELSE XRF = -D
2530 IF VRF < 0 THEN XMF = D+D+GAP ELSE XMF = -D-D-GAP
2540 VWF = 0
2560 VMF = VRF
2570 ARF = -MU * (GEE + AZF(1)) * SGN(VRF - VWF)
2580 AMF = 0
2590 GOSUB 3000
2595 PRINT #3, WALLIMP
2600 REM /* CALCULATIONS */
2610 FOR I = 1 TO INTTIME
2615 FOR J = 1 TO NUMSTEPS
2620 XWF = XWF + VWF * DELT
2630 VWF = VWF + AWF(I) * DELT
2640 XRF = XRF + VRF * DELT
2650 VRF = VRF + ARF * DELT
2660 XMF = XMF + VMF * DELT
2670 VMF = VMF + AMF * DELT
2680 REM
2690 REM
2700 REM /* CALC NEW ACCELERATIONS */
2710 XRW = XRF - XWF
2720 XMR = XMF - XRF
2730 VRW = VRF - VWF
2740 VMR = VMF - VRF
2760 FRICTION = - MU * (GEE + AZF(I)) * SGN(VRW)
2770 IF ABS(XRW)>D THEN WALLIMP = 0 ELSE WALLIMP = KW * (D - ABS(XRW)) * SGN(XRW
)
2772 IF ABS(XMR)<D THEN FUELIMP = -KI * (D - ABS(XMR)) * SGN(XMR)
2774 IF ABS(XMR)>D + .05 THEN FUELIMP = -KI * (D + .05 - ABS(XMR)) * SGN(XMR)
2776 REM /* FUELIMP = FORCE OF FUEL ON RACK;  WALLIMP = FORCE OF WALL ON RACK */
2780 IF ABS(XMR)>D AND ABS(XMR) < D + .05 THEN FUELIMP = 0
2790 ARF = FRICTION + WALLIMP / MR  + FUELIMP / MR
2800 AMF =-FUELIMP / MF
2805 IF FMAX < WALLIMP THEN FMAX = WALLIMP
2810 IF J MOD .001/DELT = 0 THEN GOSUB 3100: REM /* GRAPH POINT AND OUTPUT WIMP
*/
2815 A$ = "": A$ = INKEY$: IF A$ = "B" THEN 2900
2818 NEXT J
2820 NEXT I
2900 LPRINT TAB(25) "MAXIMUM IMPACT FORCE = "; FMAX; "LBS"
2910 CLOSE: STOP
2920 IF B = 32 THEN STOP ELSE 2910
3000 REM /* INIT GRAPH */
3010 CLS
3020 LINE (0,160) - (599,0),,B: LINE -(0,0)
```

```
3030 DEF FNCONY(Y) = 160 -  ABS(Y)* .00004
3040 DEF FNCONX(X) = 2 * X
3050 I = 0: X = 0
3060 GOSUB 3100
3090 RETURN
3100 LINE -(FNCONX(X), FNCONY(WALLIMP))
3110 X = X + 1
3120 LOCATE 22,1
3130 PRINT "FMAX = ";FMAX, I
3135 PRINT #3, WALLIMP
3140 RETURN
```

CITATIONS

Material in this report which is thought to best respond to the interrogatories is identified by page number.

PG&E Int. #	Report Page #
1	5, 11 ff
2	7, 9, 15
4 - 9	24 - 26
10, 11	5 - 20
12	23, 24
13 - 18	24 - 26
19	5 - 20
20	20 ff
21 - 27	24 - 26
28, 29	5 - 20
30	5 - 23, esp 20 ff
31, 32	5 - 14
33	23, 24
37, 38	5, 6, 25
39	24
40	17 - 20
41, 42	19, 20
43	all
44	20 - 23
46	all
47	24
48	5 - 15
49	15, 16
50	17 - 20
51, 52	19

NRC Int. #	Report Page #
1-1a	3
1-5	25

RELATED CORRESPONDENCE

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

DOCKETED
USNRC

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

86 OCT -6 P5:16

In the Matter of:	)	Docket Nos. 50-275-OLA
	)	and 50-323-OLA
PACIFIC GAS AND ELECTRIC COMPANY	)	
	)	ASLBP No. 86-523-03-LA
(Diablo Canyon Nuclear Power Plant, Units 1 and 2)	)	

OFFICE OF SECRETARY
DOCKETING & SERVICE
BRANCH

CERTIFICATE OF SERVICE

I hereby certify that copies of the SIERRA CLUB RESPONSE TO FIRST SET OF INTERROGATORIES AND REQUEST FOR PRODUCTION OF DOCUMENTS FROM PG&E AND THE NRC in the above-captioned prodeeding have been served on the following by deposit in the United States mail, first class, this 3rd day of October, 1986.

B. Paul Cotter, Jr., Chairman
Administrative Judge
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Glenn O. Bright
Administrative Judge
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dr. Jerry Harbour
Administrative Judge
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Ms. Nancy Culver
192 Luneta Street
San Luis Obispo, CA 93401

Bruce Norton, Esquire
c/o P.A. Crane
Pacific Gas and Electric Company
77 Beale Street, 31st Floor
San Francisco, CA 94106

Mrs. Jacquelyn Wheeler
2455 Leona Street
San Luis Obispo, CA 93401

Philip A. Crane, Jr., Esquire
P.O. Box 7442
San Francisco, CA 94120

Laurie McDermott, Co-ordinator
CODES
731 Pacific Street
Suite #42
San Luis Obispo, CA 93401

Mr. Lee M. Gustafson
Pacific Gas and Electric Company
Suite 1100
1726 M Street NW
Washington, DC 20036-4502

Docketing and Service Branch
Office of the Secretary
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Atomic Safety and Licensing Appeal Board
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Henry J. McGurren, Esquire
Lawrence J. Chandler, Esquire
Office of the Executive Legal Director
U.S. Nuclear Regulatory Commission
Washington, DC 20555