Crystal River Unit 3
Docket No. 50-302

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Attachment 2

Technical Basis
for the
Crystal River Unit 3
Plant Specific Procedure
to resolve
NRC Generic Letter 87-02

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Summary

Florida Power Corporation is required to respond to NRC Generic Letter 87-02, Supplement 1. FPC's response committed it to develop a Plant Specific Procedure (PSP) for Crystal River Unit 3 (CR3) to resolve NRC's concerns outlined in GL 87-02.

Florida Power Corporation is a member of the Seismic Qualification Utility Group (SQUG) and could use SQUG's Generic Implementation Procedure (GIP) for the verification of the seismic adequacy of GL 87-02 equipment in CR3. However, it is FPC's position that Florida is a low seismic risk state and implementation of the GIP (which was developed so it could be applied generically even to GL 87-02 plants in the relatively high seismic areas in the western US) is not in FPC's best interest.

This report summarizes the technical bases for the CR3 PSP. The detailed CR3 PSP itself is presented in a separate document.

We believe that the CR3 Plant Specific Procedure is a positive, responsible, and prudent response to GL 87-02.

All of the key GIP commitments and a large number of its guidelines are included in the CR3 PSP. For most GIP guidelines not specifically included in the CR3 PSP, a site- and plant-specific pre-screening of CR3 concluded that CR3 meets the GIP. For the remaining GIP guidelines not specifically included in the CR3 PSP, the CR3 PSP includes guidelines that meet the intent of the GIP. The bases for these conclusions are discussed in this report.

For almost all of this pre-screening, the basis is that CR3 is a low seismic site. For example, the CR3 SSE has a peak acceleration of only 0.1g. On the other hand, the GIP was developed so it would be acceptable to NRC even for the GL 87-02 plant with the largest SSE peak acceleration of 0.25g.

The difference between a 0.1g SSE and a 0.25g SSE is very large. Even a factor of 2.5 does not adequately convey the differences between these two SSEs. A 0.25g earthquake is a respectable earthquake. A 0.1g earthquake is hardly so. On a qualitative scale, a 0.1g earthquake probably would cause some slight damage to homes and other commercial and public buildings. On the other hand, a 0.25g earthquake probably would cause moderate to major destruction to homes and other commercial and public buildings.

This report presents technical information to substantiate some of the differences between what is reasonable to expect for a 0.1g earthquake, what is reasonable to expect for the 0.25g earthquake considered in the GIP, and why pre-screening is reasonable.

For example, a GIP caveat limits the size of cut-outs in motor control center cabinet sheet metal. The GIP concern is structural integrity of the MCC. Since the CR3 SSE is only 0.1g, the size of cutouts is not considered a credible root cause of damage to CR3 MCCs that are constructed to NEMA standards. In other words, the CR3 SSE is not large enough to damage CR3 MCCs. Thus, the GIP caveat is satisfied (that is, CR3 MCCs will not be damaged in an SSE).

Finally, as NRC stated in SSER2: *"As a result of the backfit analysis for the USI A-46 program, the staff determined that the use of the USI A-46 approach provides adequate level of safety...."*

We believe, like the USI A46 approach in GL 87-02, that the CR3 Plant Specific Procedure provides an *adequate level of safety*, especially when all the ramifications of the fact that CR3 is in a low seismic region are considered.

Background

Florida Power Corporation is required to respond to NRC Generic Letter 87-02, Supplement 1. FPC's response committed it to develop a Plant Specific Procedure (PSP) for Crystal River Unit 3 (CR3), based on the GIP, to resolve NRC's concerns outlined in GL 87-02. FPC contracted ***Gilbert/Commonwealth***, ***Programmatic Solutions***, and The ***Readiness*** Operation to help develop its plant specific procedure. This report summarizes the technical bases for the CR3 PSP. The detailed CR3 PSP itself is presented in a separate document.

Approach

Florida Power Corporation is a member of the Seismic Qualification Utility Group (SQUG) and could use SQUG's Generic Implementation Procedure (GIP) for the verification of the seismic adequacy of GL 87-02 equipment in CR3. However, it is FPC's position that Florida is a low seismic risk state and implementation of the GIP (which was developed so it could be applied even to GL 87-02 plants in the relatively high seismic areas in the western US) is not in FPC's best interest.

With this background, the following two paragraphs briefly describe the two approaches we used to develop the CR3 PSP: (1) *Meets the GIP*, and (2) *Meets the Intent of the GIP*.

Meets the GIP. In many cases, the CR3 PSP adopts the letter of the GIP. For example, the CR3 PSP adopts the GIP implementation guidelines for *seismic interaction*, *qualifications of seismic capability engineers*, *documentation*, and many other detailed screening guidelines and caveats. These areas are identified in Table 1 and Appendix D.

Meets Intent of GIP. In the vast majority of the cases where the CR3 PSP does not meet the *letter* of the GIP, the CR3 PSP meets the *intent* of the GIP. For almost all of these cases, the reason is that CR3 is a low seismic site. For example, for many electrical cabinets a GIP caveat limits the size of cut-outs in the cabinet sheet metal. The concern is structural integrity of the cabinet. Since the CR3 SSE is only 0.1g, the size of cutouts is not considered a credible root cause of damage to cabinets constructed to NEMA standards. In other words, the CR3 SSE is not large enough to damage CR3 MCCs and the GIP caveat is satisfied (that is, CR3 MCCs will not be damaged in an SSE).

For the caveats in Appendix B of the GIP however, note that *"meets the intent of the caveat"* is all that is required to <u>meet the GIP</u> (this is discussed in Section 4.1.3 of the GIP). To clarify matters in this report however, Appendix D identifies those caveats where the CR3 PSP meets the intent of the GIP as *"meeting intent,"* even though we could have stated that the CR3 PSP "*meets the GIP*." However, this is done for the purpose of more clearly communicating what the CR3 PSP is, and what it is not. This does not mean FPC does not accept Section 4.1.3 of the GIP.

The following five paragraphs describe some of the techniques we used to develop the CR3 PSP. Note, however, that they all fall into the above two approaches.

Pre-Screening. In some cases, CR3 PSP guidelines are based on a pre-screening of the equipment class, or detail, relative to the GIP (or PSP) guidelines, and the pre-screening finds that the CR3 equipment or detail meets or exceeds the guidelines. This means a case by case screening of the item or class is not required during the walkdown or other implementation of the CR3 PSP (since the screening has already been done). For example, Appendix A shows that the seismic capacity of CR3 SSEL equipment exceeds the seismic demand on it. Thus, in this case the CR3 PSP is equivalent to the GIP commitment in Section 4.1 of the GIP, even though a case by case screening will not be performed during the implementation of the CR3 PSP.

Plant Specific Implementation of GIP Bases. SQUG developed the GIP for application to a wide variety of plants and sites. For example, the GIP was developed so it could be applied to the highest seismic GL 87-02 plants, including some plants in the western US. Some GIP implementation guidelines do not vary depending on the size of the SSE. This means the GIP implies that the desired seismic margin at CR3 is larger than the desired seismic margin at the GL 87-02 plant with the largest SSE. Thus, the GIP does not always adequately reflect CR3 plant and site specific issues.

In some cases, the CR3 PSP takes credit for plant or site specific issues by interpreting the GIP bases (the "research" reports referenced in the GIP), which is allowed by the GIP. For example, this approach was used, in part, in evaluating the adequacy of CR3 raceway supports. Details are in Appendix B.

Meets GL 87-02 (2/19/87). In some cases, CR3 PSP guidelines are based on NRC's original generic letter. For example, the CR3 PSP implementation guidelines for anchorage are based, in part, on explicit guidance in GL 87-02. Details are in Appendix E.

New Information. In some cases, CR3 PSP guidelines are based on information that was not considered in developing the GIP. For example, data on the actual in-structure amplifications recorded in earthquakes at nuclear power plants are used to develop the seismic demand guidelines in Appendix A. This is allowed by the GIP (see Section 5) as long as the bases are documented (which is done in Appendix A).

Combined Approach. In some cases, combinations of the above approaches were used to develop the CR3 PSP guidelines. For example, *Plant Specific Implementation of GIP Bases* and *Pre-Screening* was used for Raceways. Details are in Appendix B.

Technical Bases for CR3 Plant Specific Procedure

Introduction. This section summarizes the technical bases for the guidance in the CR3 PSP. The technical bases fall into two major areas: *Agrees With the GIP*, and *Agrees With the Intent of the GIP*. These areas are discussed in the following paragraphs.

CR3 PSP Agrees With GIP. A large portion of the CR3 PSP agrees with the GIP. Table 1 summarizes the key parts of the GIP, and identifies those areas where the CR3 PSP agrees with GL 87-02 or the GIP. The CR3 PSP agrees with the GIP for about

75% of the elements of the GIP listed in Table 1. Some of the key areas of agreement are briefly discussed in the following.

The four major steps of the CR3 PSP are the same as those in Section 1.3 of the GIP, namely:

- Selection of Seismic Evaluation Personnel
- Identification of Safe Shutdown Equipment
- Screening Verification and Walkdown
- Outlier Identification and Resolution

For *Selection of Seismic Evaluation Personnel*, the CR3 PSP is the same as the GIP for Systems Engineers, Plant Operations Personnel, and Seismic Capability Engineers. In fact, FPC has already sent several engineers to the SQUG training on the GIP.

For *Identification of Safe Shutdown Equipment*, the CR3 PSP is the same as the GIP.

For *Screening Verification and Walkdown*, the CR3 PSP has the same basic four steps as the GIP:

- Seismic Capacity Compared to Seismic Demand
- Caveats
- Anchorage
- Seismic Interaction

For *Outlier Identification and Resolution*, the CR3 PSP definition of an outlier, and the ways they can be resolved, are identical to the GIP.

Equipment Caveats. Appendix B of the GIP has a total of 266 generic caveats for the SQUG 20 classes of equipment. The CR3 PSP accepts all 266 caveats (with the understanding that Section 4.1.3 of the GIP applies on *"meeting the intent"* of the caveats).

Seventy-nine of the 266 caveats are briefly discussed in Appendix D. Fifty-one of the 79 caveats are satisfied by pre-screening, and thus are not included for implementation the CR3 PSP. That is, we evaluated the concern that is the basis for the caveat and concluded that, based on CR3 being a low seismic site, that the concern is not a credible one for CR3 equipment. In other words, CR3 meets the intent of the caveat.

The remaining 28 of the 79 caveats are included in the CR3 PSP (all of them are anchorage issues). The CR3 PSP position on anchorage is discussed below. We believe the CR3 PSP approach to anchorage meets the intent of the GIP.

In addition, in both the GIP and the CR3 PSP, all classes of equipment include the caveat: *"No other concerns?"* Moreover, the Seismic Capability Engineers (SCEs) who will perform the CR3 walkdowns will be SQUG trained. Thus, CR3 SCEs will be familiar with all 266 caveats in the GIP. Because SCEs must evaluate and answer the question *"No other concerns?"* before they leave each item of SSEL equipment, they will evaluate any violations of the GIP caveats not included in the CR3 PSP they believe are important to the safety of each specific item of CR3 equipment.

Where the GIP caveat is included in the CR3 PSP, this is *"identified only by omission"* in Appendix D. That is, Appendix D identifies only the equipment specific caveats

where there is some difference between the GIP and the CR3 PSP that warrants mention. GIP caveats not in Appendix D are in the CR3 PSP.

Important differences between the implementation guidelines in the GIP and the CR3 PSP are identified in Table 1 or Appendix D. The remainder of this section summarizes these differences and the bases for them.

Seismic Demand. Appendix A summarizes the bases for the CR3 PSP guidance on seismic demand. Earthquake _data_ on actual in-structure amplifications recorded at nuclear power plants were used to develop the seismic demand guidelines in Appendix A. These data were not considered in developing the GIP.

The seismic demand spectra for CR3 SSEL equipment is found to be less than the SQUG Reference Spectrum (which is the earthquake-experience-based equipment capacity spectrum NRC and SQUG agreed on) for all frequencies. Thus, CR3 SSEL equipment for which earthquake-based seismic capacity is applicable has a seismic capacity greater than the seismic demand (if the applicable equipment caveats are met).

Note that this conclusion applies to the adequacy of only the *equipment* capacity itself. The adequacy of the capacity of equipment *anchorage* must be determined separately by walking down each item of SSEL equipment (see Appendix E).

This means the implementation of the CR3 PSP for GL 87-02 does not have to address the GIP issue of the seismic capacity and demand of equipment (for that equipment for which earthquake-based seismic capacity is used) on a case by case basis. In other words, the GIP seismic capacity/demand screening guideline is pre-screened by the discussion in Appendix A.

This also means that the CR3 plant specific procedure for GL 87-02 does not have to explicitly include the GIP 8 Hz guideline. This is because the GIP 8 Hz guideline is only needed when a different capacity/demand method is used than the one used in the CR3 PSP. (Method A of Table 4-1 of the GIP is not used in the CR3 PSP. The CR3 PSP uses Method B.1 of Table 4-1. Method A has the 8 Hz caveat, Method B does not.)

This also means that the CR3 plant specific procedure for GL 87-02 does not have to explicitly include the GIP guideline of evaluating the stiffness of equipment anchorage (for equipment frequency issues). The GIP anchorage stiffness guideline is pre-screened by the CR3 seismic demand/capacity pre-screening discussed above. (However, this does not mean that the base stiffness/prying action issue of Check 12 of Section 4.4.1 of the GIP is pre-screened. SCEs should still review any base stiffness/prying action details that, in their judgment, they need to in their review of equipment anchorage.)

Details are in Appendix A.

Finally, note that the Commitments in Section 4.1 of the GIP do not prescribe *how* to develop the plant-specific seismic demand. Section 4.1 specifies how to obtain seismic capacity--which the CR3 PSP agrees with, and that seismic capacity must exceed seismic demand--which the CR3 PSP also agrees with. _*Thus, the CR3 PSP approach to seismic capacity/demand meets the SQUG Commitment in Section 4.1 of the GIP*_.

Raceways. In Reference B1, SQUG documented the performance of raceways in earthquakes. Raceways have performed in an outstanding manner, even in earthquakes over five times larger than the CR3 SSE. This is particularly impressive considering that

the vast majority of these raceways are not designed for earthquakes, and are instead constructed to normal industrial practice. Raceways have a better earthquake performance record than virtually every other power plant component; this includes structures, vessels, piping, equipment, and equipment anchorage.

The primary analytical guideline in the GIP is that raceway supports should have a vertical capacity of 3 times the weight they support.

The GIP guideline is stated as a vertical capacity check. However, when we developed the vertical capacity check for SQUG, we intended the vertical load factor of 3 to account for all applicable earthquake loads, including lateral earthquake loads.

In addition, we intended the analytical guidelines to act as a *similarity evaluation*. That is, our objective is to use the analytical guidelines to ensure that CR3 raceway supports are similar to or better than supports that performed well in earthquakes.

The GIP analytical guidelines were derived from the performance of raceways in earthquakes that were larger (in many cases much larger) than the largest GL 87-02 SSE of 0.25g. To simplify the generic guidelines however, when SSRAP revised our original guidelines, they chose not to recommend that the vertical dead load seismic factor vary with the size of the GL 87-02 plant SSE. (However, we initially developed the dead load factor to vary with the SSE size. Moreover, other GIP raceway analytical guidelines still do vary according to the size of the GL 87-02 plant SSE.)

When the GIP vertical capacity check of 3 times dead load is revised to vary with the size of the CR3 SSE, we found the existing CR3 raceway design criteria satisfy it. Other existing CR3 raceway design criteria meet or exceed GIP guidelines. A brief walkdown confirmed that the CR3 raceways are of normal industrial or even more rugged construction.

We conclude that the CR3 raceways meet the intent of the GIP, and that a case by case review of the raceway systems at CR3, to the screening guidelines in the GIP or to any other guidelines in addition to the criteria used for design at CR3, is not needed to satisfy GL 87-02.

Details and additional discussion are in Appendix B.

Relays. Data on the actual performance of relays in past earthquakes are summarized in Appendix C. No claim is made that these data are complete in the sense that they describe every instance of earthquake induced relay actuation. In fact, some of the references in Appendix C allude to instances of actuation that are not included in Appendix C (because the references do not provide any details).

These data are complete in that they include all of the readily available SQUG data. SQUG is the key group that has studied the performance of power and industrial facilities in past earthquakes. Thus, these are some of the best and most complete data available on relay actuations under real world plant design, plant maintenance, plant operation, earthquake conditions, and real-world operator response.

These data are most complete in the sense that they provide a good understanding of the *types* of relay actuations that have occurred. (Note that the type of earthquake effects included in Appendix C is based on the GIP's definition of *"relay chatter,"* which includes many different kinds of physical phenomena.)

Appendix C suggests that the earthquake induced relay chatter issue has probably been overstated for a low seismic site like CR3. One way the issue has been overstated is through reports of protective relay actuation. While protective relay actuations have occurred, they are often mis-interpreted. The actuations often result from current or voltage fluctuations (that were caused by earthquake induced damage, momentary power line short circuits, or other non-relay effects) or other non-relay fluctuations such as fluctuations in oil level. These protective relays were simply performing as designed. (Stated another way, even if these protective relays were seismically qualified with very large seismic margin, they still would actuate in an earthquake, given the same current, voltage, or other non-relay fluctuations. Thus, they are a system seismic issue not a relay seismic qualification issue, and probably not an A46 issue.)

The key findings of Appendix C are that very few, if any, essential relay actuations should be expected in the event of an SSE at CR3 (because although the CR3 SSE ZPA is conservative it is still only 0.1g, and because only short duration earthquakes are expected at CR3), and that operators will be able to take timely action and reset any essential relays that actuate.

In addition, because the CR3 SSE is so small CR3 is different from many other GL 87-02 plants in that it is very likely that offsite power will not be lost in the event of an SSE at CR3. This means that CR3 operators probably will not have to address power restoring problems in the event of an SSE at CR3. This further supports our contention that operators will be able to take timely action and reset any essential relays that actuate in the event of the CR3 SSE.

Based on substantial real world data on earthquake-induced relay actuations, the conclusion of Appendix C is that: *CR3 meets the GIP*, and a case by case relay evaluation program is not required at CR3 to address GL 87-02. See Appendix C for details.

Anchorage. The CR3 PSP position on anchorage for GL 87-02 (see Appendix E) is very close to NRC's position in GL 87-02.

The technical basis for the CR3 position is that the GIP overstates the anchorage issue for a low seismic site like CR3, which has an SSE with a ZPA of only 0.1g. This is based on data on anchorage damage in past earthquakes, which was not considered in developing the GIP.

Reference E2 summarizes a site and literature survey of the earthquake performance of anchorage. For example, Reference E2 documents over 360 cases of anchorage damage. Only about 20 of the 360^+ cases of damage were in power plants. All 20 cases occurred when the free field ZPA was 0.25g or more, and the earthquake magnitude was large (greater than 7).

The conclusion of Appendix E is that it is good conservative seismic design practice to anchor equipment well. However, Appendix E also concluded that it is not difficult to design and install anchorage that will perform well in earthquakes. It is also not difficult for qualified seismic capability engineers to use judgment to evaluate the adequacy of existing anchorage for a relatively minor earthquake like the CR3 SSE. Earthquake experience clearly suggests that the detailed GIP guidelines are not required for a low seismic site like CR3, and that the CR3 PSP guideline is completely adequate to satisfy GL 87-02 at CR3--and meet the intent of the GIP.

Tanks. The CR3 PSP requires verification only of *anchorage* of vertical cylindrical ground mounted storage tanks. This is all that is required in GL 87-02. This is also consistent with the observation from past earthquakes (in Reference 1) that damage in *anchored* tanks is almost exclusively associated with tank anchorage (that is, anchor stretch or pullout). CR3 PSP anchorage verification requires anchor stretch and pullout to be evaluated. This evaluation is to be performed using calculations (using the methods in the GIP, Reference 1, Reference 2, or any other rational method).

SSER2. We reviewed NRC's comments in SSER2 on the GIP. Almost all of them are not relevant to CR3 or the CR3 PSP. For some, this is because they address issues such as modifications and replacements, which are not included in the CR3 PSP. For others, this is because of differences in approach or scope. For still others, this is because CR3, or the CR3 PSP, complies with NRC's comment.

The most important difference not included in the above categories is on third party auditors. Here NRC requested that third party auditors have broad engineering experience (in addition to the GIP requirements in Section 2.2.7). The CR3 PSP accepts NRC's request on third part auditors.

Conclusions

The technical bases for the CR3 Plant Specific Procedure have been presented and explained. A detailed comparison of the guidelines in the CR3 Plant Specific Procedure and SQUG's GIP has been presented to ease NRC's review. The CR3 Plant Specific Procedure either agrees with the GIP, or the CR3 plant meets the GIP or its intent. Where the CR3 Plant Specific Procedure differs with the GIP, this is almost always because CR3 is a low seismic site with an SSE ZPA of only 0.1g, whereas the GIP was developed so it would be applicable even for a California plant with an SSE ZPA of 0.25g. We believe, like the USI A46 approach in GL 87-02, that the CR3 Plant Specific Procedure provides an *adequate level of safety*, especially when all the ramifications of the fact that CR3 is in a low seismic region are considered.

References

1. P S Hashimoto and L W Tiong: *Earthquake Experience Data on Anchored Ground-Mounted Vertical Storage Tanks*, prepared by EQE Engineering for the Electric Power Research Institute, EPRI NP-6276, March 1989.

2. J W Reed, R P Kennedy, D R Buttemer, I M Idriss, D P Moore, T Barr, K D Wooten, J E Smith: *A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)*, prepared for the Electric Power Research Institute, EPRI NP-6041-SL, Revision 1, August 1991.

Table 1 compares the guidance given in the CR3 Plant Specific Procedure for GL 87-02 with the guidance given in the GIP and GL 87-02.

Table 1 -- CR3 Plant Specific Procedure vs GL 87-02 and GIP

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
1.1 Purpose. The purpose of the GIP is to summarize generic guidance that can be used to verify the seismic adequacy of selected equipment following a safe shutdown earthquake at all GL 87-02 plants.	Same as GIP. Not as detailed. Not complete.	The purpose of the FPSP is to summarize plant specific guidance that can be used to verify the seismic adequacy of selected equipment following a safe shutdown earthquake at Crystal River Unit 3.	N/A
1.3 Approach. The steps in a GIP evaluation are described. They include the following.			
Selection of Seismic Evaluation Personnel (Section 2).	Does not require as extensive a background as the GIP.	Same as GIP.	N/A
Identification of Safe Shutdown Equipment (Section 3).	Different functions specified compared to GIP.	Same as GIP.	N/A
Screening Verification and Walkdown (Section 4).	Many differences in details from the GIP.	Four basic steps same as GIP. Some differences in details.	See below.
Outlier Identification and Resolution (Section 5).	Included "outliers" and "deficiencies."	Same as GIP.	N/A
Relay Functionality Review (Section 6).	Similar to GIP, but not as detailed.	Detailed relay review not required because CR3 meets the GIP.	Appendix C
Tanks and Heat Exchanger Review (Section 7).	Tanks and heat exchanger anchorage included, but no detailed guidelines.	Same as GL 87-02. (Evaluate anchorage.)	For tanks, see text of main report.
Cable and Conduit Raceway Review (Section 8).	Cable trays included, but not conduit systems, but no details.	Pre-screened.	Appendix B.

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
2.0 Introduction. The responsibilities and qualifications of the individuals who will implement the GIP are defined in this section.	Similar to GIP. Not as detailed. Not as stringent.	Same as GIP.	N/A
2.1 SQUG Commitments. Commitments made by licensees are given in this section.	N/A	Same as GIP except for relay reviewers.	N/A
2.2 Systems Engineers The responsibilities and qualifications of the systems engineers are described in this section.	Systems engineers not specifically discussed.	Same as GIP.	N/A
2.3 Plant Operations Personel. The responsibilities and qualifications of the plant operations personnel are given in this section.	Similar to GIP. Not as detailed.	Same as GIP.	N/A
2.4 Seismic Capability Engineers. The responsibilities and qualifications of the seismic capability engineers are described in this section.	SCEs not defined as such. Responsibilities similar to GIP. Qualifications not as stringent.	Same as GIP.	N/A
2.5 Relay Evaluation Personnel. The responsibilities and capabilities of relay evaluation personnel are described in this section.	Relay evaluation personnel not defined as such. Responsibilities similar to GIP, not as detailed as GIP.	Relay evaluation personnel not required.	Appendix C
2.6 SQUG Training Courses. Two training courses are discussed: (1) Walkdown training course, and (2) Safe shutdown equipment selection and relay screening and evaluation.	GL 87-02 implies training required only for walkdown.	Same as GIP.	N/A

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
3.0 Introduction. This section describes in general terms the process used to select safe shutdown equipment and identifies the GIP section that provides the details.	N/A	N/A	N/A
3.1 SQUG Commitments. Commitments made by licensee are given in this section.	Not as detailed.	Same as GIP.	N/A
3.1.1 Identification of Safe Shutdown Path. This section requires selection of a safe shutdown path that ensures that the four essential functions of Reactivity Control, Reactor Coolant Pressure Control, Reactor Coolant Inventory Control, and Decay Heat Removal can be accomplished after an SSE. After identifying the safe shutdown path, this section requires identification of individual items of equipment to accomplish the four essential functions.	Different functions specified compared to GIP.	Same as GIP. However, like some other GL 87-02 plants, CR3 does not have some systems that allow it to precisely meet the GIP redundancy guidelines.	N/A
3.1.2 Assumptions Used in Identifying Safe Shutdown Path. This section identifies bounding conditions that must be observed in selecting the safe shutdown path and equipment.	Similar assumptions to GIP. Modified single failure criterion only for maintaining safe shutdown (GIP adds criterion to achieve safe shutdown).	Same as GIP.	N/A
3.3.1 Scope of Equipment. This section defines the 23 classes of equipment that should be reviewed.	Only 8 of the GIP 23 classes discussed.	Same as GIP (except for those classes of equipment not on CR3 SSEL).	N/A
3.3.2 Exclusion of NSSS Equipment	NSSS equipment not discussed.	Same as GIP.	N/A

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
3.3.3 Rule of the Box. This section explains that it is not necessary to separately evaluate subconents that are part of a component assembly.	Rule of the box not discussed.	Same as GIP.	N/A
3.3.4 Active Equipment. This section elaborates on assumptions in Section 3.1.2.	Similar to GIP. Not as detailed.	Same as GIP.	N/A
3.3.5 Inherently Rugged Equipment. This section elaborates on equipment types that need not be evaluated for seismic adequacy.	Not explicitly discussed. Probably implicit in GL 87-02 limiting its scope to active equipment.	Same as GIP.	N/A
3.3.6 Equipment in Supporting Systems. This section requires equipment in systems that support safe shutdown equipment to be identified.	Need to include supporting equipment mentioned but not discussed.	Same as GIP.	N/A
3.3.7 Equipment Subject to Relay Chatter. This section elaborates on assumption 7 of Section 3.1.2.	Not explicitly discussed in detail. Probably implicit.	Case by case review not required. Relays are prescreened.	Appendix C
3.3.8 Instrumentation. This section outlines identification of instruments to confirm that the plant is in a safe shutdown condition and to control safe shutdown equipment.	Not explicitly discussed. Probably implicit in GL 87-02.	Same as GIP.	N/A
3.3.9 Non-Safety Grade Equipment. This section permits non-safety grade equipment to be included in SSEL, provided its operation is covered by procedures.	Non-safety grade equipment not explicitly addressed.	Same as GIP.	N/A

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
3.3.10 Tanks and Heat Exchangers. This section explains the need to evaluate tanks and heat exchangers required for safe shutdown.	Scope limited to evaluation of adequate anchorage.	Same as GL 87-02. (Evaluate anchorage.)	For tanks, see main report.
3.3.11 Cable and Conduit Raceways. This section explains the need to evaluate cable and conduit raceways.	GL 87-02 included cable trays but not conduit systems.	Pre-screened.	Appendix B
3.4 Safe Shutdown Functions. This section describes the actions necessary to satisfy the four safe shutdown functions defined in the GIP.	Different functions specified compared to GIP.	Same as GIP.	N/A
3.5 Safe Shutdown Alternatives. This section discusses typical alternate methods to accomplish the four safe shutdown functions in Section 3.4.	Not discussed in detail.	Same as GIP.	N/A
3.6 Identification of Equipment. This section summarizes the five steps used to identify safe shutdown equipment.	GL 87-02 similar to GIP, but not as detailed.	Same as GIP, except for relays.	Appendix C
3.7 Operations Review of SSEL. This section suggests methods for reviewing the SSEL for compatibility with plant shutdown procedures.	Not in GL 87-02.	Same as GIP.	N/A
3.8 Documentation. This section decribes the documentation of the selection of safe shutdown systems and equipment.	Not required by GL 87-02.	Same as GIP.	N/A
4.0 Introduction. This section describes the four elements of the screening verification and walkdown (see 4.2, 4.3, 4.4, and 4.5 for detailes).	Same as GIP.	Same as GIP.	N/A

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
4.1 SQUG Committments. Licensee committments are given in this section.	Not in GL 87-02.	Same as GIP. (Our reading of Section 4.1 is that the CR3 PSP satisfies it.)	N/A
4.2 Seismic Capacity-Demand. This section addresses the comparison of seismic capacity with demand for the equipment itself.	Same as GIP, except earlier earthquake experience Reference Spectra were used.	Same as GIP. However, not done on a case by case basis. Already prescreened.	Appendix A
4.3 Equipment Class Similarity and Caveats. To use the screening guidelines in the GIP, the equipment characteristics should be similar to the earthquake experience equipment class, or GERS class, and must meet the intent of the specific caveats for the equipment class.	Similar to GIP, not as detailed. Only some equipment classes explicitly addressed.	Some GIP caveats not included because of prescreening. Anchorage caveats included but refer to CR3 PSP a roach.	Appendix D
4.4 Anchorage Adequacy. Guidance is provided to screen anchorage based on inspection, analysis, and engineering judgment.	Similar to GIP, except that GL 87-02 explicitly allows anchorage adequacy to be evaluated solely by judgment.	Same as allowed by GL 87-02.	Appendix E
4.5 Seismic Interaction. The final screening step is to evaluated seismic interaction.	Similar to GIP, except that details are not provided.	Same as GIP.	N/A
4.6 Documentation. This section specifies documentation for the screening verification and walkdown.	Not addressed in detail.	Same as GIP.	N/A
5.0 Outlier Identification and Resolution. This section defines "outliers," and how they should be documented and resolved.	Outlier defined same as GIP. No details on documentation or resolution.	Same as GIP.	N/A

Table 1 - (Continued)

GIP Guidance	GL 87-02 Guidance	CR3 Plant Specific Procedure Guidance	Basis for CR3 PS Guidance
6.0 Relay Functionality Review. This section describes how to perform a relay review.	Similar to GIP, not as detailed.	Case by case review not required. Relays are pre-screened.	Appendix C
7.0 Tanks and Heat Exchangers. This section describes the review for tanks and heat exchangers.	Scope limited to evaluation of adequate anchorage.	Same as GL 87-02.	For tanks, see text of main report.
8.0 Raceways. This section describes the raceway review.	Included, but no details.	Case by case review not required. Raceways are pre-screened.	Appendix B

Appendix A - Seismic Demand

Introduction. This appendix describes the approach used to develop the seismic demand for evaluation of GL 87-02 equipment at CR3. First, note that the SQUG *commitments* in the GIP do not prescribe *how* seismic demand is to be obtained. The *guidance* portion of the GIP does suggest ways an acceptable seismic demand can be developed, but the GIP clearly allows the use of alternative methods. If alternate methods are used, then the licensee is requested to maintain their bases at the plant site for NRC review (but prior NRC approval is not required).

However, this appendix goes beyond the GIP, in that through it FPC is advising NRC of the approach used for seismic demand at CR3 for A46 prior to its use in the plant evaluations and walkdown.

CR3 In-Structure Spectra. The following figure summarizes the SQUG Reference Spectrum and CR3 in-structure response spectra (5% damping) at elevations 187 and 162.

Figure A1 - CR3 In-Structure Spectra and SQUQ Reference Spectrum

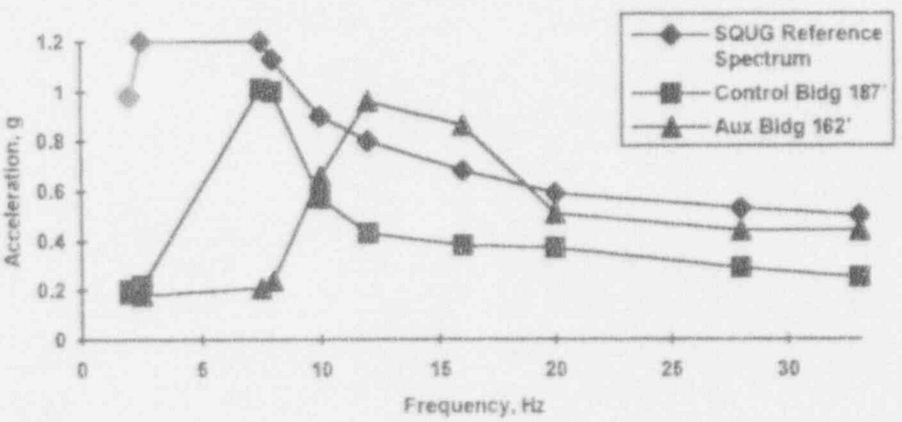


Figure A1 shows that the CR3 in-structure spectra are less than the SQUG Reference Spectrum, except around about 11 Hz to 19 Hz at Auxiliary Building elevation 162 (67 ft above free field grade). There are three items of CR3 SSEL equipment at elevations where in-structure spectra exceed the SQUG Reference Spectra. Thus, except for these three items of equipment, the agreed-upon SQUG-defined seismic capacity of the CR3 SSEL equipment (that is, the SQUG Reference Spectrum) exceeds the seismic demand on it. In other words, except for three items of SSEL equipment the CR3 SSEL equipment meet the GIP capacity/demand screening guidelines and commitment.

The purpose of the following discussion is to explain the technical basis for more realistic, but pessimistic, CR3 in-structure spectra at frequencies around about 11 Hz to 19 Hz where the calculated CR3 in-structure spectra in the Auxiliary Building at elevation 162 exceed the SQUG Reference Spectrum. The result of this discussion is that all CR3

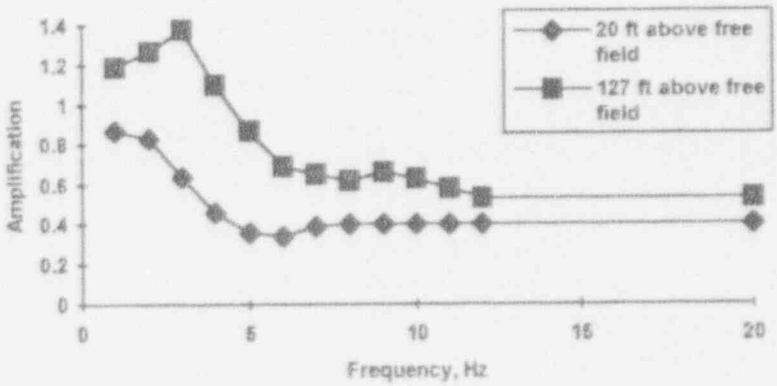
SSEL equipment, including the three items mentioned in the previous paragraph, meet the GIP capacity/demand screening guidelines and commitment.

Earthquake Data. Data on amplifications recorded in earthquakes (References A1 and A3) will now be used to illustrate the pessimism in the calculated CR3 in-structure spectra, and to obtain insight on an appropriate seismic demand for the three items of equipment in the CR3 auxiliary building at elevation 162 (which is 67 ft above free field).

The data are from a number of different earthquakes with free field ZPAs in the range of 0.01g to 0.13g. Thus, the data are appropriate for a low seismic site like CR3, which has an SSE ZPA of only 0.1g.

Only one set of data are available where horizontal earthquake recordings were made in the *free field* and in nuclear plant *structures*. The data are for measurements in three different reactors in Japan. The three reactors recorded 19, 18, and 14 earthquakes, respectively. Typically, more than one recording was made in each earthquake (for example, the earthquake motion was recorded in the two horizontal directions at a specific in-structure or free-field location.) In-structure recordings were made at 20 and 127 ft above the free field. Figure A2 is a plot of amplification versus frequency for these two elevations. *Amplification* is defined as the *frequency by frequency quotient* of the *recorded in-structure spectra* (5% damped) at elevation (20 ft or 127 ft) and the *recorded free field spectra*, versus frequency.

Figure A2 - In-Structure Amplifications from Earthquake Data



The data in Figure A2 show that the maximum recorded horizontal amplification is about 1.4 at 127 ft above free field. The amplification at 20 ft is based on the average[1] of 48 records, while the amplification at 127 ft is based on the average of 71 records. Statistically, since the amplifications are based on such a large number of records, this means that the amplification estimates are robust.

1. The basis for using the average is discussed in detail below.

These data are from a reactor building at a *soil site*. However, CR3 is a *rock site*. Therefore, to use these amplifications at a rock site like CR3 we must correct them for the effects of the different foundation materials (rock instead of soil). This is usually assumed to mean the amplifications in Figure A2 for a soil site will be increased if the same earthquakes had occurred at a rock site. However, there are data that do not support this assumption. See the section below titled *"Confirming Earthquake Data."* Nevertheless, in this section we will proceed using the assumption that because CR3 is a rock site the amplifications in Figure A2 must be *increased* to apply them to CR3.

Working backwards, the amplification of the CR3 5% damped free field SSE spectra that will ensure CR3 in-structure spectra are below the SQUG Reference Spectrum is a factor of about 5 at the closest point (at 33 Hz). In other words, the free field to in-structure amplification at CR3 would have to exceed 5 for the in-structure spectra at CR3 to exceed the SQUG Reference Spectrum.

It is prudent to expect that, even at a low seismic rock site like CR3, the maximum in-structure amplification around 11 Hz to 19 Hz might exceed that shown in Figure A2 (which is for a soil site). However, it does not appear to be reasonable to expect it would exceed 5. This judgment is reinforced considering that the larger amplification curve in Figure A2 is for an elevation of 127 ft, which is about double the elevation of 67 ft for the three items of SSEL equipment of interest in the CR3 auxiliary building.

NRC Analytical Studies. This judgment is reinforced by the analytical studies in Reference A2. These studies assessed the sensitivity of in-structure spectra in a typical shear wall structure for a variety of foundation conditions (very soft soil to infinitely rigid rock), embedded versus surface founded structure, and 110 ft of soil over bedrock versus half space of soil or rock. The following results are from Reference A2.

The sensitivity study result is that in-structure spectra peaks around 11 Hz to 19 Hz at a rigid rock site would be amplified a worst case[2] multiplicative factor of 4.9 over in-structure spectra peaks calculated at a soil site. This result assumed very soft soil (a half space with a shear wave velocity of 500 ft per second--fps), which is not considered to be representative of the soil in the sites where the data in Figure A2 were recorded.

For the next softest soil condition, 1,000 fps (which is more representative of the soil properties for the Figure A2 data--see Reference A3), the above worst case factor becomes 3.4 instead of 4.9.

In addition, these results compare 2% damped spectra. We believe the factors would be reduced below 4.9 to 3.4 if the sensitivity study had compared spectra with damping at the GIP damping of 5%.

If the rock is not assumed to be infinitely rigid, but to have a relatively stiff shear wave velocity of 3,500[3] fps, the factors of 4.9 and 3.4 (relating the quotient of the amplification of an infinitely rigid site and the amplification of a soil site) are 2.5 and 1.8, respectively.

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2. The following defines "worst case" - comparisons are made at the top of building, worst soil conditions (softest) are selected, and worst physical conditions are selected (half space and embedded foundation assumption for the soil case, infinitely rigid rock for the rock case).

3. 3,500 fps is the next stiffer foundation stiffness available in the sensitivity study.

The sensitivity study factors of 2.5 to 1.8 are considered to be acceptable and probably pessimistic factors for the rock conditions at CR3 versus the soil conditions in the earthquake data in Figure A2. This means that, around about 11 Hz to 19 Hz, the earthquake amplifications shown in Figure A2 for a soil site are not expected to be amplified more than about 2.5. Thus, the total amplification of the CR3 SSE spectra around about 11 Hz to 19 Hz is the factor of 0.53 from the data in Figure A2 times the factor of 2.5 from the analytical studies, or a total amplification of about 1.3. Since an amplification of 1.3 around about 11 Hz to 19 Hz is less than the maximum tolerable amplification of 5 discussed above (obtained by working backwards), this means that more realistic, but still pessimistic, CR3 in-structure spectra around about 11 Hz to 19 Hz are less than the SQUG Reference Spectrum.

Note that this result applies up to about 127 ft above free field. This is one indication of the pessimism in the calculated CR3 in-structure spectra. Another indication of pessimism is that the above evaluation found the amplification around about 11 Hz to 19 Hz to be at most 1.3, while the calculated in-structure spectra have an amplification of almost 10 at some frequencies.

Thus, combining these results (in the range of about 11 Hz to 19 Hz) with those in Figure A1 (for all other frequencies) supports the above judgment that, for the low seismic CR3 SSE of 0.1g, the CR3 structures will not amplify the CR3 SSE free field motion so the in-structure motion at the three SSEL equipment locations exceeds the SQUG Reference Spectrum. In short, CR3 SSEL equipment meet the GIP guidelines and commitments and seismic demand and capacity.

Confirming Earthquake Data. The above evaluation is based on an approach that combined results from earthquake data and analytical sensitivity studies. The following evaluation of new data provides an independent check on this approach.

The new data describe the quotient of the peak of the 5% damped in-structure spectra[4] and the ZPA at the top of the basemat, which the authors of References A3 and A4 called the total amplification factor (TAF). These data are from accelerometer recordings made in nuclear plant structures in earthquakes (References A3 and A4). The data are for free field ground ZPAs of 0.01g to 0.14g. The earthquake magnitudes ranged from 4.2 to 7.4. Thus they are appropriate, and probably pessimistic, data for the low seismic conditions at CR3. Records were obtained from a total of 28 separate structures and 30 different earthquakes.

These amplification data reflect at least three pessimisms: (1) they do not account for the beneficial effects (even at a rock site) of soil structure interaction, (2) the amplifications are relative to the ZPA at the top of the basemat rather than relative to the ZPA at the ground surface (which is the relation of interest here), and (3) Reference 3 found that the TAFs for a *rock site* (CR3 is a rock site) *are less* than those in Table A1. With these cautions, Table A1 displays the TAF results. The column marked *"CR3 Sa"* is the peak 5% damped in-structure spectral acceleration at the indicated height above basemat obtained by assuming the basemat ZPA is 0.1g (which is the same ZPA as the CR3 SSE).

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4. Unfortunately, the frequencies of these spectral peaks have not been published.

The values in the "CR3 Sa" column are obtained by multiplying the values in the "TAF" column by 0.1.

Table A1--Total Amplification Factor (TAF) From Earthquake Data

Structure	Height Above Basemat (ft)	No. of Data	TAF	CR3 Sa
1. BWR MKI RB	90-100	4	5.4	0.54g
2. BWR MKI RB	130-150*	7	6.6	0.66
3. BWR MKII RB	40-60	40	3.9	0.39
4. BWR MKII RB	165*	59	8.3	0.83
5. Int Conc	20	8	3.9	0.39
6. Int Conc	35	6	6.4	0.64
7. Int Conc	50-75*	20	8.5	0.85
8. Turb Bldg	60-70*	41	9.3	0.93
9. Aux Bldg	35	6	4.6	0.46
10. Aux Bldg	90	6	5.3	0.53
11. Aux Bldg	115+	6	11.4	1.14

* Operating floor

Note that all the above CR3 Sa values are less than the 1.2g peak of the SQUG Reference Spectrum (even though the CR3 Sa values are pessimistic), regardless of the elevation of the spectra are above the basemat. However, because the frequencies at which the spectral peaks occurred have not been published, we cannot state with certainty that the CR3 Sa values in Table A1 do not exceed the SQUG Reference Spectrum around those frequencies. However, these results do not contradict the previous results, as they would, for example, if CR3 Sa values were found that exceeded 1.2g.

The CR3 Auxiliary Building elevation 162 is about 67 ft above the basemat. Eight of the 11 results (Items 1, 3, 5, 6, 7, 8, 9, and 10) are in the range of 67 ft above the basemat or somewhat higher, and their CR3 Sa is 0.93g or less, which is less than the SQUG Reference Spectrum peak of 1.2g. Thus, these data tend to confirm the results in the previous paragraph.

The SQUG Reference Spectrum has a minimum amplitude of about 0.6g in the range of 11 Hz to 19 Hz. Five of the 8 results (1, 3, 5, 9, and 10) have CR3 Sa values that are less than this. Note that this includes both of the auxiliary buildings (which is the CR3 structure of interest here). These results suggest that it is highly likely that the SQUG Reference Spectrum envelops more realistic, but still pessimistic, in-structure spectra around 11 Hz to 19 Hz in the CR3 auxiliary building at elevation 162 and below. This confirms the earlier result, which was based on data and analytical studies.

Definition of Amplification. The amplification results illustrated in Figure A2 are obtained by *averaging the amplification quotients described above* over the indicated number (48 or 71) of different earthquake records, frequency by frequency. Similarly,

Reference A2 calculated amplification as the average of the quotients from 10 analyses (10 different free field time histories were input to the soil structure interaction analyses).

Amplification is properly defined as an average (of the quotients). That variations in in-structure *"amplification"* are obtained from one time history to another does not imply that the capability of the structure to amplify motion varies from one earthquake to another. This can be seen the easiest from analytical studies where the analytical model of the structure is exactly the same from one analysis to another, yet variations in "amplification" result when different time histories are used as inputs to the analysis (see the discussion below on Figure 11).

The apparent variations in amplification are a consequence of variations (from one time history to another) in the relative strengths of the frequency content (from one frequency to another) of the earthquake motion input to the building. The variations in the input motions are typically random in nature and reflect a property of the time histories rather than a property of the building amplification.

The variations in frequency content are already regulated by NRC. NRC does this by requiring plant design spectra to be a *smoothed curve* derived from response spectra from a *number of real or realistic earthquakes*.

In the past, NRC has typically not regulate this phenomena further. For example, NRC could require utilities to perform 10 different soil structure interaction analyses (where each of the 10 analyses used a different input time history and calculated in-structure spectra at every in-structure location and direction for each of the 10 analyses), and then take the mean, or mean plus one standard deviation of, for example, the calculated 10 in-structure response spectra. However, NRC does not require this added conservatism, or others, to account for the phenomena of variation in in-structure spectra.

Since NRC does not further regulate this phenomena, this suggests NRC criteria implicitly accept the average in-structure spectra.

To see why this is so, assume 10 identical plants at 10 different sites perform soil structure interaction analyses according to current NRC criteria. Each plant uses a different input time history in their soil structure interaction analysis. Assume there is no bias in selecting the 10 input time histories, and that they are randomly selected (NRC criteria allow this as long as each of the time histories match the plant design spectra according to NRC criteria).

If the resulting 10 different in-structure spectra at any given in-structure location and direction in this hypothetical example are plotted on a single figure, they will exhibit considerable variation. This is well documented[5].

Any of the 10 in-structure spectral values in this hypothetical example is acceptable to NRC, including the smallest one. Since the average of the 10 in-structure spectra is *larger* than the *smallest* acceptable value, the average value must also be acceptable.

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5. For example, see Figure 11 of Reference A4--which plots the upper and lower bounds of 3,072 spectra instead of "only" 10. Figure 11 shows that variations in in-structure spectra of more than a factor of 2 are possible with 2% damped spectra. In Figure 11, the maximum variability is a factor of 2.36 at about 3.5 Hz. Figure 11 is included on Page A-9 for the convenience of the reader.

NRC implicit acceptance of average in-structure spectra is equivalent to defining amplification using an average.

The GIP agrees with this. For example, Section 4.2.4 of the GIP contains the following:

> " *'Realistic, median-centered' in-structure response spectra are defined as response spectra which are based on (1) realistic damping levels for the structure and the effects of embedment and wave-scattering, and (2) structural dynamic analysis using realistic, best estimate modeling parameters and calculation methods such that no intentional conservatism enters into the process.* " (underline added)

Section 4.2.4 of the GIP also refers to Reference A4--the same reference from which Figure 11 was obtained--in defining realistic, median-centered spectra.

The terms *"realistic," "median-centered,"* and *"best estimate,"* are all consistent with the above use of the average (or mean) to define amplification for the CR3 A46 seismic demand.

Conclusion. The seismic demand spectra for all CR3 SSEL equipment, including SSEL equipment at elevation 162 or below with frequencies around 11 Hz to 19 Hz, is found to be less than the SQUG Reference Spectrum (which is the NRC accepted equipment capacity spectrum based on earthquake experience) for all frequencies. Thus, all CR3 SSEL equipment is considered to have a seismic capacity in excess of the seismic demand (if all applicable equipment caveats are met). Note that this conclusion applies only to the adequacy of the capacity of the equipment itself. (The adequacy of the capacity of equipment anchorage must be reviewed separately for each item of SSEL equipment, as discussed elsewhere in this report.)

This means the CR3 plant specific procedure for GL 87-02 does not have to address the GIP issue of the seismic capacity and demand of equipment on a case by case basis. The GIP seismic capacity/demand screening guideline is satisfied by the above discussion.

This also means that the CR3 plant specific procedure for GL 87-02 does not have to explicitly include the GIP 8 Hz guideline. The GIP 8 Hz guideline is satisfied by the CR3 plant specific conditions discussed above.

If any GERS are used in the CR3 A46 evaluation, the CR3 calculated in-structure spectra will be used for the seismic demand at the in-structure location and direction.

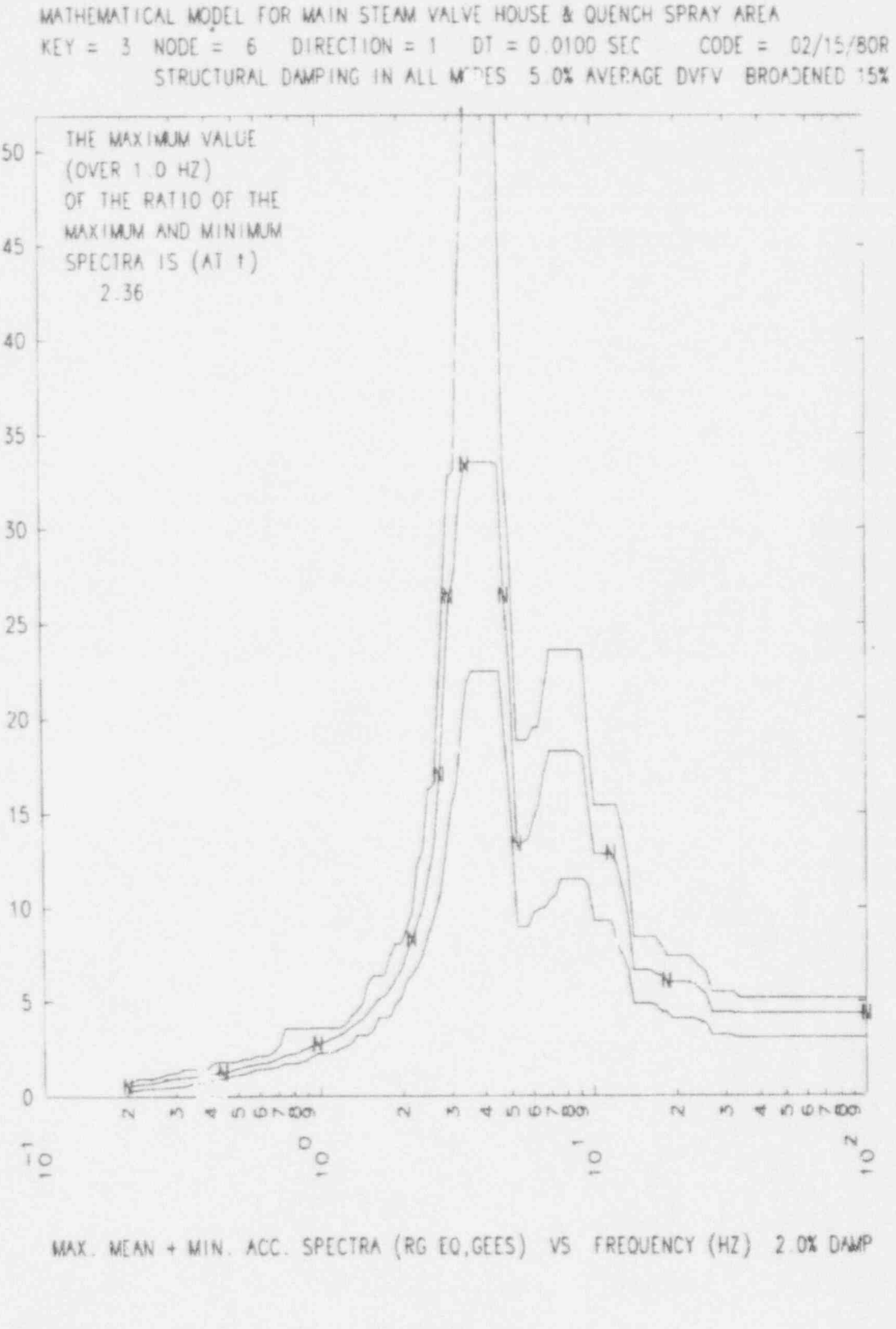
References for Appendix A

A1. *Seismic Demand Study Status Report*, presented at SSRAP/SQUG Steering Group Meeting by URS/John A Blume & Associates, March 30, 1988.

A2. J J Johnson, E C Schewe, O R Maslenikov: *SSI Response of a Typical Shear Wall Structure: In-Structure Response Spectra Comparisons*, prepared by Structural Mechanics Associates for Lawrence Livermore National Laboratory as part of the NRC's Seismic Safety Margins Research Program, SMA #12209.23.02, April 1984.

A3. D P Jhaveri, R M Czarnecki, R P Kassawara, A Singh: *Seismic Demand Evaluations Based on Actual Earthquake Records*, proceedings of the Second Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment, and Piping, Orlando, December 1988.

A4. S E Bumpus, J J Johnson, P D Smith: *Best Estimate Method vs Evaluation Method: A Comparison of Two Techniques in Evaluating Seismic Analysis and Design*, prepared by Lawrence Livermore National Laboratory for the US Nuclear Regulatory Commission, NUREG/CR-1489, May 1980.



<u>**Figure 11 from Reference A4**</u>

Appendix B - Raceways

Introduction. As NRC notes on page 10 of its SSER 2 for GL 87-02 (and SQUG has agreed to for some time): *"The staff acknowledges that these responsible individuals must exercise judgment to implement the USI A-46 program. The review engineers should utilize the technical information in the GIP-2 and the reference documents to the maximum extent practicable in determining the seismic adequacy of equipment. Where judgments are needed to make these determinations, the assumptions and basis for the judgmental conclusions should be documented as required in GIP-2 or identified in this supplement."*

The purpose of this Appendix is to describe the technical bases for the judgment that a case by case review of the raceway supports or systems at CR3, to the screening guidelines in the GIP or to any other guidelines in addition to the criteria already used at CR3, is not needed to satisfy GL 87-02.

To support this judgment, this Appendix uses the following approach:

1. Previous raceway earthquake and test experience is briefly reviewed. The conclusion is that raceways not designed for earthquakes have an excellent performance record in past earthquakes and tests. Because the CR3 SSE is much smaller than virtually all of the earthquakes in the raceway earthquake experience, and because a brief walkdown of CR3 raceways revealed they are of normal industrial construction (non-safety related systems) or of obvious rugged seismically-designed construction (safety-related systems), our conclusion is that CR3 raceways meet the intent of the GIP (that is, there will be no loss of electrical cable function in the event of an SSE at CR3). Thus, a case by case review of the raceway supports or systems at CR3, to the screening guidelines in the GIP, or to any other guidelines in additional to the criteria already used to construct the raceways at CR3, is not needed to satisfy GL 87-02.

2. The previous raceway seismic design efforts at CR3 are briefly reviewed. Since these CR3 raceways were originally designed, and were later re-evaluated, for earthquakes, our conclusion is that these CR3 raceways will perform even better than the raceways in past earthquakes (which typically had no seismic design). However, note that this review is strictly supplemental to the conclusion in (1), which is based on the performance of raceways in past earthquakes and tests, and its implications to CR3 raceways, particularly considering the construction of CR3 raceways and that CR3 is a low seismic site.

3. Analytical *evaluations* are performed on the bases for the GIP raceway screening guidelines, and GIP-like guidelines developed that are appropriate for CR3, specifically considering that CR3 is a low seismic site. The CR3 raceway seismic design criteria are also reviewed and interpreted in terms of the GIP guidelines. Again however, note that this review is strictly supplemental to the conclusion in (1), which is based on the performance of raceways in past earthquakes and tests, and its implications to CR3

raceways, particularly considering the construction of CR3 raceways and that CR3 is a low seismic site.

Earthquake and Test Experience. SQUG documented the earthquake performance of raceways in Reference B1. Raceways have performed in an outstanding manner, even in earthquakes whose free field ground response spectra were over five times larger than the CR3 SSE free field ground response spectra. This is particularly impressive considering that the vast majority of these raceways were not designed for earthquakes. Raceways have a better earthquake performance record than virtually all other power plant components; including structures, components, piping, equipment, and equipment anchorage.

The large capacity of raceways constructed to normal industrial practice to withstand seismic loads appears to be a result of the many sources of nonlinear behavior.

In addition, many raceway systems are supported overhead. For example, most CR3 raceway supports are of trapeze construction. As trapeze supports displace laterally in an earthquake, the weight of the trays or conduit causes *restoring forces* that tend to, and ultimately do, return the displaced system to its at-rest position. Unless the primary vertical load carrying capacity of supports is compromised by the lateral or longitudinal displacement (the vertical earthquake motion alone does not appear to be very capable in causing damage to supports), raceway systems will simply swing or displace back and forth like a pendulum until the earthquake is over (if the complex network-like layout of the system will even allow them to displace). (Many CR3 supports are even better off than this since they have engineered antiseismic lateral and longitudinal restraints to limit lateral displacement.)

The potential for network effects to restrain real raceway systems is evidenced by the lack of observations of lateral or longitudinal displacement of real non-seismic raceway systems in earthquakes. (This is contrasted with non-seismic piping systems, which have noted to displace several inches or more.) Because of their limited physical extent, even large scale raceway system tests are unable to realistically simulate these network effects.

The one instance of raceway structural collapse due to lateral inertial loads occurred in cantilever construction. Here, cable trays were supported from below, where the weight of the cable trays tends to displace the support and cable trays even further once the horizontal earthquake forces displaces the system laterally. Thus, in this case the weight did not cause a restoring force, and instead ultimately caused the system to collapse. Even in this case however, no loss of cable function was found (every cable was tested for electrical function after the original trays were re-installed and placed back into service). As noted above, most CR3 supports are of trapeze not cantilever construction.

Shake table tests of limited test portions of raceway system support the conclusions based on the excellent earthquake performance history of real, large scale, raceway systems. One particularly revealing series of tests (for another utility, not Florida Power Corporation) shook the same relatively large scale cable tray test system with and without lateral bracing in place. The primary difference in performance is that the lateral displacement of the braced system was less than the unbraced system. Since the vertical supports were ductile, the lateral displacement of the trays did not compromise the primary vertical

load carrying capacity of the supports. Thus, even though the shaking level was very high, neither the braced nor the unbraced test system was damaged or collapsed.

Thus, for a low seismic site like CR3, the outstanding earthquake performance of raceways constructed to normal industrial (non-seismic) practice supports the conclusion that a case by case review of raceways at CR3 is not required to satisfy GL 87-02.

This conclusion is reinforced considering the CR3 raceways that were initially designed for earthquakes, which were since been re-evaluated and modified in the light of the evolution of raceway criteria since their initial design and construction.

In the following, we present a variety of analytical investigations. However, we present them only as supplementary information to our judgment (see above) that a case by case review of raceways at CR3 is not required to satisfy GL 87-02, particularly considering that CR3 is a low seismic site. We believe the analytical investigations support this judgment.

GIP Analytical Guidelines. One GIP analytical guideline is that raceway supports should have a vertical capacity of at least 3 times the weight they support (3xDL). (The GIP also has a dead load check, and, for certain support types, a lateral load check. The lateral load check is discussed in detail in a subsequent section.)

The GIP guideline is stated as a vertical capacity check. However, when we developed this guideline, we intended the vertical capacity check (using a derived static load factor of 3xDL) to account for all earthquake loads on the supports, including vertical, lateral and longitudinal earthquake loads. In cases where a more conventional earthquake engineering approach was used to design the raceways, where raceway supports are designed to have lateral and longitudinal load resistance (as is the case for many supports at CR3), we did not intend that the vertical capacity check of 3xDL be used.

Thus, for some support types, the GIP guidelines require a dead load check, a vertical capacity check, and a lateral load check. The GIP has the curious effect of penalizing some plants, including CR3, that have raceways that were designed for earthquakes from the beginning. The reason this happened is that the GIP guidelines were primarily designed to resolve the generic problem of raceway systems that had no seismic design.

In addition, we intended the analytical guidelines to act as a similarity evaluation. That is, our intent was that the analytical guidelines would ensure that CR3 raceway supports are similar to or better than supports in the earthquake data base that performed well. In other words, we did not intend the GIP analytical guidelines to serve the same function as normal structural engineering calculations.

We proposed a vertical capacity factor to evaluate similarity because of the large number of parameters[1] that would otherwise have to be considered to evaluate the physical similarity of raceways in nuclear plants to those in the earthquake data base. We concluded a similarity evaluation would be impracticable if it was based on comparing such a large number of parameters. *We developed the vertical capacity check as a substitute for a similarity evaluation.* (Thus, a traditional earthquake resistant design, as at CR3, is as good and probably better than a similarity evaluation.) At the same time, we felt the verti-

1. For example, support type, support construction, support dimensions, support spacing, number of trays per support, tray size, tray loads, tray eccentricity, number of conduit per support, size of conduit, support bracing, system bracing, and system configuration.

cal capacity check addressed the essential issue of ensuring that the primary vertical capacity of nuclear plant raceway supports is at least equal to the capacity of earthquake data base supports that performed well.

The GIP analytical guidelines were derived from *back-calculations* (see below) on raceways that performed well in earthquakes that were larger (in many cases much larger) than the largest GL 87-02 SSE of 0.25g. To simplify the generic guidelines however, SSRAP chose not to recommend that the vertical capacity factor vary with the size of the GL 87-02 plant SSE. (However, when we initially developed the vertical capacity guideline, and presented it to SSRAP for their review, it did vary with the SSE size. Moreover, other GIP raceway analytical guidelines still do vary according to the size of the GL 87-02 plant SSE.)

In the remaining paragraphs in this section, it helps clarify the discussion to have a quantitative *figure of merit* of seismic margin. The *"seismic margin figure of merit"* (SMFOM) used here is the GIP raceway vertical capacity static load factor of 3 divided by the nuclear plant SSE ZPA. For example, at CR3 the SMFOM is 3/0.1 = 30. A SMFOM of 30 is not intended to imply that raceways that satisfy it have a seismic margin of 30. The SMFOM is only intended to provide a way to assess the relative size of the seismic margin at CR3 and other GL 87-02 plants.

Consider the case where the vertical capacity factor of 3 is applied at the GL 87-02 plant with the *largest* SSE ZPA of 0.25g. The leads to a SMFOM of 3/0.25 = 12. Since the SMFOM is 12 at the GL 87-02 plant with the largest SSE ZPA, this implies that the *minimum* raceway support SMFOM acceptable to NRC is 12.

Stated another way, the generic GIP raceway vertical capacity factor of 3 implies that the desired seismic margin at CR3 is 2.5 times the desired seismic margin at a California GL 87-02 plant[2]. We are not aware of why the seismic margin at CR3 should be larger than the margin at a California plant. Thus, the generic GIP vertical capacity raceway guideline appears to embody excessive conservatism for the low seismic conditions at CR3.

We obtain one measure of excessive conservatism by calculating the CR3 vertical capacity static load factor that has the same SMFOM relative to its SSE as the California GL 87-02 plant SMFOM does to its SSE (which had a SMFOM of 12). This implies that the plant specific vertical capacity static load factor at CR3 could be 1.2xDL instead of the generic value of 3xDL in the GIP.

At first glance, a factor as low as 1.2xDL might be viewed as unreasonably close to 1.0xDL (because it apparently does not account for earthquake loads). Such low factors are not unreasonable. They are just a natural consequence of a low seismic site. For example, if earthquakes were impossible at a site, then it would not be unusual for 1.0xDL to be the criteria (that is, a dead load criteria only). However, to fully explain why will require a discussion of the implications of the *"back calculation"* approach that we used to as the basis for the GIP screening guideline of 3xDL.

The key point is that *back-calculations* were performed on a large number of raceway supports that had experienced an earthquake and were not damaged. The back calculations were based on a set of assumptions, for example: (1) The static coefficient

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2. We realize that Rancho Seco is no longer a GL 87-02 plant. However, it was a GL 87-02 plant when the SQUG raceway guidelines were developed and accepted by NRC reviewers.

approach, (2) Simple tributary area considerations, (3) Support eccentricities were ignored in calculating loads, (4) Specified allowable loads for welds, bolts (including expansion bolts), and members, and (5) Limiting the back-calculations to consideration of the primary vertical support connection or detail.

Because of novel consequences of the back-calculation approach, it can lead to results that are, at first glance, counter-intuitive. For example, the 3xDL factor was based on using a factor of safety of 4 for expansion anchors in the back-calculations. If the factor of safety used in the back-calculations is increased to twice this, or 8 instead of 4, then this would mean the GIP screening guideline would be reduced to 1.5xDL instead of 3xDL. This is illustrated in the following schematic illustrative back-calculation:

Capacity/Dead Load = 3 (using FS of 4.)

However, if the FS is changed to 8, then the inferred support capacity in the back-calculation will be one-half that when a FS of 4 is used, but the dead load remains the same. The revised back-calculation is now as follows:

(Capacity/2)/Dead Load = (Capacity/Dead Load)/2 = 3/2 = 1.5 (using FS of 8).

In other words, when we use a FS of 8 the inferred capacity is 1.5xDL instead of 3xDL.

The point is that the absolute value of the factor (3 or 1.2 in the case being discussed here) is a consequence of the assumptions used in the back-calculations to develop it. There is no inherent reason why the factor derived from back calculations should be greater than 1.0, or why it should not be less than 1.0.

Of course, we are not saying that if the back-calculations indicate that the capacity factor should be less than 1.0, for example 0.6 (where it is obtained using the same rules and guidelines as in a dead load design or design check), that the cable tray supports should not be designed for the full dead load of 1.0xDL. All we are discussing here are the seismic guidelines. The dead load is treated in normal design using its own set of rules and guidelines, such as those in the GIP guidelines.

The conclusion of this section is that, considering the low seismic nature of CR3, and using the same technical approach as was used in developing the GIP guidelines, the GIP 3xDL (seismic) static load factor at CR3 could be as low as 1.2xDL.

Original CR3 Raceway Seismic Criteria. The original CR3 raceway seismic design criteria resulted in 15 different typical supports for cable trays and conduit. Each of the 15 supports has an acceptable vertical load and an acceptable unbalanced (unsymmetric) vertical load defined for it for field guidance. Detailed structural dynamic analyses were used to develop the support details, the required structural capacities (for example, member types and sizes, size and length of weld, location and orientation of seismic bracing, and size and number of expansion and other bolts), and the acceptable vertical and unbalanced vertical loads. (Structural dynamic analyses were also used to check stresses in the cable trays and conduit for typical spans.)

In addition, three-way restraints were provided at specified maximum horizontal distances, and at changes in direction of raceways. The three-way restraints are often made up from closely spaced trapeze supports, which are connected by 4x4x5/16 structural steel angles welded to both trapeze supports to form a three-dimensional space frame (which was dynamically analyzed to evaluate its structural adequacy). In other cases, three-way restraint is achieved by the addition of diagonal or other bracing.

A brief walkdown of the CR3 raceway supports revealed that they are of rugged construction. It is obvious that they had been designed for earthquake loads. Most cable tray trapeze supports are fabricated from 4x4x5/16 (or larger) structural steel angles welded to form a planar frame. (For these supports, the three-way restraint is typically constructed by connecting two closely spaced planar frames.) Most conduit supports are fabricated from Unistrut members. (Here the three-way restraint is typically constructed by adding bracing.) Some supports were noted to be supported from and welded to overhead structural steel, others are supported by bolting into Unistrut embeds, and still others are supported by expansion anchors into the above reinforced concrete floor.

The following analytical results were obtained by *interpreting* the original calculations that went into the development of the typical supports. These results interpret the design loads and support capacities in terms of the GIP 3xDL analytical vertical capacity guideline for the purpose of comparison with it.

The ultimate vertical load of Typical Trapeze Cable Tray Support 1 is supported by a welded connection to an overhead structural steel beam. Using the weld allowables in Table C.6-1 of the GIP, the welded support has a vertical capacity of 48,720 lbs. The cable tray dead load in this calculation is 1,800 lbs. For the purpose of comparison with the GIP guideline of 3xDL, the CR3 factor in this case is 48,720/1,800 = 27xDL, or much more than 3xDL. A number of other support types are based on this one, and they appear to have an even larger capacity relative to dead load.

The ultimate vertical load of Typical Trapeze Cable Tray Support 2 is supported by a bolted connection (2 3/4 inch bolts) to an overhead Unistrut embed. The bolted support has a vertical capacity of at least 12,800 lbs, using the plant-specific pullout allowable for 3/4 inch bolts. The cable tray dead load in this calculation is 1,800 lbs. For the purpose of comparison with the GIP guideline of 3xDL, the CR3 factor in this case is 12,800/1,800 = 7.1, or more than the GIP factor 3. The similar Typical Trapeze Cable Tray Support 3 has a CR3 factor of 14xDL.

The ultimate vertical load of Typical Trapeze Conduit Support 4 is supported by an expansion bolted connection (1/2 inch Phillips self drilling) to the overhead reinforced concrete floor. The bolts have a vertical pullout capacity of 4,580 lbs, using the allowable in Table C.2-1 of the GIP. The largest conduit dead load in this calculation is 2,373 lbs. For the purpose of comparison with the GIP guideline of 3xDL, the CR3 factor in this case is 4,580/2,373 = 1.9, or less than the GIP factor of 3, but more than the above-derived factor of 1.2. The 1.9 is the least factor we found.

The ultimate vertical load of Typical Trapeze Cable Tray Support 5 is supported by a bolted connection (6 3/4 inch bolts) to an overhead Unistrut embed. The bolted support has a vertical capacity of at least 38,400 lbs, using the plant-specific pullout allowable of 6,400 lbs for 3/4 inch bolts. The tray dead load in this calculation is 2,340 lbs. For the

purpose of comparison with the GIP guideline of 3xDL, the CR3 factor in this case is 38,400/2,340 = 16, or much larger than the GIP factor of 3.

In conclusion, all of the above factors interpreted from the original CR3 raceway seismic design criteria are larger than the 1.2xDL derived in an earlier section, and many of them are much larger than the GIP guideline of 3xDL.

Seismic Re-Evaluation of CR3 Raceways. In the 1982-3 time frame (years after CR3 was constructed and put into operation), the CR3 raceways were re-evaluated. A calculation package was developed for each individual support and the specific loads on it, and a load control program instituted for each individual support. New supports were designed in accordance with the criteria described in the following section.

CR3 Criteria for New Raceway Supports. CR3 new raceway design criteria are similar to key GIP analytical screening guidelines.

CR3 Criteria for Vertical Loads. CR3 criteria require cable tray supports to be designed for vertical factors similar to those in the GIP.

The CR3 factors vary depending on the tray width. The factors for normal dead plus live loads varies from 1.6xDL to 2.4xDL. The values of 1.6 to 2.4 are obtained using the weights in Section 8.3.9 of the GIP and assuming the CR3 trays are full[3]. Thus, this provides a fair comparison with the GIP guideline of 3xDL. In addition, CR3 criteria require the supports to be designed for a *seismic* vertical load that varied from 0.1 to 0.5, depending on the building and elevation. The combined CR3 dead, live, and earthquake factor is 1.8xDL to 3.6xDL (1.8 = 1.6 x 1.1, 3.6 = 2.4 x 1.5). Thus, the minimum CR3 design criteria factor of 1.8xDL is less than the GIP guideline of 3xDL, but it exceeds the minimum required CR3 plant specific GIP like criteria of 1.2xDL derived above. (Recall again that the minimum of 1.8 is achieved only for those supports where all the trays are fully loaded. Typical values will be larger than 1.8.) In addition, the CR3 raceways are designed for lateral and longitudinal earthquake loads, which is not required for the use of the GIP vertical capacity check of 3xDL. In other words, more earthquake loading considerations have been considered in the design and re-evaluation of the CR3 raceways than can be accounted for by the simple 3xDL GIP guideline, or was anticipated when we developed the GIP guidelines.

CR3 Criteria for Lateral and Longitudinal Loads. CR3 criteria require a three-directional restraint at the beginning, end, or along a tray run before a directional change. Lateral restraints are also required every third support, or every 30 ft, whichever is less.

A brief walkdown of the CR3 raceways revealed that they are of obvious rugged construction. Numerous three-directional restraints were noted.

For some CR3 supports, the GIP might require a check of their lateral load carrying capacity. One of the acceptable GIP screening lateral load screening guidelines is to analyze the support for the following loads:

> *"Dead load plus a transverse acceleration of 2.5 times the Zero Period Acceleration (ZPA) of the floor response spectrum for the anchor point in the plant where the raceway system is attached."*

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3. Note that this means the achieved factor at CR3 is more than 1.6 where the trays are not full.

As noted above, CR3 design criteria require many raceway supports to be designed for lateral loads. The following table displays CR3 design criteria for those buildings and elevations where 5% damped in-structure spectra are available. The results show that the *lateral* load used to design CR3 raceway supports in these buildings and at these elevations varies from 4.2 to 7.1 times the floor ZPA (x DL). The table also shows that the *vertical* dead load used to design these CR3 supports varies from 2.0xDL to 2.4xDL.

Location	CR3 Design Horizontal Acceleration/ZPA	CR3 Design Vertical Dead Load Factor
Auxiliary Building, elev 143	7.1	2.3
Auxiliary Building, elev 162	5.8	2.4
Control Building, elev 145	4.2	2.0
Control Building, elev 163	5.2	2.2
Control Building, elev 186	6.5	2.3

The above table shows that all of these CR3 cases have lateral load capacities that are larger than the GIP guideline of 2.5 times the ZPA.

On the other hand, the CR3 design criteria require the horizontal and vertical *earthquake* loading cases to be combined. This means that CR3 criteria require these supports to be designed for a minimum of 4.2xZPA lateral load plus a simultaneous 2.0xDL vertical load, while the GIP requires supports to be checked for 2.5xZPA lateral load plus a simultaneous 1.0xDL vertical load. Thus, the CR3 criteria for lateral (and longitudinal) load exceeds the GIP guideline in *all* cases. In addition, these CR3 raceways were designed from the beginning, and re-evaluated, using traditional sound earthquake engineering practice, that emphasizes lateral load resistance.

Thus, particularly for a low seismic site like CR3, where the SSE is only 0.1g, the CR3 new raceway seismic design criteria and raceway construction support the judgment that these CR3 raceways meet the intent of the GIP and a case by case review of raceways at CR3 is not required to satisfy GL 87-02.

Inclusion Rules. Finally, none of the Inclusion Rules in section 8.2.2 of the GIP, are either applicable or judged to be credible at a low seismic site like CR3. These are briefly discussed next.

Rule 1 - Cable Tray Span. CR3 raceway criteria included a stress calculation on cable trays and the allowable loads on them. Later criteria used the same span limit as in the GIP.

Rule 2 - Conduit Span. CR3 raceway criteria included a stress calculation of conduit and the allowable loads on them.

Rule 3 - Raceway Member Tie-downs. Not required for trapeze supports.

Rule 4 - Channel Nuts. CR3 uses Unistrut construction, which has acceptable channel nuts.

Rule 5 - Rigid Boot Construction. None observed in walkdown. Even if there is an occasional support with a rigid boot connection at CR3, the vast majority of the sup-

ports at CR3 do not have rigid boot connections. Thus, the possible failure of an occasional support is consistent with what is accepted by the GIP. In addition however, the raceways at CR3 are restrained laterally and longitudinally, and CR3 is a low seismic site. Thus, even if there are any rigid boot connections at CR3, the raceways at CR3 cannot move laterally sufficiently to cause the failure mode that is of concern with the rigid boot connection.

Rule 6 - Beam Clamps. Not used at CR3 for safety-related raceways.

Rule 7 - Cast-Iron Anchor Embedment. Not applicable at CR3.

Other Seismic Performance Concerns. The Other Seismic Performance Concerns in Section 8.2.3 of the GIP are *"less significant or less well-defined conditions which should be evaluated during the plant walkdown....It is not necessary for all of the raceway systems in the plant to be inspected in detail for the Other Seismic Performance Concerns. Instead, the SRT should note and evaluate any of these concerns, if and when they are noticed as a part of the walkdown. If it appears that any of the Other Seismic Performance Concerns are not met, then the SRT should exercise their engineering judgment in assessing whether the condition significantly compromises the seismic adequacy of the raceway system."* (Quoted from GIP Section 8.2.1)

None of the Other Seismic Performance Concerns were observed in a brief walkdown. In addition, neither of the two more significant ones (*Concern 1 - Anchorage*, and *Concern 8 - Hard Spots*) are considered credible considering the careful seismic design and re-evaluation performed on CR3 raceways,

Conclusion. Based on the good performance in past earthquakes of raceways not designed for earthquakes and constructed to normal industrial practice, the fact that CR3 safety-related raceways were originally designed for and later re-evaluated for earthquakes, and the fact that CR3 is a low seismic site, in our judgment the raceway systems at CR3 meet the intent of the GIP. Thus, a case by case review of the raceway systems at CR3, to the screening guidelines in the GIP or to any other guidelines in addition to the raceway seismic criteria used at CR3, is not needed to satisfy GL 87-02.

This judgment is supported by supplementary calculations interpreting the basis for the GIP vertical capacity guideline to infer a CR3-specific GIP-like guideline, and calculations interpreting the CR3 raceway design criteria in terms of GIP guidelines.

References for Appendix B

B1. *The Performance of Raceway Systems in Strong-Motion Earthquakes*, prepared by EQE Engineering for EPRI on behalf of SQUG, EPRI NP-7150-D, March 1991.

Appendix C - Relays

Introduction. It should be obvious that relay chatter is potentially much more of a problem in larger than in smaller earthquakes. Conversely, relay chatter is potentially much less of a problem in smaller than in larger earthquakes. This principal is recognized by NRC in that, in the seismic portion of the Individual Plant Examination (IPEEE--seismic IPE) program, NRC accepts different criteria for evaluation of relay chatter in lower versus higher seismic sites.

In view of the previous paragraph, and the low seismicity at CR3, it follows that relay chatter is potentially much less of a problem at CR3 than at almost all other GL 87-02 plants. As in the seismic IPE program, it is reasonable for CR3's GL 87-02 relay chatter approach to be reduced relative to other GL 87-02 plants. *Thus, the issue is not <u>whether</u> the CR3 approach to address GL 87-02 relay chatter issues can be reduced relative to other GL 87-02 plants, but by <u>how much</u>.*

The relay chatter issue is recognized to be an operator issue. That is, the issue is not that a chattering relay is damaged or inoperable after the earthquake. Instead, chatter may cause an uncommanded change of state of relays, breakers, or other devices, and operators will have to reset them after the earthquake. The issues are whether operators have sufficient knowledge to reset the devices that experienced an uncommanded change of state during or after the earthquake, whether there are a sufficient number of operators, and whether they have sufficient time to reset.

The GL 87-02 relay chatter issue arose because of reports of operators in power and industrial facilities in past earthquakes, that were collected through the data gathering efforts of SQUG. When data are available, we believe that assessments of what could happen in future earthquakes are best guided by what happened in past earthquakes[1]. Thus, to develop the CR3 approach to GL 87-02 relay chatter issues, in the following we summarize data on how relays and operators have performed in past earthquakes.

Note that earthquake reports of relay chatter often contain an element of pessimism. This is because uncommanded changes of state in an earthquake can arise from at least three different root causes: (1) fluctuations in electrical quantities such as voltage or current, (2) fluctuations in other quantities such as oil level or water pressure[2], and (3) mechanical vibration of the relay.

In root cause (1), the fluctuations are caused by phenomena such as momentary shorts caused when transmission lines swing and touch, or damaged switchyard insulators. Thus, for root causes (1) and (2), many of the relays function as designed when they actuate.

In the reports below, the root cause of relay actuation is not always clear. However, the available information is included for completeness.

The findings from an evaluation of the data summarized below are as follows.

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1. Put another way, the purpose of this paragraph is to point out that we believe that if it is fair to use earthquake data to identify concerns, then it is also fair to use earthquake data to resolve them.
2. This is discussed in Finding 1.

Finding 1. With some exceptions, operators typically are able to quickly diagnose and correct relay actuations and restart plants. This is true even though operators are acting in high stress post-earthquake conditions, and they probably are not trained as thoroughly as nuclear plant operators.

Finding 2. The earthquake data do not indicate any relay actuations at the level of the CR3 SSE (0.1g). The lowest ZPA for which these data reveal a relay actuation is 0.14g (La Villita), and this was from a Buchholz type sudden pressure switch[3].

Finding 3. The earthquake data suggest that very few relay actuations should be expected for ZPAs equal to or less than the CR3 SSE ZPA of 0.1g. This can be seen from the following table[4] and chart.

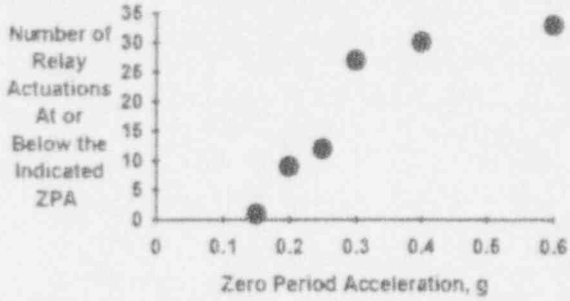
Site	ZPA	No. of Actuations
Adak	0.25	1
Olive	0.3	2
Magnolia 5	0.3	2
Concon	0.3	1
Cool Water	0.28	3 (estimate)
El Centro 4	0.42	1
El Infiernillo	0.15	1
Glendale	0.3	5
Humboldt 1&2	0.3	2
Humboldt 1	0.25	1
Ormond	0.2	4
Perry	0.18	5
San Isidro	0.6	3 (estimate)
Valley 4	0.4	2

These data plot as shown in the following chart.

3. However, when a Buchholz type sudden pressure switch actuates, it typically is only performing as designed (usually sensing a pressure change - which often results from oil sloshing). The problem is that the system may falsely interpret the earthquake induced transient pressure as loss of oil--the real function the switch is intended to sense. This is a system design defect, which can be seen by noting that *earthquake induced false actuation of sudden pressure switches would not be prevented even if the switch is seismically qualified.*

4. Note that data from mercury switches and sudden pressure relays have been omitted from this table. However, this does not change the conclusions. On the contrary, it results in a marginally pessimistic interpretation of the data--see the probabilities below.

Earthquake Data on Relay Actuations



We fit a normal distribution to these data (the above data yield a mean of 0.3g, standard deviation of 0.12, coefficient of variation, CCV, of 0.12/0.3 = 0.4), and used a standard table of the normal distribution, to interpret them statistically as follows: The probability of relay actuation for ZPAs at and below the CR3 SSE ZPA of 0.1g is about $4.7x10^{-2}$. This probability happens to decrease slightly when actuations of devices like mercury and sudden pressure switches are included.

We believe these data are skewed pessimistically. In other words, we believe the actual probability of relay actuation is less than $4.7x10^{-2}$. The reason is that the data are exclusively *"failure"* (actuation) data, rather than data that include *success* and *failure*. In addition, the data are based on a relatively large population of *weak link cases* over a relatively large population of *facilities and sites*. We believe this means these data include *more different kinds of root causes of actuation than should be expected to exist at a single site such as CR3*. This conclusion that these data are pessimistic is partially assessed in the following evaluation, which includes some effects of success data.

The following table provides an alternate estimate of the probability of relay actuation (all data from Reference C1). The important new data shown here are the total number of relays at sites. In other words, these data not only include relays that actuated, but also relays that did not actuate. The only sites we included in this table are those for which a basis exists for an estimate of the total number of relays at the site.

Plant	ZPA	No. of Actuations	Total No. of Relays
Adak	0.25g	3	71*
Burbank	0.3	5	166*
Drop IV	0.3	0	46*
El Centro	0.42	1	43*
Glendale	0.3	5	265**
Humboldt	0.25-0.3	7	38*
Metcalf	0.4	4	189**
Ormond	0.2	5	128*
Pasadena	0.2	0	127*
Rinaldi	0.5-0.75	5 (estimate)	189*
Valley	0.4	4	228*
Weighted average	0.35g		
Totals		39	1490

* This estimate of the total number of relays at the site was obtained by counting relays. However, not all relays were counted. Thus, the estimate is known to be a strict lower bound to the actual total number of relays at the site.
** This is a realistic estimate of the total number of relays at the site, also obtained by counting relays. It may be a lower bound, but this is not known with certainty. This is because the number of relays was obtained both by counting and by estimation.

The estimate from the data in the above table is that, at a ZPA of 0.35g, the probability of relay actuation is 2.6×10^{-2} (2.6×10^{-2} = 39/1490). Since 2.6×10^{-2} is less than 4.7×10^{-2}, this tends to confirm that the previous estimate is pessimistic. This point is reinforced considering that the total number of relays on which the 2.6×10^{-2} is based is a lower bound estimate. For example, the total number of relays is pessimistically estimated as 5,000 (Reference C1) rather than 1490. Thus, at a ZPA of 0.35g, the probability falls from 4.7×10^{-2} to 7.8×10^{-3} (7.8×10^{-3} = 39/5000), or one-third as much.

The probability of 7.8×10^{-3} is associated with a ZPA of 0.35g (which is 3.5 times the ZPA of the CR3 SSE) and earthquakes of longer duration than are expected at CR3. Considering these and other pessimisms discussed above, for engineering purposes we estimate that, for earthquakes with ZPAs equal to and less than the CR3 SSE of 0.1g, the probability of relay actuation is at most 1×10^{-2} (or somewhat more than 7.8x10-3).

Note that these results did not take credit for the 6,968 relays and up to 5 actuations at the Perry plant. If these data are included in the above table, then we have 44 actuations in 11,968 relays. This leads to a probability of 3.6×10^{-3}, or half the 7.8×10^{-3} developed above. We did not include these data because the Perry plant is new and all of its safety-related relays are qualified. Thus, their inclusion could be viewed as unfairly skewing the results relative to what should be expected at CR3.

The probability of 1×10^{-2} means that even if there are as many as 500[5] essential relays in the CR3 SSEL, and we assume that none of them are qualified, then we expect less than 500 x (1×10^{-2}) = 5 of them to actuate <u>in the unlikely event of a CR3 SSE</u>. This is a conditional estimate, where the condition is the occurrence of the CR3 SSE. The conditional estimate where the condition is an earthquake rather than the CR3 SSE is obtained as follows.

Combining the above probability of actuation with the probability of an earthquake at CR3, we find there is a probability of about 10^{-6} of relay actuation in the unlikely event of an *earthquake* (not specifically an SSE) at CR3[6]. This estimate means that even if there are as many as 500 essential relays in the CR3 SSEL, then we should expect less

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5. Based on the number of essential relays at other A46 plants, we believe this estimate is an accurate one. However, we are continuing to further clarify the bases for our estimate of 500 essential relays. If we conclude that a better estimate is substantially different that 500, FPC will advise NRC of this.

6. The probability of 10^{-6} is obtained from the median curve in Figure 5-1 of Reference C4 at the mean ZPA of 0.35g. This rule of thumb closely approximates the exact calculation, which integrates two probability distributions: (1) the earthquake hazard probability distribution from Figure 5-1, and (2) probability distribution of actuation given an earthquake.

than one to actuate in the unlikely event of an earthquake (not necessarily an SSE) at CR3.

Of course, there is the issue of whether these data and estimates are representative of the plant specific and site specific conditions at CR3. Until such time as there are more credible performance *data* on large populations of relays exposed to realistic plant operational, installation, and earthquake conditions, such as those discussed above and below, we continue to believe that these data are more credible, and are a better indication of what we have reasonable assurance to expect, than estimates that are based on seismic *analyses* that are typically pessimistic.

Finding 4. There is reasonable assurance that there is a large margin against relay chatter relative to the CR3 SSE of 0.1g. This is explained as follows.

From Finding 3, the COV of the actuation data is 0.4. Taken together, the probability of 10^{-2} from Finding 3 and the COV of 0.4 imply that the mean failure level is about 1.0g. This implies the margin relative to the CR3 SSE ZPA of 0.1g is about 10.

As discussed above, the raw data have a mean of 0.35g. These data are known to have a pessimistic bias, which implies the margin is a minimum of 3.5 relative to the CR3 SSE ZPA of 0.1g. Thus, that the minimum margin is 3.5 does not suggest that the margin estimate of 10 is optimistic.

Large margins are credible in view of how small CR3's SSE is. In other words, *large margins are a normal consequence of the low seismicity of peninsular Florida.*

Finding 5. Because the CR3 SSE is so low (the CR3 ZPA is only 0.1g), earthquake data suggest there is a high probability that switchyard damage will not occur in the event of the CR3 SSE. This means there is a much higher probability that CR3 will not lose offsite power in a CR3 SSE, than at many other GL 87-02 plants. Thus, CR3 operators will probably not have to deal with restoring power to vital equipment after an earthquake. This suggests CR3 operators will be more likely to be able to reset relays than operators at most A46 plants, which have larger SSE than CR3.

Conclusion. Considering these Findings: (1) If the CR3 SSE causes any relay actuations at CR3, it probably will cause only a few. Moreover, the low CR3 SSE probably will not cause loss of offsite power. (2) CR3 operators probably will not have to deal with post-SSE issues of restoring power to vital equipment. (3) Taken together, these two conclusions mean there is *reasonable assurance* that CR3 plant operators will quickly diagnose and reset any relay actuations--certainly better than at most A46 plants (which have much larger SSEs than CR3's). (4) *Thus, according to the first specific assumption*[7] *in Section 6.3.1 of the GIP, CR3 meets the GIP, and a case-by-case relay evaluation program is not required at CR3 to address GL 87-02.*

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7. Which is as follows: *"Unqualified relays are assumed to malfunction during the short period of strong motion during an earthquake. Such a malfunction, typically chatter, may result in loss of system function or inadvertent actuation of systems during the strong shaking period. It is also possible that relay malfunction during strong shaking can result in unacceptable seal-in or lockout of specific circuits which are designed to have this feature. In such cases, operator actions to reset or restore such circuits to their original condition may be acceptable provided there are sufficient time, awareness, access and procedures for the operators to take this action."* CR3 satisfies this because (1) there will be few post-SSE demands on CR3 operators and (2) we don't consider *"strong motion"* or *"strong shaking,"* to be very realistic descriptions of minor, almost inconsequential, earthquakes like the CR3 SSE of only 0.1g.

Earthquake Data. The remainder of this Appendix presents available earthquake induced relay actuation and operator action data upon which the above Findings and Conclusion are based. The data are only gathered and presented below for the convenience of the reader, who may not have the reference material readily at hand. The evaluation of the following data is presented above.

General Data. The following general earthquake data is included for the convenience of the reader.

"The data base contains no evidence of seismically induced malfunctions of horizontal pumps (inadvertent starting or stopping)." (Reference C2, page 5-8)

"The data base contains no evidence of the malfunction of motor-operated valves during an earthquake." (Reference C2, page 8-5)

"The data base contains no evidence of seismically induced malfunctions (inadvertent starting or stopping) of fans." (Reference C2, page 9-9)

"The data base contains no evidence of seismically induced malfunctions (inadvertent starting or stopping) of air handlers." (Reference C2, page 10-6)

"The data base contains no evidence of seismic malfunctions (inadvertent starting or stopping) of chillers." (Reference C2, page 11-5)

"The data base contains no evidence of seismic malfunction (inadvertent starting or stopping) [of air compressors] during an earthquake." (Reference C2, page 12-6)

"The data base contains no evidence of the seismic malfunction (inadvertent starting or stopping) of motor-generator sets." (Reference C2, page 13-4)

Specific Data. In the following, available data on earthquake induced relay actuations are summarized. The data are primarily from two SQUG publications (References C1 and C2). In each case, the source of the data is indicated. For some sites, for example, Adak Naval Station, data from <u>both</u> SQUG publications are included for completeness. This leads to some redundancy, but the flavor of both publications is retained.

Adak Naval Station. At the Adak Naval Station, which experienced an estimated peak ground acceleration of 0.25g during the magnitude 7.5 1986 Alaska earthquake, the Birchwood Substation tripped due to actuation of a General Electric IBCG protective relay on a 13.8 kV switchgear. Once the relay was reset, the substation went back on line, and normal operation resumed. (Reference C2, page 3-8)

The Birchwood Substation is a small electrical substation on Adak Island. A GE IBCG phase directional ground relay tripped the No. 1 breaker in the 13.8 kV switchgear at the substation. The operator's log indicated the trip was caused by earthquake induced vibrations. The breaker provides the tie between the NAVFAC substation and Birchwood. The power line runs underground. Thus, slapping together of power lines was discounted as the source of relay actuation. Shortly after the earthquake (the exact time was not documented) the tripped breaker was identified, the operator reset the relay at the 13.8 kV switchgear and normal operation resumed. (Reference C1, page 4-13)

At Steam Plant Number 3 on Adak Naval Station, which experienced an estimated ZPA of 0.25g during the 1986 Alaska earthquake, two pressure switches were tripped. During the earthquake, vibration of the internal push rod caused the actuation of diaphragm-type sudden pressure switches on two of the boilers. These switches are on a "hair-trigger" and are easily actuated by vibrations. The actuation of the switches tripped an auxiliary relay, which, in turn, tripped the motor control center controlling the boiler fan motor. There was no damage to any of the equipment in this system. (Reference C2, page 18-6)

Steam Plant 3 on Adak Island was operating at the time of the earthquake and had several earthquake induced actuations, none of which were identified as having been caused by relays. Two sudden pressure switches on the boilers tripped and had to be reset manually before the boilers could be relit. A boiler fan motor also tripped off which was initially believed to be caused by the earthquake induced vibrations of a fan motor contactor. After further discussions with plant personnel, it was determined that this is an automatic function when a boiler fire trips. (Reference C1, page 4-13)

Burbank Power Plant. At the Burbank Power Plant, which experienced an estimated ZPA of 0.3g during the magnitude 6.5 1971 San Fernando, California earthquake, two tripped protective relays in the generator control panel caused the gas turbine generator to fail to start on demand following the earthquake. (Reference C2, page 17-7)

The Burbank Power Plant consists of the two Olive units and the five Magnolia units.

Olive Units 1 and 2 were on line at the time of the earthquake at 6:01 a.m., and were tripped off line by spurious relay actuation. The relays were identified as GE Type CFD, which are located on the main control panel on the second floor of the Control Building. The CFD relays activate a multi-contact auxiliary relay, which trips the generator off line, trips the house transformer OCB, transfers power to the station auxiliaries from the start-up transformer, and trips the turbine stop valve.

Station power was being provided from offsite sources at the time of the earthquake. At about 6:15 a.m., offsite power was lost to the Olive units due to damage throughout the Southern California power grid. A 6:37 a.m., offsite station power was made available from Recovery Station E. The furnace purge was completed on both units at 7:00 a.m., and the boilers relit. Unit 1 was brought back on line at 8:09 a.m. and Unit 2 at 8:24 a.m. No other relay malfunctions were identified at either Olive unit. (Reference C1, page 4-5)

Magnolia Units 2 and 3 were on line at the time of the earthquake. Both Units 2 and 3 remained on line during and following the earthquake. However, reduced fuel oil pressure due to a pipe leak, and loss of steam pressure convinced the operator to manually trip both units. The auxiliary generator at Magnolia Units 1 and 2 started up. However, the plant draft fans and the feed pumps are too large to be supplied by the auxiliary generator, so the operator had to kill the fires and trip the turbine.

A startup of Magnolia Unit 5 (a gas turbine peaking plant) was attempted, but both the turbine and the generator were locked out by relay actuation and the operators could not immediately determine which relays needed to be reset. Three spurious relay actuations were found to have occurred at Unit 5 and caused the blocked start: (1) Main trans-

former sudden pressure, (2) Low voltage relay on the sequencer power supply, and (3) Loss of field.

The main transformer sudden pressure relay is a Westinghouse Type SPR. The low voltage relay on the generator sequencer power supply is a GE Type IAV. The loss of field relay is a GE Type CEH. By 6:47 a.m. operators had found the actuated relays and Unit 5 was on line. No other relay malfunctions were recorded at the Magnolia units. (Reference C1, pages 4-5 and 4-6)

City of Commerce Plant. At the City of Commerce Refuse-to-Energy Plant, which experienced an estimated ZPA of 0.4g (recorded 1 km west of plant) during the 1987 magnitude 5.9 Whittier, California earthquake, the plant operated through the main shock of October 1 without tripping off-line. The plant manager reported that the motion in the control room three floors above grade was brief but intense. Items slid from shelves and a ventilation diffuser dislodged from the ceiling. A small waterline attached to the potable water heater ruptured, apparently due to rocking of the heater tank. There was no damage to any of the primary electronic or mechanical systems in the plant. All control and instrumentation systems appeared to work properly. (Reference C7, page B-8)

Concon Refinery. At the Concon Oil Refinery, which experienced an estimated ZPA of 0.3g during the magnitude 7.8 1985 Chile earthquake, the emergency diesel generator started during the earthquake, but tripped off-line due to protective relay actuation. The relay was reset and the diesel operated properly. (Reference C2, page 17-8)

The refinery was operating at about 80 percent of capacity when the earthquake occurred. Power from the mail grid was lost during the earthquake. The on-site steam turbines (which provide power to the control rooms) functioned properly. The emergency diesel generator started automatically during the earthquake, but tripped off line almost immediately during the start sequence due to actuation of a GE Type IAC fault current protective relay. The panel containing the relay was stiffened with structural steel angles. The operator felt that contact chatter in the relay caused the trip. The generator was manually started a few minutes later and operated normally. There were no other misoperations, malfunctions, or false alarms reported with any other system. (Reference C1, page 4-15)

Cool Water Station. The Cool Water Station experienced a magnitude 7.5 earthquake, and a ZPA of 0.43g was recorded at the site. At the time of the initial event, one gas turbine of Unit 3 was on line and the Unit 3 steam turbine was in the process of being brought on line. All other turbine generators were down. The gas turbine tripped off line and shutdown due to its vibration trip system. Most circuit breakers in the 115 kV and 230 kV switchyard opened due to relay actuation on the control panels. The operators believed the relays actuated on vibration.

El Centro Steam Plant. At the El Centro Steam Plant, which experienced an ZPA of 0.42g during the magnitude 6.6 1979 Imperial Valley, California earthquake, Units 1 and 2 were shut down at the time of the earthquake, while Units 3 and 4 were operating. Both Units 3 and 4 were tripped off line by damage to a lightning arrestor on the 1-T1

transformer. This is an automatic function as the 1-T1 transformer provides station service power to Units 3 and 4. Unit 3 was brought back on line 15 minutes after the earthquake. Unit 4 required repairs to the generator exciter cooling water lines and was brought back on line 5 hours after the earthquake.

Unit 3 was tripped off line but continued generating its own station power, while Unit 4 went completely black. The Unit 4 generator was believed to have been tripped by its differential relay due to spurious relay actuation. After the earthquake, Unit 4 picked up its indoor 480V bus from Unit 3, which restored station power to Unit 4 and allowed its auxiliary systems to become operational. Unit 3 was synchronized back onto the power grid 15 minutes after the earthquake, but only operated at 10 MW because the Unit 3 cooling tower fans were locked out. The fans are energized from the outdoor 480V bus.

The outdoor 480V had two breakers that would not operate, which prevented the bus from being energized from its respective 2.4 kV bus or 480V tie bus. The 3-10 and 3-OSP breakers failed to operate. Both the El Centro operators and the breaker repair technician who serviced the breakers after the earthquake attributed their operational failure to the sensitivity of this type of breaker (GE AK-1-50) to moisture and dirt build-up. These breakers require frequent cycling to assure "on demand" operation. The breakers were placed in their test position, cycled, and placed into service 35 minutes later. The site visit verified that the breakers are mounted in an outdoor enclosure located adjacent to the Unit 3 cooling tower structure. The internal of the cabinets were found to be dusty, and moisture was falling from the cooling tower. (Reference C1, page 4-12)

El Infiernillo Power Station. At the El Infiernillo Power Station, which experienced a ZPA of about 0.15g during the magnitude 8.1 1985 Mexico earthquake, three of the five units were in operation during the earthquake. Two units disconnected from the power grid by the actuation of a high voltage circuit breaker in the station switchyard. They were tripped by faults in the transmission network in Mexico City. Thus, their relays performed their intended function. The third operating unit disconnected from the power grid due to actuation of a ground fault relay. Plant operators believe that this relay tripped due to earthquake induced vibrations on the relay, which then sent a spurious signal to the breaker. All three units were placed back into service once undamaged distribution paths were established in Mexico City, and the ground fault relay checked and reset. (Reference C1, page 4-17)

Gilroy Cogen Plant. At the Gilroy Energy Cogeneration Plant, which experienced an estimated ZPA of 0.3g during the magnitude 7.1 1989 Loma Prieta, California earthquake, both the gas and steam turbine generators were in operation at the time of the earthquake, feeding power into the local 115 kV grid. Protective relays detected an overcurrent condition in the 115 kV grid and tripped both turbine generators off-line. As the shaking continued, the local 115 kV grid blacked out, shutting off power to the Gilroy area. Loss of normal off site ac power shut down all mechanical equipment, and triggered shutdown of the gas and steam turbines. Backup power for critical circuits such as the programmable control system continued through the uninterruptible power supply.

Off site power became available about 20 minutes after the earthquake. Operators inspected the plant and, finding no damage, restarted the gas turbine about an hour after the earthquake.

However, problems prevented restart of the steam turbine. Water had seeped into the main steam line. The water source may have been earthquake-induced sloshing in the main steam drum high in the plant. Moisture reaching the hot turbine through the steam line caused minor thermal distortion in the rotor, which, in turn, caused excessive vibration as the turbine was brought up to speed. A second attempted restart also had excessive vibration. When a third restart was attempted around 11:30 pm, the turbine vibration was acceptable. The steam turbine was brought on line around midnight, about seven hours after the earthquake. A thorough inspection of the plant revealed no significant damage to either structures or equipment. The plant was kept on-line at full load for several days after the earthquake--providing much need power for the grid. (Reference C7, page B-19)

Glendale Power Plant. At the Glendale Power Plant, which experienced an estimated ZPA of 0.3g during the magnitude 6.5 1971 San Fernando, California earthquake, Units 3, 4, and 5 were in operation at the time of the earthquake, and stayed on line during and following it. One and one-half hours after the earthquake, all three units tripped off line because of system disturbances throughout the entire Los Angeles area. Units 3 and 4 were brought back on line two minutes later, and Unit 5 was brought up nine minutes later.

The operator's log documents the following relay induced trips (none of which affected the normal operation of Units 3, 4, and 5): (1) Number 1 differential, (2) Glendale-Rossmoyne 34.5 kV lines, (3) Glendale-Grandview 34.5 kV lines, (4) Glendale-Grandview South (relayed at substation), (5) Glendale-Acacia East and West (relayed at substation), Glendale-Fremont North and South (relayed at substation). All of these relays were GE Type CPD. These are pilot-wire differential type relays, which are used for the interchange of relaying information in the form of currents or voltages between the relays at the two line terminals. The relays have a current balance characteristic arranged to cause relay operation if the current entering the protected line section is not balanced by the current leaving it. Under external fault or normal load conditions these currents are in balance, and the relays will not trip. For internal faults however, the currents will not be in balance and the relays will trip the breakers at the line terminals.

The operators could not determine whether the CPD relays performed their intended function (for example, actuated by internal faults in the lines due to power lines touching), or whether the vibration of the relay contacts caused the trip. Plant operators speculated that the relay caused a spurious signal based on their experiences in causing trips with these relays when accidentally bumping or drilling holes in their cabinets. (Reference C1, pages 4-6 and 4-7)

Humboldt Bay Power Plant. At the Humboldt Bay Power Plant, which experienced an estimated ZPA of 0.3g during the magnitude 5.5 1975 Ferndale, California earthquake, actuation of a mercoid switch caused the motor-operated gas supply valve to Unit 1 to close, resulting in the tripping of the Unit 1 boiler. (Reference C2, page 18-5)

Units 1 and 2 were on line at the time of the earthquake while Unit 3 was down for scheduled maintenance. Both Units 1 and 2 had their generator oil circuit breakers (OCBs) and auxiliary transformer OCBs trip due to spurious relay actuation. Auxiliary electrical equipment associated with these units transferred to the plant startup bank, which remained energized from the plant's 60 kV bus. The plant operator's log states: "spurious auxiliary relay action caused a loss of field on both units." The loss of field relay is a Westinghouse type HLF relay. It is located on the master control board together with its MG-6 auxiliary relay. In addition, a mercoid switch spuriously actuated causing the closure of a motor-operated gas supply valve to Unit 1, which tripped a forced draft fan on the Unit 1 boiler.

At the Unit 3 nuclear unit, spurious relay action was reported on one of a pair of redundant GE type HEA relays in the refueling building related to the High Differential Pressure Protection System. The HEA relays are auxiliary relays for two mercoid type PQ protective pressure switches, which are connected in series and sense pressure changes in the High Differential Pressure Protection System. The mercoid switches spuriously actuated and tripped the HEA relay, which closed the primary system isolation valves associated with the emergency condenser and the reactor cleanup systems, and tripped the reactor cleanup pump. The switches were replaced in 1977. To ensure that the HEA auxiliary relays had not caused the isolation valve closure in the reactor clean-up pump trip, Humboldt engineers tested and seismically qualified the HEA relays. (Reference C1, pages 4-10 and 4-11)

The Humboldt Bay Power Plant experienced an estimated ZPA of 0.25g during the magnitude 7.0 1980 Eureka, California earthquake. Units 1 and 2 were on line at the time of the earthquake, while Unit 3 had been out of service since 1976. Unit 1 was tripped off line by a GE type CFD high speed differential relay. Operators felt that the CFD gave a false indication of electrical trouble within the generator. Unit 2 sustained a transient cutoff of fuel due to shaking of the gas regulating stop valve mercoid switch. At the same time, the internal mechanism of the air flow meter dislocated; therefore, Unit 2 was tripped by the operator. Unit 2 was restarted about 8 hours after shutdown. Unit 1 generator was checked and the unit was restarted, about 13 hours after shutdown. Unit 3 was inspected by plant staff after the earthquake and they found no damage. (Reference C1, pages 4-11 and A-35)

Krsko Nuclear Plant. The Krsko Nuclear Power Plant is located 2 km east of the town of Krsko on the northern bank of the Sava River in the Republic of Slovenia. On December 28, 1989, the Krsko Plant experienced a magnitude 3.9 earthquake and recorded a free field motion with a ZPA of 0.56g.

Plant operators heard an audible sound caused by the earthquake that sounded like a passing freight train. They also noticed annunciation of an earthquake on the control panel.

They interpreted the audible earthquake sound as a rupture of non-safety class piping systems, and manually tripped the plant. Plant personnel performed detailed walkdowns of the plant and found nothing unusual except the spurious high water level indication at the non-safety class level switches (Delta model 760/770) of the feed water high pressure reheaters. After the reset of the level switches, the plant went back on line and

operated smoothly. Operators concluded that the plant would have tripped automatically to protect the turbine generator by the spurious level switch signal, if the plant operator had not tripped the plant manually.

A magnitude 3.1 aftershock earthquake occurred several days later. It tripped the plant automatically on an indication of steam generator high water level. Plant personnel again performed detailed plant walkdowns. They found nothing unusual except that the non-safety class low pressure feed water reheater had a spurious level switch indication of high water level, which caused the high water level indication in the steam generator. After operators reset the level switches, the plant went back on line and operated smoothly. (Reference C3)

La Villita Power Plant. At the La Villita Power Plant, which experienced a ZPA of 0.14g during the magnitude 8.1 1985 Mexico earthquake, two of the four units were in operation during the earthquake. Both units disconnected from the power grid in the earthquake due to actuation of protective relays. This was attributed to Buchholz type sudden pressure relay actuations caused by oil sloshing in the switchyard transformers. The plant disconnect was also attributed to grounded transmission lines at the steel plant in Lazaro Cardenas. The two units were reconnected with the power grid after a brief inspection. (Reference C1, page 4-17)

Metcalf Substation. At the Metcalf Substation, which experienced an estimated ZPA of 0.4g during the magnitude 6.2 Morgan Hill, California earthquake, four relay actuations were reported. No other details are available.

New Zealand Distillery. At the New Zealand Distillery, which experienced an estimated ZPA of 0.5g during the magnitude 6.2 1987 New Zealand earthquake, a level controller was found to be non-functional following the earthquake. The controller monitors the level of the distillation column through a diaphragm-actuated differential pressure sensor. The controller is calibrated to operate at a range of 3 to 15 psi. Apparently, sloshing of the fluid in the distillation column during the earthquake caused a pressure surge, which, in turn, tripped the pneumatic overload relay within the controller. Once the relay was manually reset, the controller was operational. (Reference C2, page 18-6)

Ormond Beach Generating Station. At the Ormond Beach Generating Station, which experienced an estimated ZPA of about 0.2g during the magnitude 5.7 1973 Point Mugu, California earthquake, Unit 1 was operating at the time of the earthquake and was tripped off line. The A phase generator differential relay and the A, B, and C phase voltage unbalance relays produced targets. Plant operators felt that the earthquake induced vibrations caused the plant to trip. They supported their view by showing that the relay panel was very flexible and that an operator shaking the panel caused the relays to actuate. The panel was structurally stiffened after the earthquake to prevent this low frequency vibration in the future.

The generator differential relays are located on the main panels in the relay and instrumentation room, whose elevation is between the ground and turbine levels. They are

GE Type CFD, and are located at the top of the relay panel. They are attached using the standard four bolts to the panel face. The generator voltage unbalance relays are GE Type CFVB, also mounted near the top of the relay panel just below the CFD relays with the standard four bolts.

The log book indicates that several other control room relays targeted. These, along with operator interpretation of their causes are: (1) Generator trip - annunciator showing that the generator had tripped, (2) Low feedwater flow - due to the boiler trip, (3) Low oil pressure - probably a mercoid switch, (4) Thrust bearing - probably a mercoid switch, and (5) Turbine overspeed - normal when the turbine trips. The operators could not determine whether these target actuations were vibration induced or if they were responding as designed to another physical condition. (Reference C1, page 4-8 and 4-9)

Pacific Lumber Plant. At the Pacific Lumber Cogeneration Plant, which experienced an estimated ZPA over 0.4g in the magnitude 6.9 April 25, 1992 Petroilia, California earthquake, Unit A turbine generator was on line near full power at the time of the initial earthquake at 11:06 am. Turbine generator B was down for maintenance.

Actuation of a generator overload relay in the control room tripped Unit A off line and initiated shutdown of the boilers. In spite of the intense level of shaking, the off site supply of 60 kV power was maintained into the cogen plant. The source of 13.8 kV station power automatically transferred from Turbine Generator A to the substation's 60/13.8 kV transformer. This maintained power within the cogen plant to all operating equipment.

Operators inspected the plant after the earthquake. The most serious damage found was in the emission control system. Sway and impact of the charged plates within the electrostatic precipitators created electrical faults and disconnections. Only a portion of the electric field in one out of three precipitators was found to be operable. This was sufficient to allow a reduced level of steam generation for a limited time.

After an inspection, Boiler A was refired, and Turbine Generator A was brought back on line. Operators began the process of refiring Boiler B to increase steam generation, and power, from Generator A. The startup process requires the use of oil to fire the boiler until sufficient heat is achieved to combust wood waste efficiently.

The cogen plant appeared to be on the way back to normal operation, albeit at reduced capacity, when the second, magnitude 6.2, earthquake struck on April 26 at 12:41 am.

The second earthquake also tripped Turbine Generator A off line. Station service power was lost, so that all AC-powered mechanical equipment deenergized. The control system continued to function on power supplied from its uninterruptible power supply system. The battery rack and the UPS supplied the digital controls system, emergency lights, control power for all switchgear, and the DC lube oil pumps that allowed coast down of the turbine generator.

Shortly after the second earthquake, a check of instrumentation revealed that the 60 kV supply to the plant substation was still energized from the off site grid. The loss of station power turned out to be due to actuations of 13.8 kV circuit breakers within the plant, rather than blackout of the local grid. Once again, the 60 kV supply to the plant had been retained in spite of very strong ground shaking (an estimated ZPA of 0.4g).

Within about 10 minutes, the 13.8 kV breaker was reclosed to the plant substation and station service power was restored. The control system readout revealed that Turbine Generator A had tripped on a thrust bearing alarm. It appeared that the generator rotor had contacted and perhaps damaged the bearings during the shaking. Some time later when the turbine generator was rolled on the turning gear, the resulting *"squawk"* indicated that a restart should not be attempted. Investigations revealed that the generator casing had shifted about 1/8 inch on the concrete floor. Similar shifting was also noted on Generator B. Since it was apparent that the unit should not be restarted, operators decided to disassemble Generator A for the same overhaul that Unit B was undergoing.

When the third, magnitude 6.5, earthquake struck at 4:18 am on April 26 (with an estimated ZPA of over 0.2g), the cogen plant was already off line and no specific effects were noted. Power from the off dite grid was retained and there were no apparent malfunction in the control or power supply systems in the plant.

Both mechanical and electrical power supply systems within the cogen plant survived the earthquakes with minimal effects. Tanks and heat exchangers escaped damage. No problems were encountered in mechanical equipment such as fans, pumps, or control valves in the process of restarting the plant. Pneumatic tubing in the plant instrument and service air systems remained intact, except at several locations where sway of the boilers buckled pressure taps. (Reference C7, page B-35)

Perry Nuclear Plant. The Perry Nuclear Plant is about 56 km northeast of Cleveland, Ohio on the shore of Lake Erie. On January 31, 1986, a magnitude 5.0 earthquake occurred near Leroy, Ohio. The epicenter is estimated to be 17 km to the south of the Perry Plant, which recorded a ZPA of 0.18g. At the time of the earthquake, the Perry Plant was under pre-operational testing prior to fuel load.

There were 47,000 electrical components in 70 separate safety and non-safety systems that were energized during the earthquake. None of them experienced adverse affects like spurious starts or alarms. The 345 kV breakers in the switchyard were tripped as designed after the chattering of the turbine generator loss of excitation protective relay. This is an induction cylinder type relay. The chattering was caused by the lack of AC restraint voltage on the cylinder, which was caused because the isophase bus potential transformer was racked out. A total of five non-safety related relays actuated, of which three were in the more sensitive de-energized state. (Reference C3)

Out of a total of 6,968 identified relays, at least one (and possibly up to three) de-energized non safety-related protective relays closed contacts due to motion during the earthquake. All safety-related relays continued to operate normally through the earthquake. (Reference C5)

The East Lake fossil plant is 20 km to the west of the epicenter area. The unit 5 turbine generator was tripped by the vibration monitor--in other words, it performed as designed when it sensed vibrations from the earthquake. (Reference C3)

The Painesville Municipal Power Plant is about 17 km northwest of the epicenter. At least six boiler alarms (triggered by mercoid switches) caused the operator to manually trip the only operating unit (#5) as a precautionary measure. The tripped boiler was restarted about one-half hour after the earthquake after an inspection revealed no problems. (Reference C6)

No relay actuations at the following power plants: Ashtabula--about 33 km northwest of the epicenter, Lake Shore--about 29 km southwest of the epicenter, and Avon--about 70 km southwest of the epicenter. (Reference C6)

Puente Hills Station. At the Puente Hills Landfill Gas-to-Energy Station, which experienced an estimated ZPA of 0.4g in the magnitude 5.9 1987 Whittier, California earthquake, the plant was in operation at the time of the main shock of October 1. The operator observed the swaying of the turbine-generator structure through the control room window, which caused the operator to manually shut the plant down over concern about possible structural damage. An inspection of the plant revealed no damage.

Off site power from the nearby Mesa Substation was not lost in the earthquake. However, the blowers that extract gas from the landfill are powered from the Walnut Substation, which blacked out in the earthquake. It was not restored until late in the afternoon. Without power to the blowers, the plant could not restart. A portable generator was ordered, but required several hours to deliver because of the congested freeways (partially caused by the closure of the damaged I-5/I-605 interchange).

At about 10:30 am, off-site power was lost for one-half hour when the local grid blacked out. On loss of normal ac power, the uninterruptible power supply to the control room draws on its batteries. The UPS failed to provide adequate ac voltage, causing the automatic control system to shut down. Several batteries in the UPS were found to be defective, and had apparently been defective before the earthquake. Fortunately, off-site power was quickly restored and repair of the UPS was delayed until later.

The plant was restarted around 5:00 pm after the portable generators arrived. Plant startup and subsequent operation proceeded without problems. Close inspection of the plant revealed no significant damage to either structures or equipment. Personnel reported that superficial cracks in concrete and reinforced masonry might have been earthquake-caused, or might have been preexisting and not noticed before the earthquake. (Reference C7, page B-13)

Rinaldi Receiving Station. At the Rinaldi Receiving Station, which experienced an estimated ZPA of 0.5-0.75g during the magnitude 6.5 1971 San Fernando, California earthquake, several relay actuations were reported. They relay actuations were on typical pilot wire and sudden pressure relays. (Reference C1, pages 3-10 and 3-11)

San Cristobal Substation. At the San Cristobal Substation, which experienced an estimated ZPA of about 0.25g during the magnitude 7.8 1985 Chile earthquake, the substation was tripped off line during the earthquake when capacitor banks in the yard failed and power was lost. It took about one hour to restore power, two hours to transmit power to the city, and four hours to return the substation to normal operation. Several relays were reported to have actuated during the earthquake. Operators recounted that these were differential relays and sudden pressure relays. (Reference C1, page 4-16 and 4-17)

San Isidro Substation. At the San Isidro Substation, which experienced an estimated ZPA of about 0.6g during the magnitude 7.8 1985 Chile earthquake, the substation

was tripped off line during the earthquake. Operators indicated that the trip was due to vibration of a protective relay (or relays) in the control room. The emergency diesel generator started automatically with the loss of power and continued operating for 8 hours until power was restored. Damage in the 220 kV switchyard prevented resumption of normal operation of the substation for over 3 days. (Reference C1, page 4-16)

San Sebastion Substation. At the San Sebastion Substation, which experienced an estimated ZPA of about 0.4g during the magnitude 7.8 1985 Chile earthquake, the substation lost power during the earthquake when two protective "fault pressure relays" tripped. After an inspection, the relays were manually reset and normal operation was resumed. Plant operators attributed these trips to oil sloshing in the transformers. (Reference C1, page 4-16)

Santa Cruz Water Treatment Plant. At the Santa Cruz Water Treatment Plant, which experienced an estimated ZPA of 0.4g in the magnitude 7.1 1989 Loma Prieta, California earthquake, the plant was in operation at the time of the earthquake. Off site power was lost immediately. The computer monitoring system continued to operate on power from its uninterruptible power supply system. The emergency diesel generator started automatically and operated until off site power from the grid was restored almost 24 hours after the earthquake.

The diesel generator is sized to supply all plant mechanical equipment, but water treatment was suspended because of interruptions in the supply of raw water (the pumping stations on the San Lorenzo River and Lock Lomand Reservoir have no source of backup power). Operations resumed almost 24 hours after the earthquake, when the local grid was brought up.

Mechanical and electrical systems in the plant were undamaged. There was no significant structural damage in the operations building, the sedimentation basins, or the concrete water storage tanks, and only superficial cracking in wall plaster and brick facing. (Reference C7, page B-30)

Saugus Substation. At the Saugus Substation, which experienced an estimated ZPA of 0.35g during the magnitude 6.5 1971 San Fernando, California earthquake, inspection of the plant log and conversations with plant personnel indicate that sudden pressure relays operated to remove the No. 3A 220/66 kV transformer bank from service. The relays are typically mounted on the transformer between the oil reservoir and the main transformer body. Operators stated that alarms (no trips) were received on the No. 1A and 2A transformer banks. The alarms could have been caused by spurious relay actuation, but operators felt it is more likely that the failed lightning arrestors and insulators in the switchyard caused ground faulting, which in turn caused the alarms. (Reference C1, page 4-7 and 4-8)

UC Santa Cruz Plant. At the University of California, Santa Cruz cogeneration plant, which experienced an estimated ZPA of 0.4g in the magnitude 7.1 1989 Loma Prieta, California earthquake, the diesel-generator was operating at the time of the earthquake. The plant lost off site power, and the diesel-generator shut down as designed. The

operators checked for damage and, finding none, manually restarted the diesel engine However, when the diesel-generator was connected to the campus grid, the campus power load was too large, and an underfrequency relay tripped the diesel off-line. Operators manually disconnected electrical supply at several buildings around campus and, with the reduced load, successfully re-started the diesels. The diesel was the sole source of campus power for about 24 hours, until off site power was restored. (Reference C7, page B-25)

Valley Steam Plant. At the Valley Steam Plant, which experienced an estimated ZPA of 0.4g during the magnitude 6.5 1971 San Fernando, California earthquake, the seismic motion caused the actuation of a mercoid switch. The oscillation of the mercury in the switch, which controls the low pressure fuel gas, caused the Unit 3 boilers to trip. (Reference C2, page 18-5)

Based on discussions with later Valley Plant personnel, and on the operator's log, there were four spurious relay actuations that resulted from the seismic vibrations: (1) sudden pressure relay on the Bank F transformer, (2) Unit 1 generator differential relay, (3) Unit 4 generator differential relay, and (4) Unit 3 low pressure fuel gas mercoid switch.

Units 1, 3, and 4 were down at the time of the earthquake. Unit 2 was down for maintenance. At the time of the earthquake, station power was being supplied to all three operating units from outside sources through Bus No. 2. Station power from Bus No. 2 comes into the Valley switchyard at 230 kV and is converted to 138 kV by the Bank F transformer. The earthquake occurred at 6:01 a.m., and earthquake induced vibrations caused the sudden pressure on the Bank F transformer to trip the circuit breaker and cut off the outside station service power. This is a Buchholz type relay made by the Italian company of Savigliano. The operators immediately attempted to energize Bus No. 2, but the breakers failed to reclose. The operators assumed the bus had been damaged. Forty-eight minutes later, operators determined that the MG-6 auxiliary relay in the relay room had to be reset before the bus can be re-energized after a bus trip. The MG-6 relay acts as a lock out relay in the event of a bus trip, and was designed into the system to prevent premature resetting of the tripped breaker. Thus, the MG-6 relay is judged to have performed its intended function, and its locking out did not indicate a chatter condition during the earthquake.

Units 1 and 4 were tripped of line by spurious actuation of their generator differential relays. Unit 3 remained on line. However, during the confusion, operators assumed that all units, including the station service, had been lost. Unit 3 boiler fires had been tripped from the oscillating of mercury in the low pressure fuel gas mercoid switch. When operators discovered that Unit 3 was still on the line, they energized the tie busses to supply Units 1 and 4 station service with power generated from Unit 3 (at 6:49 a.m.). The normal offsite station service power was restored at 7:54 a.m.

The earthquake caused the turbine/generators in Units 1 and 4 to trip off line due to the spurious operation of the generator differential relays. The relays are GE model CFD differential percentage relays, which are located on the control relay boards at elevation 930 (15 ft above grade). (The principal of operation for the generator differential relay involves comparing the current entering one end of the transformer winding with the current leaving the other end of the winding. When the current difference exceeds a cer-

tain value due to an internal fault, the relay closes its contact and causes a unit bus to trip.) Once operators had inspected the generators to ensure damage had not occurred, Unit 4 was returned on line at 6:50 a.m. and Unit 1 at 7:12 a.m. (Reference C1, pages 4-3 and 4-4)

Whitewater Hydroelectric Plant. At the Whitewater Hydroelectric Plant, which experienced an estimated ZPA of 0.5g in the magnitude 6 1986 Palm Springs earthquake, the plant was in operation at the time of the earthquake. Vibration sensors on the impeller-generator tripped the plant during the earthquake. Leaks in the Colorado Aqueduct forced a reduction in flow while repairs were made over a period of several days. During this time, flow in the penstock feeding the Whitewater Plant was not available. Upon return of the aqueduct to full capacity, the plant was restarted without problems in any operating system. (Reference C7, page B-6)

Operator Response. In the following, available operator response to the earthquake is briefly documented. Unless noted otherwise, these data are from Reference C1.

Concon Refinery. Plant remained operational through the earthquake. Emergency diesel generator started on loss of offsite power, but tripped off immediately by relay actuation. Operators manually restarted generator in 10 minutes and resumed operations.

El Centro Steam Plant 3. Unit tripped from grid but continued generating its own station power after the earthquake. Operators placed the unit back on grid 15 minutes after earthquake. However, the unit was limited to 10 MW due to lack of cooling tower fans because of inoperative circuit breakers caused by build up of dirt and moisture. Problems corrected 21 hours after earthquake. About 16 hours later, operators manually tripped the unit to repair piping. Unit placed back on line about 6 hours later.

El Centro Steam Plant 4. Unit went completely black, loss of station service power. Operators restored station service from Unit 3 in 10 minutes. Inspection and repair of pipe leaks delayed returning the unit to service until 5 hours 20 minutes after the earthquake.

El Infiernillo. Both units remained on line, but plant disconnected from grid by outside system disturbances. Reconnected to grid after outside system restored (time unknown).

Glendale. One and one-half hours after the earthquake, Units 3, 4, and 5 tripped off line due to outside system disturbances (overcurrent relay trips). Operators diagnosed the situation, reset the relays, and returned all three units on line within 10 minutes.

Humboldt Bay 1 (1975). Unit tripped off line by relay actuation. Operators inspected the unit, reset relays and breakers, and returned unit to service 19 minutes after the earthquake.

Humboldt Bay 2 (1975). Unit tripped off line by relay actuation. Operators inspected the unit, reset relays and breakers, and returned unit to service 19 minutes after the earthquake.

Humboldt Bay 3 (1975). Unit down for scheduled maintenance. Mercoid switch actuation closed primary isolation valve.

Humboldt Bay 1 (1980). Unit tripped off line by relay actuation. Operators inspected the generator and placed it on line about 13 hours after the earthquake. (No details available to explain why it took so long.)

Humboldt Bay 2 (1980). Unit manually tripped because of mercoid switch actuation. Operators had to correct additional problems before placing the unit on line about 8 hours after the earthquake.

Krsko Nuclear Plant. Plant operators heard an audible sound caused by the earthquake that sounded like a passing freight train. They also noticed annunciation of an earthquake on the control panel.

They interpreted the audible earthquake sound as a rupture of non-safety class piping systems, and manually tripped the plant. Plant personnel performed detailed walkdowns of the plant and found nothing unusual except the spurious high water level indication at the non-safety class level switches of the feed water high pressure reheaters. After the reset of the level switches, the plant went back on line and operated smoothly.

A magnitude 3.1 aftershock earthquake occurred several days later. It tripped the plant automatically on an indication of steam generator high water level. Plant personnel again performed detailed plant walkdowns. They found nothing unusual except that the non-safety class low pressure feed water reheater had a spurious level switch indication of high water level which caused the high water level indication in the steam generator. After operators reset the level switches, the plant went back on line and operated smoothly. (Reference C3)

Magnolia 2. Lost outside station service power. Auxiliary generator started automatically, but operators could not start the draft fans and feed pumps. Operators manually tripped the fires and turbine. Operators inspected equipment and returned the unit to service 2 hours 45 minutes after the earthquake.

Magnolia 3. Fuel oil line broken in earthquake. Operator manually tripped the unit due to low fuel oil pressure. Fuel line repaired and unit returned to service 3 hours 25 minutes after the earthquake.

Magnolia 5. Unit off line at the time of the earthquake. Operators attempted to start it, but this was blocked by three relay actuations. Operators took 46 minutes to diagnose the blocked start, reset relays, and bring the unit on line.

Olive 1. Unit was tripped off line by actuations of the generator differential relay. Outside station service power was also lost. Thirty six minutes after the earthquake, station service power was made available from receiving station E. Operators reset relays, purged and relit the boilers one hour after the earthquake. They placed the unit back on line 1 hour 42 minutes later.

Olive 2. Unit tripped off line by actuations of the generator differential relay. Outside station service power was also lost. Thirty six minutes after the earthquake, station service power was made available from receiving station E. Operators reset relays, purged and relit the boilers one hour after the earthquake. They placed the unit back on line 1 hour 47 minutes later.

Ormond Beach 1. Unit tripped by spurious actuations of relays. Several mercoid switches also actuated. Operators inspected the unit and returned it to service a short time after the earthquake.

San Isidro Substation. Site lost power due to relay actuation. Diesel generator started and remained on line until power was restored 8 hours later. Damaged transformers in switchyard delayed normal operation for 3-4 days.

San Cristobal Substation. Failure of capacitor banks in switchyard caused loss of offsite power. It took about 1 hour to restore power, 2 hours to begin sending power, and 4 hours to regain normal operation.

San Sebastian Substation. Station lost power from a transformer trip. Station inspected, relays reset, and operations resumed.

Saugus Substation. Several sudden pressure relays actuated, tripping alarms and removing at least one transformer from service. Station damage delayed returning it to service.

Valley Steam 1. Outside station service power was lost during the earthquake, due to sudden pressure relay actuation. In addition, the units turbine generator was tripped off line by differential relay actuation. Operators restored station service power from Unit 3 19 minutes after the earthquake. Operators inspected the turbine generator and placed unit back on line 1 hour 11 minutes after the earthquake.

Valley Steam 3. Unit 3 remained on line during the earthquake. In the confusion however, operators believed all units went off line. Operators took 19 minutes to determine that Unit 3 was on line, purge and relight the boilers, and energize Unit 1 and 4 auxiliaries. Operators had to relight the boilers because the actuation of a mercoid switch shut off fuel to the boilers.

Valley Steam 4. Outside station service power lost during the earthquake, due to sudden pressure relay actuation. In addition, the units turbine generator was tripped off line by differential relay actuation. Operators restored station service power from Unit 3 19 minutes after the earthquake. Operators inspected the turbine generator and placed unit back on line 49 minutes after the earthquake.

Valley Steam. Outside station service power lost during the earthquake, due to sudden pressure relay actuation. A breaker failed to close when operators attempted to reenergize a bus. An auxiliary relay required resetting prior to closing the breaker. Operators restored outside station service power 1 hour and 48 minutes after the earthquake.

References for Appendix C

C1. Gregory S Hardy, Michael J Griffin, Sam W Swan: *The Performance of Relays in Earthquakes: A Summary of Available Data*, prepared for SQUG by EQE, October 1986.

C2. *Summary of the Seismic Adequacy of Twenty Classes of Equipment Required for the Safe Shutdown of Nuclear Plants*, prepared for SQUG and EPRI by EQE Engineering, March 1991.

C3. Chang Chen, Samir J Serhan, Zeljko Pavlovic: *Experience Data and Analytical Results of High Frequency Earthquakes*, proceedings of the Fourth Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment, and Piping, December 1992.

C4. R McGuire, G Toro, T O'Hara, J Jacobson, W Silva: *Probabilistic Seismic Hazard Evaluation for Crystal River Nuclear Generating Plant*, prepared by Yankee Atomic Electric, Risk Engineering, and Woodward-Clyde Consultants for EPRI, RP 101-53, April 1989.

C5. K M Skreiner, J D Stevenson, P R Wilson: *Relay Behavior at the Perry Nuclear Power Plant During the 1986 Earthquake in Leroy, Ohio*, prepared for the Electric Power Research Institute, report NP-6472, September 1989.

C6. J D Stevenson, P R Wilson: *The 1986 Leroy, Ohio Earthquake: Performance of Power and Industrial Facilities*, prepared for the Electric Power Research Institute by Stevenson and Associates, report NP-6558, November 1989.

C7. *Advanced Light Water Reactor (ALWR) First-of-a-Kind Engineering Project on Equipment Seismic Qualification*, prepared for Advanced Reactor Corp by MPR Associates, EQE Engineering Consultants, and ANCO Engineers. February 5, 1993.

Appendix D - Equipment-Specific Generic caveats

The purposes of this appendix are to describe any differences between the equipment caveats in Appendix B of the GIP and the caveats in the CR3 Plant Specific Procedure, and to explain the basis for the difference. Only those caveats where there is a difference are included below. If a caveat is not discussed below, the CR3 Plant Specific Procedure adopts the GIP caveat.

Generic caveat	CR3 Plant Specific Procedure Position on Inclusion of Generic caveat	Technical Basis for CR3 Plant Specific Position
1. Motor Control Centers		
MCC/BS Generic Caveat #4 *Attached Weight*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of MCC. Concern is not credible at a low seismic site like CR3.
MCC/BS Generic Caveat #7 *Cutouts*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of MCC. Concern is not credible at a low seismic site like CR3.
MCC/BS Generic Caveat #8 *Doors*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
MCC/BS Generic Caveat #9 *8 Hz Limit*	Generic caveat is not included because it's met by pre-screening.	Generic seismic capacity exceeds CR3 seismic demand at all frequencies, including 8 Hz and below. See Appendix A.
MCC/BS Generic Caveat #10 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
MCC/BS Generic Caveat #11 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
2. Low Voltage Switchgear		
LVS/BS Generic Caveat #3 *Breaker Restraint*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive structural response of breaker, based on high level test programs. Concern is not credible at a low seismic site like CR3.
LVS/BS Generic Caveat #5 *Attached Weight*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of LVS. Concern is not credible at a low seismic site like CR3.
LVS/BS Generic Caveat #8 *Cutouts*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of LVS. Concern is not credible at a low seismic site like CR3.
LVS/BS Generic Caveat #9 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
LVS/BS Generic Caveat #10 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
LVS/BS Generic Caveat #11 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
3. Medium Voltage Switchgear		
MVS/BS Generic Caveat #5 *Attached Weights*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of MVS. Concern is not credible at a low seismic site like CR3.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
MVS/BS Generic Caveat #8 *Cutouts*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of MVS. Concern is not credible at a low seismic site like CR3.
MVS/BS Generic Caveat #9 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
MVS/BS Generic Caveat #10 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
MVS/BS Generic Caveat #11 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
4. Transformers		
TRN/BS Generic Caveat #8 *Weak-Way Bending*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity of TRN. Concern is not credible at a low seismic site like CR3.
TRN/BS Generic Caveat #10 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
TRN/BS Generic Caveat #11 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
TRN/BS Generic Caveat #12 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
5. Horizontal Pumps		
HP/BS Generic Caveat #4 *Piping*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive seismic loads from piping. Concern is not credible at a low seismic site like CR3.
HP/BS Generic Caveat #5 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
HP/BS Generic Caveat #7 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
HP/BS Generic Caveat #8 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
6. Vertical Pumps		

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
VP/BS Generic Caveat #3 *Piping*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive seismic loads from piping. Concern is not credible at a low seismic site like CR3.
VP/BS Generic Caveat #5 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
VP/BS Generic Caveat #6 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
7. Fluid-Operated Valves		
FOV/BS Generic Caveat #2 *Cast Iron Body*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in cast iron. Concern is not credible at a low seismic site like CR3.
FOV/BS Generic Caveat #3 *Cast Iron Yoke*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in cast iron. Concern is not credible at a low seismic site like CR3.
FOV/BS Generic Caveat #4 *Piping > 1 Inch*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in piping. Concern is not credible at a low seismic site like CR3.
FOV/BS Generic Caveat #5 & 6 *Valve Operator Length*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in piping. Concern is not credible at a low seismic site like CR3.
FOV/BS Generic Caveat #7 *Actuator & Yoke*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in yoke or shaft. Concern is not credible at a low seismic site like CR3.
8. Motor- & Solenoid-Operated Valves		

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
MOV/BS Generic Caveat #2 *Cast Iron Body*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in valve body. Concern is not credible at a low seismic site like CR3.
MOV/BS Generic Caveat #3 *Cast Iron Yoke*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in yoke. Concern is not credible at a low seismic site like CR3.
MOV/BS Generic Caveat #4 *Piping > 1 inch*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in piping. Concern is not credible at a low seismic site like CR3.
MOV/BS Generic Caveat #5 Valve *Operator Length*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in yoke. Concern is not credible at a low seismic site like CR3.
MOV/BS Generic Caveat #6 *Actuator/Yoke Braced*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake stresses in yoke or shaft. Concern is not credible at a low seismic site like CR3.
9. Fans		
FAN/BS Generic Caveat #4 *Duct Distortion*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake loads on fan from ducts. Concern is not credible at a low seismic site like CR3.
FAN/BS Generic Caveat #5 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
FAN/BS Generic Caveat #7 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
10. Air Handlers		
AH/BS Generic Caveat #2 *Anchorage-Internal*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
AH/BS Generic Caveat #3 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
AH/BS Generic Caveat #4 *Duct Distortion*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake loads on air handler from ducts. Concern is not credible at a low seismic site like CR3.
AH/BS Generic Caveat #5 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
AH/BS Generic Caveat #7 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
AH/BS Generic Caveat #8 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
11. Chillers		
CHL/BS Generic Caveat #2 *Weak Way Bending*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake loads on structural element. Concern is not credible at a low seismic site like CR3.
CHL/BS Generic Caveat #3 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
CHL/BS Generic Caveat #4 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
CHL/BS Generic Caveat #5 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
12. Air Compressors		
AC/BS Generic Caveat #2 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
AC/BS Generic Caveat #4 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
AC/BS Generic Caveat #5 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
13. Motor-Generators		
MG/BS Generic Caveat #3 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
MG/BS Generic Caveat #5 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
MG/BS Generic Caveat #6 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
14. Distribution Panels		
DP/BS Generic Caveat #2 *Only Circuit Breakers & Switches*	Generic caveat is not included because its intent is met by pre-screening.	Concern is about earthquake vulnerability of unspecified sub-components. Concern is not credible at a low seismic site like CR3.
DP/BS Generic Caveat #3 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
DP/BS Generic Caveat #6 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
DP/BS Generic Caveat #7 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
15. Batteries on Racks		
BAT/BS Generic Caveat #9 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
16. Battery Chargers & Interteres		
BCI/BS Generic Caveat #4 *Weak-Way Bending*	Generic caveat is not included because its intent is met by pre-screening.	Concern is excessive earthquake loads on structural element. Concern is not credible at a low seismic site like CR3.
BCI/BS Generic Caveat #6 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
BCI/BS Generic Caveat #7 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
BCI/BS Generic Caveat #8 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
17. Engine-Generators		
EG/BS Generic Caveat #3 *Base Isolation*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
EG/BS Generic Caveat #5 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
EG/BS Generic Caveat #6 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
18. Instruments on Racks		
IR/BS Generic Caveat #2 *Programmable Controllers*	Generic caveat is not included because it's met by pre-screening.	Concern is that programmable controllers are not adequately represented by the earthquake data base. They are now known to be adequately represented.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
IR/BS Generic Caveat #5 *8 Hz Limit*	Generic caveat is not included because it's met by pre-screening.	Generic seismic capacity exceeds CR3 seismic demand at all frequencies, including 8 Hz and below. See Appendix A.
IR/BS Generic Caveat #7 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
IR/BS Generic Caveat #8 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.
19. Temperature Sensors	No changes.	
20. Instrumentation and Control Panels and Cabinets		
I&C/BS Generic Caveat #2 *Programmable Controllers*	Generic caveat is not included because it's met by by pre-screening.	Concern is that programmable controllers are not adequately represented by the earthquake data base. They are now known to be adequately represented.
I&C/BS Generic Caveat #3 *Strip Chart*	Generic caveat is not included because its intent is met by pre-screening.	Concern is structural integrity. Concern is not credible at a low seismic site like CR3.
I&C/BS Generic Caveat #7 *Doors*	Generic caveat for integrity is not included because its intent is met by pre-screening. Generic caveat for relays is not included because it's met by pre-screening. See Conclusion of Appendix C.	One concern is structural integrity. Concern is not credible at a low seismic site like CR3. A second concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Caveat	CR3 Plant Specific Procedure Position on Inclusion of Caveat	Technical Basis for CR3 Plant Specific Position
I&C/BS Generic Caveat #9 *Anchorage*	Generic caveat is included, but it refers to CR3 approach in Appendix E instead of Section 4.4 of GIP. Intent of generic caveat will be met in implementation.	Concern is structural integrity of anchorage. Concern is not very credible at a low seismic site like CR3. See Appendix E. Anchorage reveiw is required, but detailed GIP approach is not required.
I&C/BS Generic Caveat #10 *Relays*	Generic caveat is not included because it's met by pre-screening. See Conclusion of Appendix C.	Concern is earthquake actuation of more relays than operators can reset. Concern is not credible at a low seismic site like CR3. See Appendix C.

Appendix E - Anchorage

Background. The purpose of this section is to describe the basis for the CR3 plant specific position on anchorage for GL 87-02. NRC's position on anchorage in GL 87-02 (Reference E1) accurately reflects the consensus of the A46 program at the time:

> *"During the walk-through inspection, anchors and supports of equipment within the scope of review will be carefully inspected. The detailed guidance developed is the preferred method for review of anchorages. The detailed guidance has been developed jointly by SQUG and EPRI. It was approved by SSRAP and is being reviewed by the NRC staff. It will be approved by the NRC staff before implementation. If the adequacy of supports and anchors cannot be determined by inspection, an engineering review of the anchorage or support will be conducted. This engineering review will include a review of design calculations or the performance of new calculations and/or verification of fundamental frequency of equipment to ensure adequate restraint and stiffness."* (underline added)

CR3 Position. The CR3 plant specific procedure for GL 87-02 is very close to NRC's GL 87-02 position. However, some differences are logical since NRC's position in GL 87-02 is a generic one for all GL 87-02 plants (including the plant with the largest SSE), but CR3 is a low seismic site. The CR3 position is as follows:

> *The preferred method to determine the adequacy of anchorage, support, and anchorage load path is through the inspection and judgment of Seismic Capability Engineers (SCEs). SCEs should consider the anchorage attributes in Section 4.4.1 of the GIP, as they judge appropriate, in their evaluation of the specific anchorage, support, or load path. If SCEs cannot determine the adequacy of anchorage, support, or load path by inspection, then an engineering review of the anchorage, support, or load path should be conducted (which does not have to be performed by SCEs). The engineering review should include a review of existing design calculations or the performance of new calculations.*

Basis for CR3 Position. The basis for the CR3 position is that the GIP overstates the anchorage issue for a low seismic site. This is even illustrated by a comparison of the above quote from GL 87-02 and the current guidance in the GIP (which applies for all GL 87-02 plants).

This is also illustrated by Reference E2, which summarizes a site and literature survey of the earthquake performance of anchorage. For example, Reference E2 documents over 360 cases of anchorage damage. Only about 20 of the 360+ cases of damage were in power plants. The power plant damage occurred when the free field ZPA was 0.25g or more, and the earthquake magnitude was large (greater than 7). Reference E2 also contains the following:

"Friction clips and isolation-type anchorages, the anchorage of tall, thin electrical cabinets such as motor control centers, and the anchorage of massive items like large transformers and tanks are a source of poor performance. No damage was found for positive anchorage of pumps and motors, pipe-mounted components such as valve operators, and devices mounted to control boards, relay panels, and electrical cabinets or racks."

"Past earthquakes have caused anchorage damage, but it is clear that sufficient knowledge exists to engineer anchorage that will perform well in future earthquakes."

Reference E3 contains the following: *"Failures are rare when criteria are equal to or exceed equivalent lateral forces of 0.2W (0.2 times the weight of the equipment), even when the free-field acceleration is 0.5g or more."*

This suggests the lateral force requirement for the CR3 SSE of 0.1g could be one-fifth of this, or 0.04W. In other words, this suggests CR3 equipment could be designed for a seismic lateral force of only 4% of the weight of the equipment. We are not suggesting such an extremely low criteria. However, it does dramatize the different thought process called for when considering what is appropriate for a low seismic site.

The presentation for Reference E3 contains the following:

"Experience data based criteria and insights include effects of workmanship, and design and construction errors:

- *Some sites have poor workmanship, design & construction errors*
  (Main Oil Plant, Clearly different than nuclear)
- *With the exception of items like tanks and transformers, the errors appear to be isolated rather than pervasive (Anchorage of 4 out of 81 MCCs in SQUG data base were damaged)*
- *Tank and transformer anchorage damage may be mostly design error related*
- *Workmanship apparently is not as important as factors that can be (easily) checked*
  - *Does anchorage exist?*
  - *Are the number of bolts enough?*
  - *Is the bolt diameter large enough?*
  - *Are the nuts on the bolts?*
  - *Is there enough weld?"*

Conclusion. It is good design practice to anchor equipment well. However, it is not difficult to design and install anchorage that will perform well in earthquakes. It is also not difficult for qualified engineers to use judgment to evaluate existing anchorage for a relatively minor earthquake like the CR3 SSE. Earthquake experience clearly suggests

the detailed GIP guidelines are not required for a low seismic site like CR3, and that the above plant specific guideline is completely adequate to satisfy GL 87-02 at CR3.

References for Appendix E

E1. *Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operators, Unresolved Safety Issue (USI) A-46 (Generic Letter 87-02)*, US Nuclear Regulatory Commission, February 19, 1987.

E2. Paul D Smith: *Compilation of Earthquake Data on Equipment Anchorages*, unpublished, February 1988.

E3. W M Morrow, P I Yanev, P D Smith: *Earthquake Performance in Industrial Facilities and its Relation to Nuclear Plant Equipment Anchorages*, paper D 9/5, Transactions of the 8th International Conference on Structural Mechanics in Reactor Technology, Brussels, Belgium, August 19-23, 1985.