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REGULATORY GUIDE

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ANCHORING COMPONENTS AND STRUCTURAL SUPPORTS IN CONCRETE

A. INTRODUCTION

This regulatory guide is being issued to provide guidance to licensees and applicants on methods acceptable to the NRC staff for complying with the NRC's regulations in the design, evaluation, and quality assurance of anchors (steel embedments) used for component and structural supports on concrete structures.

General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires, in part, that structures, systems, and components (SSCs) important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. In addition, GDC 2, "Design Bases for Protection Against Natural Phenomena," and GDC 4, "Environmental and Dynamic Effects Design Bases," require, in part, that such SSCs be designed to withstand the effects of natural phenomena and to accommodate the effects of and be compatible with the environmental conditions associated with normal operation and postulated accidents. Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50 establishes overall quality assurance for SSCs important to safety. Appendix S, “Earthquake Engineering Criteria for Nuclear Power

Plants," to 10 CFR Part 50, states, in part, requirements for the implementation of GDC 2 with respect to earthquakes.[1]

Licensees and applicants may propose means other than those specified by the provisions of the Regulatory Position of this guide for meeting applicable regulations. No new standards are being imposed by this regulatory guide. Implementation of this guidance by licensees will be on a strictly voluntary basis.

The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50, which were approved by the Office of Management and Budget (OMB), approval number 3150-0011. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

B. DISCUSSION

Component and structural supports are fastened to the concrete building structure by anchors (steel embedments) that transmit forces to the concrete building structure by bearing, shear, tension, or a combination thereof. Structural failure of piping supports for safety systems and questions concerning the performance of one type of steel embedment, the expansion anchor bolt, led to the issuance of Inspection and Enforcement Bulletin (IEB) 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," in November of 1979. Review of reports required by IEB 79-02 revealed that industry practices varied. No consistency existed in the design and installation of such anchors as grouted anchors, embedded plates, or inserts. Utilities and anchor manufacturers were prompted by these inconsistencies to conduct research to answer questions raised by IEB 79-02. In October 1980, the American Concrete Institute released Appendix B, "Steel Embedments," to ACI 349-80, "Code Requirements for Nuclear Safety Related Concrete Structures." The design methodology and code standards in Appendix B to ACI 349-80 were based on a limited amount of available test data.

In December 1980, the NRC designated "Seismic Qualification of Equipment in Operating Plants" as Unresolved Safety Issue (USI) A-46. The objective of USI A-46 was to develop alternative seismic qualification methods and acceptance criteria that could be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform their intended safety functions. Since equipment is usually anchored to the concrete structure through steel embedments, it was necessary to ensure that the embedments were capable of resisting seismic loads.

In March 1988, in accordance with the provisions of 10 CFR Part 21, it was reported that tests of some expansion anchor bolts had disclosed that the previously recommended minimum

[1] Appendix S to 10 CFR Part 50 applies to applicants for a design certification or combined license pursuant to10 CFR Part 52 or a construction permit or operating license pursuant to 10 CFR Part 50 on or after January 10, 1997. However, for either an operating license applicant or holder whose construction permit was issued before January 10, 1997, the earthquake engineering criteria in Section VI of Appendix A to 10 CFR Part 100 continue to apply.

edge distance from an unsupported edge of five times the anchor bolt diameter might be insufficient to develop 100% of the recommended anchor capacity. The issue of minimum edge distance was incorporated into USI A-46.

The Seismic Qualification Utility Group (SQUG) developed a Generic Implementation Plan (GIP), including criteria and walkdown procedures, that was used to resolve the concerns of USI A-46. Following NRC approval of the GIP, each utility conducted a walkdown of its nuclear facilities using the GIP criteria and procedures.

The criteria and procedures specified for anchorage walkdown in the GIP contained specific information related to bolt strength. The GIP, including criteria and walkdown procedures, has been reviewed and accepted by the NRC.

Since the release of Appendix B to ACI 349-80 in 1980 and the resolution of USI A-46, extensive work has been done by the ACI 349 code committee and others in the industry (EPRI NP-5228). Recent testing sponsored by industry groups in the United States and Europe and by the NRC has increased the amount and type of test data available to code committees (ASCE, NUREG/CR-5434, NUREG/CR-2999, NUREG/CR-5563, and SP-130).

As a result of extensive studies and tests performed since the late 1980s, questions were raised regarding the design methodology used in Appendix B to ACI 349-80. These questions were on the shape of the anchor pullout cone under tensile loads, behavior of bolt groups, and edge conditions. Traditionally, the pullout cone has been assumed to be a 45° cone initiating at the bearing edge of the anchor (anchor head) and radiating toward the free surface of the concrete member. However, later research and test results have shown the pullout cones vary with embedment. For deeper embedments, the pullout cone was shown to be closer to a 35° cone and was also shown that the concrete breakout failures for anchor bolt groups and edge conditions were different from a bolt embedded in concrete far from concrete free edges. Based on these latest findings, a new methodology, the Concrete Capacity or "CC-Method," was proposed to the ACI 349 code committee by independent researchers (Fuchs, Eligehausen, and Breen). After an extensive review of all available test data, in February 2001 the ACI 349 code committee issued a revision to Appendix B that was based, in part, on the CC-Method.

Anchors used in nuclear power plants may need to withstand stress for long periods of time and may need to compensate for additional transient-imposed stresses as a result of environmental effects. Thus, it is necessary to carefully evaluate anchor performance, taking into consideration the environment to which the anchors are subjected (ACI 355). This Regulatory Guide 1.199 generally endorses Appendix B (February 2001) to ACI 349-01, with exceptions in the area of load combinations. In addition, the guide has supplementary recommendations in the areas of materials, installation, inservice inspection, and the use of anchors in masonry walls.

Discussion of Regulatory Positions

This regulatory guide sets forth Regulatory Positions on the New Appendix B to ACI 349-01. The reasons for each of these regulatory positions are as follows.

Regulatory Position 1 endorses Appendix B to ACI 349-01. The notations and definitions in Sections B.0, "Notation," and B.1, "Definitions," are acceptable to the NRC staff because they reflect the latest industry practices.

Regulatory Position 1.2 supplements Section B.3, "General Requirements," of Appendix B in three areas: load combinations, testing, and materials. The staff recommends that the load combinations specified in Regulatory Position 1.3 be used instead of the load combinations outlined in Section 9.2 of ACI 349-01 and specified in Section B.3.2 of Appendix B. Section B.3.3 provides for testing post-installed anchors in cracked concrete under seismic loads. The NRC staff agrees with the guidance of Section B.3.3, but also recommends that ASTM E488-96 should be used as a guide for establishing a test program because ASTM E488-96 is a recent standard based on industry consensus. Additionally, for post-installed mechanical anchors, ACI Standard ACI 355.2-01, "Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete," can be used as a guide for establishing a test program for post-installed anchors.

Section B.3.7 states that material standards should be specified by the Engineer so that embedment design is compatible with the attachment. In general, specifications provide that metal anchors be made of a material that is resistant to corrosive conditions or coated with a protective material. In the case of metal anchors, the material should be stable in the concrete of the support structure and not cause any chemical reactions that could adversely affect the concrete or any reinforcement that may be present.

Regulatory Position 1.3 endorses Section B.4, "General Requirements for Strength of Structural Anchors," of ACI 349-01. However, the staff disagrees with Section B.4.4, which provides that the load combinations of Section 9.2 of ACI 349-01 should be used. The staff agrees with the strength reduction factors given in Section B.4.4. Load factors consistent with SRP Section 3.8.4, "Other Seismic Category I Structures," should be applied to the load combinations given in Section 9.2 of ACI 349-01.

Regulatory Position 1.4 endorses Section B.5, "Design Requirements for Tensile Loading," and Section B.6, "Design Requirements for Shear Loading," of Appendix B. The NRC staff endorses Sections B.5 and B.6 because they are based on extensive test data and incorporate the latest knowledge on the subject.

Regulatory Position 1.5 endorses Section B.7, "Interaction of Tensile and Shear Forces," and B.8, "Required Edge Distances, Spacings, and Thicknesses to Preclude Splitting Failure," of Appendix B. The NRC staff endorses Sections B.7 and B.8 because they are based on test data and incorporate the latest knowledge on the subject.

Regulatory Position 1.6 endorses and supplements Section B.9, "Installation of Anchors." Tests have shown that the proper installation of anchors is of prime importance in ensuring good anchor performance. The intentions of the guide are not to specify a detailed program for anchor installation but to ensure that the factors important for good anchor performance are considered before the anchor is installed. In addition, it is necessary to provide a sufficient preload to

expansion anchors to set the anchor mechanism, limit the initial slip of the anchor, and aid in withstanding cyclic loads.

Regulatory Position 1.7 endorses Section B.10, “Structural Plates, Shapes, and Specialty Inserts,” and Section B.11, “Shear Capacity of Embedded Plates and Shear Lugs,” because they are based on test data and incorporate the latest knowledge on the subject. For Section B.12, “Grouted Embedments,” the NRC staff recommends that code requirements be followed.

Section B.9 of Appendix B states that the Engineer should specify an anchor inspection program. Regulatory Position 2 recommends the creation of guidelines to help ensure that anchors are properly installed and provide satisfactory service throughout the life of the structure. An anchor inspection program is to cover the installation and inservice conditions of anchors. An inspection of anchors during the installation stage will verify that they are of the specified size and type and that thread stripping has not occurred. Items recommended for inspection during and after the installation stage include the items discussed in Regulatory Positions 1.6 and 2 of this guide.

Appendix B to ACI 349-01 does not include masonry in its scope; therefore Regulatory Position 7 offers guidance on the use of anchors in masonry. The extensive use of anchors (expansion and others) has led to considerable concern over the behavior of anchors in concrete masonry. Manufacturers generally indicate only the load capacities for anchors tested in cast-in-place concrete and do not recommend expansion anchors for use in concrete masonry. Until recently, the use of anchors in masonry was not subject to licensing review. Even though most standards and architect/engineer's specifications prohibit the use of anchors in concrete masonry units (CMUs), a review of licensees' responses to IEB 79-02 indicated the use of anchors in CMUs.

Licensees’ use of anchors in CMUs was limited in most cases to a small number of piping supports for Seismic Category I piping in a few plants, which raised questions about the anchors' performance and capabilities in concrete block walls. The limited amount of data available on static tests performed on anchor bolts installed in concrete block walls indicates that the ultimate capacity of bolts in concrete block walls is lower than that of the same type and size anchors in cast-in-place concrete. The possibility that the block walls were constructed using pumice material also exists. Because of the high void ratio, pumice concrete masonry units are superior in terms of thermal conductivity and fire resistance. However, individual block compressive strength could be as low as 700 psi, with the average being approximately 1000 psi. The lack of strength could cause the bolt expansion mechanism to actually cut into the pumice material, resulting in limited anchorage capacity. It is also expected that, under dynamic loading, the ultimate capacity of anchors will be further reduced. Until standards addressing anchoring in masonry are developed, the use of anchors in block walls is not recommended.

C. REGULATORY POSITION

The following Regulatory Positions describe recommendations to qualify, design, install, and inspect steel embedments installed in concrete to support components and structures.

1. The procedures and standards of Appendix B to ACI 349-01 are acceptable to the NRC staff as described and supplemented below. The recommendations are applicable to the types of anchors discussed in Section B.1, "Definitions," and B.2, "Scope," of Appendix B to ACI 349-01.

1.1 The notations and definitions given in Sections B.0 and B.1 of Appendix B to ACI 349-01 are acceptable to the NRC staff. The position on grouted anchors is in Regulatory Position 1.7.

1.2 The position on load combinations is given in Regulatory Position 1.3. In addition to the guidance of Section B.3.3 of Appendix B, the testing recommendations defined in ASTM E488-96, "Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements," are acceptable to the NRC staff as a guide for establishing a testing program. Test methods not covered by ASTM E488-96 (e.g., combined tension and shear, cracked concrete) should be established and executed using good engineering judgment. ACI 355.2-01, "Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete," provides guidance acceptable to the NRC staff for determining whether post-installed mechanical anchors are acceptable for use in uncracked as well as cracked concrete. For materials consideration, the NRC staff recommends that anchors be fabricated using a material that is compatible with the environment in which they will be installed.

1.3 The load factors used in Section 9.2.1 of ACI 349-01 are acceptable to the NRC staff except for the following:

1.3.1. In load combinations 9, 10, and 11, $1.2T_o$ should be used in place of $1.05T_o$.

1.3.2. In load combination 6, $1.4\ P_a$ should be used in place of $1.25P_a$.

1.3.3. In load combination 7, $1.25P_a$ should be used in place of $1.15P_a$.

1.3.4 The NRC staff endorses Section B.4, "General Requirements for Strength of Structural Anchors," of ACI 349-01. The NRC staff endorses the strength reduction factors given in Section B.4.4; however, load factors consistent with SRP Section 3.8.4, "Other Seismic Category I Structures," should be applied to the load combinations given in Section 9.2 of ACI 349-01.

1.4 The design standards given in Sections B.5, "Design Requirements for Tensile Loading," and B.6, "Design Requirements for Shear Forces," are acceptable to the staff.

1.5 The design standards given in Sections B.7, "Interaction of Tensile and Shear Forces," and B. 8, "Required Edge Distances, Spacing, and Thickness To Preclude Splitting Failure," are acceptable to the NRC staff.

1.6 Section B.9, "Installation of Anchors," is acceptable to the NRC staff. Checks to be considered in the installation of expansion anchor bolts are:

- Hole diameter is correct
- Embedment depth is proper
- Drill hole angularity is within established limits
- Edge distance and spacing of anchors are to specified values
- Anchor is threaded properly
- Plate thickness meets specified size and thickness values
- Plate bolt-hole size is within established limits
- Anchor has been correctly preloaded
- Correct bolt diameter and length are used
- Bolt hole has been cleared of drill dust
- Concrete is sound (free of voids)
- Grout has been mixed and installed to specifications.

1.7 The design standards given in Sections B.10, "Structural Plates, Shapes, and Specialty Inserts," and B.11, "Shear Capacity of Embedded Plates and Shear Lugs," are acceptable to the NRC staff. When grouting is the only option, it is recommended that tests be performed in accordance with Sections B.12.3 and B.12.4 of Appendix B.

2. All anchors should be inspected to verify that they are of the specified size and type. Installation standards should be consistent with accepted industry-specified tolerances. Anchor systems that are external (that part or portion of the anchor that is not embedded in concrete-visible part) to the concrete surface should be inspected to assure adequate performance during the life of the structure. In addition to the provisions in Section B.9.2 of Appendix B, the NRC staff recommends the following post-installed 6-step inspection program to verify the proper installation of post-installed anchors.

2.1. Are the nut and anchor bolt tight? This step will detect certain types of installation defects: oversized holes, total lack of preload, loose nuts, damaged subsurface concrete, and missing plug (for shell type). To implement this step, it is necessary to place a wrench on the bolt head or nut and to apply a torque. A well-installed bolt should not rotate under the torque applied equal to about 20% of the normal installation torque.

2.2. Are there washers between the equipment base and the anchor bolt nut or bolt head? All bolts should have washers. Oversize washers are recommended for thin equipment bases. Lock washers are recommended where even low-level vibration exists.

2.3. Is the bolt spacing in accordance with the anchorage design?

2.4. Is the distance between the bolt and any free concrete surface in accordance with the anchorage design (edge condition)?

2.5. Is the concrete sound and uncracked? This inspection element will detect gross defects in the concrete that could affect the holding power of expansion anchor bolts. Hairline shrinkage cracks in the vicinity of an expansion bolt are not a matter of concern so

long as the design strength is based upon cracked concrete. If cracks in the vicinity exceed about 0.01 inch (0.3mm), the design strength should be appropriately reduced.

2.6. Is there a significant gap between the equipment base and the concrete surface? This inspection element will identify situations in which the equipment base is raised. This detail causes concern because shear forces result in flexural stresses in the anchor bolt. A gap of less than about 1/4 inch is not significant and should be ignored except as follows. For equipment that contains essential relays (a relay whose function is essential to plant safety in an earthquake), there should be no gap between the base of the equipment and the surface of the concrete at the bolt or anchor location. Anchorages with gaps larger than about 1/4 inch should be evaluated in more detail.

For maximum assurance of adequacy, all six of these steps should be performed for all bolts. However, adequate assurance can be achieved by a less extensive inspection program. Inspection steps 2 through 6, which are simple and mainly visual, should be applied to each bolt. However, a sampling approach might be used for the tightness check in step 1. A sampling program for expansion anchor bolts used in pipe support base plates was recommended in Appendix A of NRC IE Bulletin 79-02. The essential features of this program may be adopted for equipment anchorage as shown in Appendix A of this draft guide.

3. All quality assurance standards of ASME NQA-2,1983, "Quality Assurance Program Requirements for Nuclear Facilities," are applicable to load-bearing steel embedments and other load-bearing components of component and structural supports.

4. The concrete constituents and embedded materials should be compatible with the anticipated environmental conditions to which they will be subjected during the life of the plant.

5. Loads and forces on embedments should be properly evaluated to account for baseplate flexibility and eccentricity of connections and the dynamic (strain rate and low-cycle fatigue) effects of loads and forces.

6. The hardness, materials, and heat treatment of high-strength anchor bolts and studs ($F_y > 110$ ksi) should be carefully controlled to prevent environmental and stress-corrosion cracking.

7. Because anchors are not generally specified for masonry, the NRC staff does not recommend the use of any type of anchor discussed in this guide to attach Seismic Category I components or systems to concrete block walls that are seismically qualified, except for extremely low load applications. In locations where it is impossible to avoid the use of anchors, users should verify through appropriate means (e.g., pull test) that the supports are structurally acceptable.

D. IMPLEMENTATION

The purpose of this section is to provide information to licensees and applicants regarding the NRC staff's plans for using this regulatory guide.

Except when the applicant or licensee proposes an acceptable alternative method for complying with specified portions of the NRC's regulations, the methods described in this guide are acceptable to the NRC staff in the evaluation of anchors (steel embedments) used for component and structural supports on concrete structures. Current licensees may, at their option, comply with the guidance in this regulatory guide.

REFERENCES

ACI 349-01 and 349R-01, "Code Requirements for Nuclear Safety Related Concrete Structures," with Appendix B, "Steel Embedments," (ACI 349-01) and Commentary (ACI 349R-01) American Concrete Institute, Farmington Hills, Michigan, 2001. **Appendix B,** "Anchoring to Concrete," to ACI 349-01, "Code Requirements for Nuclear Safety Related Concrete Structures."

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IEB 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Inspection and Enforcement Bulletin, USNRC, Revision 2, November 1979. (NUDOCS Accession Number 7908220136)[1]

[1] Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>. Electronic copies may be available through NRC's Electronic Reading Room under ADAMS.

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 3.8.4, "Other Seismic Category I Structures," Revision 1, USNRC, 1981.[1]

NUREG/CR-2999, M.R. Lindquist, "Final Report on USNRC Anchor Bolt Study Data Survey and Dynamic Testing," USNRC (HEDL-MISC-7246), December 1982.[2]

NUREG/CR-5434, R. Klingner et al., "Anchor Bolt Behavior and Strength During Earthquakes," USNRC, August 1998.

NUREG/CR-5563, R. Klingner et al., "A Technical Basis for Revision to Anchorage Criteria," USNRC, March 1999.

SP-130, "Anchors in Concrete: Design and Behavior," G.A. Senkiw and H.B. Lancelot, Editors, SP- 130, American Concrete Institute, Farmington Hills, MI, 1991.

USI A-46, "Seismic Qualification of Equipment in Operating Plants," (Unresolved Safety Issue USI A-46) in NUREG-1030, "Seismic Qualification of Equipment in Operating Nuclear Power Plants," February 1987.[2]

[2] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV. Electronic copies may be available on NRC's web site in the Electronic Reading Room.

APPENDIX A
Sampling Program for Anchor Bolts

This sampling program for expansion anchor bolts used in pipe support base plates was recommended in Appendix A of NRC IE Bulletin 79-02. The essential features of this program may be adopted for equipment anchorage.

Perform inspection step 1 in Regulatory Position 2 on at least 25% of the bolts in every equipment anchorage. If the selected bolts do not pass the inspection, perform step 1 on all bolts in the anchorage.
OR

Perform inspection step 1 on a randomly selected statistical sample of bolts. The size of the sample and the number of nonconformances should be such that there is a 95% confidence of no more than 5% nonconforming bolts. This can be determined as follows:

$$R' = R + Z\left(\frac{R(1-R)}{n}\right)^{1/2} \frac{N - n}{N - 1}^{1/2}$$

where:

R' = Upper limit of the true defect rate at a specified confidence level (R' = 0.05 in this application)
R = Defect rate observed in sample
Z = Confidence coefficient for a normally distributed statistical model of test data. For a 95% confidence level, Z= 1.65.
n = Test sample size
N = Total population from which test sample was selected

Table 1 gives the allowable number of nonconforming bolts as a function of the population size N and the test sample size n.[1]

When the failure rate for this check exceeds the limitations corresponding to 95% confidence of no more than 5% nonconforming bolts, the installation procedure should be considered to be unacceptable.

[1]Adapted from: EPRI-NP-5228, May 1987.

Table 1
ALLOWABLE NUMBER OF NONCONFORMING ANCHORS

Allowable Number of Nonconforming Anchors for Test Sample Size, n												
Total Population Size, N	40	60	80	100	150	200	250	300	350	400	450	500
100	1	2	3	5	---	---	---	---	---	---	---	---
200	1	1	2	3	6	10	---	---	---	---	---	---
300	1	1	2	3	5	7	10	15	---	---	---	---
400	1	1	2	3	5	7	9	12	15	20	---	---
500	1	1	2	3	5	7	9	12	14	17	20	25
600	1	1	2	3	5	7	9	11	14	16	19	22
700	1	1	2	3	4	7	9	11	13	16	18	21
800	1	1	2	3	4	6	9	11	13	16	18	21
900	1	1	2	3	4	6	8	11	13	15	18	20
1,000	1	1	2	3	4	6	8	11	13	15	17	20

REGULATORY ANALYSIS

A draft regulatory analysis was published with the draft of this guide when it was originally published for public comment (Draft Regulatory Guide DG-1099, July 2002, ADAMS accession number ML021910490). No changes were necessary to the regulatory analysis, so a separate regulatory analysis has not been prepared for Regulatory Guide 1.199. A copy of the draft regulatory analysis is available for inspection or copying for a fee in the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.