Fermi 2
6400 North Dixie Hwy., Newport, MI 48166

Detroit Edison

10 CFR 50.55a

January 11, 2012
NRC-12-0003

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington D C 20555-0001

References: 1) Fermi 2
NRC Docket No. 50-341
NRC License No. NPF-43

2) Detroit Edison's Letter to NRC, "Request for Relief – Use of the Boiling Water Reactor Vessel and Internals Project (BWRVIP) Guidelines in Lieu of Specific ASME Code Requirements," NRC-11-0039, dated July 28, 2011 [ADAMS Accession No. ML112101480, TAC No. ME6765]

Subject: Additional Information Regarding Relief Request for Use of the BWRVIP Guidelines in Lieu of ASME Code Requirements

In Reference 2, Detroit Edison submitted a proposed relief request (RR-A39) to use the Boiling Water Reactor Vessel Internals Project (BWRVIP) guidelines in lieu of ASME Code requirements for in-service inspection of the reactor vessel internal components at Fermi 2.

During a teleconference discussion between Detroit Edison personnel and NRC staff on January 9, 2012, NRC requested a copy of the Fermi Deviation Disposition Report describing the variance from BWRVIP-25 guidance on performing the BWRVIP recommended inspections on core plate bolting. The Deviation Disposition report is provided in the enclosure to this letter for NRC information to support approval of RR-A39.

There are no new commitments included in this document.

Should you have any questions, please contact me at (734) 586-5076.

Sincerely,

Rodney W. Johnson
Manager - Nuclear Licensing

Enclosure

cc: NRC Project Manager
NRC Resident Office
Reactor Projects Chief, Branch 4, Region III
Regional Administrator, Region III
Supervisor, Electric Operators,
Michigan Public Service Commission

Fermi 2 NRC Docket No. 50-341
Operating License No. NPF-43

Enclosure to
NRC-12-0003

"Additional Information Regarding Relief Request for Use of the BWRVIP Guidelines in Lieu of ASME Code Requirements"

Deviation Disposition Report for Variance from BWRVIP-25 Guidance on Performing Recommended Inspections on Core Plate Bolting

Fermi 2

Deviation Disposition

For

Variance from BWRVIP-25 Guidance on Performing Recommended Inspections on Core Plate Bolting

Prepared by:	Richard Hambleton	Date:	3-4-11
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Reviewed by:	Marc Brooks	Date:	3-8-11
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Reviewed by:	(Additional reviewers) N/A	Date:	N/A
Approved by:	Judy Ford	Date:	3/16/11
Approved By:	Mathew Caragher	Date:	3/28/11
Approved By:	Joe Plona	Date:	3/30/11

Deviation Description

The BWR Core Plate Inspection and Flaw Evaluation Guidelines (BWRVIP-25) requires that core plate bolts be inspected by Ultrasonic (UT) or Visual (VT) methods for plants that do not have core plate wedges installed. Currently, UT has significant limitations due to bolt geometry and VT is not able to interrogate the susceptible threaded areas of the bolting. The BWRVIP is addressing this issue and intends to develop revised guidance. Until such guidance is developed, no additional actions are planned or are warranted. A plant specific analysis described below demonstrates that the core plate bolts are very flaw tolerant and are not expected to lose their ability to perform their safety function. This deviation disposition is required because the inspections required by BWRVIP-25 are not being performed. It will remain in place until December 31, 2015 or until the NRC approves revised BWRVIP guidance, whichever occurs first.

Applicable BWRVIP Guidelines

BWR Vessel and Internals Project, BWR Core Plate Inspection and Flaw Evaluation Guidelines (BWRVIP-25), EPRI Report TR-107284, December 1996

Effective Dates of Applicability

This deviation was previously evaluated and detailed in DD-2006-01 (Reference 3) which was archived. This Deviation Disposition shall remain in effect until December 31, 2015, or until the NRC approves revised BWRVIP Core Plate Inspection Guidelines, whichever occurs first.

Detailed Discussion

Background

Fermi 2 has 34 core plate bolts around the perimeter of the core plate as shown in Figure 1 and our reactor design has no core plate wedges. The function of the core plate rim hold-down bolts are to resist lateral loads imposed upon the fuel during seismic and other dynamic events. The studs are fabricated from stainless steel material ASTM A-193 Gr. B8, with ASTM A-194 Gr. 8 nuts which are designed for high temperature service.

The bolt is threaded at its upper and lower ends and is unthreaded over the remainder of its length. 34 bolts are used to secure the core plate to the core plate support ring. BWRVIP-25, Reference 1, requires that the bolts be inspected using either visual methods (EVT-1) from below the core plate or with an ultrasonic (UT) technique. In spite of significant effort on the part of the BWRVIP Inspection Focus Group and the EPRI NDE Center, the development of UT techniques for this application has been unsuccessful. The only feasible location for delivering acoustic energy to the bolt is through its upper end and access to the upper end is restricted by the presence of a keeper that is fillet welded to the top of the bolt. The resulting geometry does not allow for effective wave transmission and, consequently, a UT inspection has not been possible (as is recognized in Reference 2).

Visual inspections are also problematic. As shown in Figure 1, an EVT-1 inspection may be able to examine the unthreaded shank of the bolt. However, the threaded portion which is theoretically more susceptible to IGSCC is surrounded by the core plate and the core plate support ring and is hidden from view. Thus, meaningful EVT-1 exams cannot be performed and, in hindsight, should not have been recommended in BWRVIP-25.

The BWRVIP is currently performing analyses that will result in revised guidance for managing potential degradation of core plate bolting. This revised guidance will be implemented when issued. Until that time, the analysis described and the factors discussed in the following paragraphs provide ample assurance that the core plate bolting will continue to perform its intended function.

Analytical Justification for No Inspections
An analysis was conducted by the BWRVIP (see Attachment 1) that demonstrates the very high flaw tolerance of the core plate bolting. Cracks were assumed to initiate 360 - degrees around the circumference of all bolts with an initial crack depth equal to the thread depth. These cracks were propagated using plant specific stresses (due to pre-load in the bolt) and plant specific water chemistry history. As shown in Table 5 of Attachment 1, the resultant loss of preload was insignificant over the life of the plant. Since the preload on the bolts is maintained, the bolting retains its ability to perform its design function (i.e., resistance to lateral and vertical movement of the core plate). Given the very conservative assumptions of the analysis and the favorable result, there is very little risk in postponing core plate bolt inspections until such time as the BWRVIP publishes revised guidance.

Additional Justification
In addition to the analysis results described above, there are additional considerations that make significant degradation of the bolting unlikely in the near term. These additional considerations and the bases for not performing inspections are as follows:

- **Field Experience**
  Extensive VT-3 exams of the upper portion of the bolting have been performed at Fermi 2 and other plants in accordance with GE SIL-588. In addition, some plants have performed VT-3 exams as an alternative to the BWRVIP-25 requirements. Based on a review of BWRVIP inspection summary reports, twenty-one plants have reported the results of these inspections to the BWRVIP, and none have reported any failures or degradation. It is likely that additional inspections, not reported to the BWRVIP, have also been conducted per the GE SIL and no degradation has ever been reported to the industry. One plant was able to perform an EVT-1 of all bolts from below the core plate during an extended outage. No degradation was observed. While these exams are not sufficient to completely rule out the possibility of minor cracking in areas that cannot be observed visually, they do indicate that no degradation of consequence has occurred.

- **Hardware Redundancy**
  Depending on plant design, the core plate is typically attached to the shroud with between 30 and 72 bolts. The Fermi 2 design has 34 bolts. A generic analysis described in Reference 1 which assumed 32 bolts showed that only approximately 80% of the bolts are necessary to resist loads during faulted conditions. This indicates that a significant amount of cracking in the bolts can be tolerated before the ability of the core plate to maintain control rod alignment is compromised.

  Additionally, the Fermi design has welded alignment pins that provide redundant structural capability to the core plate bolts as shown in Figure 2. The generic analysis in Reference 1 concluded that even with 100% of the bolting failed, the stress on the aligners is less than ASME Code allowables. Thus, the aligners by themselves are capable of maintaining the horizontal position of the core plate during a seismic event. The vertical motion of the core plate (in the event of complete failure of the bolts) is limited to an acceptable value by contact with the CRD guide tube alignment tabs.

The aligner hardware is inaccessible for inspection which could be used to ensure its complete integrity and, thus credit its ability to provide redundant restraint. However, the probability that a sufficient number of bolts are failed AND significant degradation of the aligners exists is very small.

- **IGSCC Susceptibility**
The studs and nuts supplied for installation were finished/polished utilizing techniques that minimize the susceptibility of the material to IGSCC. The threads at the top of the bolt and the threads on the top nut are subjected to liquid honing and/or electro-polishing techniques to ensure smooth contact between the nut and bolt. These finishing techniques reduce surface stresses and greatly reduce the susceptibility of the components to crack initiation. The bottom of the bolt and its accompanying nut may not have received such treatment. However, even absent this stress relief, the thread-form itself reduces the crack susceptibility of the bolt. The threads are typically fabricated with a short flat region at the root of the thread. This flat region is usually rounded to blend with the thread angle. The resulting smooth transitions reduce the local stresses and thus the susceptibility of the component to cracking.

- **Mitigation**
Water chemistry during the early plant operational cycles has a significant impact on crack propagation. Historical Fermi plant specific chemistry parameters were provided and utilized in the analysis that was performed (Reference 4). Radiolysis models show that plants with hydrogen water chemistry (HWC) or noble metal chemical application (NMCA) are provided some level of protection in the region of the core plate bolting. Thus, the susceptibility of the bolting to new initiation is much reduced. In addition, the growth rate of any cracking that pre-dated mitigation will be greatly retarded. Fermi has been utilizing Moderate Hydrogen Water Chemistry (M-HWC) since 1996 and has consistently achieved >80% availability since 2002. During the last two cycles the availability has exceeded 95%. Recent Fermi chemistry performance has been consistent with the assumptions in the BWRVIP analysis performed in 2006 (Reference 4).

- **Standby Liquid Control**
The discussion above demonstrates that there is a very low probability that a sufficient degradation of the bolting could occur such that the resultant displacement of the core plate during a seismic event would inhibit or slow control rod insertion. However, in the unlikely case that such degradation did occur and control rods could not be inserted, the reactor could be brought to a safe shutdown using the Standby Liquid Control (SLC) system.

Impact on meeting the intent of the BWRVIP Guidelines

Fermi 2 is not in compliance with BWRVIP-25 for the inspections of Core Plate Bolting. As stated in BWRVIP-94, Revision 1, it is the BWRVIP expectation that all plants will revise or modify their Vessel and Internals Programs, and implement the inspection guidance contained in the BWRVIP I&E Guidelines. Fermi had previously prepared a Deviation Disposition in 2006 (DD-2006-01) that justified that no inspections were required at this location based on a structural analysis performed by the BWRVIP (Reference 3). In 2007 the BWRVIP determined that this Deviation Disposition was not required, as the NRC had been informed by the BWRVIP that this location was not inspectable.

During recent discussions between the BWRVIP and the NRC it was concluded that all plants like Fermi that do not have Core Plate Wedges installed must prepare a Deviation Disposition for this location, and forward it to the BWRVIP by March 31, 2011. This was mandated by the BWRVIP in BWRVIP Letter 2010-243 dated 10/29/2010.

This will be followed by NRC notification as part of the process. NRC notification is required for this Deviation Disposition within 45 days of Executive approval.

Conclusions

Inspection techniques are not currently available to perform the core plate bolt inspections required by BWRVIP-25. However, as described above, there is reason to believe that the bolting has a relatively low susceptibility to cracking and a very high flaw tolerance. Postulated flaws do not grow to a size that significantly reduces the bolt preload over the life of the plant. Even if significant cracking did occur in the bolting, redundant aligner hardware and structural components will prevent adverse displacement of the core plate.

And finally, even with the extremely conservative assumptions of failures of both the bolting and the redundant hardware, the SLC system could be used to bring the reactor to a safe shutdown. Given the low likelihood that the function of the core plate will be compromised by bolting failures, there is little risk in postponing a detailed inspection of the bolts until such time as the BWRVIP develops revised guidance.

References

1. "BWR Vessel and Internals Project, BWR Core Plate Inspection and Flaw Evaluation Guidelines (BWRVIP-25)," EPRI Report TR-107284, December 1996.
2. "BWRVIP-94, Revision 1: BWR Vessel and Internals Project, Program Implementation Guide," EPRI Technical Report 1011702, December 2005
3. Deviation Disposition DD-2006-01 – Deviation Disposition for Variance from BWRFIP-25 Guidance on Performing Recommended Inspections on Core Plate Bolting (Archived)
4. BWRVIP Letter 2006-041, Results of Core Plate Bolt Preload Loss Calculations: Fermi

Reporting Requirements

Based on the requirements in BWRVIP-94, Revision 1, NRC notification is required of this Deviations Disposition within 45 days of Utility Executive approval of this Deviation Disposition. This Deviation Disposition will be included in the RVIM Program Plan.

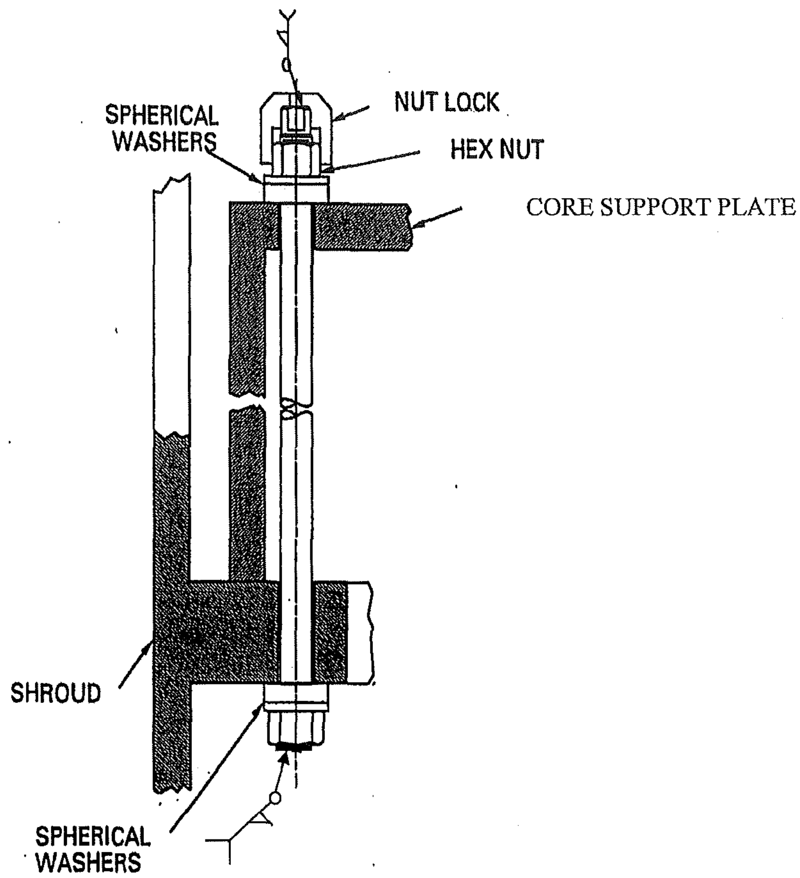


Figure 1 Core Plate Bolting Configuration

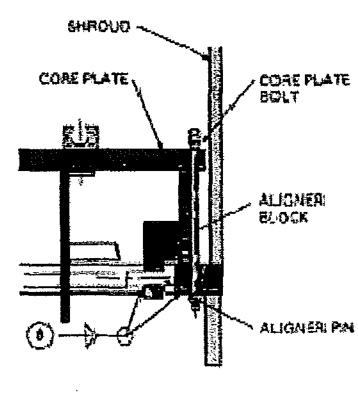


Figure 2 Typical Aligner Pin Configuration

ATTACHMENT 1

BWRVIP EVALUATION OF BWR CORE PLATE RIM HOLD-DOWN BOLTS
January 31, 2006

The BWR Core Plate Inspection and Flaw Evaluation Guidelines (BWRVIP-25) recommend a UT or EVT-1 examination of the core plate rim hold-down bolts for all plants that have not installed core plate wedges. These bolts are the only location in the core plate requiring inspection. Utilities have determined the EVT-1 examinations are, at best, extremely difficult to perform, and are of limited value. The Inspection Committee of the BWRVIP has attempted to develop a UT technique, and has had some level of success. However, the UT examination can only be performed on a limited number of existing bolt configurations, and delivery hardware for the inspection equipment has not been developed.

The BWRVIP embarked upon a program to justify the elimination of core plate rim hold-down bolt inspections. The basis for this program is that even if bolt cracking had occurred early in plant life, sufficient preload will be maintained at the end of plant life (60 years) to assure functionality of the core plate to limit lateral displacement of the fuel under seismic and other dynamic events. Structural Integrity Associates (SI) was contracted to evaluate plants that do not have core plate wedges installed.

Briefly described herein is the program undertaken to evaluate the core plate rim hold-down bolts for all plants, and the results of the evaluation. Sample calculations are presented for two plants (Plant 1 and Plant 2), with detailed calculations for all plants including Fermi 2 provided under separate cover. While this methodology was not successful for several plants evaluated in this study, it was successful for Fermi 2 and Table 5 provides a summary of results that demonstrates insignificant loss of preload after 60 years of operation.

1.0 Methodology

A required function of the core plate bolting is to resist lateral loads imposed upon the fuel during seismic and other dynamic events. This resistance is provided by friction between the bottom of the core plate and the shroud core plate support ring as a result of preload in the bolting. If it can be demonstrated that postulated cracks in the bolts, propagated for the life of the plant, will not result in a significant reduction in preload, then the function of the bolting will not be degraded. In this case, it can be argued that no inspections of the bolting would be required.

The following analytical approach was used to calculate the reduction in preload for individual plants:

1. Determine the initial bolt preload.
2. Assume an initial crack configuration.
3. Propagate the crack through the bolts using BWRVIP-14 crack growth rates considering plant specific water chemistry history.
4. Determine the loss of preload due to the calculated crack depth at various times over the life of the plant.

Ideally, the calculated remaining preload would be compared to the required (design) preload to determine if sufficient preload remains to perform the safety function of the bolting. However, design information for the bolting was not readily available. Consequently, the calculated reduction in preload was compared to the initial preload. If the reduction was a small fraction of the initial preload, it was judged that the bolting function would not be impaired.

Details of the calculations are described below.

Initial Preload

The initial preload information for each plant was not typically available. However, the torque applied during installation was obtained from each utility. This torque was converted to a bolt preload using commonly accepted relationships [1] between torque, bolt diameter, and an assumed factor considering a Never-Seeze lubricant, at an assumed temperature of 70°F.

Initial Crack Distribution

Several different crack distributions and initiation times were evaluated during the course of the project. The standard initial crack distribution adopted for all plants consists of 360° cracking around the circumference of the hold-down bolt, emanating from the thread root, with the crack depth equal to the thread depth. Calculations were performed for each plant with this crack distribution and an assumed initiation time of 5 years after plant startup.

Crack Propagation

The propagation of the initial crack was calculated for the life of the plant. The crack growth rate was calculated using the following equation from BWRVIP-14 [2]:

$$\frac{da}{dt} = \left((K)^{2.181} e^{-0.787\,\mathrm{Cond}^{-0.586} + 0.00362\,\mathrm{ECP} + \frac{6730}{T_{ABS}} - 35.567} \right) \left(\frac{3600}{25.4} \right) 10.3$$

where:

	da/dt	=	crack growth rate (in/hr)
	K	=	stress intensity factor ($\mathrm{MPa}\sqrt{\mathrm{m}}$)
	Cond	=	conductivity (μS/cm)
	ECP	=	electrochemical corrosion potential (mV(SHE))
	T_{ABS}	=	temperature (°K)

This corresponds to the 95th percentile crack growth rate.

Note that the equation requires values for conductivity, ECP, temperature and stress intensity factor. A uniform temperature of 550°F was assumed for all calculations. Historical, plant-specific values for conductivity and ECP were provided by each plant, and these time-dependent values were used in the calculations.

The stress intensity factor is a function of the depth of the assumed crack and the remaining preload in the bolt. An initial crack growth rate was used to calculate the new depth of the crack over a prescribed time increment. Using the new crack depth, the amount of preload lost due to the crack can be determined (as described below), and a new stress intensity factor can be calculated for use at the next time step. This process is repeated for the life of the plant (or until the remaining preload is "lost") with time-dependent values of conductivity, ECP and stress intensity factor used at each time step. For future times, it was assumed that the water chemistry variables were within the EPRI Water Chemistry Guidelines.

Reduction in Preload Due to Cracking

Preload losses typically occur in reactor internal components due to radiation and temperature effects. However, one of the premises in the program described herein is that the hold-down bolts will crack early in life. Consequently, preload will also be reduced due to cracking. The effects of temperature and cracking are considered in the analyses, while the effects of fluence were not.

Using a bolt configuration appropriate for each plant and an assumed crack distribution, a finite element model of the bolt was developed and a number of elastic-plastic analyses were performed to determine the amount of preload reduction as a function of crack depth. The first analysis for each plant imposed the specified initial preload, with material properties at 70°F. The resulting displacement calculated from the analysis was then used in numerous cracked models for each plant, in order to determine loss of preload as a function of crack depth. In these analyses, material properties at 550°F were used and, consequently, the analyses include loss of preload due to both the flaw and the reduction in material yield strength with temperature. Only the loss of preload due to cracking is presented in the plots herein.

A curve-fit of this data was used to calculate the loss of preload for a particular crack depth and to determine the stress intensity factor for use in the crack growth equation above. The new crack depth and loss of preload were calculated at a number of time steps for the life of the plant. The result is a graph showing preload loss (or remaining preload) as a function of time.

For the linear elastic fracture mechanics (LEFM) analyses that were performed, one of the assumptions in the analyses was that the threads are part of the crack. In order to verify if this assumption is valid, LEFM analyses were performed using the ANSYS finite element code. Two axisymmetric analyses were performed. The first analysis modeled the threads, and the second did not model the threads. The model with the threads is shown in Figure 1, while the model without the threads is shown in Figure 2, both models having the same outside diameter and crack depth.

The results from the two analyses, for a constant applied load, were within 2% of each other, and within 3% of a handbook solution. Therefore, assuming that the threads were part of the crack was validated.

2.0 Example Calculations

Sample calculations are presented in this section for two plants (Plants 1 and 2).

Plants 1 and 2 – Standard Initial Crack Configuration

Tables 1 and 2 present the bolt configuration data for Plant 1 and Plant 2, respectively. The hold-down bolts are the same for both plants, with the thread geometry shown in Figure 3. Initial preload was determined to be 20.7 kips for Plant 1, and 11.0 kips for Plant 2 using the methodology described in Section 1.0. Water chemistry data for the two plants is shown in Tables 3 and 4.

The analyses assumed a 360° crack initiated at 5 years. Figure 4 shows a picture of the axisymmetric finite element model, including the threads. Using the methodology described in Section 1.0, the remaining preload as a function of crack depth was calculated for both plants (Figures 5 and 6). The Plant 2 bolts do not lose a significant amount of preload until the crack reaches a depth of 60% of the radius, while Plant 1 starts to lose preload at smaller crack depths. Utilizing these plots and an iterative calculation of crack depth, plots of loss of preload vs. time were calculated (Figures 7 and 8). As shown, the preload for Plant 1 decreases much faster than that for Plant 2. This is driven by a combination of higher preload and poor water chemistry early in life for Plant 1 versus Plant 2.

3.0 BWRVIP Fleet / Fermi Analysis

Fermi 2 and each plant without wedges was evaluated in a fashion similar to the methods described above utilizing the standard 360° crack initiated after 5 years of operation with the calculation proceeding for 60 years or until "failure." Table 5 presents only the analysis results for Fermi 2 which did not exhibit a significant loss of preload after 60 years of operation.

4.0 Conclusions

The results presented are based upon conservative assumptions, including an assumed initial crack configuration of 360° around the bolt circumference and include consideration of actual plant water chemistry conditions since start of operation. The results demonstrate that the loss of preload is negligible and that the core plate bolts are very flaw tolerant and are not expected to lose their ability to perform their safety function.

5.0 References

1. Electric Power Research Institute, "Good Bolting Practices," EPRI Report No. NP-5067, 1987.

2. BWR Vessel and Internals Project, "Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14)," EPRI Report No. TR-105873, March 1996.

3. Forman, R.G. and Shivakumar, V., "Growth Behavior of Surface Cracks in the Circumferential Plane of Solid and Hollow Cylinders," Fracture Mechanics: Seventeenth Volume, ASTM STP 905, 1986, pp. 59-74.

Table 1
Input Data for Plant 1

Parameter	Value
Initial Bolt Torque	330 ft-lbs
Temperature	550°F
Hold-Down Bolt Diameter(1,2)	1.125 in

Notes: 1. The bolt material is A193, Grade B8.
2. The hold-down bolts are 1 1/8-12UNF-2A.

Table 2
Input Data for Plant 2

Parameter	Value
Initial Bolt Torque	175 ft-lbs
Temperature	550°F
Hold-Down Bolt Diameter(1,2)	1.125 in

Notes: 1. The bolt material is Type 304.
2. The hold-down bolts are 1 1/8-12UNF-2A.

Table 3
Plant 1 Water Chemistry Data

Period [1]	Water Conductivity μS/cm	ECP mV (SHE)
3/77-8/84	0.578	+200
9/84-5/90	0.300	+200
6/90-12/94	0.130	-230[2]
1995	0.253	-230
1996	0.142	-230
1997	0.090	-230
1998	0.131	-230
1999	0.091	-230
2000	0.132	-230
1/2001-7/2002	0.086	-230
8/2002-12/2002	0.179	-230
1/2003-3/2037	0.100[3]	-230[3]

Notes:
1. Year begins on January 1 and ends on December 31 where month is not specified.
2. ECP of -230 mV (SHE) assumed to start on 06/90.
3. Conductivity of 0.1μS/cm and ECP of -230 mV (SHE) are assumed for these years.

Table 4
Plant 2 Water Chemistry Data

Period	Water Conductivity μS/cm	ECP mV (SHE)
2/75-7/82	0.332	+50
8/82-6/87	0.200	+50
7/87-9/96	0.175	-200
10/96-12/2002	0.100	-230[1]
1/2003-2/2035	0.100[2]	-230[2]

Notes:
1. ECP of -230 mV (SHE) is conservatively assumed instead of -525 mV (SHE) for these years.
2. Conductivity of 0.1μS/cm and ECP -230 mV (SHE) are assumed for these years.

Table 5
Summary of Results for Fermi 2

Hold-down Bolts (34)	Initial Preload[1] (pounds)	Preload Loss After 60 Years[2] (pounds)
2.5-16UN-2A	67,765	84

Notes: 1. At time of installation at ambient temperature.
2. Based upon crack initiation after five years of operation.

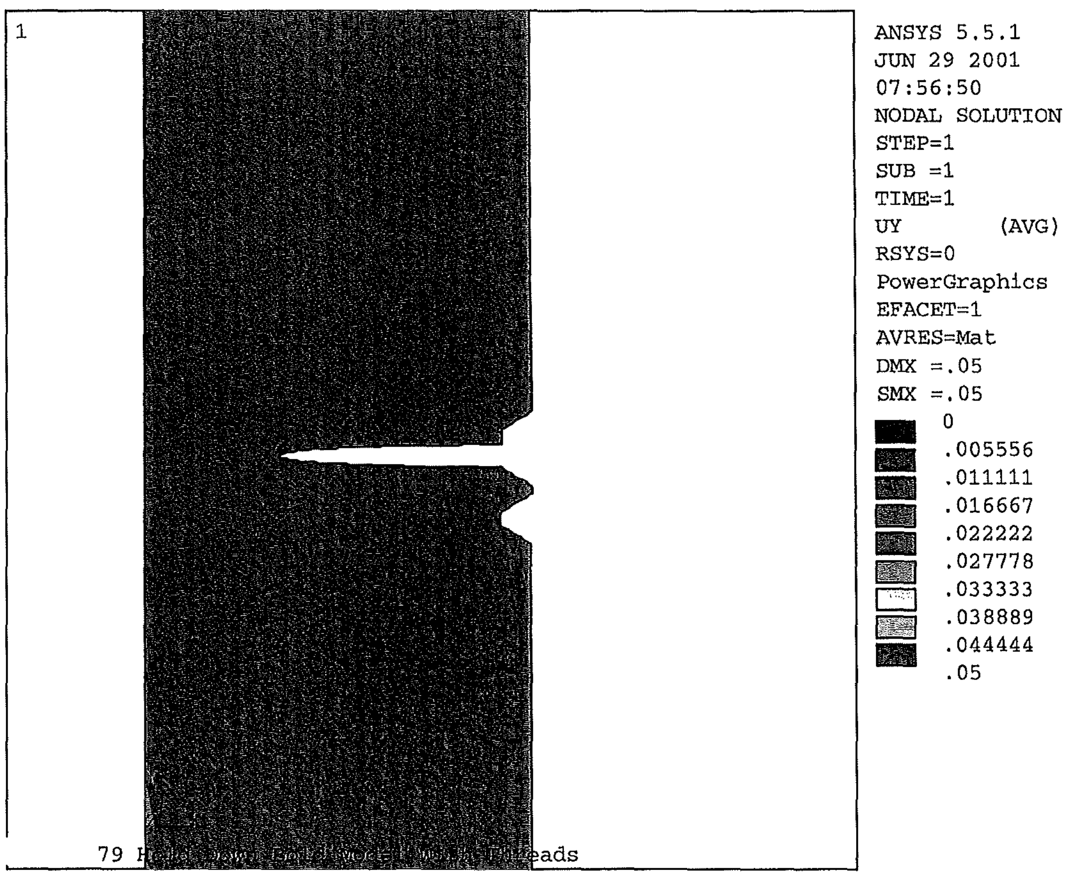


Figure 1.
Magnified View of Threaded Hold-down Bolt With Crack – LEFM Analysis

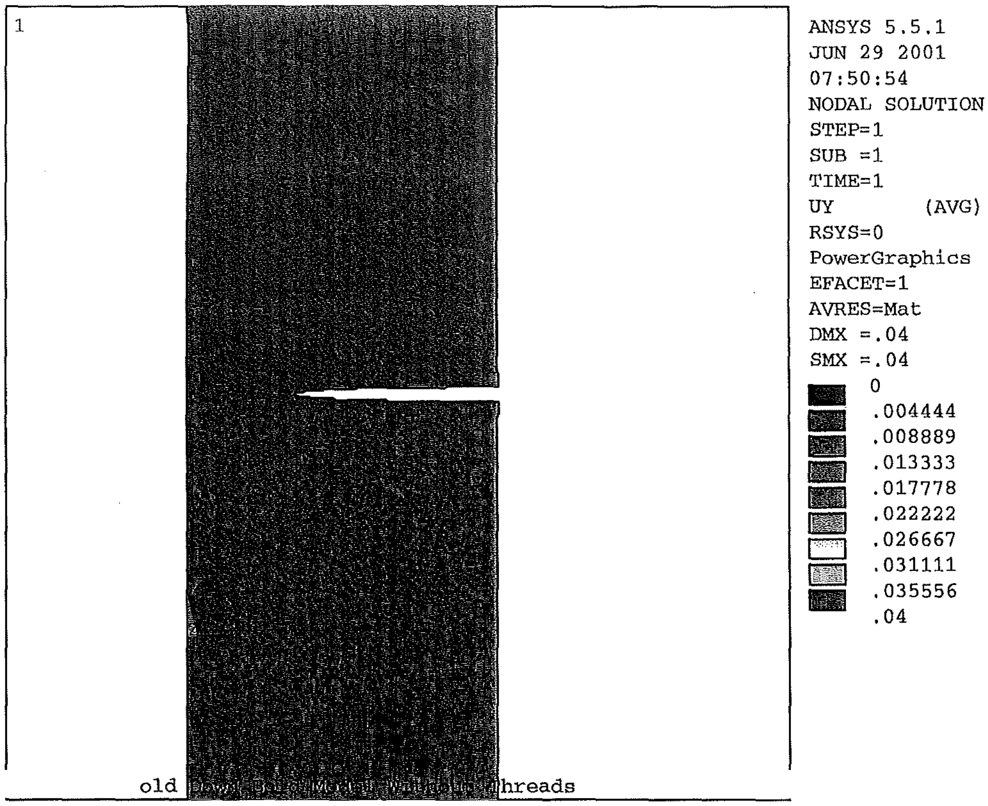
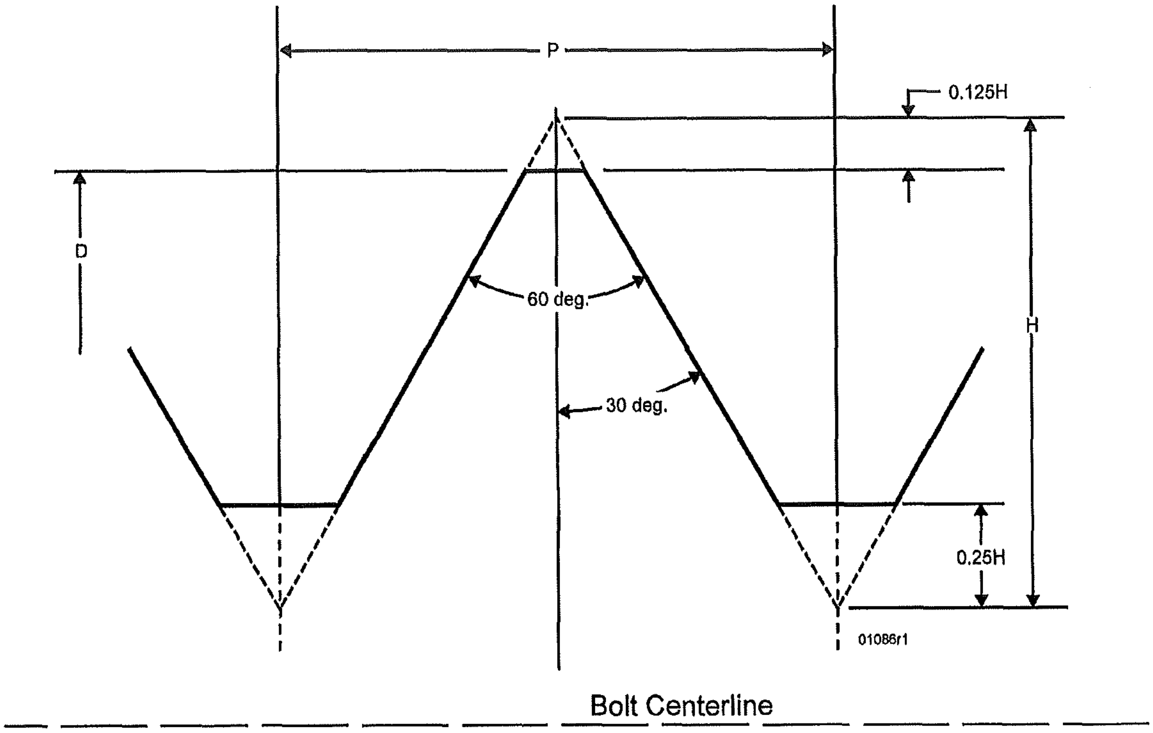


Figure 2.
Magnified View of Threadless Hold-down Bolt With Crack – LEFM Analysis



Nomenclature: D = 1.125"
P = 0.083333"
H = 0.072169"

Figure 3.
Geometry of 1 1/8 - 12UNF-2A Hold-down Bolt Threads

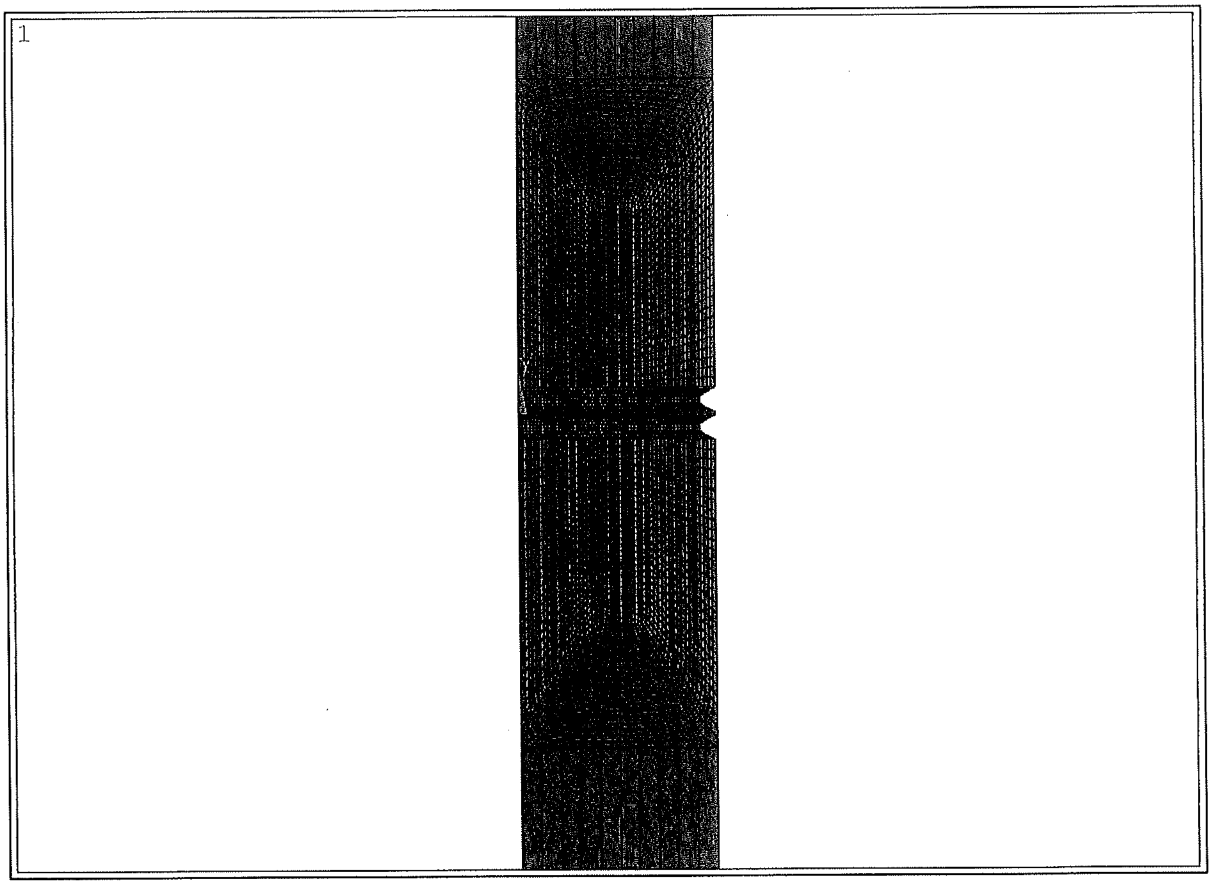


Figure 4.

Axisymmetric Hold-down Bolt Model

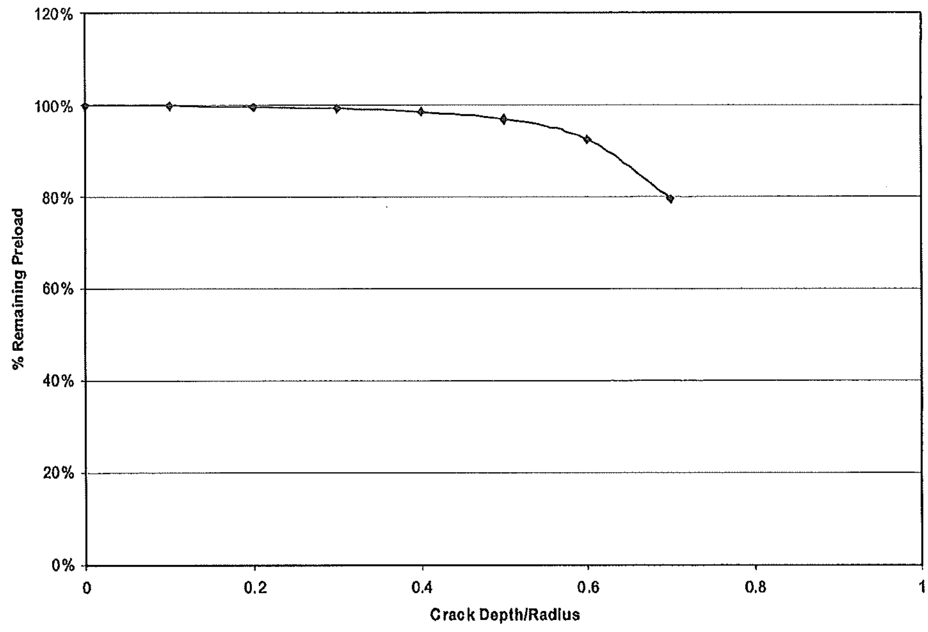


Figure 5.
Plant 1 Remaining Preload vs. Crack Depth Ratio

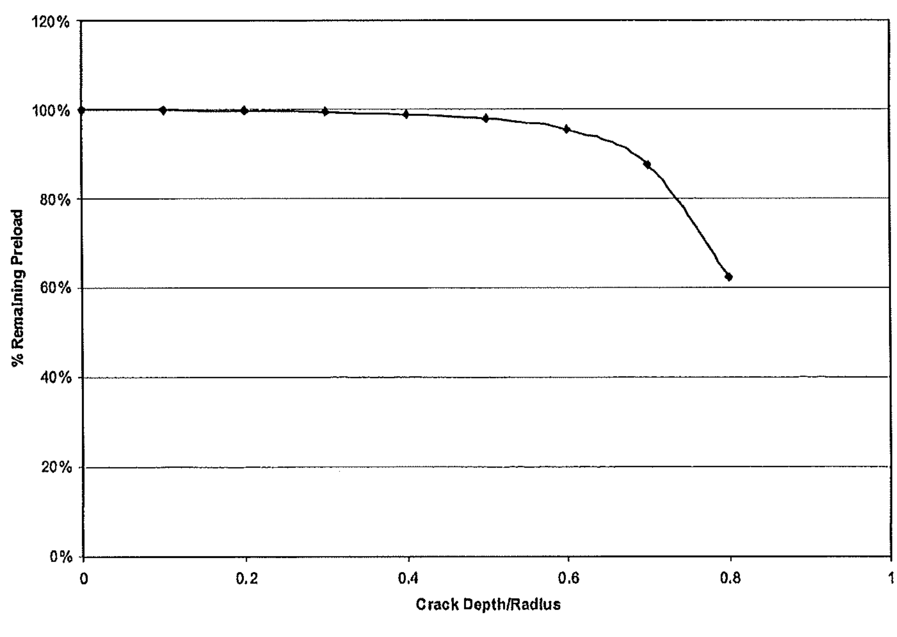


Figure 6.
Plant 2 Remaining Preload vs. Crack Depth Ratio

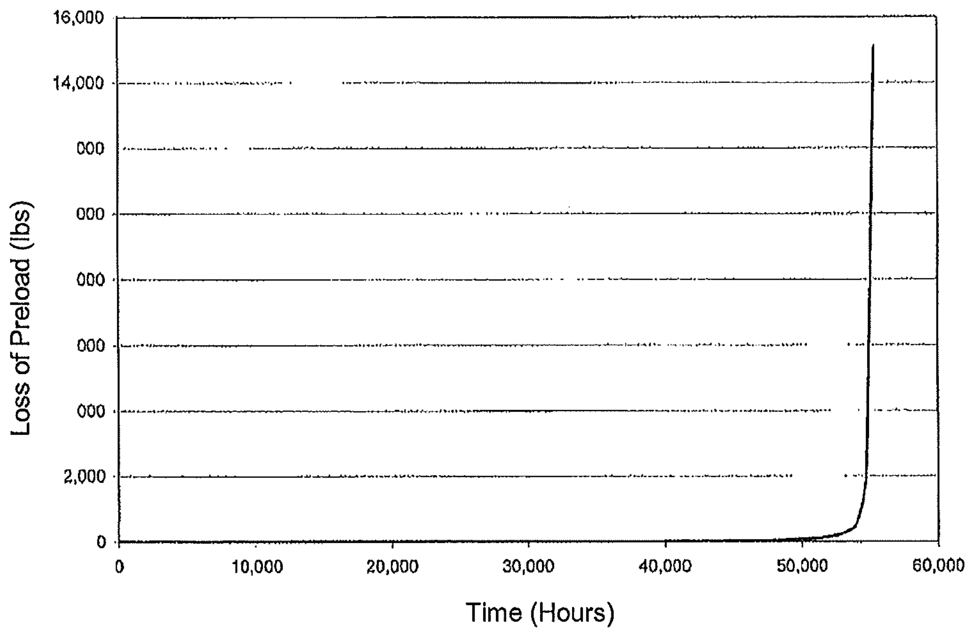


Figure 7.
Loss of Preload vs. Time for Plant 1

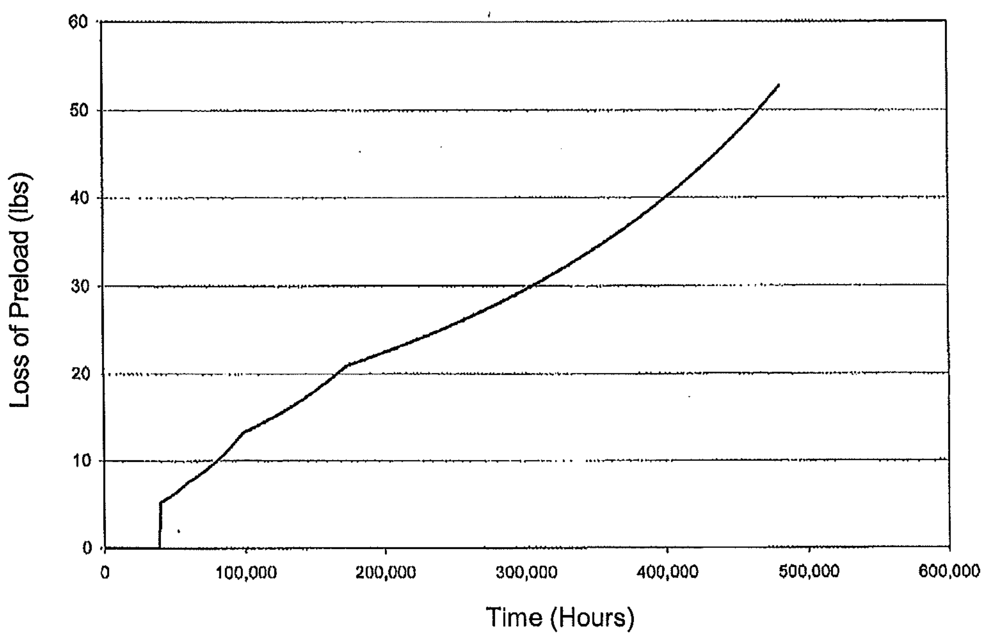


Figure 8.
Loss of Preload vs. Time for Plant 2