

BEFORE THE FLORIDA PUBLIC SERVICE COMMISSION

DOCKET NO. 100437-EI

PROGRESS ENERGY FLORIDA, INC

OCTOBER 10, 2011

IN RE: EXAMINATION OF THE OUTAGE AND REPLACEMENT
FUEL/POWER COSTS ASSOCIATED WITH THE CR3 STEAM
GENERATOR REPLACEMENT PROJECT, BY PROGRESS ENERGY
FLORIDA, INC.

TESTIMONY & EXHIBITS OF:

GARRY MILLER

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1 **I. INTRODUCTION AND QUALIFICATIONS.**

2 **Q. Please state your name and address.**

3 A. My name is Garry Miller. My business address is 100 East Davie Street, TPP 15,
4 Raleigh, North Carolina 27601.

5

6 **Q. By whom are you employed and in what capacity?**

7 A. I am employed by Progress Energy, Inc. in the Nuclear Engineering Group and
8 serve as Vice President – Nuclear Engineering.

9

10 **Q. Please describe your duties and job responsibilities in that position.**

11 A. As Vice President – Nuclear Engineering, I am responsible for all system
12 engineering, design engineering, and technical program functions in Progress
13 Energy's nuclear generation fleet.

14

15 **Q. Please summarize your educational background and work experience.**

16 A. I have a Bachelor of Science degree in Nuclear Engineering from the North
17 Carolina State University. I also have a Masters degree in Mechanical

1 Engineering from North Carolina State University.

2 I have over 30 years of experience in the nuclear industry. My experience
3 involves engineering and maintenance experience at all of Progress Energy's
4 nuclear plants and the corporate office for nuclear operations. I have held
5 Engineering Manager positions at the Brunswick Nuclear Plant and Robinson
6 Nuclear Plant. I was also the Chief Engineer for Nuclear Generation Group
7 (NGG). Additionally, I was the Maintenance Manager at Progress Energy's
8 Harris Nuclear Plant.

9
10 **II. PURPOSE AND SUMMARY OF TESTIMONY.**

11 **Q. What is the purpose of your direct testimony?**

12 A. The purpose of my direct testimony is to explain the Crystal River Unit 3 ("CR3")
13 October 2, 2009 delamination root cause investigation, and to describe the
14 reasonable and prudent management actions to understand, investigate, and
15 resolve the factors that caused the October 2009 delamination. My testimony
16 further supports the testimony of Jon Franke regarding the prudence of PEF's
17 actions with respect to the CR3 steam generator replacement ("SGR") project
18 during which the October 2009 delamination occurred.

19
20 **Q. What was your role with respect to the CR3 delamination root cause**
21 **investigation?**

22 A. I was responsible for the root cause investigation and assessment. I was assigned
23 responsibility for undertaking the condition assessment and associated testing and
24 analyses to complete a root cause analysis of the October 2, 2009 delamination. I

1 led the PEF team that developed the root cause assessment plan and implemented
2 it. I also led the retention of necessary industry experts, including Performance
3 Improvement International, LLC (“PII”), to assist me with the root cause
4 investigation and analysis. The delamination root cause assessment work was
5 performed under my direction and control. I was intimately involved in the work
6 necessary to determine the root causes of the October 2009 delamination and the
7 work done to review, evaluate, and validate that work. Finally, I also led and was
8 involved in the quality assessment and controls of that work that assisted the
9 Company in confirming the results of the root cause assessment. As such, I
10 directly participated in the development of the root cause assessment report.

11
12 **Q. Please summarize your testimony.**

13 A. I led the Company’s root cause investigation to determine why the October 2,
14 2009 CR3 wall delamination occurred, and what could be done to repair the
15 delamination and prevent its recurrence. I was on-site at CR3 to lead this
16 investigation within two weeks of the October 2009 wall delamination. Under my
17 leadership, the Company assembled a team of industry experts from within and
18 outside the Company to assist in the root cause investigation. Our mission was to
19 perform a complete condition assessment of the Bay 34 delamination and to
20 determine the technical root cause of the wall delamination, as well as the
21 “programmatic” root cause; or what program or organizational factors, which may
22 have played a role in causing the delamination. We performed the root cause
23 investigation in accordance with our standard implementing procedures for our
24 corrective action program for our nuclear power plants, and with industry

1 standards. These implementing procedures are consistent with Nuclear
2 Regulatory Commission (“NRC”) requirements for such programs and industry-
3 leading programs.

4 We retained world-renowned industry and subject matter experts,
5 including PII, to assist us with the root cause investigation. We investigated and
6 reviewed prior industry experience to determine what information was available
7 to the Company on the SGR project. We further investigated the CR3 design,
8 CR3 construction, CR3 materials, engineering modeling analyses and
9 calculations, construction techniques, environmental and human factors, and
10 PEF’s management of the SGR project to determine what caused the October
11 2009 CR3 wall delamination during the construction opening activities on the
12 SGR project. We employed state-of-the-art investigative tools and methods to
13 assist us in determining the causes of the delamination. All of our work was then
14 independently reviewed by the Company and third-party experts retained just for
15 this independent review. Our root cause investigation was comprehensive and
16 thorough.

17 Upon discovery of the delamination, we notified the NRC. The NRC sent
18 a Special Inspection Team to the site to independently review the delamination,
19 our actions leading up to the delamination, and our response, including our root
20 cause analysis. This Special Inspection Team included NRC inspectors from
21 various technical disciplines and with subject matter expertise in regulatory
22 requirements, nuclear operations, nuclear design engineering, and analysis. These
23 NRC inspectors independently reviewed our root cause investigation and issued
24 their own report on that investigation. The inspectors spent hundreds of hours on

1 siteover the course of their extensive review. They concluded that the CR3
2 containment wall delamination root cause investigation was comprehensive and
3 thorough, and that it complied with the Company's standard Corrective Action
4 Program ("CAP") procedures consistent with NRC requirements. They found no
5 violations, which is rare for a NRC Special Inspection Team.

6 The Company's root cause investigation and assessment report determined
7 that the causes of the CR3 wall delamination were unprecedented, unpredictable,
8 and, therefore, unpreventable. We concluded that the technical root cause of the
9 CR3 wall delamination was the combination of: 1) tendon stresses; 2) radial
10 stresses; 3) industry design engineering analysis inadequacies for stress
11 concentration factors; 4) concrete strength properties; 5) concrete aggregate
12 properties; and 6) the de-tensioning sequence and scope. The root cause
13 investigation revealed that another factor, the process of removing the concrete
14 itself, likely contributed to the extent of the delamination after it occurred at CR3.
15 All of these factors contributed to increased localized stresses as the CR3
16 containment structure responded to the construction opening activities that
17 exceeded the ability of the concrete to withstand cracking thereby leading to the
18 delamination. Absent any one of these factors or contributing causes, the
19 delamination likely would not have occurred.

20 The reaction of the CR3 containment structure and the stresses created by
21 that reaction were not predicted by the industry standard engineering modeling
22 analyses and calculations employed on the SGR project and, initially, during the
23 root cause investigation. We simply could not simulate the delamination and
24 determine the technical causes of the CR3 wall delamination using the then

1 existing industry standard engineering modeling analyses and calculations. The
2 failure of these industry standard engineering modeling analyses and calculations
3 to predict the CR3 wall delamination was the programmatic root cause of the
4 delamination.

5 The necessary corrective action to repair the delamination and prevent its
6 recurrence required the development of engineering modeling analysis changes to
7 create first-of-a-kind, state-of-the-art engineering models to accurately simulate
8 and, therefore, predict the delamination. These engineering models were
9 developed during our root cause investigation and they enabled us to determine
10 the technical causes of the delamination.

11 The NRC inspectors independently reviewed the results of our root cause
12 investigation. These NRC inspectors concluded that the CR3 wall delamination
13 was unprecedented and that the determination of the technical contributing causes
14 to the delamination was reasonable and adequately supported by the evidence.
15 The NRC inspectors further agreed that the corrective actions developed and
16 taken by the Company were appropriate and addressed the causal factors of the
17 delamination.

18
19 **Q. How is your testimony organized?**

20 **A.** My testimony is organized into three parts. First, I describe the physical causes of
21 the October 2, 2009 delamination determined by the Company's root cause
22 assessment. I also explain why these physical causes were not attributed in the
23 root cause assessment to any action that PEF took or any action PEF should have
24 taken that it did not take in managing the SGR project. Rather, the root cause

1 assessment demonstrates that the October 2009 delamination physical causes
2 were unprecedented, unpredictable, and unpreventable. Consequently, the
3 October 2009 delamination was not the result of any error or omission by PEF
4 resulting from imprudence.

5 Second, I explain the organization and implementation of the root cause
6 assessment for the October 2009 wall delamination. In this section, I demonstrate
7 the steps PEF took to reasonably and prudently manage the root cause assessment.

8 Finally, I explain the root cause assessment itself, providing detail on the
9 scope of the assessment and the development of additional information used in the
10 assessment. In particular, I will explain the enhancement in the industry standard
11 engineering calculations and modeling analyses that were needed to develop
12 models that were capable of predicting and therefore identifying the causes of the
13 October 2009 CR3 wall delamination. These engineering models were critical to
14 determining the causes of the delamination and how to repair the delamination.

15
16 **Q. Do you have any exhibits to your testimony?**

17 **A. Yes, I am sponsoring the following exhibits to my testimony:**

- 18 • Exhibit No. ___ (GM-1), a diagram plot of the October 2009 delamination
19 around the construction opening in the CR3 containment building;
- 20 • Exhibit No. ___ (GM-2), a picture of the separation in the concrete within
21 the vertical plane of the horizontal tendons in the CR3 containment
22 structure;
- 23 • Exhibit No. ___ (GM-3), a cross section view of the layout of the
24 horizontal and vertical tendons in the CR3 containment wall;

- 1 • Exhibit No. ____ (GM-4), the PII Root Cause Assessment report for the
- 2 October 2009 delamination in the CR3 containment building;
- 3 • Exhibit No. ____ (GM-5), Bechtel's Review of Creep Effects on Behavior
- 4 of Restored Containment Structure for the CR3 SGR project;
- 5 • Exhibit No. ____ (GM-6), the Significant Adverse Condition Investigation
- 6 Report, Action Request ("AR") Number 358724;
- 7 • Exhibit No. ____ (GM-7), CAP-NGGC-0205, titled "Condition Evaluation
- 8 and Corrective Action Process;"
- 9 • Exhibit No. ____ (GM-8), Progress Energy Chief Executive Officer
- 10 ("CEO") briefing on October 21, 2009 regarding the October 2009
- 11 delamination and the Containment Root Cause Investigation Team;
- 12 • Exhibit No. ____ (GM-9), a chart of the work flow process for the
- 13 Containment Root Cause Investigation Team;
- 14 • Exhibit No. ____ (GM-10), Request for Proposal No. J009-010 220434;
- 15 and
- 16 • Exhibit No. ____ (GM-11), the computer modeling simulation of the
- 17 October 2009 wall delamination event.

18 These exhibits were prepared under my direction or they are documents routinely
19 relied upon by me and others in the Company in the usual course of our business
20 and they are true and correct. I have also included the NRC Special Inspection
21 Team ("SIT") Special Inspection Report as Exhibit No. ____ (GM-12) to my
22 testimony, and the NRC summaries of public meetings regarding the October
23 2009 delamination, including presentations made by PEF and the NRC at the

1 meetings, as Exhibit No. ___ (GM-13) to my testimony. These exhibits are public
2 records that can also be found in the NRC Public Document Room or from the
3 Publicly Available Records (“PARS”) component of the NRC’s document system
4 (“ADAMS”) accessible from the NRC website at [http://www.nrc.gov/reading-
6 rm/adams](http://www.nrc.gov/reading-
5 rm/adams). They are the type of documents that are routinely relied upon by me
7 and others in the Company in the usual course of our nuclear operations for the
8 Company, and they are true and correct.

9 **III. THE OCTOBER 2009 CR3 WALL DELAMINATION AND WHY IT**
10 **OCCURRED.**

11 **A. Description of the October 2009 CR3 Wall Delamination.**

12 **Q. What is a delamination?**

13 **A.** A delamination is a separation in a solid material, in this case concrete, causing a
14 void or gap within the material.

15
16 **Q. Where did the October 2009 delamination occur at CR3?**

17 **A.** The delamination occurred in the containment building wall we refer to as Bay 3-
18 4. There are six buttresses around the CR3 containment building numbered one
19 through six. The wall that delaminated was the wall between buttresses No. 3 and
20 No. 4.

21
22 **Q. Please describe the October 2009 delamination.**

23 **A.** The delamination occurred during the creation of the containment opening in the
24 CR3 containment building wall that was used to move the existing once through

1 steam generators (“OTSGs” or “steam generators”) out of the building and the
2 new OTSGs into the building. The opening in the concrete wall was
3 approximately 25 feet wide by 27 feet high. The construction opening was cut
4 with high pressure water nozzles in a process called hydro-lazing. Hydro-lazing
5 is a multi-step process that washes away or “lazes” off the concrete in layers. The
6 October 2009 delamination was first identified after several hydro-lazing steps
7 were completed. The exterior concrete had been lazed down to the outer steel
8 rebar mat, about six inches of concrete. Contractors then removed the steel rebar
9 mat, and recommenced the hydro-lazing. At that time, workers observed water
10 exiting the concrete wall at a point below and to the right of the construction
11 opening. This indicated to the workers on site that water was moving within the
12 concrete wall. Once enough concrete was removed so that the tendons could be
13 removed, the Company conducted an inspection of the construction opening.
14 During that inspection, personnel observed a separation within the concrete. This
15 separation was identified relatively early in the hydro-lazing process to create the
16 containment opening. Approximately 25 percent of the concrete in the
17 construction opening had been removed when it was identified.

18
19 **Q. Did you observe the delamination?**

20 **A.** Yes, I did. I observed the delamination at the construction opening and also
21 obtained and reviewed information collected from our assessment of the
22 delamination condition during our root cause investigation. This information was
23 collected from visual inspection reports and pictures, measurements, ultra-sound

1 devices, and core borings, among other investigative tools. Based on this
2 information we were able to determine the extent of the delamination.

3 The separation or gap in the concrete was located approximately ten
4 inches from the outer surface into the 42-inch thick containment wall. The
5 separation extended around the containment opening in an hourglass shape
6 centered on the construction opening. Exhibit No. ___ (GM-1) to my testimony is
7 a plot of the delamination around the construction opening in the CR3
8 containment building.

9 As you can see from this exhibit, the construction opening sits in the
10 narrower middle of the hourglass shape of the delamination. As you can also see
11 from this plot diagram, the delamination separation varied in size from as small as
12 $1/64^{\text{th}}$ inch up to $2\ 3/8^{\text{th}}$ inch. The wider gaps were located closer to the
13 construction opening and directly above and below the opening. The October
14 2009 delamination covered an area approximately 60 feet wide and 80 feet high.

15
16 **Q. Was the October 2009 delamination located within a particular area of the**
17 **concrete containment building?**

18 **A.** Yes. The separation was aligned with the vertical plane of the horizontal tendons,
19 meaning that the separation ran vertically from horizontal tendon to horizontal
20 tendon in the containment wall. Exhibit No. ___ (GM-2) is a picture of this
21 separation within the vertical plane of the horizontal tendons.

22 As discussed in greater detail in Mr. Franke's testimony, the horizontal
23 tendons are part of the pre-stress system of the CR3 containment wall. The
24 horizontal tendons are comprised of a series of three individual tendons that make

1 a full hoop that surrounds the CR3 containment building. Each group of three
2 horizontal tendons is paired with another group of three horizontal tendons that
3 are offset by one buttress. Each individual horizontal tendon spans across two
4 bays and ends at the vertical buttresses where they are attached to the containment
5 structure. The vertical tendons are spaced around the circumference of the
6 containment building. The vertical tendons are attached to the foundation and the
7 ring girder at the dome. The horizontal and vertical tendons are bundles of steel
8 wires, greased, and encased in 5 1/4 inch steel sleeves or conduit. The steel wires
9 in the steel conduit are mechanically pulled tight and placed under stress that is
10 maintained by shims placed under anchor heads at the ends of the tendons where
11 they terminate at the buttresses in the containment structure. Each tendon wire is
12 threaded through the anchor head and secured by a button head (or cap). The
13 horizontal tendons are located approximately ten inches into the concrete wall
14 from the outer surface and the vertical tendons are located just inside and adjacent
15 to the horizontal tendons. Exhibit No. ___ (GM-3) is a cross section view of the
16 layout of the horizontal and vertical tendons in the CR3 containment wall.

17
18 **B. A Summary of the Unpredictable Causes of the October 2009 Delamination.**

19 **Q. What is your understanding of what caused the October 2009 delamination?**

20 **A.** In technical terms, the immediate cause of the October 2009 delamination was the
21 redistribution of stresses as a result of the containment building's response to the
22 containment opening activities. This redistribution added stress across the
23 vertical plane of the horizontal tendons that exceeded the tensile capacity or
24 strength of the concrete in that area. As a result, the concrete in this plane

1 cracked, and the crack propagated along the vertical plane of the horizontal
2 tendons where it joined with other cracks from the same radial stresses to form the
3 gap or separation in the concrete. The propagation of the cracks in the vertical
4 plane of the horizontal tendons created the hourglass shape of the gap or
5 separation in the concrete around the construction opening. See Exhibit No. ____
6 (GM-1) to my testimony.

7 In non-technical terms, the act of relaxing the tension on the concrete
8 containment wall by de-tensioning the vertical and horizontal tendons in the
9 containment opening, and then creating the containment opening in that wall,
10 caused unpredictable stresses to occur in the area where the containment opening
11 was created when the CR3 containment building responded to the de-tensioning
12 activities. Put another way, the entire CR3 containment building “moved” in
13 response to the tendon de-tensioning activities at the construction opening,
14 increasing rather than lessening the localized stresses across the vertical plane of
15 the horizontal tendons in response to these activities, and, ultimately, exceeding
16 the tensile strength of the concrete causing the separation that formed the October
17 2009 delamination. The delamination did not exist prior to the SGR project; it
18 occurred on the SGR project as a result of the CR3 containment building’s
19 response to the SGR project activities.

20
21 **Q. What were the containment opening activities at CR3 for the SGR project?**

22 **A.** To move the once through steam generators out of the CR3 containment building
23 and to move the new OTSGs into the building a construction opening was created
24 in the CR3 containment wall. Briefly, a description of the activities associated

1 with moving the OTSGs out of and into the CR3 containment building includes
2 creating the construction opening by first de-tensioning the vertical and horizontal
3 tendons in the proposed opening area, removing the concrete, steel rebar, tendons,
4 and remaining concrete down to the carbon steel liner, and cutting a hole in the
5 steel liner; then, after the removal of the old OTSGs and replacement with the
6 new steam generators, re-welding the previously removed section of the carbon
7 steel liner, replacing the tendons, rebar, and concrete to close the construction
8 opening in the containment wall, and finally, retensioning the tendons to restore
9 the compressive stress in the containment wall.

10 De-tensioning refers to the release of the tension in the steel cables in the
11 conduit by cutting the button heads or removing the shims. The button heads are
12 the attached at the ends of the steel wires in the tendon bundles and restrain the
13 wires at the anchor plate. To de-tension the tendons in the area of the
14 construction opening a de-tensioning scope and sequence plan was developed.
15 The de-tensioning scope refers to the number of horizontal and vertical tendons
16 that had to be de-tensioned to create the construction opening in the containment
17 building. The de-tensioning sequence refers to the order in which the horizontal
18 and vertical tendons are de-tensioned. Re-tensioning is the opposite of de-
19 tensioning and refers to the increase in tension on the tendons by capping the ends
20 with button heads, pulling them tight, and installing shims to hold the tendons
21 under tension. There was also a scope and sequence for re-tensioning the
22 tendons.

23 This summarizes a portion of the complex engineering and construction
24 work necessary to create and close the construction opening in the CR3

1 containment building. Obviously, each of the steps in this process involves more
2 complex actions and required detailed engineering analyses and construction
3 work plans to accomplish each step of the process to create the construction
4 opening and close it to return CR3 to commercial service.

5
6 **Q. What happened during the activities that created the construction opening at**
7 **CR3 for the SGR project to cause the October 2009 delamination?**

8 A. There were a number of contributing factors that culminated during the
9 construction opening activities at CR3 to create the October 2009 delamination.
10 We learned through the root cause assessment that I describe in detail later in my
11 testimony that these contributing factors worked in combination with each other
12 to cause the October 2009 delamination. None of these contributing factors,
13 standing alone, caused the October 2009 delamination. Rather, each one was a
14 necessary contributing factor in a complex interaction of all of them as a whole to
15 cause the October 2009 delamination. These contributing factors to the October
16 2009 delamination at CR3 are described in detail in the root cause assessment
17 report attached as Exhibit No. ___ (GM-4) to my testimony.

18 Briefly, however, these contributing factors to the October 2009 CR3
19 containment wall delamination are: 1) tendon stresses; 2) radial stresses; 3)
20 industry design engineering analysis inadequacies for stress concentration factors;
21 4) concrete strength properties; 5) concrete aggregate properties; and 6) the de-
22 tensioning sequence and scope. The root cause investigation revealed that another
23 factor, the process of removing the concrete itself, likely contributed to the full
24 extent of the October 2009 delamination after it occurred at CR3.

1 **Q. How did you determine the contributing factors to the October 2009 CR3**
2 **delamination?**

3 A. We determined the contributing factors to the October 2009 CR3 delamination
4 only after developing state-of-the-art computer models to simulate the
5 delamination based upon data collected from our root cause investigation. The
6 state-of-the art computer models were created by PII and they employed a
7 complex process of simultaneous and multiple engineering calculations using the
8 data and information made available to PII after the October 2009 delamination
9 event at CR3 based upon our root cause investigation. The models allowed PII to
10 work backwards in time to determine what factors contributed to the delamination
11 by starting with information that was not previously known about how the CR3
12 containment structure behaves. Without this information and the modeling
13 enhancements performed by PII, we would have been unable to simulate the
14 October 2009 delamination to determine the factors contributing to that
15 delamination.

16 This is one reason the October 2009 delamination was unpredictable.
17 When we commenced the root cause investigation we reviewed the industry
18 standard engineering calculations and computer modeling analyses for the SGR
19 project that I discuss in more detail later in my testimony to see if they revealed
20 the cause of or could predict the delamination. Rigorous application of these
21 standard engineering calculations and computer modeling analyses to the
22 information available to the SGR project team before the delamination did not
23 predict the October 2009 delamination. The conservative stress margins produced

1 by these modeling analyses still indicated that there was no delamination even
2 after the October 2009 delamination occurred.

3
4 **Q. If standard industry engineering models and analyses did not predict the**
5 **delamination how did you determine what caused the October 2009**
6 **delamination?**

7 A. Using data obtained from the delamination, we developed more sophisticated and
8 accurate computer modeling. We changed the inputs for the various stress values
9 and other material property characteristic values used in the industry standard
10 engineering calculations and modeling analyses based on (1) information
11 collected during the root cause investigation from various destructive and non-
12 destructive tests or investigation tools; and (2) information developed from the
13 engineering modeling analyses; all of which was only available as a result of the
14 October 2009 delamination. This information was not available to PEF or its
15 engineers and contractors prior to the October 2009 delamination. Even if they
16 wanted to change the stress and material property input values in the industry
17 standard engineering calculations and modeling analyses used on the SGR
18 project, they could not do so because they had no information on what the inputs
19 should be. The SGR project team did not have the detailed information we
20 learned after the October 2009 delamination occurred that allowed us to change
21 the input values to what they should be to simulate the October 2009 delamination
22 and, therefore, determine what caused it.

23 This is another reason the October 2009 delamination was unpredictable.
24 We determined that the industry standard engineering calculations and modeling

1 analyses could not simulate the delamination and determine the delamination
2 causes even with the information we learned about the delamination in the root
3 cause investigation. As we learned more about the actual design stresses in the
4 CR3 containment building, and modified the industry standard engineering
5 calculations and models to account for those stresses, those calculations and
6 models continued to demonstrate significant margins to delamination at CR3. In
7 other words, standard computer modeling analyses, before and after the
8 delamination took place, insisted that the October 2009 delamination was not
9 possible given the stresses involved. It took both the additional information we
10 learned as a result of our root cause investigation and the enhanced engineering
11 modeling analyses we developed during the investigation to simulate the October
12 2009 delamination and understand what caused it.

13
14 **Q. How did the contributing factors interact in the enhanced engineering**
15 **models to establish the cause the October 2009 delamination at CR3?**

16 **A.** We found that the October 2009 delamination was caused by an indivisible
17 combination of all the contributing factors. The exact contribution of each factor
18 to the October 2009 delamination could not be determined in the enhanced
19 computer modeling analyses that were developed to simulate the delamination
20 and determine the delamination causes. If any one of the contributing factors was
21 not accounted for in the enhanced computer modeling of the CR3 containment
22 building, however, the CR3 delamination did not occur within the model, but the
23 percentage contribution of each factor to the October 2009 delamination could not
24 be precisely determined.

1 We were able to establish a failure modes timeline in the root cause
2 assessment, however, that identified how the contributing factors chronologically
3 combined to contribute to the delamination. All potential contributing factors to
4 the delamination were called failure modes in the root cause assessment. The
5 particular failure modes that caused the October 2009 delamination converged
6 over time to create the delamination. These failure modes correlate with five time
7 periods: (1) the original CR3 structural design from the 1970's; (2) the original
8 material selection and construction of CR3 in the 1970's; (3) the aging of
9 materials over the thirty-plus year operation of CR3 from the 1970's to 2009; (4)
10 the determination and execution of the de-tensioning scope and sequence for the
11 SGR project in 2009; and (5) the physical removal of concrete in 2009. The
12 timeline is shown separately on page 15 and on page 30 of the root cause
13 assessment report, attached as Exhibit No. __ (GM-4) to my testimony.

14 The timeline demonstrates that almost all of the contributing factors pre-
15 existed the SGR project. The CR3 design features and concrete material
16 properties were inherently part of the construction of the CR3 containment
17 building. Consequently, the tendon design and tendon and radial stresses were an
18 inherent part of the CR3 design and construction. The industry engineering
19 analyses were also established at the time of the SGR project. The scope and
20 sequence of the de-tensioning on the SGR project was the only contributing factor
21 to the October 2009 delamination within the control of the SGR project team. But
22 even the de-tensioning scope and sequence was constrained by both the industry
23 standard engineering models and analyses and industry standard de-tensioning
24 practices at the time of the SGR project. Until the contribution of all these factors

1 to the October 2009 delamination was understood, there was no reason to suggest
2 changes in the industry standard engineering models and analyses or the industry
3 standard de-tensioning scope and sequence practices at the time of the SGR
4 project. This understanding was not available to PEF or its engineers and
5 contractors on the SGR project before the October 2009 delamination occurred.
6 As a result, PEF could not prevent the delamination prior to the October 2009
7 delamination occurring at CR3.

8
9 **C. The October 2009 Delamination Contributing Factors.**

10 **Q. If de-tensioning contributed to the October 2009 delamination, why did the**
11 **tendons in the containment wall have to be de-tensioned on the SGR project**
12 **in the first place?**

13 A. The vertical and horizontal tendons in the construction opening in the CR3
14 containment building were de-tensioned on the SGR project for two reasons. The
15 most fundamental reason for de-tensioning tendons that pass through the location
16 of the proposed temporary construction opening is because they had to be
17 removed to move the old OTSGs out of the containment building and the new
18 OTSGs into the building. These tendons were blocking the transport path for the
19 OTSGs through the construction opening and, therefore, they had to be removed.
20 Accordingly, these tendons were de-tensioned in a controlled fashion and
21 removed to allow for safe removal of the concrete in the temporary construction
22 opening and to prepare the transport path for the OTSGs.

23

1 Q. What was the second reason for de-tensioning tendons as part of the
2 construction opening activities for the SGR project at CR3?

3 A. The second reason to de-tension the vertical and horizontal tendons in the
4 construction opening is to relax the concrete sufficiently in preparation for
5 placement of the new concrete in the construction opening in the containment
6 building wall. The CR3 containment building has to be returned to its pre-
7 stressed state after the construction opening is closed for the containment building
8 to perform its function of providing compressive strength to the concrete liner
9 barrier that forms the interior wall of the containment building. The overall
10 design objective for a pre-stressed containment structure like the CR3
11 containment building is to maintain compressive stress through the concrete
12 thickness for the life of the nuclear power plant. The magnitude of the
13 compressive stress is determined by the magnitude of the design basis pressure
14 expected to occur due to the prescribed loss of coolant accident (“LOCA”)
15 condition.

16 To return the containment building to this level of compressive stress,
17 then, when concrete is removed and replaced, it must be done at a near zero stress
18 state. Tendons located where the concrete is removed and must be replaced,
19 therefore, are de-tensioned in preparation for the new concrete. Once tendons are
20 retensioned, concrete compressive stress is returned to the design basis level.
21 Tendon forces that exist when new concrete is placed cannot be used to develop
22 compression in the new concrete. Put another way, the stress in the containment
23 building had to be relaxed by de-tensioning the tendons in the construction
24 opening so that the pre-stress within the concrete structure could be restored once

1 the concrete was replaced in the temporary construction opening in the
2 containment building.

3 To explain further, the new concrete placed in the temporary construction
4 opening to close the opening acts differently from the aged concrete, even if it is
5 the same mixture and contains the same material properties, because it is new and
6 has not aged or cured to the extent of the adjacent, existing 30-plus-year-old
7 concrete. The scope and process of replacing the tendons in the new concrete in
8 the containment opening requires that they and other, surrounding tendons be de-
9 tensioned before re-tensioning to allow time for the new concrete to develop
10 sufficient strength to withstand the stresses of re-tensioning and to re-establish a
11 near uniform pre-stress in the replacement concrete and the surrounding concrete.
12 This reason can be found in one of the Containment Shell Analysis Calculations
13 for the SGR project. This calculation expresses that one significant goal of the
14 SGR project team is to restore the pre-stress within and around the steam
15 generator access opening to the design basis level prior to the SGR project as
16 reflected in the Containment Shell Analysis for Steam Generator Replacement,
17 Design Criteria, Calculation No. S06-0002, Rev. 1, p. 15, attached as Exhibit No.
18 ____ (JF-19) to Mr. Franke's testimony.

19
20 **Q. Were these reasons for the de-tensioning activities for the construction**
21 **opening work on the PEF SGR project supported by industry standard**
22 **engineering analyses?**

23 **A. Yes. Industry standard engineering analyses at the time of the SGR project called**
24 **for de-tensioning of the tendons in the construction opening in the containment**

1 building for the two reasons that I have just explained. For example, this industry
2 standard engineering analysis is reflected in the CR3 containment shell analysis
3 for the SGR project where the stated goal of de-tensioning the hoop and vertical
4 tendons is to minimize the pre-stress in the concrete that will be removed for the
5 access opening. See Calculation S06-0002, Containment Shell Analysis for
6 Steam Generator Replacement, Design Criteria, rev. 1, attached as Exhibit No.
7 ____ (JF-19) to Mr. Franke's testimony.

8 Importantly, at the time of the SGR project, the industry standard analysis
9 demonstrated that relaxation of the tendons by de-tensioning them reduced the
10 stresses within the area de-tensioned in the building and that redistribution of
11 stresses would not exceed the tensile capacity of the concrete. De-tensioning the
12 tendons in the proposed containment structure opening area to reach a near zero
13 stress state in that area was accepted industry engineering and construction
14 practice at the time of the SGR project precisely because of what the industry
15 standard analysis demonstrated. This accepted industry standard analysis proved
16 to be wrong at CR3, however, when the CR3 containment building responded to
17 the de-tensioning activities. This response to the de-tensioning activities on the
18 SGR project in the area of the opening in the CR3 containment building was
19 unexpected and unpredictable.

20
21 **Q. Were the industry standard engineering analyses applied to the construction**
22 **opening work on the PEF SGR project?**

23 **A.** Yes. On the PEF SGR project, Sargent & Lundy ("S&L") provided the
24 engineering work to support the construction activities associated with creation of

1 the containment opening, including the de-tensioning scope and sequence, in the
2 CR3 containment building. To perform this engineering work S&L used an
3 industry standard engineering model to analyze the de-tensioning and re-
4 tensioning of the containment building prior to the creation of the containment
5 opening.

6 The industry standard engineering models incorporated structural analysis
7 methods known as Finite Element Analysis ("FEA"). S&L performed FEA
8 calculations and studies using well accepted Finite Element Models ("FEMs").
9 These FEMs were created using an industry standard engineering software
10 program called GTSTRUDL to generate two dimensional models of the
11 containment building. The models included the containment shell, dome,
12 basemat, representative soil springs in the rock foundation, and the equipment
13 hatch. The models further utilized thin plate elements including both quadrilateral
14 and triangular plate elements to create the cylindrical shell analysis of the
15 containment building. These models included material properties for the existing
16 concrete at the time of the SGR project (compressive strength, Young's Modulus,
17 Poisson's Ratio), limiting tensile stresses (maximum membrane tensile stress and
18 maximum membrane plus bending tensile stress), and the value for the modulus
19 of elasticity, among other input variables. Source values for these inputs were the
20 original design documents for CR3 from Gilbert Commonwealth, the CR3 Final
21 Safety Analysis Report ("FSAR"), and the Design Basis Document for the
22 Containment, among other sources identified in the reference material in
23 Calculation S06-0002, Containment Shell Analysis for Steam Generator

1 Replacement, Design Criteria, rev. 1, attached as Exhibit No. ____ (JF-19) to Mr.
2 Franke's testimony.

3 S&L used the industry standard FEA analysis in the FEM engineering
4 models to evaluate potential stresses involved in the creation of the construction
5 opening based on the material inputs or values and the modeling parameters
6 within the FEM engineering models. These stresses included the compressive and
7 tensile forces of the concrete and the pre-stressed tendons and the stresses created
8 by the de-tensioning and retensioning activities in and around the construction
9 opening. These engineering evaluations are documented in the engineering
10 calculations associated with the SGR project engineering activities.
11

12 **Q. If the cause of the October 2009 delamination was the redistribution of**
13 **stresses as a result of the containment building response to the construction**
14 **opening activities on the SGR project, did the industry standard engineering**
15 **models used on the project account for this redistribution of stress?**

16 **A.** Yes, they did. The S&L FEM evaluated the concrete stresses that existed in the
17 concrete after the opening had been created and after it was restored. Creating the
18 temporary construction opening in the containment wall results in a redistribution
19 of dead weight around the opening and a loss of pre-stress directly above and
20 below the opening, as well as some reduction and redistribution in prestress
21 adjacent to the opening. Restoration of the temporary construction opening does
22 not affect the dead weight redistribution that occurred during the creation of the
23 opening (only the dead weight of the wet concrete placed in the opening is
24 added), however, re-tensioning the tendons adjacent to and within the opening

1 restores most of the pre-stress (but not all due to the effects of creep) to the new
2 concrete placed in the opening. The S&L FEM accounted for all of these forces
3 during all phases of the SGR project.

4 The concern in applying the industry standard engineering models and
5 calculations was that this redistributed dead load and the effects of creep in the
6 new concrete made it more difficult to restore the original pre-stress levels in the
7 replacement concrete area when the tendons that were removed or de-tensioned to
8 create the construction opening were replaced and re-tensioned after the
9 replacement concrete was placed in the opening. The engineering challenge then,
10 in non-technical terms, was to de-tension, create the opening, replace the concrete
11 and tendons, and re-tension the building to a level of pre-stress that met the CR3
12 containment building's design basis.

13 An example of this industry understanding at the time of the SGR project
14 is reflected in the opinion PEF obtained from Bechtel Power Corporation
15 ("Bechtel") regarding the "creep" effects of concrete on the behavior of the
16 restored containment structure. Creep refers to the effect of long-term pressure or
17 stress on the shape of the concrete. Bechtel was asked to provide an independent,
18 third-party review of S&L's approach to evaluating creep effects on the behavior
19 of the restored CR3 containment building. Bechtel was one of the most
20 experienced engineering and construction firms with construction projects
21 involving the creation of construction openings in post-tensioned, pre-stressed
22 nuclear containment buildings.

23 As Bechtel made clear in its written opinion, de-tensioning reduced, it did
24 not increase, the stresses on the concrete, therefore, the concern was for the

1 redistribution of compressive stresses on the restored concrete in the construction
2 opening. The challenge according to Bechtel, then, was to create as much of a
3 stress-free state as possible by de-tensioning the tendons in and around the
4 containment opening to ensure that upon re-tensioning, the pre-stress level in the
5 new concrete is restored as much as possible to the original pre-stress level. As
6 previously noted, restoring 100 percent pre-stress in the concrete placed in the
7 temporary construction opening is not possible due to dead load and residual pre-
8 stress redistribution that occurs during creation of the opening. Also, after re-
9 tensioning the effects of differential creep between the new and old concrete will
10 also impact how the re-tensioning forces are distributed between the new and old
11 surrounding concrete. *See* Bechtel's Review of Creep Effects on Behavior of
12 Restored Containment Structure for the CR3 SGR project attached as Exhibit No.
13 ____ (GM-5) to my testimony. Bechtel expressed no opinion or concern regarding
14 the impact of any stresses on the existing, aged concrete around the construction
15 opening in its analysis of the creep effects in the concrete for the restored CR3
16 containment structure.

17
18 **Q. Did S&L incorporate the industry understanding regarding the impact of the**
19 **redistribution of stresses on the concrete in its engineering calculations for**
20 **the PEF SGR project?**

21 A. Yes. S&L performed preliminary studies utilizing the industry standard
22 engineering models to determine the optimum number of vertical and hoop
23 tendons to de-tension inside and outside the proposed opening area to ensure near
24 uniform pre-stress after restoration that meets the design basis requirements. The

1 primary driver in these engineering analyses and calculations was the difference
2 in material property values between the old and new concrete that I previously
3 mentioned. For example, one concern in these engineering analyses was the
4 differential in the creep factor between the new replacement concrete and the
5 adjacent older concrete, as evidenced by the Bechtel opinion that I previously
6 described. As I also noted above, a simple definition of creep is the tendency of a
7 solid material to move or deform over time in response to stresses or long-term
8 pressures. The rate of the movement or deformation -- the creep factor -- is a
9 function of the concrete material properties, temperature, compressive stress on
10 the concrete, and the exposure time of the concrete to the compressive stresses.
11 Accounting for these factors involved complicated engineering calculations and
12 analyses.

13 Generally, however, creep rate is higher in new concrete than older
14 concrete, which meant a creep differential had to be calculated for the new,
15 replacement concrete in the construction opening and the adjacent, remaining old
16 concrete in the building. This differential can lead to the transfer of pre-stress
17 load to the old concrete, which can reduce the ability of the replacement concrete
18 to resist design loads. It can also leave the replacement concrete vulnerable to the
19 re-tensioning forces occasioned by the stresses from the circumferential and
20 meridional bending movements of the tendons when they are re-tensioned in the
21 replacement concrete and surrounding area. These issues were addressed in the
22 Bechtel report, attached as Exhibit No. ____ (GM-5) to my testimony, in which
23 Bechtel agreed with the S&L calculations with respect to creep and other material

1 properties in defining the redistribution of stresses during the construction
2 opening activities and the de-tensioning scope for the CR3 SGR project.

3 In S&L's engineering analyses, S&L determined that during the time
4 frame between the cold shut down of CR3 and full restoration of the SGR project
5 access opening, the pre-stress in the containment shell cylinder is reduced due to
6 the removal and de-tensioning of a number of vertical and hoop tendons within
7 the access opening. The reduced pre-stress calculation was based on the number
8 of tendons removed and de-tensioned and considered the expected tendon forces
9 for the remaining tendons at the time of steam generator replacement. The
10 expected pre-stress at the time of replacement was determined based on the
11 average effective pre-stress considering all losses due to concrete shrinkage,
12 concrete creep, steel relaxation, and elastic shortening of the replacement concrete
13 in the construction opening.

14 S&L Calculation S06-0004, Containment Shell Analysis for Steam
15 Generator Replacement – Properties of New Concrete for Access Opening and
16 Number of Hoop and Vertical Tendons to be De-tensioned, attached as Exhibit
17 No. ___ (JF-23) to Mr. Franke's testimony, for example, evaluated the properties
18 of the new concrete in the opening, the existing concrete around the opening, and
19 provided the October 2009 and revised tendon de-tensioning studies for the SGR
20 project. These S&L calculations were based on the requirements of American
21 Concrete Institute ("ACI") 209R-92, Prediction of Creep, Shrinkage, and
22 Temperature Effects in Concrete Structures. They were partially developed by
23 Professor Domingo Carreira, Chairman of the ACI sub-committee that prepared
24 ACI 209R-92. S&L also performed optimization studies using the standard

1 industry engineering models to check whether pre-stress could be restored both
2 inside and outside the access opening. The calculations determined that the pre-
3 stress levels in and around the opening after re-tensioning would be at levels
4 similar to those before the SGR project outage. This result, based on the standard
5 engineering model analyses and calculations at the time of the SGR project, was
6 confirmed in our root cause assessment. *See* the CR3 root cause assessment
7 report, pp. 69-70, attached as Exhibit No. ___ (GM-4) to my testimony.

8 As a result, consistent with the industry standard engineering and
9 construction practices at the time of the SGR project, S&L focused on the need to
10 restore the required pre-stress level to the new concrete in the containment
11 building opening while accounting for the loss of residual compressive stresses
12 within the opening due to deadweight and pre-stress load redistribution (resulting
13 from creating the opening) and the effects of creep. If the resulting pre-stress
14 level in the new concrete is sufficiently less than the original pre-stress level that
15 existed prior to de-tensioning, the new concrete may be disadvantaged in terms of
16 its ability to resist design loads of the containment building.

17
18 **Q. Was the engineering work prepared by S&L reviewed for compliance with**
19 **industry standard engineering practices?**

20 A. Yes. Once S&L had completed their work, the PEF project team submitted
21 S&L's calculations to PEF's engineering group and to third-party reviewers with
22 experience using the engineering standard models and analyses on other, similar
23 projects to the SGR project for acceptance testing and analytical review. This
24 process involved multiple analyses, meetings, question and answer ("Q&A")

1 sessions, and follow up items to verify S&L's work. This review process was
2 documented in accordance with established engineering procedures, prior to
3 PEF's acceptance of S&L's work, that we reviewed during the root cause
4 assessment.

5
6 **Q. Did S&L account for the CR3 design features and concrete material**
7 **properties that were found to contribute to the October 2009 delamination in**
8 **your root cause investigation in S&L's engineering analyses for the SGR**
9 **project?**

10 **A.** Yes. During our root cause investigation we reviewed the SGR project material
11 to determine if the CR3 design and concrete material properties that were
12 identified as contributing factors to the delamination in the root cause
13 investigation were addressed in planning the construction opening in the
14 containment building on the SGR project. We found that this information was
15 made available to S&L and reviewed or analyzed in the course of S&L's
16 engineering work for the SGR project.

17 For example, PEF provided S&L with the original Gilbert Associates
18 design documentation, drawings, and calculations for the CR3 containment
19 structure, the CR3 FSAR, and other design basis documents for the CR3
20 containment building. PEF also provided S&L the root cause assessment report
21 for the dome delamination that occurred at CR3 in 1976 during initial
22 construction of the facility. This information was used by S&L to develop the
23 necessary analyses needed to evaluate the creation of the SGR containment
24 opening. This material, among other source material, is identified as reference

1 material by S&L in S&L Calculation S06-0002, Containment Shell Analysis for
2 Steam Generator Replacement, Design Criteria, rev. 1, pp. 2-4, Attachment 3, p. 1
3 of 9, attached as Exhibit No. ____ (JF-19) to Mr. Franke's testimony.

4 This material included information about the particular CR3 containment
5 building design features and the distribution of stress in the containment building.
6 In particular, the post-tensioning system was described in the material, including
7 the original manufacturer (Prescon Corporation), testing and supply, and the
8 details of the CR3 tendon system as installed. These details are included in
9 Figures 5-24 and 5-25 of the FSAR Ref. 1 based on Section 5.2.2.3.1 of the
10 FSAR, Ref. 1, and Prescon Corporation drawings, References 31 through 37. The
11 minimum ultimate tensile stress of the tendons was also provided together with
12 the calculated relaxation value in the tendon tensions over the life of CR3.

13 The material also included information regarding the design basis analysis
14 and design of the CR3 containment shell and dome. This included the original
15 overall engineering modeling analysis of the containment shell and dome, the
16 local additional reinforcement required for shell attachments and penetrations, and
17 the analysis of the openings due to equipment and personnel hatches. The design
18 basis loads and load combinations were provided in Table 5-3 of the FSAR, Ref.
19 1, and the design basis operating and accident pressures were provided in Section
20 5.2.1.2.1 of Ref. 1 and pages 10 to 12 of Ref 2. Where necessary design inputs
21 for the S&L containment analyses and calculations were not available from the
22 design basis documents, drawings, and calculations, they were prepared by S&L
23 based on the original Gilbert design analysis calculations and quality control

1 documents for CR3 and analysis results for the containment shell in the FSAR
2 were used as benchmarks for the S&L inputs in the S&L FEMs.

3 The material provided to S&L included information used to determine the
4 material property values for the existing concrete at the time of the SGR project.
5 These material properties included the compressive strength of the concrete (6720
6 psi), the Young's Modulus of Elasticity (2500 ksi), and the Poisson's Ratio (.2).
7 The concrete compressive strength was calculated in Calculation S00-0047 based
8 on a statistical evaluation pursuant to ACI 318-71 based on aged original concrete
9 cores pursuant to ACI 225R-91. The concrete Poisson Ratio is similar to the
10 original design basis calculations. The value for the modulus of elasticity was
11 chosen because it was the value used in the original design basis calculations.
12 Additionally, the material concrete properties included the ability of the concrete
13 to withstand tensile stress, or in lay terms, the stress involved in pulling on the
14 material until it cracks or breaks. Accordingly, the material property values
15 included the maximum membrane tensile stress and the maximum membrane plus
16 bending tensile stress. These limiting tensile stresses were calculated based on
17 the formulae contained in CR3 FSAR Section 5.2.3.3.1 and ACI 318-63, Section
18 1504.

19 The material provided to S&L further included the root cause assessment
20 of the dome delamination at CR3 during initial construction of the CR3 nuclear
21 facility. This report is specifically referenced in S&L Calculation S06-0002,
22 Containment Shell Analysis for Steam Generator Replacement, Design Criteria,
23 rev. 1, at page 3, reference item 21, and discussed at page 5 and is Exhibit No.
24 ____ (JF-19) to Mr. Franke's testimony. As a result, S&L was provided all

1 documentation regarding the CR3 containment building, including documentation
2 containing information on the particular CR3 design features and concrete
3 material properties that were later identified as some of the contributing factors to
4 the delamination that occurred during the CR3 SGR project.

5
6 **Q. What specifically did S&L do with this information?**

7 **A.** S&L incorporated this information in its engineering analyses and calculations of
8 the effect of the construction opening and restoration activities on the behavior of
9 the containment structure. These engineering analyses are documented in the
10 following S&L SGR project Calculations:

- 11 • S06-0002, Containment Shell Analysis for Steam Generator
12 Replacement, Design Criteria;
- 13 • S06-0003, Containment Shell Analysis for Steam Generator
14 Replacement, Benchmarking;
- 15 • S06-0004, Containment Shell Analysis for Steam Generator
16 Replacement – Properties of New Concrete for Access Opening
17 and Number of Hoop and Vertical Tendons to be Detensioned;
- 18 • S06-0005, Containment Shell Analysis for Steam Generator
19 Replacement – Shell Evaluation during Replacement Activities;
- 20 • S06-0006, Containment Shell Analysis for Steam Generator
21 Replacement – Evaluation of Restored Shell;
- 22 • S08-0008, Containment Shell Analysis for Steam Generator
23 Replacement – Evaluation of Restored Shell at 60-years; and

- S09-0025, Containment Shell Analysis for Steam Generator Replacement – Evaluation for Refueling Prior to Restoration of Access Opening.

In performing these engineering analyses, S&L created several FEMs to accurately model the geometry and stiffness properties of the containment building shell and foundation, both with and without the access opening. Design basis loads and load combinations, including the construction loads expected during the steam generator replacement were applied to the models and the resultant stresses were shown to be compliant with the design basis acceptance criteria. The engineering modeling analyses confirmed that all allowable stress limits were met and had ample margins.

Q. You mentioned that the material provided S&L included a root cause investigation report on a prior dome delamination at CR3, what was the prior CR3 dome delamination?

A. In April 1976, in the latter part of construction of CR3 and prior to commercial operation of the facility, workmen identified a delamination of the concrete in the center area of the dome of the CR3 containment building. Subsequent investigation revealed a circular void or separation in the center of the dome in the concrete layer in the plane of and immediately above the outer tendon layers in the CR3 dome. The delamination apparently occurred during the initial tensioning of the tendons in the dome. The delamination was repaired by partial de-tensioning, removing the outer delaminated layer of concrete, installing radial reinforcing and replacing the concrete before re-tensioning the dome tendons.

1 This corrected the delamination. There was no further dome delamination during
2 re-tensioning of the dome tendons. There also was no delamination during the
3 initial construction of the containment wall, including the tensioning of the
4 horizontal hoop and vertical tendons in the containment wall, and for thirty plus
5 years of commercial operation at CR3.

6
7 **Q. Can you describe the CR3 dome and CR3 dome delamination?**

8 A. Yes. The CR3 dome is a shallow hemispherical concrete dome roof over the
9 carbon steel liner plate at the top of the CR3 containment building. The CR3
10 dome is 36 inch thick concrete and covers the containment with an inside
11 diameter of 130 feet. Imbedded in the concrete are 123 tendons in tendon
12 conduits or sleeves (like the horizontal and vertical tendons in the containment
13 wall), stretching across the dome and connected to the CR3 ring girder below the
14 dome of the containment building. The dome tendons are tensioned in the same
15 relative manner as the horizontal and vertical tendons around the CR3
16 containment building. The geometric pattern of the dome tendons, however, is
17 significantly different from the hoop pattern of the horizontal tendons and the
18 vertical tendons in the CR3 containment wall. The dome tendons span the entire
19 dome in an overlapping configuration that creates a convex tendon cage that
20 mirrors the shape of the dome.

21 The dome delamination involved a circular area of approximately 105 feet
22 in diameter in the center of the CR3 dome. The approximate depth of the
23 delamination was fifteen inches, with a maximum gap of approximately two
24 inches between the concrete layers. There were no visible cracks in the concrete

1 surface of the dome, nor were there any other visible signs of the delamination.
2 For this reason, it is unclear if the delamination occurred during initial tensioning
3 of the dome tendons, but during the root cause investigation of the dome
4 delamination, construction records were reviewed that indicated a loud noise or
5 boom from the building while initial tensioning of the dome was underway, after
6 completing that day the tensioning sequence that brought the dome tensioning to
7 nearly two-thirds completion. Certainly too, the dome delamination was
8 discovered after the dome tendons were initially tensioned and the dome was fully
9 pre-stressed. Consequently, the dome delamination appears to have occurred
10 during initial tensioning of the CR3 dome tendons.

11 The dome delamination root cause investigation resulted in a 1976 final
12 report issued by Gilbert Associates, the original engineer for the design of the
13 CR3 containment building. The conclusion of this report was that radial stresses
14 combined with biaxial compression to initiate laminar cracking in a concrete
15 having lower than normal direct tensile capacity and limited crack arresting
16 capability. The laminar cracking that occurred means that the separation was a
17 flat sheet separation. This radial stress is created by the convex curvature of the
18 pre-stressed dome tendons and the dome concrete associated with the geometric
19 design of the CR3 dome.

20
21 **Q. What are radial stresses?**

22 A. Tensioning hoop tendons in post-tensioned, pre-stressed containment structures
23 results in radial compression on the region of the containment wall structure to the
24 inside of the tendons and radial tension on the region of the containment wall

1 outside the tendons. This is called radial stress. The radial concrete compressive
2 stress occurs because the tensioned hoop tendons press inward on the containment
3 concrete adjacent to the tendons. Radial tension stress on the outer region of the
4 containment wall occurs because the tendons pull away from the containment
5 wall concrete behind the tendons, thus, resulting in this region of the wall being in
6 tension. In lay terms, then, radial stress existed because tensioned hoop tendons
7 pushed in on the concrete on the inside of the tendons and pulled against the
8 concrete on the backside of the tendons. Radial stress, however, is typically quite
9 small even at its maximum, which occurs during initial tensioning of the tendons.

10
11 **Q. What caused the CR3 dome delamination?**

12 A. The causes of the CR3 dome delamination are associated with the unique stresses
13 created by the geometric design of the dome upon the concrete materials during or
14 immediately after initial tensioning of the dome tendons. The biaxial
15 compression unique to this geometric design combined with the thermal
16 temperatures during the dome construction increased the radial stresses across all
17 the dome tendons in the tensioned, pre-stressed state to the point that the concrete
18 cracked and separated.

19 A similar delamination occurred during construction of the Turkey Point
20 Unit 3 dome in 1970. The Turkey Point Unit 3 dome delamination occurred
21 during tensioning of the dome tendons, three months after the last concrete was
22 placed. The root cause of the Turkey Point 3 dome delamination was found to be
23 a combination of insufficient concrete contact area and unbalanced post-tensioned
24 loads on the dome concrete. Both prior dome delaminations involved the

1 placement of post-tensioned loads on concrete domes during the initial
2 construction of the facilities.

3
4 **Q. Did S&L specifically address the CR3 dome delamination in its analyses for**
5 **the creation of the construction opening in the containment building for the**
6 **SGR project?**

7 A. Yes, the CR3 engineering team and S&L studied the prior CR3 dome
8 delamination despite the differences between the circumstances of the CR3 dome
9 delamination and the CR3 containment opening work for the SGR project.

10 PEF engineers and S&L reviewed the 1976 dome delamination report
11 which described the concrete aggregates used, why they were used, and
12 confirmed that the aggregates met regulatory design requirements for these
13 construction materials. The CR3 dome delamination causes were considered,
14 including the concrete aggregate strength, when S&L reviewed the CR3
15 containment building design, material properties, and prior experience to develop
16 their analyses for the SGR project. S&L determined that the concrete aggregate
17 was of sufficient strength to withstand the stresses created by the temporary
18 construction opening in the containment building and concluded that the prior
19 dome delamination had no impact on the containment shell engineering analyses
20 being performed for the CR3 containment wall opening.

21 S&L reached this conclusion because the typical, average radial stress
22 values used in the standard industry calculations at the time of the SGR project
23 were several factors less than the tensile strength of the concrete. Additionally,
24 based on standard engineering principles and the ACI code, the CR3 containment

1 shell concrete properties, i.e., compressive, shear, and tensile strengths, at the time
2 of the SGR project, were significantly higher than when originally tested for the
3 dome delamination report due to age hardening over the 30 plus years of
4 commercial operation. Also, de-tensioning the tendons, based on industry
5 experience and understanding at the time of the SGR project, reduced the already
6 small radial stresses. Finally, the industry understanding at the time of the SGR
7 project was that the maximum radial tensile stress applied to the CR3 containment
8 shell occurred during original pre-stressing of the hoop tendons when the tendons
9 are initially stressed to 80 percent of their guaranteed ultimate tensile strength
10 (“GUTS”). As a result, industry standard engineering practice at the time of the
11 SGR project did not factor radial stresses into the engineering models for the
12 expected stresses in a post-tensioned, pre-stressed containment structure before
13 and after the creation of a construction opening in the containment structure.

14 S&L operated under this industry understanding and practice when it
15 considered the CR3 dome delamination and root cause investigation in its
16 application of these standard engineering models to calculate the stresses in
17 evaluating the structural impacts associated with creating the construction
18 opening and the loads that the reactor building wall was supporting during
19 implementation of the construction opening activities and replacement of the
20 OTSGs in the CR3 containment building. S&L’s engineering analyses and
21 calculations demonstrated through these various stages of modification to the CR3
22 containment building that all stresses were within allowable limits with ample
23 stress margins. S&L concluded that the activities involved in the creation of the

1 temporary access opening would have no effect on the overall structural integrity
2 of the CR3 containment building.

3
4 **Q. What did you conclude about the CR3 dome delamination in your root cause**
5 **investigation?**

6 A. The circumstances of the prior CR3 dome delamination were sufficiently different
7 from the CR3 containment building delamination that we found the prior dome
8 delamination inapplicable to the delamination that occurred on the SGR project.
9 Only the concrete materials and the absence of radial reinforcement involved in
10 the CR3 dome and wall delaminations were the same, but significantly, the age of
11 the concrete involved in the two delaminations were very different. The concrete
12 involved in the CR3 dome delamination was relatively early its life while the
13 concrete involved in the SGR project containment wall delamination was over 30
14 years old and had withstood over 30 years of operation. As a result, the concrete
15 material properties of the two sets of concrete – for example, the concrete creep,
16 elasticity module, tensile strength, compressive strength, among other properties -
17 - were different for the CR3 dome delamination and the SGR project containment
18 building wall delamination. Due to age hardening over the past 30 years of
19 commercial operation, the elastic modulus, compressive, tensile, and shear
20 strengths of the containment shell concrete are all higher than when first tested
21 during construction and for the dome delamination root cause investigation report.
22 ACI 318 (the design basis code for the containment structure) contains standard
23 equations for calculating the increase in concrete strength due to time.

1 The CR3 dome delamination also involved the initial tensioning of all the
2 tendons in the CR3 dome. The SGR project delamination involved the de-
3 tensioning of horizontal and vertical tendons and the removal of concrete only in
4 the area of the construction opening in a single bay of the CR3 containment
5 building. The tensioning of the dome tendons increased the radial stresses as a
6 result of biaxial compression stresses caused by the unique geometry of the dome
7 construction. The CR3 containment building delamination involved localized de-
8 tensioning, not tensioning, under geometric stresses that were very different from
9 the dome. All of these circumstances rendered the CR3 dome delamination
10 substantially different from the SGR project wall delamination.

11 As a result of these differences, the prior CR3 dome delamination
12 information was of little to no value to us in determining the cause of the CR3
13 wall delamination in the root cause investigation for the SGR project. Indeed,
14 when we applied this information in our root cause investigation of the CR3
15 containment wall delamination using the same industry standard engineering
16 modeling analyses and calculations that S&L used on the SGR project we came to
17 the same conclusion that S&L did, namely, that there were ample margins for the
18 radial or tensile stresses within the concrete for the de-tensioning of the tendons to
19 create the construction opening in the CR3 containment wall.

20
21 **Q. Can you explain how you concluded that there was no reason to expect a**
22 **delamination in the CR3 containment wall even though there was a prior**
23 **delamination in the CR3 dome?**

1 A. Yes. We had the CR3 dome delamination information available to us in the root
2 cause investigation, just like S&L had it when S&L was preparing the engineering
3 calculations for the construction opening on the SGR project. Even with this
4 information, we were unable to simulate the delamination and determine the
5 causes of the CR3 containment wall delamination. There was no indication,
6 based on this information and applying the industry standard engineering
7 modeling analyses and calculations at the time of the SGR project, that there
8 would be a delamination in the CR3 containment wall.

9 To begin with, as I noted above, the CR3 dome delamination occurred
10 during the initial tensioning of the dome tendons during the construction of CR3.
11 Radial stresses are at their maximum during the initial tensioning of the tendons.
12 The SGR project construction opening work involved de-tensioning, not
13 tensioning, of the horizontal and vertical tendons in the construction opening area.
14 De-tensioning the tendons should lower, not increase, radial stresses because the
15 tendon stresses were being reduced from the maximum state of stress to a zero
16 state of stress, not increased from zero stress to the maximum state of stress, as
17 was the case during initial tensioning of the tendons. For this reason, as I
18 explained above, accepted industry practice at the time of the SGR project did not
19 account for radial stresses during the containment analysis for such projects
20 involving de-tensioning to create a construction opening in a pre-stressed, post-
21 tensioned containment structure.

22 Additionally, as I also explained above, radial stresses historically are
23 typically quite low and therefore they are inconsequential in the industry standard
24 containment structure analyses for construction openings in containment

1 structures. The CR3 dome delamination root cause assessment report concrete
2 tensile strength and radial stress calculations confirmed this industry standard
3 engineering practice.

4 The average splitting tensile strength of the concrete, as reported in the
5 root cause assessment report for the CR3 dome delamination for the dome
6 concrete, was 708 psi. Tensile strength is normally determined by the splitting
7 tensile strength test because no standard ASTM test method is available for direct
8 concrete tensile strength testing. This tensile strength was higher than the
9 calculated radial stress, based on the theoretical geometry of the top tendon group
10 in the dome of 41 psi, and the maximum radial tensile stress due to full initial pre-
11 stress tensioning of 55 psi, thus, indicating ample stress margins. The conclusions
12 that the radial tensile stresses were low and that they were far below the tensile
13 strength of the CR3 concrete in the dome in the dome delamination root cause
14 assessment report were consistent with standard industry engineering experience
15 and practice at the time of the SGR project.

16 Based on these standard engineering calculations, the dome delamination
17 root cause investigation concluded that additional factors caused the radial tensile
18 stresses in the dome to be higher than the calculated radial stresses from the dome
19 design. These additional factors caused the radial tensile stresses to exceed the
20 design calculated radial stresses and, in localized areas of the dome, these radial
21 stresses exceeded the dome concrete tensile strength resulting in the delamination.

22
23

1 Q. **What were the additional factors that caused the radial stresses in the CR3**
2 **dome to exceed the calculated, as-designed radial stresses?**

3 A. These additional factors included the solar thermal effects on the tendon grease
4 used in the dome tendon conduits, the solar thermal effects on the dome concrete
5 itself given the total exposure of the dome concrete to the sun during construction,
6 and the impact loads during construction of the dome. All these factors,
7 according to the CR3 dome delamination root cause assessment report, increased
8 the radial stresses on the dome concrete during construction of and the initial
9 tensioning of the dome tendons. These factors were specific to the construction of
10 the CR3 dome.

11 Likewise, other identified factors that contributed to the radial stresses in
12 the CR3 dome leading to the dome delamination were also unique to the CR3
13 dome construction. The particular tendon alignment during actual construction of
14 the geometric placement of the dome tendons increased the curvature of the
15 tendons from the designed curvature, thus, likely creating increased loads and
16 radial tensile stresses in localized areas from the designed load and calculated
17 radial tensile stresses. In other words, the dome tendons could not be placed in
18 the exact spatial location in the geometric design because of physical limitations
19 with the tendon materials and the complexities associated with the actual
20 construction of the overlapping tendons in the dome. As a result, the tendon
21 alignment was slightly higher near the periphery and slightly lower at the apex
22 than designed, increasing the curvature of the tendons as constructed compared to
23 the curvature as designed. This increased curvature increased the loads and, thus,
24 radial stresses in localized areas of the dome. The increased radial stresses in

1 these areas caused them to exceed the calculated, as-designed radial stresses and,
2 in some areas, the tensile strength of the concrete, thus, contributing to the dome
3 delamination.

4 Additionally, the tendon tensioning sequence in the dome contributed to
5 the increase in the radial stresses beyond the calculated, as-designed radial
6 stresses. The tendon tensioning sequence was designed to balance the increase in
7 the radial stresses across the dome associated with increasing the tension in the
8 dome tendons. Though designed in a balanced sequence, the actual tendon
9 tensioning was not completely balanced, and this led to an increase in the radial
10 stresses above the calculated, as-designed radial stresses. The tendon sequencing,
11 then, also contributed to the increase of the radial stresses in the dome beyond the
12 tensile strength of the dome concrete and, thus, contributed to the dome
13 delamination.

14
15 **Q. Were any of these additional factors that led to an increase in radial stresses**
16 **in the CR3 dome tendons above the expected radial stresses present on the**
17 **SGR project?**

18 **A.** No. None of these additional factors that contributed to the increase in radial
19 stresses in the dome beyond the calculated, as-designed radial stresses were
20 present in the construction activities associated with creating the construction
21 opening in the CR3 containment wall on the SGR project. The containment wall
22 was not directly exposed to the solar thermal effects and the 30-plus, year-old
23 containment wall concrete was much less susceptible to such effects and
24 construction loads than the relatively new concrete in the dome at the time of the

1 CR3 dome delamination. The tendon alignment in the containment wall was also
2 different from the tendon alignment in the dome. The containment wall tendon
3 alignment presented none of the additional radial stresses associated with the
4 curvature of the dome tendons in the geometric convex design of the CR3 dome.
5 Finally, the SGR project involved de-tensioning, not tensioning, of the tendons to
6 create the construction opening in the CR3 containment wall. Consequently, none
7 of the additional factors that explained why the radial stresses were higher in the
8 dome than the engineering calculations of the as-designed radial stresses said they
9 should be were present on the SGR project. There was, therefore, no reason to
10 question the standard engineering calculations for the SGR project.

11 Indeed, after the delamination was discovered in the CR3 containment
12 wall, a specific calculation, Calculation S09-0054, was performed to calculate the
13 radial stresses in the containment wall using the industry standard engineering
14 calculations at the time of the SGR project. The average radial stress in the CR3
15 containment wall was calculated at 28.1 psi. Applying a calculated reduction in
16 the cross-sectional concrete area in the modeling analysis to account for the
17 presence of the hoop tendon conduits, the radial stresses increased to 38.7 psi.
18 Applying a further, similar calculated reduction to account for the presence of
19 both the hoop and vertical tendon conduits, the radial stress increased to 45.5 psi.
20 These radial stresses are still well below the tensile strength of the CR3 concrete
21 at 708 psi, as reported in the CR3 dome delamination root cause assessment.
22 These calculations demonstrated that there was a substantial margin for the tensile
23 strength of the CR3 concrete given the calculated radial tensile stresses in the
24 CR3 containment wall based on the industry standard engineering modeling

1 analyses and calculations that S&L used on the SGR project. There was, then, no
2 reasonable basis to conclude that there would be a delamination in the CR3
3 containment wall during the SGR project based on the prior CR3 dome
4 delamination.

5
6 **Q. Did the prior CR3 dome delamination reveal the cause of the October 2009**
7 **CR3 containment wall delamination on the SGR project?**

8 A. No. The causes and circumstances of the two events were completely different.
9 As the CR3 wall delamination root cause assessment confirmed, the 2009 CR3
10 wall delamination was the result of a combination of factors that were not relevant
11 to the CR3 dome delamination, other than the fact that both involved the same
12 type of concrete. Consequently, the prior CR3 dome delamination information
13 was simply not helpful to understanding how the 2009 delamination occurred in
14 the CR3 containment building wall on the SGR project and what the causes of
15 that delamination were. We confirmed in the root cause assessment for the CR3
16 wall delamination that there were sufficient margins for radial tensile stresses
17 within the CR3 containment wall on the SGR project based on the industry
18 standard engineering modeling analyses and calculations. As I previously
19 indicated, we were unable to simulate the CR3 wall delamination and determine
20 the delamination causes using these industry standard engineering modeling
21 analyses and calculations. In fact, even with the rigorous application of the
22 typical engineering standard computer modeling tools during the root cause
23 investigation, PII was unable to reproduce the delamination. The industry
24 standard modeling tools continued to predict a large tensile stress margin and,

1 therefore, a large margin to delamination that simply did not exist even after the
2 delamination occurred. As a result, PEF, its engineers, and its contractors on the
3 SGR project could not recognize that the industry standard engineering modeling
4 tools were incapable of predicting the delamination prior to the delamination
5 occurring on the SGR project. Of course, we were able to recognize that the
6 industry standard engineering models were incapable of predicting the
7 delamination because the delamination had in fact occurred when these
8 engineering modeling analyses continued to predict sufficient stress margins, and
9 thus, margins to delamination in the CR3 containment structure.

10
11 **Q. What did you have to do with the industry standard engineering modeling**
12 **analyses to simulate the CR3 containment wall delamination?**

13 A. We developed state-of-the-art computer modeling, involving the creation of
14 proprietary, first-of-a-kind computerized engineering analyses, to create
15 advanced, three-dimensional ("3-D") engineering modeling analyses. We
16 incorporated the information we learned from our delamination root cause
17 investigation into these enhanced computer modeling analyses. The enhanced
18 computer modeling analyses, together with the information we learned about the
19 CR3 containment structure in the root cause investigation, were used to determine
20 the cause of the delamination. In other words, we had to develop the computer
21 models to explain how the delamination occurred at CR3. Existing industry
22 standard engineering model analyses, as I explained above, could not explain the
23 delamination.

1 Generally stated, we made six improvements to the industry standard
2 engineering models following the wall delamination that were necessary in the
3 enhanced engineering models to predict the delamination. These six methodology
4 improvements are:

- 5 1. Use of fracture energy parameters, versus tensile strength, as failure
6 thresholds;
- 7 2. Modeling of visco-elastic effects of concrete creep, in conjunction with the
8 fracture energy based fracture thresholds, to account for stress reversal effects;
- 9 3. Use of a 360 degree, whole containment model to more accurately reveal
10 realistic displacements;
- 11 4. Incorporation of creep fracture phenomenon around the tendon sleeves to
12 account for a lower tensile strength near the tendon conduits;
- 13 5. Use of fine model meshes to reveal local stress concentrations for crack
14 initiation; and
- 15 6. Use of variable elasticity and fracture toughness based upon local strain.

16 Without these sophisticated changes in the engineering modeling that
17 accounted for contour changes in the CR3 containment building as the project
18 activities progressed, the delamination could not have been accurately predicted.

19 The fact that these six major engineering modeling changes only occurred
20 after the CR3 delamination, demonstrates that it was not possible for these
21 breakthroughs to occur prior to the SGR project. The only reasonable way to
22 identify these modeling deficiencies is to benchmark the engineering codes in the
23 models against industry experience. There was no viable industry experience
24 using these engineering models on similar projects involving the creation of

1 construction openings in containment walls that demonstrated these engineering
2 codes were inaccurate. The models therefore predicted large margins of safety
3 that did not exist before the CR3 delamination.
4

5 **Q. Was the lack of adequate industry engineering models to predict the**
6 **delamination determined to be a contributing factor in the CR3**
7 **delamination?**

8 A. Yes. It was the programmatic root cause for the CR3 wall delamination. We
9 determined in the root cause investigation that the inability of industry accepted
10 engineering modeling tools to predict the delamination was the central issue
11 associated with the CR3 wall delamination. Because the only practical
12 delamination contributing root cause subject to any Company control was the
13 tendon de-tensioning scope and sequence, and because the tendon de-tensioning
14 scope and sequence was determined by application of industry standard
15 engineering models and calculations on the SGR project, we concluded in the root
16 cause investigation that PEF's use of these industry standard engineering models
17 and analyses on the SGR project was the reason the delamination was
18 unpredictable and unpreventable and, therefore, the ultimate or central cause of
19 the delamination.
20

21 **Q. How were the enhanced engineering models developed in the CR3 root cause**
22 **investigation used to determine the causes of the CR3 containment wall**
23 **delamination?**

1 A. The CR3 containment building was “built” in the enhanced 3-D computerized
2 engineering models. It included the CR3 design features and steel and concrete
3 material properties, represented by the calculations of the values of their
4 properties and stresses through initial design information and information gained
5 from the investigative tools used to collect information during the root cause
6 investigation. This information was used in a cylindrical, coordinate computer
7 modeling system. Computer model plots were developed with this information to
8 develop tensile and compressive stresses in the concrete wall due to the horizontal
9 and vertical tendons.

10 PII developed a Global Visco-elastic Abaqus computer model to address
11 local stress conditions within the model based upon a Lee-Fenves concrete
12 damaged plasticity approach and including properties such as creep and concrete
13 Poisson’s ratio, among others. This model further included individual tendons and
14 specifically modeled the steel properties of the liner, rebar, and tendon conduits.
15 Use of the model allowed PII to incorporate realistic material parameters and
16 radial displacements that agreed with the benchmarking data obtained from the
17 root cause investigation to determine why and how the delamination occurred.

18 Once the computer model was created, computer simulations began
19 through various computer iterations that were so complex, they took days or
20 weeks to run. The sheer size of the global computer model that was necessary to
21 model the entire containment structure and the localized stress impacts and forces
22 required a vast series of calculations in the computer iterations for these models.
23 The global model has approximately 250,000 elements and 5 million degrees of
24 freedom (parameters to describe the nodes on each element). The various sub-

1 models have from 125,000 to 1.3 million degrees of freedom each. And, there are
2 a total of 2,681 discrete geometric cells and 10,696 surface patches (locations in
3 the model where loads are applied) in the global model. The bay walls have 10 to
4 12 elements through each cross-section, consisting of both solids and continuum
5 shells. The result was that the enhanced computer modeling allowed PEF to
6 simulate the forces within the CR3 containment structure in the most realistic
7 manner possible in the industry. These results were the product of months of
8 work by a team of engineers using special order high speed and capacity
9 computers.

10
11 **Q. How was this computer modeling used to simulate the CR3 containment**
12 **structure?**

13 A. Computer simulations to determine radial stress displacements were performed
14 for the following milestones: (1) Un-tensioned (circa 1973); (2) Fully tensioned
15 (circa 1976); (3) Fully tensioned in 2009 (after 30 years of concrete and other
16 material (e.g., steel, creep, etc.); (4) Post-SGR project de-tensioning; and (5) Post-
17 SGR project opening completion. *See* the root cause investigation report, pages
18 32 to 61 and attachments 1 and 2 included as Exhibit No. ___ (GM-4) to my
19 testimony. These milestones represented when the CR3 building was built,
20 placed under pre-stress conditions with the tensioning of the containment building
21 tendons, and, then, when the building was led through the de-tensioning activities
22 associated with the creation of the temporary construction opening in Bay 3-4 of
23 the building for the SGR project after thirty plus years of commercial operation.

24

1 **Q. What did the enhanced computer model reveal in the simulated milestones**
2 **for the CR3 containment structure?**

3 A. To begin with, the CR containment building was first in a symmetrical state when
4 construction of the containment building was complete, but prior to pre-stressing
5 any of the structure's tendons. At this point, the structure's stresses consisted
6 primarily of the dead load of the CR3 containment structure itself, which was
7 symmetrically distributed around the building. *See* Figure 7.2 on page 33 of the
8 root cause assessment report attached as Exhibit No. ____ (GM-4). Figure 7.2
9 shows the cylindrical CR3 containment building looking at Bay 3-4 which
10 contained the equipment hatch located between buttresses 3 and 4 in the building.
11 The only significant difference in Bay 3-4 from the rest of the bays in the
12 containment building is the presence of the reinforced equipment hatch.

13 The next symmetric state existed when the CR3 containment building was
14 fully tensioned. The tendon tensioning pattern during initial construction of the
15 CR3 containment building was nearly symmetrical and, therefore, distributed the
16 stresses added to the building in its post-tensioned, pre-stressed state around the
17 building. *See* Figure 7.3 on page 34 of the root cause assessment report attached
18 as Exhibit No. ____ (GM-4). The transition from the initial symmetrical state to
19 the fully tensioned symmetrical state was smooth and free from the localized
20 redistributions of stresses and strains that can promote delamination in concrete
21 areas susceptible to fracturing and separating under the localized redistribution of
22 stresses and strains that occur from changes to the building. Figure 7.3
23 demonstrates those areas of the containment structure that contracted under the
24 force of the fully pre-stressed tendons. The inner or center part of each bay

1 (including the inner or center part of Bay 3-4 above the equipment hatch)
2 contracted the most, leading to a deflection inward in these areas of the bays to
3 the containment building. Figure 7.8 on page 39 of the root cause assessment
4 report provides a cross section view of Bay 3-4 in the PII global model after the
5 initial tensioning of the CR3 containment building in 1975. This view profiles the
6 radial displacement upon full initial tensioning of the CR3 containment building.

7 Figure 7.4 on page 35 of the root cause assessment report attached as
8 Exhibit No. ___ (GM-4) reflects the next milestone, the effects of over 30 years of
9 creep of the concrete and other materials in the containment structure. Creep
10 results in the gradual displacement of concrete under long term stress and the
11 creep effects result in additional and narrowing contraction or deflection in the
12 inner or center regions of the bays. This additional narrowing of the deflection
13 also occurred in the inner or center region of Bay 3-4 above the equipment hatch.
14 This is also demonstrated in the cross section view of Bay 3-4 in the PII global
15 model in Figure 7.9 on page 40 of the root cause assessment report. Additionally,
16 the buttresses to the bays deflect inward slightly too, forming a gradual "C"
17 shaped curve vertically up and down the containment building. These effects
18 were expected at CR3 because the containment building was in a pre-stressed
19 state for over 30 years.

20 The next milestone is completion of the SGR project de-tensioning scope
21 and sequence in Bay 3-4 in 2009. This de-tensioning consisted of 17 horizontal
22 and 10 vertical tendons located in the area of the construction opening in Bay 3-4
23 for the SGR project. This area is located at elevations 183 feet to 210 feet on the
24 building with the maximum effect at elevation 197 feet. Figure 7.5 on page 36 of

1 the root cause assessment report attached as Exhibit No. ____ (GM-4)
2 demonstrates this milestone. The de-tensioning results in the beginning formation
3 of a bulge in the center of Bay 3-4 as the tendons are de-tensioned there with a
4 slight formation of an “S” shaped curve now compared to the prior “C” shaped
5 curve. The effects of de-tensioning are continued in the development of the
6 computer modeling case represented in Figure 7.6 on page 37 of the root cause
7 assessment report attached as Exhibit No. ____ (GM-4). Figure 7.6 reflects the
8 containment-wide response to the de-tensioning activities in Bay 3-4 for the SGR
9 project.

10 Figure 7.6 shows the formation of an hourglass-shaped bulge in the center
11 of Bay 3-4 above the equipment hatch and located around the construction
12 opening where the de-tensioning activities occurred. This hourglass shape
13 matched the actual pattern of the delamination in Bay 3-4 that occurred during the
14 construction opening activities on the SGR project. The formation of the bulge
15 occurs as a result of the radial stresses around the containment building in
16 response to the de-tensioning activities in Bay 3-4. The peak displacement occurs
17 in the fully de-tensioned areas just above and below the bulge in the middle of
18 Bay 3-4. When looking at Bay 3-4 from the outside, at the end of de-tensioning,
19 the wall has an “S” shape with two concave curves and one convex curve. This is
20 also graphically demonstrated in the cross section view of Bay 3-4 in the global
21 model in Figure 7.10 on page 41 of the root cause assessment report. The areas of
22 high radial displacement are identified in red. The maximum curvatures occurred
23 at elevations 173 and 220 in the “S” curve in the global model. The actual
24 maximum gap widths in the delamination occurred at elevations 175 and 216 in

1 the CR3 containment structure. This demonstrated that there was almost
2 complete agreement between the prediction of the delamination in the PII global
3 model and the actual delamination that occurred at the CR3 containment structure.
4

5 **Q. How did the computer simulation in the enhanced computer models**
6 **demonstrate the delamination event?**

7 A. Figure 7.11 on page 42 of the root cause assessment report shows the CR3
8 containment structure wall radial displacement at the various milestones in the
9 simulated computer model of the CR3 containment structure that I just discussed.
10 There is no radial displacement in the un-tensioned milestone case (the straight
11 line in Figure 7.11) and uniform displacement in the fully tensioned milestone
12 case, as demonstrated by the almost uniform bell curves at that milestone. Creep
13 over thirty years of commercial operation increased the displacement to about one
14 inch inward by 2009, as shown in the maximum bell curve line in Figure 7.11.
15 The SGR project de-tensioning creates a double peak radial displacement line (the
16 "S" curve). Figure 7.12 on page 44 of the root cause assessment report attached
17 as Exhibit No. ___ (GM-4) shows the predicted effect of delamination. The wall
18 separates into an inner section and an outer section. The predicted shape and
19 depth of the separation in the enhanced computer model is in general agreement
20 with the actual plot of the depth and hourglass shape of the separation or
21 delamination that formed in Bay 34 shown in Figure 7.14 on page 45 of the root
22 cause assessment attached as Exhibit No. ___ (GM-4) to my testimony. The
23 location of the peak radial displacement caused by the redistribution of stresses
24 within the computer modeling matched the location of the widest gap of the

1 delamination in Bay 3-4 of the CR3 containment building. The delamination was
2 therefore accurately simulated when the CR3 containment building was allowed
3 to redistribute or displace stresses in response to the de-tensioning activities
4 undertaken to create the construction opening in the CR3 containment building on
5 the SGR project in the enhanced computer model.

6
7 **Q. What do you mean by the redistribution of stresses, how did that occur?**

8 A. The CR3 containment building is normally in a symmetric state of loads and
9 deformations and, thus, stresses, within the building. When changes cause the
10 building to transition from a symmetrical state to a non-symmetric state, the
11 building experiences a redistribution of stresses that may exceed its capacity to
12 withstand those stresses in areas most susceptible to them. The de-tensioning
13 activities on the SGR project were a change to the building's symmetrical state
14 prior to de-tensioning that forced the CR3 containment structure to transition out
15 of its existing symmetrical state. During this transition, stresses were
16 redistributed in the CR3 containment building to the area in and around the
17 containment opening where the tendons were de-tensioned. Consequently, even
18 though the tendons were being de-tensioned in that area, thus, relaxing the pre-
19 stresses caused by tendon tensioning, tensile stresses increased due to the re-
20 distribution of stresses around the building that was occurring because the
21 building was transitioning out of one symmetrical state and seeking another
22 symmetrical state. The delamination occurred when these redistributed tensile
23 stresses exceeded the capacity of the concrete to withstand these stresses in those
24 areas most susceptible to the increased stresses. This area was the vertical plane

1 of the horizontal tendons adjacent to the vertical tendons in the containment
2 opening area where the tensile and radial stresses were already the highest and,
3 thus, the separation initiated there and spread. The stresses were redistributed to
4 the point where they exceeded the concrete capacity to resist cracking, thus,
5 initiating the delamination at those points.

6
7 **Q. How did this redistribution or displacement of stresses impact the localized**
8 **stress conditions where you previously testified the delamination occurred?**

9 A. These localized areas were the vertical planes of the horizontal tendons adjacent
10 to the vertical tendons located on the inner side of the horizontal tendons in the
11 construction opening that were de-tensioned. The vertical plane of these
12 horizontal tendons is where the radial tensile stresses met along the hole created
13 by the horizontal tendon conduit or sleeves creating the highest stress for the
14 concrete material in that area. The stresses in these areas under normally
15 tensioned conditions are demonstrated graphically in the enhanced computer
16 models in Figures 3.4 and 3.5 on pages 22 and 23 of the root cause assessment
17 report attached as Exhibit No. ___ (GM-4) to my testimony.

18 These areas within the CR3 containment structure were the most
19 susceptible to delamination because the factors found to contribute to the
20 delamination converged in these areas. The layout of the horizontal tendon and
21 vertical tendon sleeves or conduit in the CR3 containment wall is shown in the
22 cross-section diagram in Figure 3.2 on page 19 of the root cause assessment report
23 attached as Exhibit No. ___ (GM-4) to my testimony. They are located at a depth
24 of about ten inches from the outer containment wall with a pair of tendons about

1 every 39 inches. There is no radial steel reinforcement in this area. A tendon
2 sleeve or conduit is the outer casing that holds the wires of each tendon and
3 measures about 5.25 inches in diameter. This is a large diameter tendon conduit
4 or sleeve for post-tensioned, pre-stressed containment structures. The CR3
5 tendons also contain 163 wires of 7 mm (0.276") diameter wire. Compared to
6 other six buttress designed (like CR3) containment structures, the CR3 tendon
7 design includes more wires and larger diameter wires. The importance of these
8 design differences is that the larger the tendon cross section created by the larger
9 conduit and larger number and size tendon wires, the higher the peak compressive
10 stress on the concrete immediately in contact with the tendon conduit or sleeve.
11 This directly translates to higher peak radial tensile stresses at the vertical
12 centerline of the hoop tendons.

13 At the depth of the horizontal and vertical tendons in the concrete from the
14 outer layer of concrete in the CR3 containment wall, given the size of the tendon
15 conduit (5.25 inches in diameter) and how close together they are (two conduits in
16 every 39 inches), 27 percent of the cross-sectional area has the concrete displaced
17 by tendon sleeves. The displacement of concrete at this location increases the
18 stress on the remaining concrete at exactly the location of the radial tensile stress
19 at the top and bottom of each horizontal tendon sleeve. The average radial stress
20 in this location is 1.4 times what it would be without the displacement of the
21 concrete by the tendon conduit. And, as I explained previously, the CR3 concrete
22 met all design requirements and had excellent compressive strength. But the
23 concrete, in particular the limestone aggregate, was softer than other aggregates
24 and, therefore, more susceptible to tensile stresses.

1 As a result, the contributing factors to the delamination converged in the
2 vertical plane of the horizontal tendons adjacent to the vertical tendons when they
3 were de-tensioned for the CR3 SGR project. High stress areas existed along all
4 the horizontal tendon planes where horizontal tendons were adjacent to vertical
5 tendons both inside and outside the planned construction opening in the CR3
6 containment building. This can be graphically seen in Figures 3.4 and 3.5 on
7 pages 22 and 23 of the root cause assessment report attached as Exhibit No. ____
8 (GM-4) to my testimony.

9 Figure 3.4 illustrates the high stresses and displacement of concrete by the
10 tendon sleeves. The de-tensioning activities increased these localized stresses
11 further when tendons were de-tensioned to create the CR3 construction opening in
12 the containment building. These increased radial tensile stresses for the
13 delamination conditions are shown in Figure 7.29 on page 59 of the root cause
14 assessment report attached as Exhibit No. ____ (GM-4) to my testimony. As
15 demonstrated in the enhanced computer model in Figure 7.29, these increased
16 radial tensile stresses are located at the 12 and 6 o'clock positions around the
17 horizontal tendon conduit adjacent to the vertical tendon conduit in the model of
18 the CR3 containment structure. This is the location along which the delamination
19 propagated from the top and bottom of the holes to the next hole vertically and
20 propagated circumferentially (azimuthally) around a segment of the building as
21 shown in Figure 7.28 on page 58 of the root cause assessment report. It is likely
22 that small cracks formed at these intersections, but then stopped propagating when
23 they reached a location where the stress was too low to continue.

1 In summary, CR3's specific design results in an area of reduced concrete
2 area and, thus, high radial tensile stress around the tendon sleeves that are inside
3 the concrete containment structure. Considered alone, the stresses involved in the
4 CR3 containment design are well within the capability of the concrete material
5 used. However, when stresses occur for other reasons, such as the redistribution
6 of stresses resulting from de-tensioning of tendons and cutting the opening, these
7 additional stresses at CR3 contribute to the overall high stress condition in these
8 localized areas of the CR3 containment structure and lead to the delamination.

9
10 **Q. Based on your root cause assessment work, then, did PEF prudently manage**
11 **the de-tensioning scope and sequence on the CR3 project even though it was**
12 **a contributing factor to the delamination?**

13 A. Yes. As I explained, we evaluated the de-tensioning scope and sequence on the
14 SGR project during the root cause assessment. We found that both the de-
15 tensioning scope and sequence were determined after engineering calculations
16 and modeling analyses were performed using industry standard engineering
17 calculations and modeling analyses. The results indicated sufficient stress
18 margins to perform the SGR project de-tensioning scope and sequence, even
19 though the de-tensioning sequence had been divided into two phases with only
20 part of the de-tensioning performed prior to creation of the construction opening
21 in the containment wall. PII confirmed in its modeling analyses that application
22 of the industry standard engineering calculations and models at the time indicated
23 sufficient stress margins as shown on pages 69-70 in the root cause assessment
24 report attached as Exhibit No. ____ (GM-4) to my testimony.

1 Additionally, our root cause investigation included a survey of the scope
2 and sequencing of the de-tensioning on other construction projects in the industry
3 involving the creation of construction openings in post-tensioned, pre-stressed
4 containment structures. These projects are identified in the Significant Adverse
5 Condition Report, Action Request (“AR”) Number 358724, attached as Exhibit
6 No. ___ (GM-6) to my testimony. This report includes a summary of the
7 similarities and differences of those projects to the CR3 SGR project.

8 We concluded from this investigation that both the de-tensioning scope
9 and sequence on the SGR project were within industry acceptable de-tensioning
10 scope and sequencing practices. The de-tensioning scope on the SGR project was
11 confirmed by engineering standard calculations and models and reviewed by
12 engineers and contractors with prior de-tensioning experience on similar projects.
13 Further, when the de-tensioning scope was divided into two phases, with the first
14 phase applying only to de-tensioning the tendons within the intended containment
15 opening prior to creation of the opening, and the second phase following the
16 movement of the steam generators out and into the building, this change in scope
17 was confirmed by further application of the standard engineering calculation
18 models. Further, the actual de-tensioning sequence that was implemented on the
19 SGR project was consistent with the de-tensioning sequences employed on other,
20 similar projects in the industry. The tendon de-tensioning on the SGR project was
21 sequential, starting from the bottom and proceeding to the top of the tendons to be
22 de-tensioned. This sequence was consistent with the tendon de-tensioning
23 sequence used on some of the similar projects in the industry.

1 In sum, our root cause investigation revealed that PEF prudently employed
2 a de-tensioning scope and sequence that was consistent with standard engineering
3 and construction practices at the time of the SGR project. Indeed, our root cause
4 investigation revealed that the industry understanding behind the established de-
5 tensioning scope and sequence practices was, as I described previously, simply
6 inadequate for the CR3 containment building. As a result, even if PEF had
7 implemented the original, total planned de-tensioning scope consistent with
8 industry practices on other, similar projects or employed other, industry standard
9 de-tensioning sequences on the SGR project, the delamination still would have
10 occurred at CR3, and it likely would have been worse. There was no way PEF
11 could have known this at the time of the SGR project and, therefore, there was no
12 way PEF could have prevented the delamination by changing the de-tensioning
13 scope and sequence for the SGR project.

14
15 **Q. Why would the delamination be worse if more tendons were de-tensioned**
16 **around the containment opening in the CR3 containment building?**

17 **A.** In simple terms, we determined in the root cause assessment that the complex
18 local stress conditions in the de-tensioning area were impacted by the response of
19 the building as a whole to the de-tensioning activities, redistributing and adding
20 stresses to those local stress conditions to the point that the fracture capacity of
21 the concrete was exceeded, and the concrete separated or delaminated. As a
22 result, de-tensioning more tendons in the localized area around the containment
23 opening consistent with industry standard engineering and construction practices

1 would have exacerbated this response within the entire containment structure and
2 made the delamination worse.

3 To explain further, when a temporary construction opening is going to be
4 made in post-tensioned, pre-stressed concrete containment structures like CR3,
5 the local area in and around the construction opening is generally the only area
6 where tendons have to be de-tensioned. In other words, if a hole is being cut in
7 the containment structure in a specific bay, only the tendons in that specific bay in
8 the containment structure have to be de-tensioned. This was standard engineering
9 and construction practice on all prior industry projects involving temporary
10 construction openings cut into post-tensioned, pre-stressed containment
11 structures. See Exhibit No. ___ (GM-6) to my testimony.

12 After the delamination took place at CR3, however, we discovered as a
13 result of our root cause assessment that CR3 is not like other containment
14 structures because tendons all around the CR3 containment building have to be
15 de-tensioned in a very specific order, not just in the area where the construction
16 opening is being created, to avoid delamination. As a result, de-tensioning the
17 tendons located around the CR3 construction opening as well as the tendons
18 located within the construction opening would not have avoided the delamination.
19 Based on the results of our root cause investigation it would have made the
20 delamination worse.

21
22 **Q. Would increasing the number of tendons de-tensioned or changing the order**
23 **the tendons were de-tensioned reduce these stresses and prevent the**
24 **delamination?**

1 A. No. De-tensioning the tendons outside the planned containment opening as well
2 as inside the opening would have involved the same increased radial tensile
3 stresses on the concrete in the planes of those horizontal tendons that are
4 graphically illustrated in Figure 7.29 of the root cause assessment report and that
5 exceeded the fracture capacity of the concrete and led to the delamination. These
6 peak stresses increased due to the growing number of de-tensioned tendons,
7 causing the redistributed stresses along the plane to increase, leading to the
8 delamination that occurred. Increasing the number of de-tensioned tendons
9 further in the area around the construction opening would have exacerbated the
10 delamination. This would result in increases in stresses in the horizontal planes of
11 the additional de-tensioned tendons, extending and expanding the bulges that led
12 to the delamination, thus, making the breadth and depth of the delamination
13 worse.

14 Altering the sequence for the de-tensioned tendons in and around the
15 construction opening in the CR3 containment building also would not have
16 prevented the delamination. Changing the order of the tendons de-tensioned
17 would not change the end-points in the horizontal tendon planes at the intersection
18 of the vertical and horizontal tendons, which is the highest stress condition.
19 Because these same high stress conditions existed regardless of the order of the
20 tendons de-tensioned in and around the construction opening, changing that order
21 would not have affected the localized redistribution of stresses that occurred as
22 the CR3 building responded to the de-tensioning occurring in and around that
23 construction opening.

24

1 **IV. THE ROOT CAUSE INVESTIGATION AND ASSESSMENT.**

2 **Q. When did PEF commence the root cause assessment?**

3 A. PEF commenced the root cause investigation or assessment shortly after the
4 delamination was first recognized. At this point, PEF SGR project personnel
5 concluded that the extent of the separation was more than localized cracks
6 adjacent to the cut concrete visible in the SGR opening. Hydro-demolition was
7 suspended until the condition could be evaluated by Design Engineering. The
8 SGR project team immediately began the process of creating an action plan to
9 address the condition at that time. This was the commencement of the root cause
10 investigation.

11 The SGR project team determined that without further concrete removal,
12 the extent of the containment wall separation could not be fully assessed. The
13 SGR project team also determined that continued hydro-demolition did not pose
14 any safety or further risk of damage to the plant. Accordingly, PEF re-started
15 hydro-demolition concurrently with the development of the action plan for
16 investigating the separation that was found. Further hydro-demolition revealed a
17 gap running vertically in the plane between the horizontal tendons about ten
18 inches deep into the concrete from the outside surface. Later that day, a Nuclear
19 Condition Report (“NCR”) 358724 – Containment Delamination was generated to
20 document the condition discovered and to formalize a full assessment of the
21 condition. The NCR was classified as a Significance Level 1, which required a
22 formal root cause assessment of the cause of the event and the identification of
23 corrective actions to prevent recurrence. A copy of NCR 358724 is included as
24 Exhibit No. ___ (GM-6) to my testimony.

1 Plant management assigned personnel independent from the SGR project
2 team to conduct the root cause assessment. Lead responsibility was assigned to
3 Charles Williams, an experienced manager from the Harris nuclear power plant.
4 He was supported by other experienced engineering personnel from CR3 as well
5 as other Progress Energy locations, and the team began to assemble on site on
6 October 8, 2009, less than a week after the delamination event.

7 Concurrent with the formation of the initial Root Cause Assessment Team,
8 hydro-lazing of the temporary construction opening in the CR3 containment wall
9 continued through October 8, 2009. Shortly after the Root Cause Team leader
10 arrived on site, the concrete had been removed from the opening and the area was
11 available for a more comprehensive inspection. Based on the extent of the
12 delamination observed at that time, the Root Cause Assessment Team recognized
13 that the assessment of the condition would require additional resources and efforts
14 were immediately initiated to bring in other Progress Energy personnel as well as
15 external technical experts. Based on this better understanding of the extent of the
16 delamination, on October 10, 2009, I was asked to take the lead as the Project
17 Manager of the CR3 Containment Root Cause Investigation and I reported to the
18 site in this position on October 12, 2009. In my role as Project Manager, I
19 reported directly to Progress Energy's Chief Nuclear Officer.

20
21 **Q. Did you report the CR3 containment wall delamination to the NRC?**

22 **A.** Yes. Plant licensing personnel reviewed the identified CR3 containment wall
23 condition against the reporting criteria contained in 10 C.F.R. 50.72 and 10 C.F.R.
24 50.73. This review included a determination of (1) any operation or condition

1 which was prohibited by CR3's technical specifications; (2) any event or
2 condition that resulted in the condition of the nuclear plant, including its principal
3 safety barriers, being seriously degraded; and (3) any event or condition that
4 could have prevented the fulfillment of the safety function of structures or
5 systems that are needed to shut down the reactor and maintain it in a safe
6 condition, remove residual heat, control the release of radioactive material, or
7 mitigate the consequences of an accident. The CR3 plant licensing personnel
8 concluded that none of the reporting criteria under 10 C.F.R. Part 50.72 and 50.73
9 applied since the delamination occurred after CR3 had entered an operational
10 MODE (various operating and shutdown states defined in the CR3 license) in
11 which the CR3 containment building was not required to be operable. However,
12 in the interest of public and regulatory awareness of the October 2009
13 delamination, PEF did make a voluntary notification to the NRC on October 7,
14 2009 under the provisions of 10 C.F.R. 50.72.

15
16 **Q. Why didn't PEF simply fill in the gaps in the outer wall of the concrete, in
17 other words, why did PEF even need to conduct this root cause investigation?**

18 **A.** PEF needed to be sure that the CR3 containment building performed its safety-
19 related function and met its design basis license requirements when CR3 re-
20 commenced operations. The CR3 containment building is a safety-related nuclear
21 structure. In the CR3 reactor building, there are three safety-related barriers that
22 keep any sudden build-up of heat, pressure or radiation from escaping the reactor
23 and reactor building. The first is the metal cladding encasing the nuclear fuel
24 itself, the second is the reactor vessel where the nuclear fuel is located together

1 with the coolant piping system, and the third is the carbon steel containment liner.
2 The carbon steel liner is three-eighths inch thick and it covers the inside of the
3 CR3 containment building. It is protected externally by the 42 inch thick concrete
4 wall that is strengthened with the hundreds of tightened or tensioned vertical and
5 horizontal steel tendons that I previously described. If the building suffered a
6 major LOCA, much of the water in the reactor system would flash to steam and
7 the pressure would rise inside the building. The pre-stressed steel tendons inside
8 the containment structure and the thick concrete wall are there to help maintain
9 the strength in the structure to withstand these pressures.

10 In fact, upon the initial start-up of the facility one of the tests the facility
11 must pass is the Structural Integrity Test (“SIT”) before nuclear operations can
12 commence. The SIT involves subjecting the CR3 containment building to 115
13 percent of the building’s design pressure to ensure the containment building can
14 withstand any pressures that might build up because of any design basis LOCAs
15 within the reactor building. The CR3 containment building passed this SIT prior
16 to the commencement of commercial operations at CR3.

17 PEF needed to be sure that the CR3 containment structure was capable of
18 performing the safety-related function when it re-commenced operations. Upon
19 discovery of the delamination, PEF conducted an operability evaluation and
20 determined that the CR3 containment structure was capable of maintaining its
21 integrity during postulated shutdown accident scenarios and, thus, performing its
22 safety-related function as long as the CR3 plant was in shutdown condition.
23 However, if the delamination had gone undetected, or if the delamination was
24 repaired without fully understanding what caused the delamination to occur, the

1 containment building might not have been able to withstand the internal pressure
2 associated with an operating MODE accident such as a LOCA. As a result, the
3 root cause investigation was necessary to determine why the delamination
4 occurred and, therefore, how to repair the delamination with confidence that the
5 safety-related function of the CR3 containment structure was not impaired and the
6 license basis for the building was met.

7
8 **Q. What do you mean by the license basis requirements?**

9 A. CR3, like every other nuclear facility in the United States, has a NRC license to
10 operate. This license is premised on a detailed license application that provides a
11 detailed description and analysis of the design, construction, and operation of the
12 plant. NRC approval of the license for the nuclear facility is based in part on the
13 NRC's review and approval of this license application. Upon approval by the
14 NRC, the utility must continue to operate the nuclear facility in accordance with
15 this approved license application. This establishes the plant's license basis. The
16 utility cannot make changes to the plant's license basis without obtaining
17 approval for the change in a license amendment approved by the NRC.

18 With regard to the CR3 containment building delamination issue the most
19 pertinent design basis criteria are set forth in the Final Safety Analysis Report
20 ("FSAR") that was filed with the NRC as part of the operating license for CR3
21 and in the Industry Codes (e.g., the American Concrete Institute's building code
22 requirements for reinforced concrete, "ACI 318-63" that governed the design and
23 construction of the CR3 containment building). These design basis criteria cover
24 a range of factors, such as the strength of the concrete and the ability of the CR3

1 containment building to handle loads from seismic events, high winds, and other
2 events up to and including a LOCA. To ensure that this license basis requirement
3 was maintained, PEF had to determine what caused the delamination. Only then
4 could PEF be assured that the delamination repairs adequately addressed the
5 causes of the delamination such that the license basis requirement was satisfied.

6 PEF determined that a root cause investigation was necessary and would
7 also be consistent with the NRC's requirements for nuclear power plant
8 maintenance and operations. Criterion XVI, "Corrective Action," of Appendix B
9 of 10 C.F.R. Part 50, entitled "Quality Assurance Criteria for Nuclear Power
10 Plants and Fuel Reprocessing Plants," requires that measures shall be established
11 to assure that conditions adverse to quality, such as failures, malfunctions,
12 deficiencies, deviations, defective material and equipment, and non-conformances
13 are promptly identified and corrected. If the event or condition is identified as a
14 significant condition, which was the case with the October 2009 CR3 wall
15 delamination, PEF must implement measures to determine the cause of the
16 condition and what corrective action must be taken to ensure the event or
17 condition does not recur. The identification of the event or condition, the cause of
18 the event or condition, and the corrective action taken must further be
19 documented and reported to the appropriate levels of Company management.
20 PEF's root cause investigation of the October 2009 CR3 wall delamination
21 complied with these necessary measures.

1 **Q. Did the NRC reach a similar conclusion regarding the investigation into the**
2 **root cause of the October 2009 CR3 wall delamination?**

3 A. Yes. The NRC inspectors concluded that the CR3 wall delamination was not a
4 reportable event to the NRC under 10 C.F.R. Part 50.72 and 10 C.F.R. Part 50.73.
5 The NRC inspectors also evaluated the safety significance of the delamination
6 event and concluded that the CR3 wall delamination did not represent an
7 immediate safety concern because the plant was shut down when the October
8 2009 wall delamination occurred. Accordingly, the NRC Team concluded that
9 the delamination did not represent an increase in risk to the public. The NRC did
10 conclude, however, that the discovery of the CR3 wall delamination was
11 important because the CR3 containment building supports the carbon steel liner,
12 one of the three main barriers that protect public safety; the concrete delamination
13 was not expected; and it had not been seen previously during the steam generator
14 replacement activities at other nuclear projects. As a result, the NRC inspectors
15 determined that the CR3 wall delamination possibly raised generic adverse
16 implications because the structural integrity of the CR3 containment was not fully
17 known and the concrete separation was not well understood. For these reasons,
18 the NRC inspectors initiated their own independent investigation to better
19 understand the CR3 wall delamination issues.

20
21 **Q. Having decided to initiate a root cause investigation of the CR3 wall**
22 **delamination, what was the purpose or goals of the Company's delamination**
23 **root cause investigation?**

1 A. The goal of the root cause analysis team in conducting the root cause
2 investigation was to determine what caused the separation in the concrete in Bay
3 3-4, why the separation occurred, when it happened, the extent of the condition,
4 what PEF could do to fix it, and whether it could have been prevented. As I just
5 explained, determining why the delamination occurred would assist PEF in
6 determining the delamination repairs to ensure that the license basis requirements
7 and safety-related function of the CR3 containment structure was met when PEF
8 re-commenced commercial operations at CR3.

9
10 **Q. Did PEF have in place any procedures or processes to handle a root cause**
11 **investigation like the CR3 delamination root cause investigation?**

12 A. Yes. PEF's Nuclear Generation Group has an established Corrective Action
13 Program ("CAP") that complies with the requirements of Criterion XV and
14 Criterion XVI of 10 C.F.R. 50, Appendix B. The program is implemented via
15 procedure CAP-NGGC-0205, "Condition Evaluation and Corrective Action
16 Process." A copy of this procedure is included as Exhibit No. ____ (GM-7) to my
17 testimony. This procedure, among other things, provides guidance to effectively
18 conduct a structured Root Cause Evaluation ("RCE") to identify cause(s) and
19 develop appropriate corrective action(s), and prepare applicable reports and
20 records. The performance of a RCE for the CR3 October 2009 containment wall
21 delamination was identified as a required action under NCR 358724, which I
22 previously discussed. The CR3 Containment Root Cause Team was put in place
23 to conduct the RCE in accordance with the provisions of this procedure. As I
24 previously discussed, I was assigned as the Project Manager of the CR3

1 Containment Root Cause Team and I had overall responsibility for the root cause
2 investigation. The CR3 Containment Root Cause Team was established
3 independent from the CR3 SGR Project Team. This allowed the SGR Project
4 Team to maintain their focus on the successful completion of other aspects of the
5 SGR project while the RCE was being conducted.

6
7 **Q. Please describe the organization that was established to conduct the**
8 **investigation for the CR3 containment delamination.**

9 A. As I previously testified, the mobilization of a Root Cause Assessment Team
10 began shortly after the delamination was identified. When Mr. Williams arrived
11 on site on October 8, 2009, he quickly identified that the RCE required significant
12 effort and that resources and technical expertise beyond what existed at Progress
13 Energy was needed in order to do a thorough and timely evaluation. His initial
14 assessment was that at least three functional teams (Root Cause, Design Basis,
15 and Correction Action/Repair) were needed. Mr. Williams advised management
16 of his preliminary assessment of the required effort and began the process of
17 assembling additional staff and technical expertise both from within Progress
18 Energy as well as from external sources. Shortly thereafter, plant and corporate
19 senior management determined that an extensive and focused effort was required,
20 and I was appointed as Project Manager of the Containment Root Cause
21 Investigation reporting directly to Progress Energy's Chief Nuclear Officer.
22 Exhibit No. ___(GM-8) to my testimony is a copy of the Progress Energy Chief
23 Executive Officer ("CEO") briefing on October 21, 2009 that shows at slide 9 the
24 corporate reporting relationship that was established.

1 Mr. Williams and I led a team kick-off meeting with the members that had
2 already been mobilized on site on October 12, 2009. From the kick-off meeting
3 we determined that a fourth functional team was needed to be responsible for
4 coordinating and conducting activities associated with determining the condition
5 of the containment structure. Thus at this point, the on-site team consisted of four
6 functional teams -- (1) the Condition Assessment Team, (2) the Root Cause
7 Assessment Team, (3) the Design Basis Team, and (4) the Corrective
8 Action/Repair Team -- as shown on slide 11 of Exhibit No. ____ (GM-8). The
9 exhibit also shows the staffing that had been identified by that time or shortly
10 thereafter. All four of the functional teams worked under my supervision.

11 Slide 10 of Exhibit No. ____ (GM-8) shows how the Containment Root
12 Cause Investigation Team was linked to other parts of the Progress Energy
13 organization and how independent oversight of the team's work was
14 accomplished. In addition to the project organization, a project work flow
15 summary was prepared to visually show how each of the teams fit into the overall
16 evaluation process to determine a root cause and to identify appropriate corrective
17 actions and repairs for the containment. The work flow process is shown on
18 Exhibit No. ____ (GM-9) to my testimony.

19
20 **Q. How was the CR3 Containment Root Cause Investigation Team selected?**

21 **A.** The CR3 Containment Root Cause Investigation Team included engineers and
22 managers from within Progress Energy with a breadth of experience on complex
23 nuclear power plant design, maintenance and construction projects. The CR3
24 Containment Root Cause Investigation Team also included engineers from peer

1 utilities with nuclear operating facilities in the industry. Engineers from the VC
2 Summer and Three Mile Island nuclear plants, and from the corporate offices of
3 Exelon and the Southern Company participated on the CR3 Containment Root
4 Cause Investigation Team.

5
6 **Q. What steps did PEF employ to implement the root cause investigation
7 procedure?**

8 A. PEF began by selecting a company to conduct a formal root cause analysis for the
9 CR3 delamination event. The CR3 Containment Root Cause Investigation Team
10 immediately solicited proposals from companies who had the background and
11 experience to potentially provide professional root cause analysis services to help
12 us determine the cause of the delamination in the CR3 containment building wall.

13
14 **Q. How was that request for proposals administered?**

15 A. PEF issued Request for Proposal No. J009-010 220434 for professional root cause
16 analysis services. A copy of Request for Proposal No. J009-010 220434 is
17 included as Exhibit No. ___ (GM-10) to my testimony. Eight companies
18 provided bids in response to Request for Proposal No. J009-010 220434. The
19 Root Cause Investigation Team developed evaluation criteria to guide the
20 evaluation process to screen and select the appropriate bidder. Each criteria was
21 assigned a weighting factor based on the importance of that criteria to
22 accomplishing the expected work. The evaluation criteria were as follows:

1 (1) *Root Cause Method* – does the vendor propose to use a rigorous and structured
2 root cause analysis approach that is proven to provide reliable, consistent, and
3 accepted results?

4 (2) *Technical Expertise* – does the vendor have technically qualified staff, with
5 experience in concrete structures and their potential failure modes, as well as
6 the analytical tools to investigate, analyze, and determine contributing root
7 causes?

8 (3) *Regulatory Credibility* – does the vendor have experience with root cause
9 analyses that have received scrutiny from the NRC, and does the NRC respect
10 and recognize the vendor as a qualified root cause analysis provider?

11 (4) *Schedule* – How does the vendor’s schedule support PEF’s needs on the CR3
12 project?

13 (5) *Special* – Any additional relevant attributes, such as recent similar projects
14 that may help provide insights into the CR3 condition.

15 (6) *Appendix B Program* – Does the vendor have an approved 10 C.F.R. 50,
16 Appendix B program?

17 Each of the eight bidders were rated on the six criteria on a scale from one to four,
18 with four being the strongest and one being the weakest score. The rating on each
19 criteria was multiplied by the weighting factor and the scores were totaled to
20 provide an overall score and ranking for each bidder.

21
22 **Q. Who did PEF ultimately select to perform the root cause evaluation?**

23 A. Based on the evaluation, Performance Improvement International, LLC (“PII”)
24 ranked highest of the eight RFP respondents and was selected to assist PEF in the

1 performance of the October 2009 CR3 wall delamination root cause analysis. PII
2 was selected because of their extensive track record, solving more than 5,000
3 complex cases without recurrence of the events or conditions that led to the
4 incident investigated. In fact, PII has helped more than 80 percent of U.S. nuclear
5 utilities to set up their root cause programs and train their root cause engineers.
6 Moreover, PII has trained many NRC and Department of Energy (“DOE”) staff
7 by using the rigorous PII root cause investigation methodology. Further, between
8 1996 and 2001, PII trained and mentored more than fifty senior root cause
9 engineers at CR3 with PII’s rigorous root cause methodology.

10
11 **Q. Were there other reasons for selecting PII to perform the root cause**
12 **analysis?**

13 **A.** Yes. Beyond this comprehensive track record, there are several other reasons
14 why PII was uniquely qualified to perform the root cause analysis for PEF:

- 15 (1) PII’s root cause methodology has been well received by NRC, Institute of
16 Nuclear Power Operations (“INPO”), U.S. Nuclear Utilities, and CR3
17 management;
- 18 (2) PII’s root cause team was led by Dr. Chong Chiu, who is well respected by
19 the NRC and in the nuclear industry;
- 20 (3) PII’s root cause team included expertise in every aspect of potential
21 containment delamination issues (e.g., concrete failure mode analysis, testing
22 result analysis, materials, containment structure analysis, construction
23 performance analysis, concrete composition analysis, and severe
24 accident/containment integrity analysis); and

1 (4) PII's root cause team was knowledgeable of and very sensitive to nuclear
2 safety regulations regarding containment integrity, nuclear safety operability
3 issues, and public perceptions of containment integrity in the nuclear industry.
4 The team included members with utility nuclear reactor operational and
5 licensing experience.

6 PII's root cause methodology also involves a structured approach to
7 development of all possible failures modes and disciplined failure mode-scenario
8 evidence proofing matrix analysis, all widely accepted in the nuclear industry. In
9 addition to PII's root cause methods, PII agreed to perform special testing and/or
10 utilization of appropriate analytical techniques as needed. In summary, retaining
11 PII ensured PEF that the root cause work on the CR3 delamination would be
12 performed with a proven root cause methodology that was well known to the
13 NRC (including all Region II management) and CR3 root cause engineers.

14 In addition to PII, PEF retained experienced consultants and engineers to
15 assist PII to develop complicated calculations, methods, conduct third party
16 reviews, and develop best practices for the root cause analysis and repair process.
17 Along with Dr. Chiu, PII's professional team and other root cause team members
18 included subject matter experts, material experts, structural experts, and root
19 cause investigation and testing experts. The resumes of participants in the
20 October 2009 CR3 wall delamination root cause analysis are contained in the root
21 cause assessment report included as Exhibit No. __ (GM-4) to my testimony.
22
23

1 **Q. How was the October 2009 CR3 wall delamination root cause assessment**
2 **conducted?**

3 A. As I previously indicated, PEF organized the CR3 Containment Root Cause
4 Investigation Team to move forward with examination of the delamination and
5 perform a detailed condition assessment of the CR3 containment building,
6 conduct the Root Cause Assessment to determine how and why the October 2009
7 wall delamination occurred, and to develop a repair plan. The Root Cause
8 Investigation Team work was performed under CR3's Appendix B program.
9 CR3's Appendix B program conforms to common, accepted practice in the
10 nuclear industry and 10 C.F.R. 50, Appendix B – Quality Assurance Criteria for
11 Nuclear Power Plants and Fuel Reprocessing Plants. The four separate branches
12 or groups of the Root Cause Investigation Team, i.e., the (1) Root Cause
13 Analysis; (2) Design Basis Analysis; (3) Repair Alternatives Analysis; and (4)
14 Condition Assessment, focused on their particular strategic area, with appropriate
15 information sharing and cross-checking among each group, such that each group's
16 efforts fed into the common goals of understanding the cause of the event,
17 determining the extent of the problem, and identifying the repairs necessary to
18 satisfy the design basis requirements of the containment structure. Analysis
19 cross-checking was also conducted by the SGR project team performing peer
20 reviews before implementing any repairs at CR3. See Exhibit No. ____ (GM-8) to
21 my testimony.

22

23

1 **Q. Was the Root Cause Investigation Team subject to PEF's project**
2 **management oversight and controls policies and procedures?**

3 A. Yes. PEF used internal and external resources to develop an organizational and
4 reporting structure to effectively assess the root cause of the delamination.
5 Project controls were established for contract administration, scheduling, and
6 financials. Oversight and independent review was conducted by the Plant Nuclear
7 Safety Committee ("PNSC"), Nuclear Safety Review Committee ("NSRC"), and
8 Nuclear Safety Oversight Committee ("NSOC"). The Progress Energy Nuclear
9 Safety Oversight Committee and a Containment NSOC Sub-Committee
10 (comprised of industry experts and Progress Energy vice presidents) reported to
11 Progress Energy's CEO and Board of Directors. The CR3 Containment Project
12 Manager also had direct interfaces with the Nuclear Energy Institute ("NEI") and
13 Institute of Nuclear Power Operations ("INPO"), the NRC, the media and public
14 inquiries, Progress Energy's Senior Management Committee ("SMC"), and
15 Progress Energy's Board of Directors.

16
17 **Q. What was PII's role with the Root Cause Investigation Team on the CR3**
18 **October 2009 wall delamination root cause investigation?**

19 A. PII was responsible to the Root Cause Analysis Team, under my overall direction,
20 to perform the detailed Root Cause Assessment of the October 2009 CR3 wall
21 delamination. The Root Cause Analysis Team was led by PEF's Charles
22 Williams and was supported by other Progress Energy engineers as well as third-
23 party reviewers. The third-party reviewers included engineers from peer utilities
24 and AEs such as Worley Parsons. Worley Parsons is the same firm that

1 conducted the root cause investigation and determined the successful repairs for
2 the 1976 CR3 dome delamination, although at that time Worley Parsons was
3 known as Gilbert/Commonwealth.

4
5 **Q. Were the other groups or branches of the Root Cause Investigation Team**
6 **supported by Progress Energy engineers and third party experts?**

7 A. Yes. Each group or branch of the Root Cause Investigation Team had
8 experienced Progress Energy engineers or managers and third party experts
9 assigned to it. For example, PEF had expert assistance with the Design Basis
10 Analysis. MPR Associates, Inc. was chosen to lead the analysis and Worley
11 Parsons provided third-party owner's support. Structural Preservation Systems
12 led the Repair Analysis. Structural Preservation Systems was the largest concrete
13 repair contractor in the United States. Structural Preservation Systems performs
14 more than 4,000 concrete repair projects per year, including many as complicated
15 as the CR3 delamination repair. Wiss, Janney, Elstner, Inc. provided expert third-
16 party owner's support for the Repair Alternative Analysis, Design Basis Analysis,
17 and Root Cause Assessment teams. Wiss, Janney, Elstner, Inc. is a structural
18 engineering and materials science firm specializing in structural condition
19 assessments and design of repairs and retro-fits for reinforced and post-tension
20 concrete structures.

21 For the Condition Assessment and laboratory testing, Construction
22 Technology Laboratories ("CTL") assisted the Condition Assessment Team by
23 performing non-destructive testing on containment wall surfaces. Laboratory
24 tests were conducted by MacTec and Soil & Materials Engineers ("S&ME").

1 Other field data was collected and analyzed by Sensing Systems, Inc.; Core
2 Visual Inspection Services (“Core VIS”), Nuclear Inspection & Consulting Inc.;
3 Precision Surveillance; Gulf West Surveying Inc.; and AREVA.

4
5 **Q. Was the October 2009 CR3 wall delamination root cause investigation**
6 **prudently managed by PEF?**

7 A. Yes. We successfully completed the root cause investigation, determined the
8 delamination causes, and successfully developed a delamination repair plan that
9 was successfully employed to repair the October 2009 CR3 wall delamination.
10 Additionally, PEF successfully managed the root cause investigation consistent
11 with the Company’s project management and project controls policies and
12 procedures.

13
14 **V. ROOT CAUSE INVESTIGATION.**

15 **Q. Can you explain how each aspect of the root cause investigation was carried**
16 **out by PII and the Root Cause Investigation Team?**

17 A. Yes. I will start with the Condition Assessment although all aspects of the root
18 cause investigation were carried out concurrently with overlapping project
19 management to ensure proper and timely communication of information across all
20 parts or groups of the root cause investigation to efficiently manage the
21 investigation.

22 The goal of condition assessment activities was to characterize the extent
23 of delamination at the SGR project construction opening and determine the
24 condition of other portions of the CR3 containment structure. This condition

1 assessment was accomplished through visual inspections and measurements,
2 various non-destructive and destructive testing procedures, and state-of-the-art
3 sensory devices. Non-destructive testing was performed using an Impulse
4 Response (IR) method. The IR test method uses gauges and computer models to
5 measure the stress waves generated by a hammer. The resulting bending behavior
6 of the stress waves is analyzed based on an average mobility factor to characterize
7 the structural integrity of the containment structure. The presence of voids or
8 delaminations in the containment structure will result in an increased average
9 mobility value. Sound concrete, on the other hand, results in a low average
10 mobility factor in the IR testing.

11 IR testing was performed for all CR3 containment bays except in local
12 areas where potential radiation exposure or physical restrictions due to the
13 location of plant equipment and fixtures precluded testing. Still, the entire
14 exterior surface of Bays 1-2, 2-3, and 6-1 were tested, 90 percent of the exterior
15 surface of Bay 4-5 was tested, and 80 percent of the exterior surface of Bay 5-6
16 was tested. More than 100 concrete cores were also bored to confirm IR test
17 results and visual boroscopic examination of the core bore holes helped identify
18 the presence of any delamination. Also, ASME Section XI IWL visual
19 inspections of the affected areas were performed. The visual inspections and core
20 borings allowed the condition assessment team to correlate results from the two
21 techniques with the IR testing results and, thus, more accurately define the extent
22 of the delamination. For example, in isolated areas with elevated mobility factors
23 in the IR testing the visual inspections and core borings analyses were conducted
24 to verify whether the average mobility readings accurately reflected voids or

1 delaminations in the containment structure. Other condition assessment
2 techniques included Impact Echo equipment to determine the depth of the
3 delamination, strain gauges, tendon lift-off measurements, and core bores to
4 obtain samples for testing concrete material properties and to test for
5 contaminants in the concrete.

6
7 **Q. What were the results of the Condition Assessment analysis?**

8 A. Delamination was only found in Bay 3-4 which lies between buttresses 3 and 4 of
9 the six-buttress CR3 containment building that contains the equipment hatch and
10 SGR project temporary construction opening. Through the use of the non-
11 destructive examination techniques and confirmatory core boring that I have just
12 described, the delamination was determined to form an hour glass shape, centered
13 on the construction opening, and extending to the more heavily reinforced areas
14 above (the ring girder around the top of the containment building) and below (the
15 equipment hatch), and to the buttresses on either side. *See* the photo on page 103
16 of the root cause assessment report attached as Exhibit No. __ (GM-4) to my
17 testimony. No delaminations were found in the CR3 containment wall in any
18 other CR3 containment bays or in the dome.

19 To determine the age of the wall delamination in Bay 3-4, petrographic
20 analysis was done. As I explained earlier, a petrographic analysis is a visual and
21 microscopic analysis of cementitious materials performed by a qualified
22 petrographer. The analysis was performed in general accordance with the
23 applicable sections of ASTM C 856-04, "Standard Practice for Petrographic
24 Examination of Hardened Concrete." In simplified terms, this analysis looks for

1 small air bubbles and crystallizing growth in the core bores and fracture surface of
2 the concrete in the delamination areas. Both small air bubbles and crystallization
3 are indicators that the delamination existed for some time because it takes an
4 extended period of time for crystallization to occur. None of this growth was
5 present in the core bores or on the fracture surface. As a result, we concluded that
6 the CR3 delamination occurred during the construction opening activities on the
7 SGR project. It was not a pre-existing condition.

8
9 **Q. What was the purpose or goal of the Design Basis Analysis Team?**

10 A. The purpose of the Design Basis Analysis Team was to provide design basis
11 analysis and modeling support for any needed past operability analyses and to
12 provide modeling and analysis support for any potential or planned repairs.

13
14 **Q. Can you also explain the purpose or goal of the Repair Alternatives Analysis
15 Team?**

16 A. Yes. The objective of the Repair Alternatives Analysis team was to identify
17 potential repair alternatives and the key parameters for the decision regarding
18 each alternative; identify the risks for each repair alternative; and identify the
19 appropriate investigation that must be conducted to justify each repair alternative.
20 The Repair Alternatives Analysis Team initially planned to describe each repair
21 alternative, the challenges and risks to implement each repair alternative; the
22 construction methodology, tasks, and schedule; any licensing issues; testing
23 needs; and monitoring requirements. Early in the delamination root cause
24 investigation, however, the Company determined that the viable repair option

1 required removal of the delaminated concrete and replacement of the concrete.
2 This was a significant undertaking and required the services of a major
3 construction organization. Accordingly, the Repair Alternatives Analysis Team
4 was phased out and the responsibility for planning and executing any repair plan
5 was assigned to the Progress Energy Nuclear Generation Major Projects Group
6 and the Containment Repair Team (“CRT”) was formed to lead any repair efforts.
7

8 **Q. Can you generally describe the process employed by the Root Cause Analysis**
9 **Team to determine the root cause of the October 2009 delamination?**

10 A. The Root Cause Analysis Team started by identifying all potential causes for the
11 October 2009 CR3 wall delamination. The Root Cause Analysis Team initially
12 identified nine categories or groupings of potential causes of or contributors to the
13 delamination. The nine categories were: (1) Containment Design; (2) Concrete
14 Construction; (3) Concrete Materials; (4) Concrete Shrinkage, Creep, and
15 Settlement; (5) Chemical or Environmental Aging; (6) Concrete-Tendon-Liner
16 Interaction; (7) Concrete Removal Processes; (8) Operational Events; and (9)
17 External Events. The Root Cause Analysis Team and PII then identified potential
18 causes or failures modes within each category. The Root Cause Analysis Team
19 and PII identified seventy-five (75) potential failure modes that could cause or
20 contribute to the delamination of the CR3 containment building.

21 Together with PII we systematically assessed the individual importance of
22 each potential factor or failure mode to the delamination event. Each failure
23 mode (called an “FM” and assigned a number) was investigated, tested, and
24 analyzed. Primary to this analysis was the identification, retention, and analysis

1 of information needed to either confirm or refute the Failure Mode as a
2 contributing factor to the delamination event. As a result, each failure mode was
3 evaluated using "Support/Refute" methodology. This methodology is further
4 supported by "Cause and Effect" and "Equipment Performance" analyses where
5 appropriate. The results of this analysis were developed and internally reviewed
6 by PII, then independently reviewed by PEF, and by third-party reviewers.

7 Of the 75 potential failure modes, 67 were refuted in the root cause
8 analysis. This meant we determined that these 67 potential failure modes did not
9 cause or contribute to the CR3 wall delamination. Eight (8) failure modes were
10 confirmed in our root cause analysis. This meant that we determined that these
11 eight failure modes were contributors to the delamination. The analysis sheets for
12 each of the 75 failure modes can be found in the root cause assessment report,
13 Attachment 6, attached as Exhibit No. __ (GM-4) to my testimony.

14
15 **Q. What were the eight failure modes that contributed to the delamination?**

16 **A.** As I previously explained, the factors contributing to the delamination were: (1)
17 tendon stresses; (2) radial stresses; (3) design for stress concentration factors; (4)
18 concrete strength properties; (5) concrete aggregate properties; (6) the de-
19 tensioning sequence and scope (which were combined), and (7) the process of
20 removing the concrete itself, which likely contributed to the extent of the
21 delamination after it occurred. These factors are accounted for in the following
22 eight failure modes in the root cause analysis: (1) the tendon stresses are analyzed
23 in FM 1.1, "excessive vertical and hoop stress;" (2) the radial stresses are
24 analyzed in FM 1.2, "excessive radial tensile stresses and the lack of radial

1 reinforcement;" (3) the design for stress concentration factors are analyzed in FM
2 1.15, "inadequate design analysis methods of radial tensile stresses;" (4) the
3 concrete strength properties are analyzed in FM 2.12, "inadequate strength
4 properties;" (5) the concrete aggregate properties are analyzed in FM 3.4,
5 "inadequate aggregates;" (6) the de-tensioning sequence and scope are analyzed
6 in FM 7.3 and FM 7.4, "inadequate de-tensioning sequence and scope;" and (7)
7 the concrete removal itself is analyzed in FM 7.5, "added stress due to removing
8 concrete at the opening." As I previously explained too, all of these failure modes
9 acted in concert to contribute to the delamination, none were sufficient by
10 themselves to cause the delamination, all were necessary contributing factors to
11 the delamination. The individual assessment or analysis of each of the
12 contributing failure modes to the delamination are contained in Attachment 6 to
13 the root cause assessment report attached as Exhibit No. ___ (GM-4) to my
14 testimony.

15
16 **Q. How were these failure modes determined to be contributing factors to the**
17 **delamination?**

18 A. As I previously testified, detailed finite element analyses were performed that
19 incorporated the information learned about the delamination and the containment
20 structure during the root cause investigation. The enhanced engineering modeling
21 analyses was then used to model the CR3 containment building and recreate the
22 delamination. This evidence and the computer modeling simulation of the
23 delamination event were necessary to understand the convergence of these failure
24 modes and identify them as contributing factors or causes of the CR3 wall

1 delamination. The computer simulation is attached as Exhibit No. __ (GM-11) to
2 my testimony.

3
4 **Q. Can you briefly summarize how these failure modes converged in the**
5 **enhanced engineering modeling analyses to produce the delamination?**

6 A. Yes. Higher vertical and horizontal tendon stresses and radial stresses, in
7 particular in the planes of the horizontal tendons directly above the center of the
8 horizontal conduit adjacent to the vertical tendons, were identified. These higher
9 stresses were attributed to the size and number of the of the tendons and the
10 location of radial reinforcements in the CR3 containment building design
11 compared to some of the seven other six-buttress, post-tensioned, pre-stressed
12 containment structures that were built in the United States. CR3 has larger
13 tendons and fewer of them and radial reinforcement in the containment wall only
14 at select high stress areas like around the equipment hatch. As a result, the pre-
15 stressed tendons at CR3 generated higher tendon compressive, radial and tensile
16 stresses when compared to other plants. Further, as I explained earlier, the
17 concrete and aggregate at CR3 had high compressive strength but lower tensile
18 strength and less ability to arrest cracking, which was further limited by the lack
19 of radial reinforcements in the area around the tendons in the CR3 containment
20 wall. All of these design and material properties were inherent in the CR3 design
21 and construction, all were typical of the design and construction of nuclear
22 facilities at the time CR3 was built, and all met the design and construction
23 requirements for CR3. But all of these design and material properties also
24 converged with the de-tensioning activities at CR3 for the SGR project to result in

1 the redistribution of stresses within the entire CR3 containment structure that
2 caused the CR3 wall delamination.

3
4 **Q. Did PEF's evaluation of these contributing factors in the root cause**
5 **investigation reveal the likely occurrence of the delamination before it**
6 **occurred?**

7 A. No. For the reasons I previously explained, industry standard engineering
8 modeling analyses and construction procedures that PEF used on the SGR project
9 did not reveal or indicate the possibility of a delamination taking place. Quite to
10 the contrary, the industry standard engineering analyses that were employed on
11 the SGR project indicated sufficient stress margins during the containment
12 construction opening activities at CR3. PEF determined in the root cause
13 investigation that even using conservative parameters in the industry standard
14 engineering modeling analyses, it was impossible, for all practical purposes, for
15 the delamination to have occurred. PII's modeling analyses in the root cause
16 investigation confirmed, then, that appropriate engineering modeling and analysis
17 tools did not exist to accurately predict the delamination and it was virtually
18 impossible to recognize the inability of the industry accepted engineering
19 modeling and analysis tools to predict the delamination at the time of the SGR
20 project. Six major changes in the development of a state-of-the-art engineering
21 modeling analysis were needed to accurately predict the delamination and
22 determine its causes. Without these computer modeling enhancements to the
23 engineering standard model analyses, the delamination simply could not be
24 predicted.

1 Q. Was the Company's root cause investigation of the CR3 delamination a
2 reasonable and prudent investigation?

3 A. Yes. The CR3 delamination was a comprehensive, thorough root cause
4 investigation that met all Company requirements for conducting root cause
5 investigations. NRC inspectors, in fact, agreed with this conclusion. As I
6 explained above, the NRC sent a Special Inspection Team to CR3 to examine the
7 activities associated with the CR3 wall delamination and to examine the
8 Company's evaluation of the delamination condition, the root cause evaluation,
9 and the planned corrective action. The NRC assembled a large team of both
10 internal and external experts, including inspectors and individuals with subject
11 matter expertise in regulatory requirements, concrete and containment design and
12 analysis, nuclear operations, nuclear design engineering, and material property
13 analysis.

14 The NRC team independently reviewed the Company's analysis and work
15 to assure that the CR3 containment building met its original license design bases
16 and that public health and safety would not in any way be compromised. The
17 Company undertook its engineering, licensing, construction, and root cause
18 investigation work with complete transparency to the NRC, who closely inspected
19 all of the Company's work. The NRC team issued its Special Inspection Report
20 detailing its findings and observations based on this examination. In that Special
21 Inspection Report, the NRC determined that the Company's root cause
22 investigation was comprehensive and thorough, and conducted in accordance with
23 the Company's standard implementing procedures. A copy of the NRC Special
24 Inspection Report is attached as Exhibit No. ____ (GM-12) to my testimony.

1 Further, as I previously testified, our root cause investigation did identify
2 the contributing causes of the CR3 wall delamination, confirmed by the enhanced
3 engineering modeling analyses, that demonstrated to us how the delamination
4 occurred. With this information we were able to develop a reasonable repair
5 alternative that we successfully employed at CR3 to correct the October 2009
6 CR3 wall delamination. The building was successfully detensioned for the repair,
7 existing delamination was removed, replacement concrete was placed in the
8 construction opening and the delaminated areas, and the replacement concrete and
9 remaining concrete in Bay 3-4 did not suffer any further delamination conditions.
10 As a result, the purpose for the root cause investigation was met.

11
12 **Q. What was the NRC Special Inspection Team role in the CR3 wall**
13 **delamination root cause investigation?**

14 **A.** The NRC SIT was formally chartered with, among other things, reviewing the
15 circumstances surrounding the delamination, assessing the adequacy of PEF's
16 maintenance and inspection programs, assessing PEF's activities related to
17 determining the root cause of the event and the extent of condition of the building,
18 assessing PEF's corrective action or repair in addressing the containment
19 delamination issue, collecting data necessary to assess the safety significance of
20 any findings, and determining any potential industry-wide generic issues to make
21 recommendations for any appropriate follow-up actions. See enclosure 2 to
22 Exhibit No. ___(GM-12) to my testimony, which is the NRC's Charter
23 establishing the CR3 Containment Building Special Inspection Team.

1 The SIT arrived on site on October 13, 2009, less than two weeks after the
2 October 2, 2009 delamination, and spent hundreds of man hours at the CR3 plant
3 and off-site conducting its inspection. The SIT members collected and reviewed
4 documents gathered as part of the Root Cause Investigation, sat in on various
5 meetings related to the investigation and met with personnel working on the
6 project as needed. They also submitted formal requests for information which
7 were responded to by the investigation team. In addition, the SIT reviewed all of
8 the PII Failure Mode descriptions and supporting documentation and they
9 reviewed the final PII Root Cause Report. The NRC effort was the largest and
10 longest SIT they had ever conducted, which is indicative of the complexity of the
11 root cause effort and the thoroughness of their independent review. Upon
12 completion of its inspection and examination, the NRC SIT issued the Special
13 Inspection Report containing its findings and observations regarding its inspection
14 and examination of the CR3 delamination that is attached as Exhibit No. ____
15 (GM-12) to my testimony.

16
17 **Q. Did the NRC take any other steps or actions in reviewing PEF's actions with**
18 **respect to the CR3 wall delamination?**

19 A. Yes. Throughout the extended CR3 outage, the NRC also held public meetings to
20 discuss the status of PEF's root cause analysis and later the Company's repair
21 efforts and re-start activities. The NRC held formal public meetings on
22 November 20, 2009, June 30, 2010, July 15, 2010, and September 2, 2010,
23 Exhibit No. ____ (GM-13) to my testimony includes the NRC's summaries of
24 those public meetings, including presentations made by PEF and the NRC at those

1 meetings. At the November 20, 2009 meeting, PEF provided its initial analysis of
2 the delamination, the status of its root cause review, and the extent of the
3 delamination condition at the CR3 containment building. Company
4 representatives also answered questions from the NRC and members of the
5 public.

6 Following the completion of its root cause analysis, PEF briefed the NRC
7 at a second public meeting on June 30, 2010. During that meeting, PEF provided
8 the NRC with the Company's root cause analysis, and its repair plan. PEF also
9 explained the licensing basis for completing all containment building repairs
10 without the need for a license amendment. On July 15, 2010, the NRC held a
11 follow up meeting to further discuss PEF's licensing approach to the containment
12 building repair activities. On September 2, 2010, the NRC SIT presented their
13 report and conclusions in a public meeting held in Crystal River.

14
15 **Q. What standard did the NRC Special Inspection Team apply to the Company**
16 **as a nuclear power plant licensee when investigating nuclear power plant**
17 **safety related to the October 2009 CR3 wall delamination?**

18 **A.** The NRC SIT applied the same assessment to the Company with respect to the
19 October 2009 CR3 wall delamination that it applies to all nuclear power plant
20 licensees when regulating nuclear power plant safety. The NRC assesses the
21 results achieved by management retrospectively. Favorable results are required
22 by NRC standards, yet those standards for management performance are not
23 always written and are subject to differing interpretation by regional
24 administrators, inspectors, and senior management personnel of the NRC. The

1 reason is that the NRC is concerned that licensees are in compliance with its
2 requirements for safe operation of nuclear power plants. It does not matter to the
3 NRC whether a licensee is prudent or imprudent, by the standard applied by a
4 Public Service Commission. As a result, a utility may be prudent in decisions it
5 makes in light of current knowledge and yet fail to meet the performance
6 standards of the NRC, which are only results oriented and evaluated with the use
7 of hindsight.

8
9 **Q. Does the NRC's standard for measuring management performance use**
10 **hindsight?**

11 **A.** Yes, the NRC, in effect, evaluates the results of plant management decisions
12 primarily based on hindsight and causal factor analysis. In evaluating events that
13 occur at nuclear power plants, the NRC utilizes its knowledge of the outcome and
14 analyses that can only be performed with the benefit of hindsight in determining
15 the safety implications of the event. In evaluating licensee regulatory
16 performance, the NRC also uses hindsight. For example, performance indicators
17 are evaluated retrospectively by NRC senior managers. The indicators do not
18 focus on management prudence. The consideration of the alternatives facing
19 plant management and the quality of the decision-making in light of the
20 knowledge available at the time the decision was made is not relevant to the
21 NRC's evaluation of licensee performance.

22
23
24

1 **Q. What is the purpose of NRC Inspection Reports?**

2 A. NRC Inspection Reports have three fundamental purposes. First, and most
3 important, the reports provide the formal documented results of the NRC
4 inspections to the licensee so that the licensee is clearly cognizant of NRC
5 findings and may take appropriate corrective action when warranted. These
6 reports also are used to communicate the inspection results to NRC management
7 and to the public. Additionally, they constitute the NRC conclusions regarding
8 licensee regulatory and safety performance in the areas examined.

9

10 **Q. Does the NRC use hindsight when preparing inspection reports?**

11 A. Yes, the NRC judges plant performance based on results regardless of the
12 reasonableness of actions taken by licensees utilizing information available at the
13 time the actions were taken. These after-the-fact judgments by the NRC are
14 reflected in the inspection reports.

15

16 **Q. Did the NRC Special Inspection Team ultimately issue an inspection report
17 regarding the October 2009 CR3 delamination?**

18 A. Yes, as I indicated previously, the SIT issued a Special Inspection Report
19 regarding the CR3 delamination. The NRC SIT completed its inspection on
20 September 2, 2010, and held a public meeting on the 2nd to discuss the Special
21 Inspection results with PEF. The NRC issued its formal, written inspection report
22 on October 12, 2010. *See* Exhibit No. ____ (GM-12) to my testimony.

23

24

1 **Q. What were the NRC Special Inspection Team's findings?**

2 A. Even using hindsight, the NRC concluded that the delamination was an
3 unprecedented event and that the Company's response to the delamination was
4 appropriate and in accordance with PEF's standard implementing procedures for
5 root cause investigations. The NRC further concluded that the Company's root
6 cause assessment was comprehensive and thorough and that delamination root
7 causes identified by the Company in its root cause assessment were -- based on
8 the NRC SIT's determination after conducting its independent examination of the
9 root cause assessment -- reasonable and adequately supported by appropriate
10 evidence.

11 Specifically, the NRC determined that PEF's root cause "investigation
12 results reasonably supported their conclusion that the technical root cause of the
13 delamination was attributable to the scope/sequence of tendon de-tensioning used
14 for the creation of the SGR construction opening, in combination with other
15 contributing factors related to certain design features of the CR3 containment
16 structure, the materials used in the containment concrete, and the activities related
17 to the cutting of the SGR opening." The inspectors further determined that the
18 "approach and inputs used in developing fracture-based computer models used to
19 simulate the delamination were reasonable." In sum, the NRC Special Inspection
20 Team Special Inspection Report recognizes that the CR3 root cause delamination
21 was reasonably and prudently conducted by PEF.

22 The NRC also concluded that the corrective actions developed and
23 implemented to prevent recurrence or exacerbation of the delamination were

1 appropriate. The NRC SIT found no violations of NRC regulatory requirements.
2 The NRC recommended no further corrective action beyond those already taken
3 by the Company to repair the delamination itself.

4 The NRC further observed that standard industry analysis tools were
5 limited in their ability to predict the potential for delamination failures for major
6 modification activities such as the creation of steam generator replacement
7 construction openings involving the de-tensioning of tendons in containment
8 structures. The NRC SIT noted that research may be required to determine if
9 there is any significance or impact as a result of pre-stressing forces in post-
10 tensioned containments in the nuclear industry.

11 This potential recommendation followed from the NRC SIT's recognition
12 of the limitations of typical industry calculations using industry standard
13 engineering analyses and models at the time of the SGR project to accurately
14 reflect all potential stresses. This conclusion is consistent with the Company's
15 own conclusion that the CR3 delamination was not only unprecedented but also
16 unpredictable at the time of the Company's SGR project. *See Exhibit No. ____*
17 *(GM-12) to my testimony.*

18
19 **VI. CONCLUSION.**

20 **Q. Were the Company's actions with respect to the root cause investigation and**
21 **assessment of the causes of the CR3 wall delamination prudent?**

22 **A.** Yes. The Company undertook a comprehensive and thorough investigation of the
23 root cause of the CR3 wall delamination. This root cause investigation involved

1 third-party engineering and construction experts from around the world and it
2 involved state-of-the-art investigative tools, methods, and analyses. The root
3 cause investigation was implemented in accordance with established, industry-
4 accepted procedures for the conduct of such an investigation consistent with all
5 applicable regulatory requirements and standards. The results of our investigation
6 were independently reviewed and verified by third-party experts. In sum, our root
7 cause investigation fully and completely vetted the causes of the delamination.
8 As a result of this investigation, we determined that the CR3 wall delamination
9 was an unprecedented, first-of-a-kind event in the industry that was unpredictable
10 and, therefore, unpreventable. This was the reasonable and prudent determination
11 based on our root cause investigation.

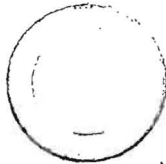
12
13 **Q. Does this conclude your testimony?**

14 **A. Yes.**



DN 07381-11

Docket 100437-EI



COMPACT
disc
DIGITAL DATA

In re: Examination of the outage and replacement
fuel/power costs associated with the CR3 steam
generator replacement project,
by Progress Energy Florida, Inc.

Exhibits of Gary Miller
Submitted for filing Oct. 10, 2011

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