

MINERAL, VIRGINIA USA M_w 5.8 EARTHQUAKE OF 2011: RESPONSE AND LONG TERM INITIATIVES AT NORTH ANNA NUCLEAR PLANT

Divakar Bhargava¹, David Heacock², and Eric Hendrixson³

¹Principal Engineer, Dominion Nuclear, USA

²President and Chief Nuclear Officer, Dominion Nuclear, USA

³Director, Nuclear Engineering, North Anna Power Station, Dominion Nuclear, USA

ABSTRACT

On August 23, 2011, a M_w 5.8 earthquake occurred with its epicenter approximately 11 miles southwest of North Anna Power Station at a depth of 3.7 miles. The North Anna plant, owned and operated by Dominion Generation, has two 3-loop Westinghouse pressurized water reactors that generate 1.92 gigawatts of power. Within a few seconds of the earthquake, the Reactor Trip Breakers opened on negative flux rate trip. Dominion determined the root cause of the automatic shut-down to be a synergistic combination of seismically induced conditions which included core barrel movement, detector movement, and small reactivity effects from core movement. Within seconds, Reserve Station Service Transformers and Switchyard Transformer #2 tripped due to sudden pressure relay actuations causing a loss of offsite power. Seismic monitors at various locations at the plant recorded vibratory motions from the earthquake. Response spectra developed from the recorded time-histories at the plant exceeded the plant's design basis or the safe-shutdown earthquake (SSE) spectra at certain frequencies bands in all three directions.

As a result of the Mineral event, the plant performed comprehensive inspections, surveillance and functional testing and analytical evaluations. There was no damage to safety systems and only minor damage to a few non-safety systems. The regulating body – US Nuclear Regulatory Commission (NRC) – was satisfied with Dominion's actions and plans and allowed the restart of the plant just 80 days after the event. NRC and Dominion agreed on a set of long term actions which have been completed.

This paper describes the recorded data from the earthquake and its analysis, the challenges faced, and significant actions taken by the plant personnel. It also describes the key long term initiatives. They are: a variety of analytical evaluations of safety-significant structures, systems and components to the loads developed from the recorded vibratory motions, installation of new seismic monitors at the plant, and implementation of a long-term seismic margin management program.

INTRODUCTION

Following the M_w 5.8 Mineral, Virginia earthquake at 13:51 hours on August 23, 2011, one of the immediate tasks for Dominion Nuclear was to characterize the earthquake for its impact on the North Anna Nuclear Station and inform its significance to various stakeholders including the NRC. In addition to characterizing the earthquake, this paper describes the inspections and investigations at the plant in the weeks following the earthquake and the long term actions that were completed following the restart of the plant. The lessons learned from this earthquake, including initiatives in the US nuclear industry, are also discussed in this paper.

The vibratory motions from the earthquake were recorded at the North Anna plant in all three orientations by two types of instruments at several locations in the plant. Since North Anna plant did not have free-field instruments, the most appropriate and reliable location to determine the characteristics of this earthquake was at the top of the basemat of the Containment structure. North Anna site is primarily a rock

site; the Containment is on rock with a shear wave velocity of about 5600 ft/sec. The earthquake was characterized by developing response spectra and other parameters from the recorded time-histories at this location. The response spectra were compared to North Anna's Operating Basis Earthquake (OBE) and Design Basis Earthquake (DBE) which showed that the Mineral earthquake spectra exceeded the OBE and DBE spectra in certain frequency bands. Cumulative Absolute Velocities (CAV), a damage parameter, were also developed which, in one orientation, marginally exceeded a previously established criterion developed by Electric Power Research Institute (EPRI). Arias Intensity cumulative energy plots developed from the time-histories demonstrated a lack of significant energy content and showed that the strong motion durations of this earthquake were small in each direction.

Detailed walkdowns, inspections, and functional and surveillance tests were performed at the plant during the plant shutdown. The lack of damage to safety-related structures, systems and components (SSC) from these inspections and tests corroborated the characterization of the earthquake.

Following the restart, several long-term actions were agreed to between Dominion Nuclear and the NRC. The long term actions of significance and their resolution are discussed in this paper. Dominion completed these actions within one and a half year after the restart to meet the schedule set by NRC.

The lessons learned from Dominion's response to this earthquake continue to have a profound impact on the US commercial nuclear power industry. Actions and guidance in the US in response to this earthquake by the USNRC, EPRI, Institute of Nuclear Power Operations (INPO), American Nuclear Society (ANS) and individual nuclear plants are discussed in this paper.

CHARACTERIZATION OF THE MINERAL, VIRGINIA EARTHQUAKE

The instruments that recorded the earthquake motions at the North Anna plant were located at various elevations in two structures, the Reactor Containment building and the Auxiliary Building. Two types of instruments were used: the Engdahl scratch plates that recorded 12 discrete spectral accelerations between 2 and 25 Hz, and the Kinometrics Model FBA-3 analog recorders that recorded the acceleration time-histories. Based on analyses and discussions with experts, Dominion Nuclear determined that the Kinometrics recorder data at the containment basemat of Unit 1 provided the most reliable indication of the earthquake characteristics. Amplified response spectra (ARS) were developed from the recorded and baseline corrected time-histories at this location. The corrected time-histories, labeled as CW026, were digitized at 0.005 second intervals and had durations of about 18 seconds. They are shown in Figures 1, 2 and 3 for the East-West, North-South and the vertical orientations respectively.

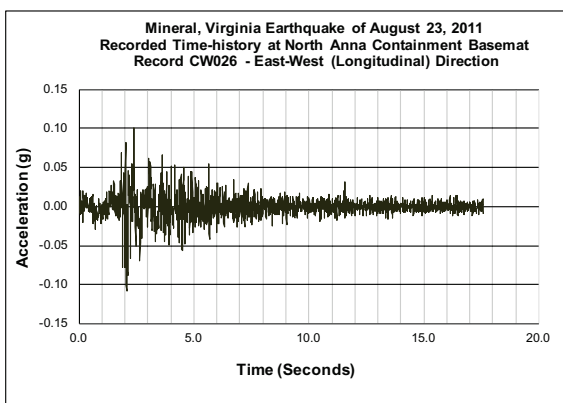


Figure 1 - Mineral, VA Earthquake Time-History – Cont. Basemat, East-West Direction

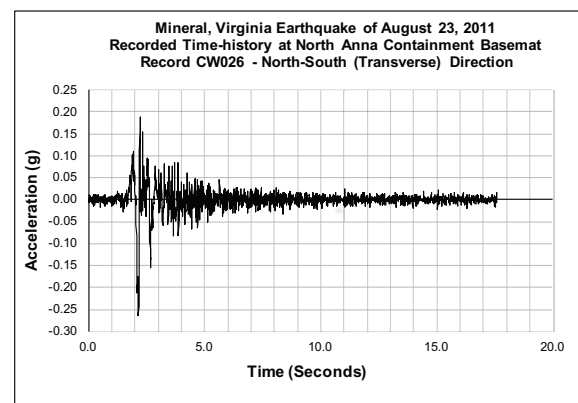


Figure 2 - Mineral, Virginia Earthquake Time-History – Cont. Basemat, North-South Direction

The peak ground acceleration (PGA) values at the containment basemat and a comparison with the OBE and DBE PGA values (rock) are shown below in Table 1. The recorded PGA values at the plant were consistent with the contours plotted in the vicinity of the North Anna plant on the publicly available website of the United States Geological Survey (USGS).

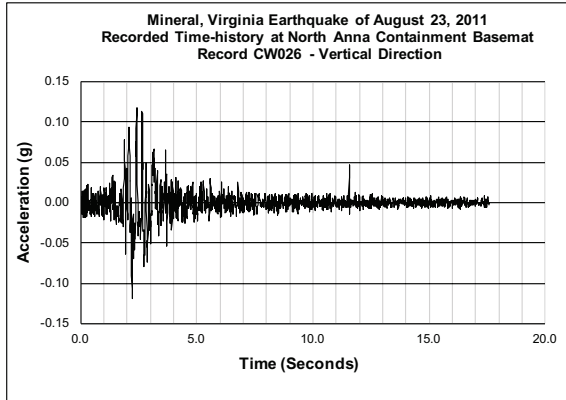


Figure 3 - Mineral, Virginia Earthquake Time-History - Cont. Basemat, Vertical Direction

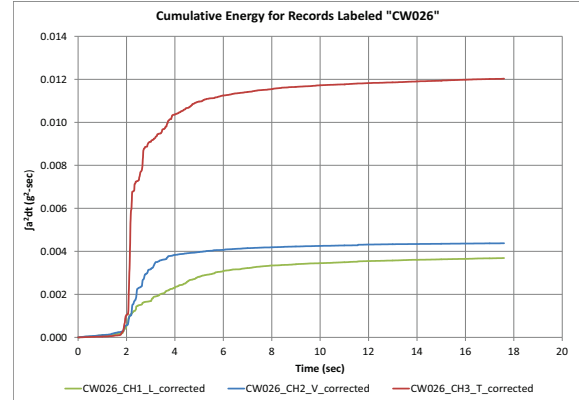


Figure 4 – Cumulative Energy of Mineral Virginia Earthquake – Cont. Time histories

Figures 1, 2 and 3 visually indicate that the strong motion duration of the earthquake was small. This was confirmed by developing the cumulative energy plots for each of the three time-history records labelled as CW026. The effective strong motion durations of these records, defined as the duration between the times associated with 5% and 75% of the total cumulative energy, were calculated to be 3.1 seconds in the East-West direction, 1.5 seconds in the vertical direction and 1.0 second in the North-South direction.

Table 1 – Comparison of PGAs from OBE, DBE and Mineral Earthquake

	North Anna OBE PGA-Rock	North Anna DBE PGA-Rock	August 23, 2011 Event Containment Basemat
Horizontal-N-S	0.06g	0.12g	0.264g
Horizontal-E-W	0.06g	0.12g	0.109g
Vertical	0.04g	0.08g	0.118g

Previous Seismic Programs and Plant Improvements at North Anna

North Anna Units 1 and 2 underwent a thorough seismic review in the 1990s under two NRC programs – the Unresolved Safety Issue (USI) A-46 and the Individual Plant Examination of External Events (IPEEE). The USI A-46 program evaluated plant components in a safe shutdown equipment list (SSEL) that included 20 classes of equipment, tanks and heat exchangers, cable trays and conduits, and relays for the design basis spectra. The IPEEE was performed to identify vulnerabilities for a beyond design basis event and a seismic margin assessment was performed using a median-centered ground response spectrum shape anchored to 0.3g PGA. High-confidence-of-low-probability-of-failure (HCLPF) capacities of structures, systems and components (SSC) were calculated and, where needed, procedural changes and modifications to improve the capacity of components were made. The IPEEE showed that the vast majority of plant SSCs, with a few exceptions, had a minimum capacity of 0.3g expressed in terms of PGA. This perspective helped in assessing the impact of the Mineral earthquake on North Anna.

Response Spectra from Recorded Motions

The time-history data captured by the Kinometrics recorder at the containment basemat was analyzed to calculate the 5% damped response spectra in all three orientations. These spectra were compared with the design OBE, DBE and IPEEE response spectra (Figures 5 and 6). The Kinometrics data shows that the OBE and DBE response spectra at the containment basemat were exceeded in all three directions; however, in the frequency range most damaging to equipment, 2 to 10 Hz, the DBE was not exceeded in the E-W direction, it was exceeded on average by about 12% in the N-S direction, and by about 21% in the vertical direction. While these exceedances are at the basemat of the containment, a comparison of the response spectra from the recorded time-histories of this earthquake to the calculated DBE in-structure response spectra (ISRS) at the operating deck of the containment structure showed that the exceedances were smaller and only in narrow frequency bands in the 2 to 10 HZ range. This implied that the design ISRS were likely calculated in a conservative manner. This is significant because other than a few tanks and yard equipment, safety-related SSCs are located within structures and are designed and qualified to the calculated DBE and OBE ISRS. It can be seen that both the horizontal and vertical spectra from the Mineral event were completely enveloped by the corresponding IPEEE spectrum.

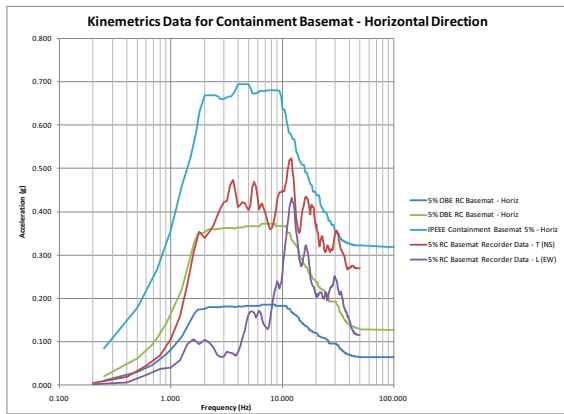


Figure 5 - Comparison of Horizontal Spectra

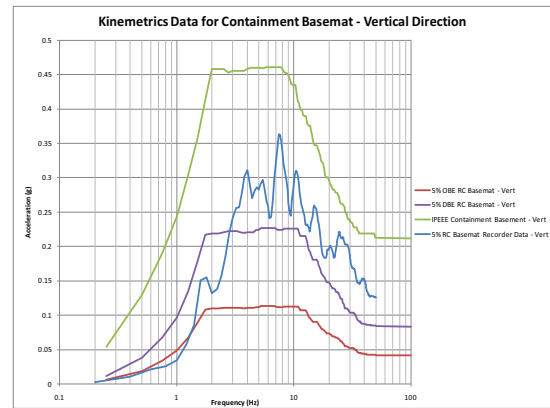


Figure 6 - Comparison of Vertical Spectra

Cumulative Absolute Velocity and Containment Base Shear

The cumulative absolute velocity (CAV), a key indicator of an earthquake’s damage potential, was calculated for each of the three directions of the recorded time-history motions of the Mineral event at the containment basemat. While the CAV criteria are applicable for records in the free-field, it was judged that the Containment basemat recordings are a reasonable representation of the free-field since the Containment is founded on rock. As shown in Table 2, the CAV values in the east-west and vertical directions were well below the very conservative threshold of 0.16g-sec defined in NRC Regulatory Guide (RG) 1.166 for OBE exceedance. The CAV threshold was exceeded by less than 10% in the North-South direction.

Table 2 - Cumulative Absolute Velocities

EPRI / NRC CAV Threshold	East-West (g-sec)	North-South (g-sec)	Vertical (g-sec)
0.16 g-sec	0.125	0.172	0.110

As a result of discussions with the NRC staff in the weeks following the Mineral earthquake, comparisons were performed with the design basis and IPEEE earthquakes for two parameters. In one analysis, CAV values were developed from the OBE and DBE synthetic time-histories that were originally used in the dynamic analysis of the containment to develop the ISRS. While the CAV values from these time-histories were much higher than those from the Mineral VA earthquake, this comparison is of limited value because an infinite number of time-histories can be derived to match the ground OBE or DBE spectra. The second parameter was the Containment base shear, considered as one representation of the earthquake's influence on the structure. Analyses of the Containment Building were conducted using input motions from the August 23, 2011 event, North Anna's design basis earthquake, and the IPEEE review level earthquake anchored to 0.3g PGA. The calculated base shear values at the containment exterior shell were 16,316 Kips, 17,530 Kips and 30,177 kips from the Mineral earthquake, design basis earthquake and the IPEEE review level earthquake respectively.

Characterization Summary

The characterization of the Mineral Virginia earthquake of August 23, 2011 showed that the earthquake did not have a significant damage potential at North Anna plant as revealed from the low CAV values, small effective strong motion durations and energy and other evaluations and parametric comparisons. These evaluations showed that the exceedances above the OBE/DBE response spectra were not of significance. The plant had also made improvements during the IPEEE effort and there were inherent margins in SSCs above the design basis. The characterization pointed to the expectation that North Anna's seismic design would have substantial margins to withstand the Mineral earthquake. This was corroborated from the detailed inspections and surveillance and functional tests as discussed next. Dominion's report on the earthquake characterization was peer reviewed by five independent expert consultants. The reviewers had only minor comments and concurred with the characterization. One reviewer, and later a published technical paper, expressed a concern that the East-West and Vertical records from the Kinometrics recorders appeared to be reversed at the Containment basemat. Dominion plant personnel thoroughly reviewed the orientation of the channels and determined that the records were not reversed.

The results of these assessments were instrumental in disseminating the significance of this earthquake with the stakeholders. The NRC staff concluded that the licensee's characterization of the ground motion from the August 23, 2011, earthquake for its impact on the North Anna plant was reasonable and acceptable.

PLANT INSPECTIONS, ANALYSES AND TESTS:

In the days and weeks immediately following the earthquake, several phases of walkdown inspections covering the entire plant were performed. Teams of engineers from Dominion systematically performed walkdowns of all structures, equipment, tanks, heat-exchangers and piping and other distributed systems. No damage to safety-related structures, systems and components and their supports or to equipment anchorages was observed at the plant; however, there were indications of configuration changes and some damage to the seismically designed Independent Spent Fuel Storage Installation (ISFSI). On Pad 1, there were indications the Transnuclear TN-32 casks had moved but there were no indications of physical damage to the casks. On Pad 2, two Horizontal Storage Modules (HSM) indicated minor cracks on the bases but they were cosmetic in nature and did not impact the structural integrity of the HSMs. The radiological conditions remained unchanged for both pads at the ISFSI. There was also minor damage to a few non-safety systems such as concrete spalling in the base pedestal of a demineralizer tank in the Turbine building. In addition, walkdowns were performed by two separate expert teams, each consisting of well-known industry consultants together with Dominion engineers. These teams inspected structures, equipment, piping and safety and non-safety related tanks and found no evidence of damage. There were

examples of non-safety, non-seismic SSCs that were considered prone to damage, yet none was identified. For example, the large, unanchored Primary Grade Water Storage Tanks and several unreinforced masonry walls located throughout the plant remained intact without damage. In a severe earthquake, damage would likely be evident in water tanks as found at the Kashiwazaki-Kariwa plant in Japan after the 2007 Niigata earthquake. The NRC inspection teams also performed plant inspections and reached similar conclusions. In addition, components in 13 groups, for which the calculated HCLPF capacities during IPEEE were calculated to be below 0.3g, were inspected in much greater detail by trained and experienced seismic review teams. None of these components showed evidence of damage from the Mineral earthquake.

Functional and Surveillance Tests

Dominion performed more than six hundred surveillance tests to verify that the SSCs performed as expected. This included instrumentation functional and calibration tests, pump and valve performance tests, and Integrated System Design Basis functional tests. Extensive Non Destructive Examinations were also performed for supports, welds, buried piping, Reactor Vessel Internals and Nuclear Fuel. All of these tests and examinations were completed satisfactorily with no indication of damage to any safety-related structure, system or component.

Reactor Vessel and Reactor Internals

Using the recorded acceleration time-histories at the Containment basemat, Westinghouse analyzed a dynamic system model of the reactor vessel and its internals in response to an NRC request for additional information. The Unit 1 and 2 components analyzed were: Lower support plates, Upper core plates, Guide tubes and Core barrel lower radial keys. It was shown that sufficient margin existed in these components to withstand the loads resulting from the August 23 seismic event.

The inspections, analyses and tests showed that there was no functional damage to safety systems.

LONG TERM ACTIONS:

Based on extensive reviews including augmented team inspections at the plant, dozens of phone calls and meetings with Dominion, and Dominion's written responses to information requests, the NRC staff concluded in a letter dated November 11, 2011 that Dominion had acceptably demonstrated that no functional damage has occurred to those features necessary for continued operation, and that North Anna Units 1 and 2 can be operated without undue risk to the health and safety of the public. The NRC issued a detailed "Technical evaluation related to plant restart after the occurrence of an earthquake exceeding the level of the operating basis and design basis earthquakes". Both units went on line a few days later. The NRC also issued a "Confirmatory Action Letter" on November 11, 2011 which included ten long term actions, each with a specific completion schedule. These actions were jointly agreed between Dominion and NRC prior to the restart. Dominion completed the actions and submitted summary reports to the NRC on schedule. Five significant actions and their closure are discussed below.

Action 1: Dominion will perform long-term evaluations of plant structures, systems and components in accordance with RG 1.167/EPRI NP-6695, Section 6.3. Any anomalies identified during the evaluations will be entered into the corrective action system and evaluated for extent of condition.

Closure for Action 1: The long term evaluations consisted of the following steps:

- Calculation of seismic loads, i.e., structural loads and in-structure response spectra (ISRS) derived from the recorded time-histories of the August 23, 2011 earthquake.

- Comparison of seismic loads of the earthquake with design basis seismic loads.
- Seismic re-evaluation of representative structures, ASME Class 1 piping systems and equipment where the calculated loads may have exceeded the design basis loads.

ISRS for each of the safety related structures were developed based on the recorded time-histories at the containment basemat (elevation 216') as the starting point. Soil - structure interaction (SSI) analysis using the best estimate shear wave velocity profiles were performed for the soil founded structures and fixed base analyses for rock-founded structures. For each structure and floor elevation, ISRS were compared to the existing ISRS from the Design Basis Earthquake (DBE). Selected safety-related reinforced concrete and structural steel structures were analyzed to determine the potential areas of high load demand. These analyses showed that the calculated forces and moments were well below their allowable capacities based on ultimate strength design. About 10% of the ASME Class 1 piping systems, judged to have the highest calculated stresses, were evaluated for the spectra from the August 23, 2011 earthquake. The calculated stresses were significantly below the ASME Section III, Level C allowable and the structural integrity of the pipe-supports was maintained. The resultant seismic moments at fatigue sensitive locations were compared with the resultant seismic moments used in the existing fatigue evaluations and it was shown that the August 23, 2011 earthquake had insignificant effects on component fatigue. Comparison of loads on equipment nozzles and branch line nozzles with the loads used in qualification of equipment nozzles was also favorable. Representative safety-related equipment was selected for reevaluation to the ISRS developed for the August 23, 2011 earthquake. These included electrical/mechanical equipment qualified by analysis as well as via shake-table testing, tanks and heat exchangers and the IPEEE low capacity items with HCLPF capacity less than 0.3g. No major equipment or their supports were identified with excessive stress or deformation requiring further evaluation, inspections or testing, with two exceptions. Analyses of two groups of low HCLPF capacity components – the 120V Vital AC bus cabinets and the refueling water storage tank (RWST) for both units showed that the anchorages of these cabinets and the overturning moment capacity of the RWST exceeded their corresponding acceptance criteria. In accordance with the EPRI NP-6695 procedure, the anchorages of these components were inspected in detail. No deformation or anomalies were found and it was concluded that the August 23, 2011 earthquake did not cause any damage to these components or their anchorages.

Action 2: Dominion will implement a design change to replace the existing seismic equipment and Main Control Room indication with upgraded and enhanced seismic monitoring instrumentation equipment, which includes installation of a permanent, free field seismic monitor. Permanent, seismically qualified backup power to a new seismic monitoring panel will also be installed including a backup battery power supply. The seismic instrumentation will be installed and maintained in accordance with RG 1.12, Revision 2, *Nuclear Power Plant Instrumentation for Earthquakes*. The project will also install seismic recording instrumentation at the station Independent Spent Fuel Storage Installation (ISFSI) pad.

Closure for Action 2: The seismic instrumentation in the plant was replaced with a new system. Free-field instruments, as well as instruments at different elevations of the Reactor Containment and Auxiliary Building and at the ISFSI pad were installed. A new seismic monitoring panel and a backup battery power supply were installed in the control room. The plant abnormal procedure and other procedures in response to an earthquake were updated.

Action 3: Dominion will perform a re-evaluation of the plant equipment identified in the IPEEE review with HCLPF capacity < 0.3g, which will include an assessment of potential improvements.

Closure for Action 3: During the IPEEE review for North Anna Unit 1 and 2, thirteen groups of structures, systems, and components (SSCs) were determined to have HCLPF capacities less than 0.3g. After the Mineral earthquake, the detailed walkdown inspections for the low HCLPF components showed

no sign of damage or anomaly from the earthquake. Therefore, even though the calculations showed that these components have calculated HCLPF capacities $< 0.3g$, each component withstood the August 23, 2011 earthquake extremely well. The previous calculations of components with HCLPF $< 0.3g$ were reviewed and more realistic analyses were performed. Four groups of SSCs - the Emergency Condensate Storage Tanks, the 4160V Emergency Busses, the Reactor Trip Breaker cabinets, and the Component Cooling Pumps - were shown to have their HCLPF capacities greater than $0.3g$. For other components, HCLPF capacities could not be readily shown to be above $0.3g$ but potential conservatisms in their analyses were noted. Methods to improve their seismic capacity, including physical modifications, were identified. However, no modifications were made because a seismic probabilistic risk assessment (PRA) using site-specific seismic hazard curves is currently being performed and better insights to improve plant's safety are expected from this PRA.

Action 4: Dominion will perform a comparison of the calculated load from the August 23, 2011 earthquake and the existing leak-before-break (LBB) analysis and submit the results.

Closure for Action 4: Dominion performed a comparison of the calculated load from the August 23, 2011 earthquake and loads used in the leak-before-break (LBB) analysis for the main reactor coolant loop. Loads during August 23, 2011 earthquake remained under the previous LBB evaluations at all locations except the axial load at one weld, which exceeded the previously evaluated axial load by about 1%; however, the resultant bending moment during the August 23, 2011 earthquake was much smaller.

Action 5: Dominion will implement a long term Seismic Margin Management Plan (SMMP) to address the impact of the August 23, 2011 earthquake. Specifically, to ensure adequate seismic margins are maintained for plant SSCs, Dominion will revise the design change process for North Anna Station to require explicit evaluation of plant modifications for the effects of the August 23, 2011 earthquake using ISRS for the event for the Containment, Auxiliary Building, and other buildings containing safety related SSCs developed based on actual time-histories recorded during the event. In support of future plant design changes, the evaluation of plant SSCs will require design verification and code compliance with the stresses, loads, accelerations, and displacements generated from the analysis with the design basis ISRS and the analysis with the ISRS for the August 23, 2011 earthquake, whichever are higher.

Closure for Action 5: Dominion implemented a long term SMMP to address the impact of the August 23, 2011 earthquake. The SMMP provides additional assurance that North Anna can operate safely in the long-term and is capable of withstanding another earthquake. ISRS for the August 23, 2011 earthquake for buildings containing safety related SSCs were developed based on the time-histories recorded at the Containment basemat. Detailed guidance for evaluating piping systems and supports and for the seismic qualification of new and replacement equipment under the SMMP was provided in Dominion's Nuclear Standard on equipment seismic qualification. The loads and ISRS calculated from this earthquake are used as an additional DBE case, but not as another OBE case. As an alternative, it is acceptable to envelop the ISRS from the DBE and the August 23, 2011 earthquake. The applicable codes, standards and other criteria for the SMMP remain the same as those being used for North Anna's design basis.

CONCLUSIONS AND LESSONS LEARNED

The earthquake characterization, inspections, tests and the long term actions discussed in this paper required substantial resources. Dominion's effort prior to restart, including analyses, plant inspections, tests, and communication with stakeholders took more than 100,000 hours and cost \$21 million. Substantial effort was also required to complete the long term evaluations; however, much of that effort seemed redundant and did not result in enhancing earthquake safety of the plant.

After a significant event such as the Mineral earthquake, the nuclear plant staff must be prepared to provide relevant information to the public and other stakeholders. In the days and weeks following the earthquake, Dominion Nuclear continuously interacted with the NRC as well as with local government, media and other stakeholders. Responses to questions from the Virginia State Governor's office were provided almost immediately after the event and frequent interactions with the local media continued until the plant restart. Dominion submitted several reports to the NRC and interacted regularly with the NRC staff. The NRC conducted public meetings, with Dominion's participation, at their headquarters including a meeting with NRC's Commissioners, as well as public meetings in the Louisa County where the plant is located. The accuracy, transparency and detailed nature of these communications were a major reason of the success in obtaining NRC's permission to restart the plant in 80 days.

Specific lessons from the North Anna plant were disseminated throughout the nuclear industry. During the earthquake, sudden pressure relay actuations on the Reserve Station Service Transformers (RSST) caused the transformers to trip offline. Trips of transformers on sudden pressure can take significant time to test and verify integrity prior to re-energizing. A second issue was that the earthquake panel in the control room momentarily lost power during the event; plants should evaluate if there is sufficient backup power systems and alternative power supplies to seismic monitoring panels in the event of a loss of normal power.

Several industry notices and reports were issued based on North Anna's experiences from the Mineral earthquake. This paper's authors participated in developing or reviewing these documents and provided insights. The Institute of Nuclear Power Operations (INPO) issued an event report, IER 12-12, in February 2012 for plants to review their seismic instrumentation. In February, 2013, NRC issued Information Notice 2012-25, "Performance Issues with Seismic Instrumentation and Associated Systems for Operating Reactors". The purposes of the INPO and NRC notices were to advise nuclear plant owners to avoid some of the pitfalls that existed at North Anna. In October 2012, EPRI issued a technical update for NP-6695, "Guidelines for Nuclear Plant Response to an Earthquake", which previously addressed only OBE exceedance. The update defines a matrix with five earthquake damage levels based on exceeding OBE or SSE and six action levels for inspections and includes experience-based damage potential with a CAV threshold. In early 2015, a working group of the Standard's Committee of American Nuclear Society (ANS) prepared a draft standard, ANSI/ANS-2.23, on "Nuclear Plant Response to an Earthquake", which is similar to the EPRI technical update of NP-6695. The NRC plans to update Regulatory Guides 1.166 and 1.167 in the near future. There has been a substantial interest by the US operating plants in upgrading their seismic instrumentation and post earthquake procedures based on North Anna's experience and some plants have upgraded their instrumentation.

In summary, while the Mineral earthquake exceeded North Anna's OBE and DBE spectra, its energy content and strong motion durations were small and the plant performed extremely well. Nuclear plants are conservatively designed for seismic loads and have margins beyond their design bases, as demonstrated by this and other earthquakes at nuclear plants globally. The Mineral earthquake and North Anna's response continue to have a profound impact on the US commercial nuclear power plant industry as well as internationally. The fact that North Anna was able to meet the challenges and restart in less than three months after the event is a tribute to the hard work of Dominion's team of professionals. This quick and successful restart has a far reaching implication in that a prolonged shutdown could have impacted not only Dominion and Virginia's economy, but potentially the future of the nuclear power industry for new builds and relicensing of existing units in the US. The review of earthquake safety at North Anna plant is continuing. In response to NRC's post-Fukushima safety initiatives, a seismic PRA is being conducted which uses recently developed site-specific hazard curves from a probabilistic seismic hazard analysis. From the analysis of numerous aftershocks that followed the Mineral earthquake, a new "Quail Fault" was recently identified near the North Anna plant; however, a review showed that the recent probabilistic hazard curves developed for the seismic PRA are not impacted by this new fault.

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