April 6, 2007

MEMORANDUM TO: J. E. Dyer, Director
Office of Nuclear Reactor Regulation

THRU: John A. Grobe, Associate Director
for Engineering and Safety Systems
Office of Nuclear Reactor Regulation

FROM: Michele G. Evans, Director **/RA/**
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SUBJECT: WOLF CREEK PRESSURIZER NOZZLE ALLOY 82/182 WELD FLAWS: LIC-504 ASSESSMENT, INTEGRATED RISK-INFORMED DECISION MAKING PROCESS FOR EMERGENT ISSUES

The Office of Nuclear Reactor Regulation issued Office Instruction LIC-504, "Integrated Risk-Informed Decision Making Process for Emergent Issues," Revision 2, on February 12, 2007. The process described in this document and its predecessor versions formed the basis for the decision making process used to address the results of the Wolf Creek pressurizer nozzle dissimilar metal weld inspections obtained in mid-2006. The purpose of this memorandum is to document the integrated risk-informed assessment of the options considered in the regulatory decision reached. The LIC-504 assessment for this issue is provided in Enclosure 1. The decision authority and evaluation team for this issue are listed in Enclosure 2.

On October 11, 2006, Wolf Creek reported to the U. S. Nuclear Regulatory Commission (NRC) that the presence of five circumferential indications in pressurizer surge, safety, and relief nozzle dissimilar metal butt welds had been discovered and that they were not acceptable under Section XI of the American Society of Mechanical Engineers (ASME) Code. Personnel knowledgeable of non-destructive examination methods interpreted the results and determined the indications to be flaws, most likely caused by primary water stress corrosion cracking (PWSCC). The weld material is Alloy 82/182 which is susceptible to PWSCC.

The concern with these flaws is that they are circumferential and of much larger size than have been previously discovered. Past indications have been axial or short circumferential flaws. This is also the first time that multiple circumferential indications have been identified in a single weld. This called into question the assumptions and evaluations that the industry has made in developing the timeliness guidelines for inspection of these welds.

The NRC staff performed fracture mechanics analyses of the flaws in each of the three Wolf Creek nozzle welds utilizing various assumptions. These analyses were performed to gain insights on how long it would have taken for leakage or rupture to occur if the flaws had been left in service. For the flaws identified in the relief and safety nozzles, the analyses indicated

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that the flaws could have resulted in a loss of coolant accident in less than three years and a number of those analyses indicated the accident could occur without prior leakage warning of the impending failure. A pipe rupture in any of the three locations would result in a loss-of-coolant accident that would unnecessarily challenge the safety features of the plant.

The NRC staff analyses were performed during November 2006. As these results became available the staff discussed the generic implications of the analysis results for plants with similarly susceptible welds and options for regulatory action. The options discussed by the staff focused on the appropriate time frame for industry to complete pressurizer nozzle weld inspections and weld mitigations and the implementation of enhanced leakage monitoring until their actions are completed.

Industry's position was that the plants should be permitted to complete their inspection/mitigation activities during their next scheduled refueling outages. The next scheduled refueling outages for the plants with welds susceptible to PWSCC range from Spring 2007 to Spring 2008, except for one plant with a Fall 2008 outage[1]. Industry also indicated that the leakage monitoring programs at the affected facilities are adequate to ensure prompt action in the event of leakage. Industry's proposal is considered as the base case or Option 1 in the enclosed LIC-504 assessment.

In making a regulatory decision to address the Wolf Creek pressurizer nozzle weld inspection results, the NRC staff considered four other options. Option 2 would require all affected plants to shutdown immediately and not restart until the inspection or mitigation activities were completed. Options 3 - 5 all involve adoption of an enhanced leakage monitoring program with daily leakage monitoring and specified action levels and action statements. Options 3 - 5 differ only with respect to the time frame for completion of the inspection/mitigation activities. Option 3, 4, and 5 correspond to completion inspection/mitigation of affected welds by June 2007, December 2007, and June 2008, respectively.

In assessing these options, the NRC staff interacted heavily with industry to obtain and assess all the information available related to the issue. The NRC staff used this information to assess the pros and cons of these options in terms of the principles for risk-informed decision making. After many internal discussions, the staff concluded that licensees need to complete inspections or mitigations of the pressurizer nozzle Alloy 82/182 welds by the end of 2007 and implement enhanced leakage monitoring in the near-term until the inspections or mitigations are completed. This decision corresponds to Option 4.

The NRC staff concluded that Option 1 would not provide adequate assurance of pressure boundary integrity because of the long time period of operation with reduced safety margins and because the industry leakage monitoring programs vary from plant to plant, do not contain specified action statements and, therefore, their effectiveness cannot be evaluated.

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[1]This plant was originally planning its weld mitigate activities during a Fall 2008 refueling outage but has since decided for operational reasons to schedule a mid-cycle outage during 2007. The weld mitigation activities at this plant will take place during the 2007 mid-cycle outage.

The NRC staff concluded that Option 2, immediate shutdown, would promptly provide assurance that the intended safety margins are restored to a level higher than the level prior to discovery of the condition identified at Wolf Creek. This option, however, would result in virtually all qualified welders using up their maximum allowed dose limits before the work could be completed. Industry would have to train numerous workers, possibly from other industries, and use less experienced welders and inspectors as a consequence of radiation exposure. This option would likely result in weld rework and lower quality welds, which would adversely impact safety.

Option 3 would provide assurance that the intended safety margins are restored within a relatively short time period during which reliance is placed on enhanced leakage monitoring as a compensatory measure. However, similar to Option 2, as a consequence of radiation exposure, the intended safety margins may be adversely affected by weld quality issues.

The NRC staff concluded that Option 4 represents the optimal decision. This option would require high reliance on required uniform enhanced leakage monitoring programs. Since leakage before complete loss of integrity is not assured, leakage monitoring is not complete compensation for a potentially degraded condition. For this reason, NRC staff concluded that the inspections and mitigations should be completed as soon as possible without introducing the unintended consequences of weld quality issues. Based on information provided by industry, NRC staff concluded that, while this option would place a high burden on industry, it is feasible for industry to complete the inspections and mitigations within the schedule of Option 4 without compromising weld quality.

Option 5 would provide assurance that the intended safety margins are restored by the middle of 2008. PWSCC results in further degradation over time and leakage before complete loss of integrity is not assured. Given the potential consequences of this safety issue and the uncertainties associated with the condition of uninspected plants, the NRC staff does not consider that the safety concerns for reactor coolant system integrity are adequately offset by relying on enhanced leakage monitoring until mid-2008.

For a more complete understanding of the decision making process used to address the Wolf Creek pressurizer nozzle inspection results, the reader is referred to the enclosed LIC-504 assessment.

Enclosures:
1. LIC-504 Assessment on the Wolf Creek Pressurizer Nozzle Weld Flaws
2. Wolf Creek LIC-504 Decision Authority and Evaluation Team

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WOLF CREEK PRESSURIZER NOZZLE ALLOY 82/182 WELD FLAWS

LIC-504 ASSESSMENT, INTEGRATED RISK-INFORMED DECISION MAKING PROCESS FOR EMERGENT ISSUES

1. PURPOSE

The purpose of this assessment is to summarize the safety issues related to the pressurizer nozzle weld flaws found at Wolf Creek in October 2006, the regulatory options considered and the assessment of those options in the decision making process used to determine what regulatory actions to take to address the issues.

2. BACKGROUND

On October 11, 2006, Wolf Creek reported to the NRC, in an 8-hour notification, that the presence of five circumferential indications in pressurizer surge, safety, and relief nozzle dissimilar metal butt welds had been discovered that were not acceptable under Section XI of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code). An indication is the response or evidence from a nondestructive examination (NDE) that requires interpretation to determine its relevance. Personnel knowledgeable of NDE methods interpreted and determined the indications to be flaws, most likely caused by primary water stress corrosion cracking (PWSCC). The weld material is Alloy 82/182 which is susceptible to PWSCC. The surge nozzle weld contains three circumferential indications, while one safety nozzle weld and the relief nozzle weld each contain one circumferential indication.

Wolf Creek personnel inspected the welds pursuant to industry-sponsored guidelines. The personnel who measured the flaws were qualified to detect flaws, but were not qualified for flaw length sizing, and the procedure used was not qualified for depth sizing. Notwithstanding, Wolf Creek NDE personnel evaluated the length and depth of the flaws. NDE personnel from the Electric Power Research Institute (EPRI), who administer the qualification examinations to industry personnel, were contacted and independently confirmed the identification and length sizing of the flaws and the depth sizing information obtained by Wolf Creek personnel.

The concern with these flaws is that they are circumferential and of much larger size than have been previously discovered. Past indications have been axial or short circumferential flaws. This is also the first time that multiple circumferential indications have been identified in a single weld. This raised questions regarding the assumptions and evaluations that the industry has made in developing the timeliness guidelines for inspection of these welds.

The NRC staff performed fracture mechanics analyses of the flaws in each of the three Wolf Creek nozzle welds utilizing various assumptions. Only the largest of the three flaws in the surge nozzle was analyzed. These analyses were performed to gain insights on how long it may have taken for leakage or rupture to occur if the flaws had been left in service. All scenarios analyzed for the surge nozzle flaw indicated that there would have been ample time from the onset of leakage for the licensee to identify the leak and take appropriate action prior to a failure of the weld. However, for the flaws identified in the relief and safety nozzles, the analyses indicated that the flaws could have resulted in a loss of coolant accident in less than three years and a number of those analyses based on various assumptions indicated the accident could occur without prior leakage warning of the impending failure. A pipe rupture in any of the three locations would result in a loss-of-coolant accident that would unnecessarily challenge the safety features of the plant. During November 2006, the NRC staff analyses were performed. As these results became available the staff continued to discuss the implications of the analysis results and options for regulatory action. The options discussed by the staff in that time frame and the pros and cons of these options in terms of the principles for risk-informed decision making are captured in Section 3 below. After many internal discussions, the staff concluded that licensees need to complete inspections or mitigations of the pressurizer nozzle Alloy 82/182 welds by the end of 2007 and implement enhanced leakage monitoring in the near-term until the inspections or mitigations are completed.

The NRC communicated the need for near-term enhancements to the industry through public meetings held on November 30, 2006, December 20, 2006, and February 2, 2007. Licensees submitted letters voluntarily committing to enhanced inspection and leakage monitoring requirements. After teleconferences with specific licensees held between February 12 through February 23, 2007, the licensees submitted supplemental commitment letters addressing the NRC staff's concerns regarding inspection, compensatory actions, and reporting of inspection results.

Based on the above information, NRR issued Confirmatory Action Letters (CALs) to Pressurized Water Reactor (PWR) licensees confirming their commitment to inspect the pressurizer surge, spray, safety, and relief nozzle welds by December 31, 2007, to implement enhanced reactor coolant system leakage monitoring until the inspections are complete, to repeat butt weld examinations every 4 years until the welds are either removed from service or mitigated, and to report inspection results to NRR.

In a February 14, 2007, letter from NEI to J.E. Dyer, industry proposed performing advanced finite element fracture mechanics analyses to address NRC staff concerns that rupture could occur without prior evidence of leakage. For plants to operate beyond December 31, 2007, without having inspected these welds, the NRC will have to evaluate the analyses currently being conducted by industry and find reasonable assurance that crack conditions similar to that found at Wolf Creek will remain stable and not lead to rupture without significant time from the onset of detectable leakage. There are nine plants with outages scheduled in the first six months of 2008. These plants have committed to shutdown by the end of 2007 to inspect or mitigate the pressurizer nozzle welds. However, if the advanced finite element fracture mechanics analyses provide reasonable assurance to the NRC staff that PWSCC will remain stable and not lead to rupture without significant time from the onset of detectable leakage, the NRC will consider a request from those plants with 2008 outages to relax their commitment to shutdown in 2007. This condition was reflected in the CALs issued to these nine plants.

The long-term resolution of this issue is expected to involve changes to the ASME Code, and will involve changes to the NRC regulations in Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Section 50.55a (10 CFR 50.55a), "Codes and Standards." The development of the NRC regulations, whether the rule adopts the ASME Code standards or defines separate requirements, will likely benefit from additional operating experience, continuing assessments, and analysis being conducted by the NRC and the MRP.

<u>Degree of conservatism in the regulatory analysis of this issue</u>

The industry program for inspecting and mitigating welds subject to this degradation mechanism was developed based on the information available prior to the Wolf Creek inspection findings. This program is described in Materials Reliability Program (MRP):
Primary System Piping Butt Weld Inspection and Evaluation Guidelines, dated July 2005 and known as MRP-139. The available information indicated to the NRC staff that there was a serious safety issue with PWSCC. Based on operating experience the NRC staff believed the industry baseline inspection schedule under MRP-139 was generally adequate, if completed without taking deviations to the schedule. With the exception of NRC staff concerns regarding inspection of small bore dissimilar metal butt welds, the time frame of the MRP-139 inspection program for addressing the issue at the affected plants was considered to provide appropriate margins to failure. There are relatively few small bore piping welds in the pressurizer nozzle connections, but the inspection and mitigation of these welds are being performed on the same schedule as the larger welds. However, the Wolf Creek indications caused the NRC staff to assess the results of the inspection to determine what could have happened if the flaws had been left in service. The results of the NRC staff analyses are of interest for other PWRs, since there is no information that demonstrates that the flaws found at Wolf Creek could not occur at other plants. These analyses were not bounding calculations or best estimate calculations. The analyses did show under certain assumptions that the flaws in the safety and relief nozzles could exhibit rupture prior to evidence of leakage. There were a number of areas of potential non-conservatisms in the analyses, such as not considering potential linkage of the three surge nozzle flaws and using the loads from Wolf Creek which may not be bounding. There are also a number of uncertainties in the analyses, such as the weld residual stress distribution, the condition of the welds at uninspected plants, and the actual shape and depth of the flaws identified at Wolf Creek. There were also some areas of conservatism in the analyses, such as the assumption that the residual stress distribution is axisymmetric.

3. EVALUATION AND ASSESSMENT OF OPTIONS AGAINST THE FIVE KEY PRINCIPLES OF RISK INFORMED REGULATION

Option	Schedule for inspection/mitigation	Enhanced leakage monitoring program
1	June 2008	No
2	Immediate	Not necessary
3	June 2007	Yes, until welds inspected or mitigated
4	December 2007	Yes, until welds inspected or mitigated
5	June 2008	Yes, until welds inspected or mitigated

3.1 Option 1 - Base Case: No changes in the existing regulatory and industry programs; industry proceeds on present schedule of the industry program under MRP-139. Under this schedule, all the pressurizer nozzle welds would not be inspected or mitigated until at least mid-2008.

3.1.1 Compliance with Regulations

This issue involves the reduction in confidence in the capability of the reactor coolant system pressure boundary at affected plants. The reactor coolant system pressure boundary is considered one of the principal fission product barriers in the general design criteria and integral to defense-in-depth of the plant.

The five circumferential indications discovered at Wolf Creek are believed to have had sufficient ASME Code, Section XI, margin on structural integrity at the time of their discovery. Most of these flaws could not have been left in service because of the high growth rate of PWSCC and the margins on structural integrity required by the ASME Code, Section XI. Therefore, this degraded condition required corrective actions in accordance with the ASME Code, which is incorporated by reference into NRC regulations by 10 CFR 50.55a. Wolf Creek's corrective actions were to construct weld overlays on the original welds. These actions were planned by this licensee, regardless of the outcome of the inspections.

As discussed in Section 2, the results of the NRC staff's fracture mechanics analyses were that for the relief and safety nozzle welds, rupture could occur without prior evidence of leakage, if the flaws had been left in service. Since there was no basis to distinguish Wolf Creek from other PWRs with Alloy 82/182 pressurizer nozzle welds, the staff concluded that the current inspection requirements do not provide adequate assurance that reactor coolant system (RCS) pressure boundary integrity will be maintained for butt welds comprised of Alloy 82 and 182 material exposed to pressurizer temperatures. Consequently, without additional actions by the affected licensees, the NRC staff would have lacked the requisite reasonable assurance that the health and safety of the public would be protected by the current RCS inspection requirements. The long-term resolution of this issue is expected to involve changes to the ASME Code, and will involve changes to the NRC regulations in 10 CFR 50.55a.

3.1.2 Defense-in-Depth

This issue directly impacts only one barrier, the reactor coolant pressure system boundary. Barrier integrity is impacted, since the issue involves the potential for reduction in capability of the reactor coolant system pressure boundary, which is one of the principal fission product barriers. The effect is an increase in the probability for failure of that boundary, not an assured loss of the boundary. Therefore, the effects of this issue are most appropriately addressed by the principles concerning margin and risk, rather than defense-in-depth.

However, this issue may increase the frequency of a loss of coolant accident (LOCA) in the size range requiring emergency core cooling system (ECCS) operation in the recirculation mode. Therefore, plants affected by this issue that are concurrently susceptible to containment sump clogging (as described in Generic Safety Issue (GSI) -191) will have a compounded increase in their frequency of core damage. Many plants have replaced their sump strainers and most of the plants will have replaced their sumps by the end of 2007. The compounding effect is diminishing as sump strainers are replaced. The weld cracking issue may increase the likelihood of a LOCA, and the potential for sump clogging increases the failure probability of the systems designed to mitigate LOCA events. This compounding effect is considered in the context of defense-in-depth.

This option would require a high degree of reliance on plant leakage monitoring programs which vary from plant to plant and which leave to plant management the final decision on actions to shutdown and look for the source of leakage. In addition, leakage before complete loss of integrity may not be assured, so leakage monitoring is not complete compensation for a potentially degraded condition.

LOCA events are included in virtually every light water reactor probabilistic risk assessment (PRA) and include defense-in-depth afforded from multiple barriers as well as mitigation equipment redundancy. However, as discussed in depth in Section 3.1.4, it is not feasible at this time to estimate the impact of this degradation mechanism on the likelihood of having a LOCA within a given period of time.

3.1.3 Safety Margins

The safety margin impacted by this degradation mechanism is the margin that exists as a result of compliance with the ASME Code and other regulatory requirements and inspection programs. Other margins would not be affected. Based on the Wolf Creek operating experience, the safety margin requirement may not be assured for welds that have not been recently inspected or mitigated. For any weld affected by PWSCC, this reduction in safety margin could be significant, because a potential pipe failure would result in a LOCA, up to and including a large break LOCA. The conditional core damage probability given a LOCA for a “typical” plant is in the 1E-3 to 1E-2 range, assuming there are no additional adverse influences (e.g., unresolved containment sump clogging issues).

Statistical techniques may be used to estimate the increase in LOCA probability over a given period due to the degradation. As discussed in Section 3.1.4, this has been done by the industry, using piping fragility and a set of crack-related hazard curves that show increasing hazard over time. However, the NRC staff has concluded that available data and current lack of understanding of the underlying physics of the degradation mechanism make any estimate of the risk too unreliable to support regulatory decision making.

This option allows the industry to continue on the MRP-139 schedule, including industry allowed extensions, to inspect and mitigate susceptible welds. Any flaws or cracks in the welds have the potential to grow over time. This option allows for an indeterminate level of margin reduction for up to 18 months after January 1, 2007. Under the industry program, plants may postpone inspection/mitigation activities beyond the industry schedule “required” by MRP-139. The “required” industry schedule called for completion of baseline inspection/mitigation by December 31, 2007.

3.1.4 Risk Assessment

EPRI provided a letter report, “Implications Of Wolf Creek Pressurizer Butt Weld Indications Relative to Safety Assessment and Inspection Requirements,” MRP 2007-003, dated January 2007. The staff had previously reviewed the contents of that report as presentation slides, draft versions, and some supporting Excel spreadsheets. Section 9 provides a relatively simple probabilistic model that was “used to estimate the probability of a critical size flaw occurring in the remaining uninspected nozzle butt welds prior to planned inspections...” The MRP report concluded that from their model the differences in core damage accident

probability between the various options were in the 10^{-8} range. The EPRI analysis did not include analysis of uncertainties, but claimed to be conservative.

The staff made a cursory review of the EPRI risk model and discovered several highly unrealistic assumptions, some of which were conservative and some that were non-conservative. An example of each is the following.

- The probability of larger cracks being present in the uninspected reactors was based on extrapolation of a mathematical function that was fit to 35 randomly generated "undetectable" flaws (to represent the inspections that found no circumferential cracks) in addition to the 6 circumferential cracks that were found. The fit was dominated by the 35 synthesized data points and under-predicted the real data. This under-prediction effect becomes highly magnified by the large degree of extrapolation required to find the probability of a flaw at the size that would result in failure.

- The probability of failure as a function of flaw size was constructed from a combination of NRC staff calculations, some of which were for normal operating stresses and some of which included "safe shutdown earthquake" stresses in addition to operating stresses. This resulted in a hazard function curve with a mean value that was low and a standard deviation that was too large. Both effects tended to make the risk appear higher than a realistic curve would have indicated.

Other modeling concerns were also noted, including use of a single point (the 75^{th} percentile) of the crack growth rate data for all crack growth calculations, and the use of a "generic" conditional core damage frequency for LOCAs that did not consider the effects of the ECCS sump operability issue that concurrently affects some of the uninspected plants.

The staff made some informal suggestions to EPRI that were intended to produce a more useful model. The suggestions included:

- Fitting the 6 available flaw size data points directly and then multiplying the resulting probabilities by the fraction (6/41) of inspected welds that contained circumferential flaws.

- Fit the hazard curve only to the failure calculations that used only the operational stresses. If necessary, produce a second hazard curve with the failure calculations that include earthquake stresses and use the frequency of the earthquakes to adjust the risk contribution from the second hazard curve.

EPRI contractors followed the first suggestion and partly followed the second suggestion, informally providing the results to the staff in an Excel spreadsheet and discussing it by telephone.

Further staff review of the flaw data fitting and extrapolation process indicated that it was not adequate to support a reliable prediction of the probability of failure. The EPRI fit used a "median rank regression" fit to a Weibull distribution. The staff compared this to a maximum likelihood estimator fit to an exponential distribution. Both fit the available data very well, but an extrapolation of the staff's fit exceeded an extrapolation of the EPRI fit by three orders of magnitude at the flaw size where the hazard curve was truncated on the low end. The two fits continue to diverge in the region where their convolution with the hazard curve produces the risk estimate. Because there is no physical basis for determining which fit (if either) is "correct," this comparison only serves to illustrate the large degree of uncertainty in predicting the probability that there are near critical size flaws in the uninspected plants. Another indication of this uncertainty is the sensitivity of the staff's fit to the new data from Wolf Creek. The effect of including the Wolf Creek data is an order of magnitude increase at the low end of the hazard function.

Based on these observations, the staff concluded that the available data and current lack of understanding of the underlying physics of the degradation mechanism made any estimates of the risk too unreliable to support a regulatory decision. This was stated in a public meeting on December 20, 2006. As a result, the draft EPRI document was not revised to reflect the informal information exchanges on the risk quantification.

Other risk insights are potentially useful to the regulatory decision-maker:

- Failures of butt welds due to circumferential cracks could result in leaks or ruptures. Experience has shown that leaks are more likely than ruptures, but analysis indicates that ruptures are possible and more likely for the smaller pipe connections (i.e., spray lines and valve headers) than large connections (i.e., surge line). There is insufficient experience and no analysis that is adequate to bound the leak-before-break probability for these welds to levels that would help assure that the risk is low enough.

- Failures of the subject butt welds due to large circumferential cracks would produce medium or large LOCAs at the pressurizer. PRAs typically indicate conditional core damage probabilities (CCDPs) for these types of LOCAs are in the 10^{-3} to 10^{-2} range. However, those estimates are very sensitive to probability that the ECCS will function when the recirculation mode is initiated. These typical CCDP values are based on nominal failure probabilities for ECCS recirculation failures, and do not account for the sump problems that have been identified in some of the same plants that have uninspected butt welds. CCDPs for plants with inadequate sumps may be as high as the 10^{-1} range.

- The butt weld flaws affect only one layer of the three barriers that provide defense-in-depth against release of the radioactive materials in the reactor core.

- This issue does potentially impact the risk from seismic events, because a degraded pipe will be more likely to fail during an earthquake than a non-degraded pipe. However, given the low probability of a seismic event in the timeframe during which this degradation will be addressed, even for Option 1, the risk contribution from seismic events is judged to be very low.

3.1.5 Performance Measurement

For Option 1 the performance measurement strategies or compensatory measures are the existing leakage monitoring programs. These programs are not uniform across the PWR fleet and actions to be taken in response to increases in unidentified leakage are decided on a case-by-case basis by the management at each plant. This management strategy is assessed in 3.1.2, above.

3.2 Option 2 - Require all affected PWRs to shutdown immediately until all Alloy 82/182 pressurizer nozzle welds are either inspected or mitigated.

3.2.1 Compliance with Regulations

In the base case, the NRC staff concluded that:

- the current inspection requirements do not provide adequate assurance that RCS pressure boundary integrity will be maintained for butt welds comprised of Alloy 82 and 182 material exposed to pressurizer temperatures.

- the NRC staff lacks the requisite reasonable assurance that the health and safety of the public will be protected by the current RCS inspection requirements.

The proposed actions for Option 2, would provide the requisite reasonable assurance that the health and safety of the public would be protected upon restart of the affected plants.

3.2.2 Defense-in-Depth

This option would remove the contribution of potentially degraded welds to concerns about defense-in-depth and safety margins.

3.2.3 Safety Margins

Option 2 would promptly provide assurance that the intended safety margins are restored to a level higher than the level prior to discovery of the condition identified at Wolf Creek. For plants that would mitigate the welds, the safety margin is similar to that of plants when first placed into operation. For plants that would inspect but not mitigate the welds, safety margin would be adequate because the required inspections and reinspection frequency would provide reasonable assurance that PWSCC would not compromise the reactor coolant pressure boundary.

This option, however, would result in virtually all qualified welders using up their maximum allowed dose limits before the work could be completed at all facilities. Industry would have to train numerous workers, possibly from other industries, and use less experienced welders and inspectors as a consequence of radiation exposure. This option would likely result in weld rework and lower quality welds, which would negatively impact safety.

3.2.4 Risk Assessment

Immediate shutdown of all affected plants would reduce risk of a LOCA resulting from the degradation described herein. However, the magnitude of any risk decrease is indeterminant. The potential for lower quality welds may increase LOCA frequency following weld repairs.

3.2.5 Performance Measurement

For Option 2 no performance measurement strategies or compensatory measures are proposed or necessary, since the option requires prompt shutdown of the affected plants to either inspect or mitigate the affected welds.

3.3 Option 3 - Require all affected PWRs to shutdown by June 30, 2007 to inspect or mitigate Alloy 82/182 pressurizer nozzle welds. Require all PWRs with uninspected or unmitigated pressurizer nozzle Alloy 82/182 welds to implement enhanced leakage monitoring frequency, action levels, and required actions if thresholds for changes in unidentified leakage are exceeded.

3.3.1 Compliance with Regulations

The proposed actions for Option 3, which is the combination of inspecting or mitigating the welds by June 30, 2007, and an enhanced leakage monitoring program, would provide reasonable assurance for the following reasons. Only about 50 U.S. pressurizer nozzle welds have been inspected, to date, with 4 welds with indications identified. One weld had a small axial indication and the remaining three welds with indications were found at Wolf Creek. Based on this limited data set, it appears that large PWSCC flaws would exist at most in a small number of weld locations, if any. If any serious PWSCC flaws are present in the pressurizer nozzles, under Option 3 they will be left in service for a short period of time. Also, limited operating experience with degradation by stress corrosion cracking has led to leaks prior to complete loss of structural integrity. Although this operating experience is not sufficient to demonstrate that the probability of rupture without leakage is adequately low to control risk, it does present an opportunity to prevent ruptures if leakage can be detected. A required uniform enhanced leakage monitoring program provides assurance that if leakage occurs from a pressurizer nozzle weld, it will be detected promptly and the plant will be shutdown and inspected.

3.3.2 Defense-in-Depth

Section 3.1.2 assesses defense-in-depth for Option 1. The discussion in Section 3.1.2 on the impact of the issue on only one barrier and the potentially compounded increase in core damage frequency due to containment sump clogging apply equally to Option 3.

This option would require high reliance on required uniform enhanced leakage monitoring programs. Since leakage before complete loss of integrity is not assured, leakage monitoring is not complete compensation for a potentially degraded condition, but this is offset by the relatively short time period before inspections or mitigations would take place. A negative impact of this option on barrier integrity is the potential weld quality issue discussed in Section 3.3.3.

3.3.3 Safety Margins

Option 3 would provide assurance that the intended safety margins are restored within a relatively short time period, but the intended safety margins may be adversely affected by weld quality issues. This option would result in many welders using up their maximum allowed dose limits by or before June 2007. Industry would have to use some less experienced welders because of radiation exposure. This option may result in lower quality work and the possible need for rework, which is considered to be a negative impact on safety.

3.3.4 Risk Assessment

At present, it is not feasible to estimate the magnitude of the change in risk compared to the base case. Nevertheless, the potential for lower quality welds may increase LOCA frequency following weld repairs.

3.3.5 Performance Measurement

For Option 3 the monitoring measure would require a uniformly consistent enhanced leakage monitoring program across the PWR fleet. The program would require daily monitoring of unidentified leakage. The program would also require action levels based on day-to-day change in unidentified leakage and on increase in unidentified leakage above a baseline. The program would require shutdown of the plant, if the leakage is sustained for 72 hours and if it could not be confirmed that the leakage was from a source other than the pressurizer nozzle dissimilar metal welds. Although operating experience is not sufficient to demonstrate that the probability of rupture without leakage is adequately low to control risk, the enhanced leakage monitoring program provides assurance that if leakage occurs from a pressurizer nozzle weld, it will be detected promptly and the plant will be shutdown and inspected.

3.4 Option 4 - Require all affected PWRs to shutdown by December 31, 2007, to inspect or mitigate Alloy 82/182 pressurizer nozzle welds. Require all PWRs with uninspected or unmitigated pressurizer nozzle Alloy 82/182 welds to implement enhanced leakage monitoring frequency, action levels, and required actions if thresholds for changes in unidentified leakage are exceeded.

3.4.1 Compliance with Regulations

The proposed actions for Option 4, which is the combination of inspecting or mitigating the welds by December 31, 2007, and an enhanced leakage monitoring program, would provide reasonable assurance for the following reasons. Only about 50 U.S. pressurizer nozzle welds have been inspected, to date, with 4 welds with indications identified. One weld had a small axial indication and the remaining three welds with indications were found at Wolf Creek. Based on this limited data set, it appears that large PWSCC flaws would exist at most in a small number of weld locations, if any. If any serious PWSCC flaws are present in the pressurizer nozzles, under Option 4 they will be left in service for about an additional year. Limited operating experience with degradation by stress corrosion cracking has led to leaks prior to complete loss of structural integrity. Although this operating experience is not sufficient to demonstrate that the probability of rupture without leakage is adequately low to control risk, it does present an opportunity to prevent ruptures if leakage can be detected. A required uniform enhanced leakage monitoring program provides assurance that if leakage occurs from a pressurizer nozzle weld, it will be detected promptly and the plant will be shutdown and inspected. Plants will be inspecting or mitigating the welds throughout the time period until December 31, 2007, so the exposure of the public to the safety concerns of this issue would be continually reduced as plants complete the intended actions.

While Option 4 results in exposure to the potential for PWSCC to degrade pressurizer nozzle welds for up to a year from the end of 2006, Option 4 is not expected to result in weld quality problem and worker exposure issues. Therefore, Option 4 was judged to be the optimal

decision with respect to establishing reasonable assurance that the health and safety of the public would be protected.

3.4.2 Defense-in-Depth

Section 3.1.2 assesses defense-in-depth for Option 1. The discussion in Section 3.1.2 on the impact of the issue on only one barrier and the potentially compounded increase in core damage frequency due to containment sump clogging apply equally to Option 4.

This option would require high reliance on required uniform enhanced leakage monitoring programs. Since leakage before complete loss of integrity is not assured, leakage monitoring is not complete compensation for a potentially degraded condition. For this reason, NRC staff concluded that the inspections and mitigations should be completed as soon as possible without introducing the unintended consequences of weld quality issues. Based on information provided by industry, NRC staff concluded that, while this option would place a high burden on industry, it is feasible for industry to complete the inspections and mitigations within the schedule of Option 4 without compromising weld quality.

3.4.3 Safety Margins

Option 4 would provide assurance that the intended safety margins are restored within a time period of one year without safety margins being negatively affected by weld quality issues.

3.4.4 Risk Assessment

At present, it is not feasible to estimate the magnitude of the change in risk compared to the base case.

3.4.5 Performance Measurement

No change from Option 3.

3.5 Option 5 - Allow licensees to complete the pressurizer nozzle Alloy 82/182 weld inspection and mitigation activities during their next planned outages for these activities, which extend out to June 2008. Under Option 5, all licensees with uninspected or unmitigated pressurizer nozzle Alloy 82/182 welds would be required to implement enhanced leakage monitoring frequency, action levels, and required actions if thresholds for changes in unidentified leakage are exceeded.

3.5.1 Compliance with Regulations

The proposed actions for Option 5 are similar to Option 4, except the time frame for completing the action is extended for an additional half year for nine PWRs. Industry prepared a white paper entitled, “Implications of Wolf Creek Pressurizer Butt Weld Indications Relative to Safety Assessment and Inspection Requirements,” to provide a technical basis for their proposed completion schedule during the next scheduled outage for each plant. However, the staff found that while the white paper (MRP 2007-003, Attachment 1), provided qualitative information in support of the industry position, it did not provide quantitative information to support the industry schedule. The NRC staff considered that the schedule of proposed Option 5 did not provide the requisite level of assurance of structural integrity. The reasons for this are the extended time frame for exposure to this safety issue from the discovery of the condition at Wolf Creek until mid-2008; the results of its fracture mechanics analyses that rupture could occur without prior evidence of leakage; the consequences of a potential rupture of a pressurizer nozzle; and the uncertainties regarding the condition of the uninspected/unmitigated welds. The NRC staff also considers that, while there would be consequences of lost power with mid-cycle shutdowns, it is feasible for the industry to complete the inspections/mitigations by the end of 2007. The NRC staff does not consider that the safety concerns for reactor coolant system integrity are adequately offset by relying on enhanced leakage monitoring until mid-2008.

By letter dated February 14, 2007, Nuclear Energy Institute (NEI) indicated that the Materials Reliability Program is undertaking an important task intended to refine the crack growth calculations pertaining to the Wolf Creek pressurizer dissimilar metal weld ultrasonic indications. These additional calculations are intended to extend the work documented in MRP 2007-003 and reinforce the industry conclusion that the industry inspection schedules for pressurizer nozzle welds do not need to be accelerated. These studies are being conducted to address the NRC staff's concerns regarding the potential for rupture without prior evidence of leakage from circumferentially oriented PWSCC in pressurizer nozzle welds. The goal of these studies is to reduce conservatisms and uncertainties in previous analyses and determine whether PWSCC in pressurizer butt welds will progress through-wall and exhibit detectable leakage prior to causing a rupture. At the conclusion of this industry program, the NRC staff will evaluate the industry analyses and document the results of the staff evaluation. If the advanced finite element fracture mechanics analyses provide reasonable assurance to the NRC staff that PWSCC will remain stable and not lead to rupture without significant time from the onset of detectable leakage, the NRC will consider a request from those plants with 2008 outages to relax their commitment to shutdown in 2007. This condition was reflected in the CALs issued to these nine plants. Therefore, the information from the industry studies may, in the future, provide a sufficient basis for Option 5.

3.5.2 Defense-in-Depth

Section 3.1.2 assesses defense-in-depth for Option 1. The discussion in Section 3.1.2 on the impact of the issue on only one barrier and the potentially compounded increase in core damage frequency due to containment sump clogging apply equally to Option 5.

As discussed in Section 3.5.1, the NRC staff considers that the schedule under this option for completing the necessary actions to restore safety margins places undue reliance on enhanced leakage monitoring.

3.5.3 Safety Margins

Option 5 would provide assurance that the intended safety margins are restored by the middle of 2008. PWSCC results in further degradation over time and leakage before complete loss of integrity is not assured. Given the potential consequences of this safety issue and the uncertainties associated with the condition of uninspected plants, the NRC staff does not consider that the safety concerns for reactor coolant system integrity are adequately offset by relying on enhanced leakage monitoring until mid-2008.

3.5.4 Risk Assessment

At present, it is not feasible to estimate the magnitude of the change in risk compared to the base case.

3.5.5 Performance Measurement

No change from Option 3.

5. CONCLUSIONS

The NRC staff performed fracture mechanics analyses of the flaws in each of the three Wolf Creek nozzle welds utilizing various assumptions. These analyses were performed to gain insights on how long it would have taken for leakage or rupture to occur if the flaws had been left in service. For the flaws identified in the relief and safety nozzles, the analyses indicated that the flaws could have resulted in a loss of coolant accident in less than three years and a number of those analyses indicated the accident could occur without prior leakage warning of the impending failure. This could unnecessarily challenge the safety features of the plant.

Based on these analyses and consideration of the uncertainties associated with the issue, the NRC staff performed an assessment of various regulatory options against the principles of risk-informed decision making. The NRC staff performed an evaluation of a risk assessment performed by industry and concluded that available data and current lack of understanding of the underlying physics of the degradation mechanism made any quantitative estimates of the risk too unreliable to support a regulatory decision. Therefore, the NRC staff's assessment of the options was based primarily on the other principles.

The staff concluded that licensees need to complete inspections or mitigations of the pressurizer nozzle Alloy 82/182 welds by the end of 2007 and implement interim enhanced leakage monitoring. This decision was based on the judgement that completing the actions by the end of 2007 would provide an appropriate balance of restoring safety margins within a time frame that would avoid compromising weld and inspection quality without placing undue reliance on the compensatory measure of enhanced leakage monitoring.

6. REFERENCES

1. Memorandum from J. E. Dyer to Michael R. Johnson, March 12, 2007, Communication Plan for the Issuance of Confirmatory Action Letters Regarding Pressurizer Alloy 82/182 Butt Weld Issue (ML070740142)

2. Materials Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guidelines (MRP-139), July 2005 (ML052220110), (Non-Proprietary Version ML052150196)

3. MRP 2007-003 Attachment 1, Implications of Wolf Creek Pressurizer Butt Weld Indications Relative to Safety Assessment and Inspection Requirements, January 2007 (ML070240159)

4. Draft Report on Evaluation of Circumferential Indications in Pressurizer Nozzle Dissimilar Metal Welds at Wolf Creek Power Plant, January 2007, by D. Rudland, D.-J. Shim, H. Xu, and G. Wilkowski, Engineering Mechanics Corporation of Columbus (ML070460305)

5. Letter from Jay Thayer, NEI, to J. Dyer, NRC, Feb 14, 2007, Refined Crack Growth Calculations Supporting Industry Response to Wolf Creek Pressurizer Dissimilar Metal Weld Inspections (ML070600674)

6. Letter from J.E. Dyer, NRC, to Jay Thayer, NEI, March 5, 2007, Response to NEI letter on Refined Crack Growth Calculations Supporting Industry Response to Wolf Creek Pressurizer Dissimilar Metal Weld Inspections (ML070640401)

7. Memorandum from Michele G. Evans to John A. Grobe, March 7, 2007, Justification Regarding Actions in Confirmatory Action Letter on Dissimilar Metal Butt Welds (ML070660614)

8. Office Instruction LIC-504, Revision 2, Integrated Risk-Informed Decision-Making Process for Emergent Issues, Effective Date - February 12, 2007 (ML070440213)

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