SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO THE EVALUATION OF THE PRESSURIZED THERMAL SHOCK SCREENING CRITERIA

CONSUMERS POWER COMPANY

PALISADES PLANT

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EXECUTIVE SUMMARY

This report presents the NRC staff's evaluation of Consumers Power Company's (the licensee) assessment of the Palisades reactor pressure vessel (RPV) relative to the requirements of 10 CFR 50.61 commonly referred to as the "pressurized thermal shock (PTS) rule." The PTS rule provides calculational procedures and screening criteria that limit the amount of irradiation-induced embrittlement to assure that the RPV will maintain adequate margins against failure during postulated PTS events. The limiting weld in the Palisades RPV has a combination of accumulated fluence and chemistry (copper and nickel) that result in a high level of predicted embrittlement.

During the fall of 1994, the licensee performed material properties tests and chemistry analyses of newly acquired samples of weld material that had been fabricated using the same procedures and weld wire heat number as the limiting weld in the RPV. These material samples were acquired from the shells of the steam generators that had been removed from service at Palisades. These tests and analyses indicated that the degree of embrittlement of the Palisades RPV could be higher than previously calculated. With the new data included in the evaluation, analyses performed in accordance with the PTS rule indicate that the Palisades RPV will satisfy the requirements of the PTS rule until the end of the plant's 14th refueling outage, scheduled for late 1999.

As part of its review the staff noted that there was a large variability in the reported chemistry data, i.e., copper and nickel, for the limiting RPV weld. To assess this concern the NRC staff employed the Palisades plant-specific chemistry and fluence data and performed RPV failure frequency calculations similar to those in SECY-82-465, "Pressurized Thermal Shock," dated November 23, 1982, which established the basis for the PTS screening criteria. These analyses demonstrated that the margins of safety intended by the PTS rule will be satisfied through the 14th refueling outage, even considering the variability observed in the Palisades chemistry data.

As a result of the above evaluations, the NRC has determined that the Palisades RPV can be operated in compliance with the requirements of 10 CFR 50.61 through the plant's 14th refueling outage. Also, in accordance with 10 CFR 50.61, three years prior to exceeding the PTS screening criteria the licensee shall submit a plant-specific analysis to determine if operation beyond the screening criteria is acceptable. We understand that the licensee plans to thermally anneal the reactor vessel. Submission of information on annealing will obviate the need for a plant-specific analysis.

# 1.0 INTRODUCTION

## 1.1 Summary of the PTS Rule

The pressurized thermal shock (PTS) rule, 10 CFR 50.61, adopted on July 23, 1985 and revised on May 15, 1991, established screening criteria that are a measure of a limiting level of reactor vessel material embrittlement beyond which operation cannot continue without further plant-specific evaluation. The screening criteria are given in terms of reference temperature, $RT_{PTS}$. The screening criteria are 270°F for plates and axial welds and 300°F for circumferential welds. The $RT_{PTS}$ is defined as

$$RT_{PTS} = I + \Delta RT_{PTS} + M$$

where (a) I is the initial reference temperature, (b) $\Delta RT_{PTS}$ is the mean value in the adjustment in reference temperature caused by irradiation, and (c) M is the margin to be added to cover uncertainties in the initial reference temperature, copper and nickel contents, fluence, and calculational procedures.

The initial reference temperature is the measured unirradiated value as defined in the American Society of Mechanical Engineers (ASME) Code, Paragraph NB-2331. If measured values are unavailable for the heat of material of interest, generic values may be used. The generic values are based on the data for materials of all heats that were made by the same vendor using similar processes. The generic values of initial reference temperature for welds are defined in the PTS rule.

The $\Delta RT_{PTS}$ depends upon the amount of neutron irradiation and the amounts of copper and nickel in the material and is calculated as the product of a fluence factor and a chemistry factor. The fluence factor is calculated from the best estimate neutron fluence at the clad-weld-metal interface on the inside surface of the vessel at the location where the material receives the highest fluence at the end of the period of evaluation. The chemistry factor may be determined using credible surveillance data or from the chemistry factor tables in the PTS rule. The chemistry factors in the tables depend upon the best-estimate values of the amount of copper and nickel in the material. Regulatory Guide (RG) 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," contains criteria for determining whether surveillance data is credible. The term "best-estimate" is not well defined statistically, but has normally been interpreted as the mean of the measured values.

The margin term is intended to account for variability in initial reference temperature and the adjustment in reference temperature caused by irradiation. The value of the margin term is dependent upon whether the initial reference temperature was a measured or generic value and whether the adjustment in reference temperature was determined from credible surveillance data or from the chemistry factor tables in the PTS rule.

A more detailed discussion of the PTS rule and reactor vessel integrity in general is provided in NUREG-1511, "Reactor Pressure Vessel Status Report," published by the NRC in December 1994.

1.2 Background on Palisades PTS Evaluations

The staff previously issued an interim PTS safety evaluation for the Palisades plant in a letter dated July 12, 1994. In the interim safety evaluation, the staff concluded that the Palisades reactor vessel would reach the PTS screening criterion in the year 2004, prior to the expiration of the Palisades license in 2007. This conclusion was based on evaluation of the data that were available at that time. The staff indicated that this conclusion could change based on test results from the retired steam generators, which contained weld metal that was fabricated using the same heats of weld wire (heats W5214 and 34B009) as the limiting welds in the Palisades reactor vessel beltline.

The $RT_{PTS}$ value calculated in the interim PTS safety evaluation was determined using a generic value of initial reference temperature and $\Delta RT_{PTS}$ based on the chemistry factor tables in the PTS rule. A generic value of initial reference temperature was used because the limiting weld materials did not have measured values in accordance with ASME Code, Paragraph NB-2331. The chemistry factor tables were used because the weld material in the Palisades surveillance capsules did not satisfy the credibility criteria in RG 1.99, Revision 2. Specifically, they were fabricated using a different heat of weld wire than the welds in the reactor vessel beltline.

The chemistry factor for the limiting beltline welds was determined from best-estimate values of copper and nickel of 0.20 percent and 1.02 percent, respectively. The limiting Palisades beltline welds were fabricated with tandem primary electrodes and a cold nickel wire feed. The best-estimate value of the percent copper for welds fabricated using W5214 weld wire was determined from seven welds and the best-estimate value for the percent nickel was determined from fourteen welds. All the welds were fabricated using W5214 weld wire. Some of the welds were fabricated using tandem primary electrodes and some were fabricated using single primary electrodes. Since the measured amount of copper in a weld fabricated using tandem primary electrodes represents the average amount of copper from two coils of weld wire and the measured amount of copper in a weld fabricated using a single primary electrode represents the amount of copper from a single coil of weld wire, the staff used a weighted average to determine the best estimate of the amount of copper for the welds. The best estimate for the amount of nickel was the simple average of the nickel values, since these welds were fabricated with a single nickel wire.

The retired steam generators contained weld metal fabricated using the same heats of weld wire as the limiting welds in the Palisades reactor vessel beltline. The licensee decided to remove material from the steam generators to acquire additional copper and nickel data from three welds in each steam generator and the initial reference temperatures for each heat of weld wire. The copper and nickel measurements from the retired steam generators were to be added to the previous weld data to determine the best-estimate values of copper and nickel for the Palisades limiting welds.

The licensee provided information from the test results from the Palisades steam generators in a letter from K. M. Haas to the NRC dated November 8, 1994, and in letters from R. A. Fenech to the NRC dated November 10, 1994, and November 18, 1994. The licensee withdrew the November 8, 1994, and November 18, 1994, letters in a letter dated January 23, 1995. The information in the January 23, 1995, letter supersedes the previous submittals. The staff and the licensee discussed the test results in a meeting in NRC headquarters on November 21, 1994. Additional information requested by the staff was provided by the licensee in letters from R. A. Fenech to the NRC dated December 14, 1994, December 28, 1994, and January 16, 1995. The licensee provided a revised PTS analysis in a January 13, 1995, letter from R. A. Fenech to the NRC. The licensee provided a neutron fluence map and information on the limiting PTS transient for the Palisades reactor vessel in a letter from K. M. Haas to the NRC dated March 31, 1995. This report provides the staff's assessment of the licensee's revised PTS analysis which incorporates the new material property and chemistry data. The staff's assessment of the initial reference temperature, increase in reference temperature, and margin term used to determine the $RT_{PTS}$ value are presented in Sections 2.0, 3.0, and 4.0, respectively. Section 5.0 provides the failure probabilities of the Palisades RPV and Section 6.0 provides the overall evaluation of the $RT_{PTS}$ value for the Palisades RPV.

## 2.0 INITIAL REFERENCE TEMPERATURE

### 2.1 Introduction

The PTS rule requires that credible measured values of initial reference temperature, as defined in the ASME Code, Paragraph NB-2331, be used to determine the $RT_{PTS}$ value of a material. Paragraph NB-2331 of the ASME Code requires the initial reference temperature to be determined from both drop weight and Charpy impact tests. The drop weight test determines the nil-ductility transition temperature, NDTT. The Charpy impact test is used to determine the temperature corresponding to 50 ft-lb absorbed energy. The initial reference temperature is defined as the higher of the NDTT or the temperature 60°F below the temperature corresponding to 50 ft-lb absorbed energy.

The PTS rule requires that the initial reference temperature for the Palisades reactor vessel weld be -56°F, if credible values are unavailable. This value of initial reference temperature is the generic mean value of the population of all RPV welds fabricated by Combustion Engineering. As discussed in Section 1.1, if the generic mean value is used for the initial reference temperature, the standard deviation (17°F) of the database should be considered in determining the amount of margin to be added to determine the $RT_{PTS}$ value for the material. The result is that if the generic mean value for the initial reference temperature is used to determine the $RT_{PTS}$ value for a material, the PTS rule requires a margin term of 66°F. This is further explained in Section 4.0. If a credible heat-specific measurement of the initial reference temperature exists, it should be used and the margin term used in the $RT_{PTS}$ calculation should be reduced to 56°F. As discussed below, concerns were raised as to whether the initial reference temperature measured from the steam generators is credible and directly applicable to the Palisades reactor vessel welds. The staff's review focused on determining whether it is most appropriate to use the initial reference temperature measurements from the steam generator welds as credible heat-specific values with the reduced margin term or to use the generic value with the larger margin term for the assessment of the critical weld in the Palisades reactor vessel.

2.2 Evaluation of Data From Palisades Retired Steam Generators

In an attempt to determine a heat-specific value for the initial reference temperature of weld wire heat numbers W-5214 and 34B009, the licensee conducted Charpy V-notch impact and drop weight tests on weld material removed from the retired Palisades steam generators that were fabricated using W-5214 and 34B009 weld wire. Both welds were fabricated with tandem RACO 3 type filler wire with the addition of a cold-fed nickel wire of type NI 200, heat N7753A. The welds were made using the same weld wires (i.e., the same heats of weld wire) and type of welding flux (type 1092) as those which were used for the axial welds in the Palisades RPV. The weld wire of primary interest is W-5214, since it is the limiting Palisades weld with respect to the PTS rule. W-5214 was used to fabricate all three upper axial welds of the Palisades RPV. The lower axial welds of the RPV were fabricated with both W-5214 and 34B009. The current surveillance program at Palisades does not include these welds.

The licensee reported to the staff the Charpy and drop weight test results from the retired steam generators at the November 21, 1994, meeting at NRC Headquarters. The data is contained in the November 30, 1994, meeting summary.

The drop weight and Charpy impact tests on the retired steam generator welds fabricated using heat number W-5214 weld wire resulted in a measured initial reference temperature of -20°F. Testing of the steam generator welds fabricated using heat number 34B009 weld wire resulted in a measured initial reference temperature of -50°F. In both cases the drop weight test data was the controlling factor in determining the initial reference temperature. These values are within the range of the generic Combustion Engineering initial reference temperature data that is reported in Combustion Engineering report CEN-189, December 1981. However, the -20°F value reported for the W-5214 material is near the upper range of the data. The Combustion Engineering database reports the initial reference temperature for 78 welds that were fabricated by Combustion Engineering and are representative of the welds in the Palisades RPV. The data range from -80°F to -10°F, have a mean value of -56°F and a standard deviation of 17°F.

2.2.1 Evaluation of Thermal Embrittlement and Mechanical Property Data

In its submittal, the licensee suggested that the higher initial reference temperature (-20°F) for the steam generator W-5214 weld may have been a consequence of thermal embrittlement due to long-time service at the operating temperature (>500°F) in the steam generator. For weld 34B009, however, such effects were not observed.

The staff, with the assistance of the NRC Office of Nuclear Regulatory Research and its contractors, reviewed the issue of thermal embrittlement of RPV steels under nominal reactor operating conditions. This review included (1) data from the literature regarding relatively low-temperature thermal embrittlement of RPV steels, (2) relevant data from the power reactor-embrittlement database (PR-EDB), (3) potential mechanisms of thermal embrittlement in low-alloy steels, (4) the mechanical property and chemical composition data reported by the licensee, and (5) treatment of thermal embrittlement by other countries. Details of this review are provided in [Ref. 1]. A summary of the review follows

The review of data from the literature concentrated on the shift in the ductile to brittle transition temperature as a consequence of aging time for base metals, heat-affected-zone (HAZ) materials, and weld metals. For base metals typically used in fabrication of U.S. RPVs, the majority of data indicates little effect of aging at temperatures in the 500 to 600°F range, even for times as great as 100,000 h (11 calendar years). Less data are available for HAZ and weld materials, but similar statements apply. The staff concluded that the data regarding evidence for thermal embrittlement of RPV steels is inconclusive.

A review of the PR-EDB did not reveal convincing evidence of thermal embrittlement. Although there are a few instances of relatively large shifts in the 30 ft-lb transition temperature at low fluences, the excessive scatter in the data and overall level of uncertainty in the shift measurement render those results inconclusive.

With regard to evaluation of mechanisms of thermal embrittlement, the staff concludes that thermal embrittlement in U.S. RPV steels is mechanistically possible in the RPV operating temperature range (500°F - 600°F), but is not likely to occur. Key factors are time, temperature, and composition. The temperature factor is particularly critical as studies have shown that long-term thermal embrittlement in RPV steels would be minimal at RPV operating temperatures due to slow diffusion kinetics even with consideration of some phosphorus segregation (potential for temper embrittlement). The combined effects of irradiation and thermal embrittlement for the long term have not been conclusively determined.

Regarding the drop-weight and Charpy impact tests on the Palisades steam generator welds, the higher than expected transition temperatures obtained for the W-5214 weld (SG-A) were major factors in suspecting that the weld metal may have experienced thermal embrittlement as a consequence of long-time exposure during operation of the steam generator. It was noted that similar tests on the 34B009 weld removed from a similarly exposed Palisades steam generator weld did not result in unexpectedly high transition temperatures. The NDTT results for the SG-A weld, although higher than expected based on comparisons with the Combustion Engineering generic weld database, did fall within the range of NDTTs in the database. For drop-weight tests with low-alloy steels, scatter within a given heat of steel can vary by at least ±20°F.

In its December 14, 1995, submittal, the licensee suggested that the fabrication procedure for the brittle weld crack starter bead, having changed from either a one-pass or a two-pass (pre-1991) to a one-pass only (current Palisades SG-A data) process, added increased variability to the NDTT results. The submittal did not indicate which process was used for generation of the NDTT data constituting the generic Combustion Engineering database. Other weld data upon which such a comparison could be based are limited. The possibility exists that additional variability could be introduced from this source with a potential bias toward higher NDTT values for the one-pass process. However, the staff concludes that a convincing argument for increased variability on this basis has not been made.

Regarding the treatment of thermal embrittlement effects by regulatory authorities in other countries, the review indicated that the United Kingdom (U.K.) and Russia attempt to account for such effects in their embrittlement predictions. Details are provided in [Ref. 1]. In general, the differences between the U.S and foreign plants in composition of the RPV steels (typically foreign steels have higher phosphorus) and operating characteristics (temperature, in particular), make application of their models to U.S. light-water reactors uncertain. For example, the U.K. model is applicable to the mild steels used in Magnox reactors.

In summary, the staff concludes that evaluation of the available data (including Palisades steam generator data) and mechanistic models regarding thermal embrittlement of RPV steels does not provide convincing evidence of a thermal embrittlement effect on the properties of the steels in the unirradiated condition. Additionally, the staff concludes that a convincing argument has not been made for increased variability in initial reference temperature, on the basis of variations in drop weight test specimen preparation. Possible effects of thermal embrittlement or test methods on the initial reference temperature appear to be within the normally expected statistical variation in material properties.

### 2.2.2 Evaluation of Post-Weld Heat Treatment Effects

Under certain conditions, thermal exposures during component fabrication and operation have been shown to contribute to changes in toughness properties of low-alloy steels. Exposure in the post-weld heat treatment (PWHT) range, typically 1100°F-1150°F, results in microstructural changes, characterized by changes in the distribution and morphology of precipitates. The rate of cooling from the PWHT temperature will also affect precipitation, thereby altering toughness. Temper embrittlement may occur when sensitive material is either slow cooled or held in the temperature range of 700°F to 1100°F. The effects of temper embrittlement may be minimized by rapid cooling of the material through the embrittling temperature range.

The licensee provided cooling times, rates, and temperatures from the final PWHT for the Palisades steam generators and reactor vessel. The reactor vessel cooling rate was significantly faster than either of the steam generators. The licensee concluded that although the cooling rates for both steam generators were generally slow, there was no obvious difference due to the thermal histories that could account for the differences in Charpy impact properties.

Oak Ridge National Laboratory carried out an analysis [Ref. 1] to determine if differences in the stress relief times and temperatures would be expected to give rise to the differences in mechanical properties between the Palisades steam generator welds and the Palisades reactor vessel welds. These calculations indicated that no significant differences would be expected. Based upon the results of this analysis and review of the Palisades PWHT histories, the staff concludes that the heat treatment differences between the steam generator welds and the RPV welds would not be expected to have any significant effect upon the properties.

2.3 Evaluation of Other W-5214 Data

The licensee also provided unirradiated Charpy impact test data from surveillance welds from Indian Point 2, Indian Point 3 and Robinson 2, which were fabricated using heat number W-5214 weld wire. These surveillance welds were not drop-weight tested. Hence, they did not have reported values of initial reference temperature. However, their Charpy impact data were significantly greater than the values from the retired steam generators, which would indicate that the initial reference temperatures for the surveillance welds could be lower. Based on evaluation of the Charpy impact data from the surveillance welds, the staff has concluded that the initial reference temperatures could vary from -42°F to -93°F, depending upon whether the Charpy or the extrapolated drop-weight test data is controlling.

The variability in initial reference temperature results from measurement error and the variability of properties within a heat of material. The generic value of initial reference temperature and its standard deviation account for this variability. The variability observed in the NDTT and Charpy data within heat W-5214 weld material indicates that the use of a single data point to determine the initial reference temperature of this weld is not appropriate.

2.4 Assessment of Initial Reference Temperature

The staff has compared the initial reference temperature from the Palisades steam generator to the generic Combustion Engineering test data. The Combustion Engineering database consists of 78 data points; 4 of the data points are greater than or equal to -20°F. (The highest initial reference temperature from the Palisades steam generators is -20°F.) Therefore, there is approximately a 10-percent chance that one of the two steam generator data points would be greater than or equal to -20°F. Hence, there is no statistical basis for concluding that the initial reference temperatures from the Palisades steam generator welds did not come from the same population as the generic Combustion Engineering database.

The staff has evaluated the industry data for thermal aging and concludes that there is no conclusive evidence that thermal aging at steam generator operating temperatures could contribute to the embrittlement of the Palisades W-5214 steam generator material. The variability in NDTT measurements and the Charpy impact test data from unirradiated surveillance data and the retired steam generators indicates that welds fabricated from W-5214 could have initial reference temperatures ranging from -20°F to -93°F. Therefore, the staff concludes that it is more appropriate to use the generic database than the single data point from the retired steam generator. It is important to note that the use of the generic value of -56°F with the larger margin term (margin term for the initial reference temperature is 2 times 17°F, the standard deviation for the generic data) to account for variability in the generic data adequately accounts for the probability that the initial reference temperature could be as high as -20°F. Hence, the staff concludes that the generic value of initial reference temperature (-56°F) and its standard deviation (17°F) should be used to determine the $RT_{PTS}$ value for the Palisades reactor vessel welds.

## 3.0 ADJUSTMENT IN REFERENCE TEMPERATURE

### 3.1 Fluence Evaluation

Palisades flux reduction measures were implemented with cycle 8. To reduce the flux on the axial limiting weld in cycle 8, thrice-burned fuel assemblies were used and the four outer fuel rod rows were replaced with stainless steel rods. In cycle 9, sixteen thrice-burned assemblies which incorporated hafnium clusters (in addition to the stainless steel rods) were placed in the periphery of the core. Eight new stainless steel shielded assemblies were added in cycle 10 to reduce the flux on the circumferential weld. Cycle 11 is using 16 thrice-burned assemblies with steel rods in each to replace an equal number of assemblies introduced in cycle 8.

The staff conducted detailed calculations for the estimation of the Palisades pressure vessel fluence. The objectives of these calculations were to (1) audit the submitted fluence estimates which were performed by Westinghouse for the pressure vessel and (2) to investigate the potential differences caused by the revised ENDF/B-VI iron inelastic scattering, hydrogen, and oxygen cross sections. The staff's calculations were carried out by Brookhaven National Laboratory (BNL). The calculations were performed with the source data up to and including cycle 9. The source data from cycle 9 was similar to that in cycle 10. The Palisades plant is currently operating in fuel cycle 11. The required plant operating and design data, including (1) geometry of the core, reactor internals, vessel and reactor cavity; (2) power and exposure distribution; (3) operating temperatures, and (4) parameter uncertainties, were obtained from the licensee and Westinghouse. The DORT discrete ordinates transport code [Ref. 2] was used to calculate the transport of the core neutrons to the vessel. The MESH code [Ref. 3] was used to determine the space-energy dependent core neutron source in the $(r,\theta)$ geometry for input to DORT. The 47-group SAILOR library [Ref. 4] was used in the original and updated forms using the ENDF/B-VI cross sections.

Two sets of the 47-group SAILOR cross section libraries were derived by collapsing the ENDF/B-IV and ENDF/B-VI 171 fine group cross sections using spatially dependent spectra for a typical pressurized water reactor configuration. The U-235, U-238, Pu-239, Pu-240, Pu-241, and Pu-242 fission spectra were used in the MESH calculation of the neutron source. Similarly, the ENDF/B-VI fission spectra for U-235, U-238, Pu-239 and Pu-241 were processed with NJOY [Ref. 5]. For E>1.0 Mev, both methods yielded fluxes which agreed within 1.0 percent. The capsule dosimeter reaction rates were calculated using ENDF/B-VI, 47-group cross sections using NJOY.

The neutron source estimates included the effects of the strong radial power distribution gradient in the peripheral assemblies, by accounting for pin-wise variation. The increased number of neutrons per fission and the spectral effects associated with the presence of Pu in the fuel were also taken into account.

The neutron transport calculations were performed in an $(r,\theta)$ eighth core geometry, boot strap, fixed source mode. The approximations included $P_3$ inelastic scattering, $S_8$ quadrature and vacuum boundary conditions on the outer radial boundary. A detailed comparison of the fluence best-estimate values and the associated uncertainties was carried out for the BNL vs the submitted fluence values. The comparison included the effects of the ENDF/B-IV vs ENDF/B-VI for the iron, oxygen, and hydrogen cross sections. The results indicated that the licensee estimated peak vessel fluence and its uncertainty are within the ±20 percent ($1\sigma$) staff recommended value. This uncertainty will be used in the Monte Carlo simulation that is discussed in Section 5.0 of this safety evaluation.

The PTS analysis was performed using the cycle 9 flux for the limiting weld of 1.73E15 n/(cm$^2$-effective full power day) and an end of cycle 10 cumulative fluence value of 1.25E19 n/cm$^2$. The peak flux at the limiting weld was equivalent during cycles 9 and 10.

3.2 Chemical Composition of W-5214 Welds

3.2.1 Licensee Evaluation of Chemistry Data

The mean value of the adjustment in reference temperature caused by irradiation ($\Delta RT_{PTS}$) in the PTS rule is determined from the best-estimate weight percent copper and nickel for each reactor vessel beltline weld. Since the chemical composition of the actual welds in the Palisades reactor vessel beltline has not been measured, the PTS rule permits that the chemical composition be determined using welds which were fabricated using the same heat of weld wire as the Palisades beltline welds. The PTS rule indicates that the best-estimate weight percent copper and nickel will normally be the mean of the measured values for a plate or forging or for weld samples made with the weld wire heat number that matches the critical weld.

The Palisades beltline welds were fabricated using weld wire heat numbers 27204, W-5214, and 34B009. As discussed in previous safety evaluations the limiting beltline welds with respect to PTS were the axial welds fabricated using heat number W-5214 weld wire. The best-estimate weight percent copper for welds fabricated using heat number W-5214 weld wire was previously determined from seven welds and the best-estimate weight percent nickel was determined using fourteen welds. The best estimate of the amount of copper was determined using a weighted average, where the amount of copper from welds fabricated with tandem electrodes was weighted by two and the amount of copper from welds fabricated with a single electrode was weighted by one. The best estimate for the amount of nickel was the simple average of the nickel values of all welds fabricated using a cold nickel wire feed and heat number W-5214 primary electrodes.

Chemical analyses of the weld material from the retired steam generators were performed to increase the size of, and thus increase the accuracy of, the industry database for welds fabricated using weld wire from heat numbers W-5214 and 34B009. The test results of these chemical analyses are identified in Tables 1 and 2. When the copper and nickel measurements from the Palisades steam generators are combined with the previous data, the beltline welds with heat numbers W-5214 weld wire remain the limiting welds.

Each steam generator shell was fabricated from three shell segments that were joined using three axial welds. The steam generator welds in each shell were fabricated together as a group to reduce the amount of weld distortion. Based on the weld geometry and the weight of each coil, the licensee determined that all the axial welds in a shell segment were fabricated using a total of six coils of weld wire. Since the axial welds were fabricated using tandem electrodes, the axial welds were most likely fabricated with three combinations of tandem electrodes. After considering the sequence of the welding and the consistency of the test results, the licensee concluded that the measurement from the steam generator welds represented three unique combinations of weld wires. The welds were fabricated from double U machined grooves. The welds were started from the outside diameter (OD) side of the groove. After approximately 1-1/2 inches of weld material was deposited in each groove, the grooves were back gouged to sound metal and welding continued on the inside diameter (ID) side of the weld joint. After completing the three welds from the ID, the welds were completed on the OD side of the groove. Based on this sequence of welding, the licensee identified three sets of measurements that represent the three combinations of tandem electrodes used to fabricate the steam generator welds. The licensee performed a statistical F test of the steam generator data and determined that the data is consistent with the hypothesis for analyzing the steam generator data as three separate sets of data representing three combinations of tandem electrodes. The average percent copper for each set of the combination of electrodes was 0.348, 0.277, and 0.226, respectively.

The heat number W-5214 weld database for the percent copper consists of test results from a nozzle cutout from Indian Point 3, a surveillance weld from Indian Point 3, a surveillance weld from Indian Point 2, a surveillance weld from Oyster Creek 1, a surveillance weld from Robinson 2, the Robinson reactor vessel torus-flange weld, a sample from the 1-042 longitudinal weld seam from the Indian Point 2 reactor vessel and the three Palisades steam generator welds. Table 3 identifies the amount of copper in all the welds for heat number W-5214 except for the Palisades steam generator welds. To provide a common basis for comparing the copper measurements from different samples and to determine a best-estimate weight percent copper, the licensee determined whether the measurements from a sample represented weld metal from one or more unique combinations of weld wires. The combination of weld wires was determined by examining the weld record for the sample to determine the number of weld coils used to fabricate the sample and the locations of the measurements from the sample. The licensee's estimate of the number of unique combinations of weld wires in each weld is identified in Table 3. The licensee determined that the weld database for heat number W-5214 consists of eleven unique tandem arc weld combinations and two single arc welds (Table 4). Since a tandem arc represents the amount of copper from two coils, the number of coils represented in the heat number W-5214 database is 24 (2x11 for tandem arc welds and 1x2 for single arc welds). A weighted average (2 for tandem arc and 1 for single arc) of the data results in a mean value of 0.212 percent copper. The median value for the percent copper is 0.19 percent.

The licensee evaluated the heat number W-5214 copper data using a t-test and a Fisher's Exact test. The t-test indicates that the data from the steam generators may not be from the same population as the other welds. However, the licensee indicated that since the distribution does not appear to be normally distributed, the t-test may not be appropriate. As an alternative, the licensee performed the Fisher's Exact Test, a non-parametric test. As a result of this test, the licensee concluded that the steam generator data and the other weld data could be from the same population.

The average of all the nickel measurements from the three Palisades steam generator welds is 1.10 percent. When this data is added to the other welds the mean value for the percent nickel in heat number W-5214 welds is 1.02 percent. Table 5 identifies the weld nickel data for heat number W-5214 welds.

3.2.2 Staff Evaluation of Chemistry Data

The mean value from a weighted average of the unique combinations of welds in the W-5214 weld database is an acceptable method of determining the best-estimate percent copper in accordance with the PTS rule. Figure 1 contains a histogram of the tandem W-5214 percent copper data. The 11 tandem weld combinations are identified as individual datum. The two single arc welds are identified as a single datum using their average value. The data are clearly not normally distributed. It is a skewed distribution with a standard deviation of 0.070 percent copper. For this reason, the staff agrees with the licensee that the use of a t-test to compare the steam generator data with the other data may be inappropriate. Accordingly, a non-parametric test should be used. However, the Fisher's test used by the licensee is not the best test for this purpose because it is relatively insensitive to differences in the populations being compared (i.e., it has low power). A better test is the Mann-Whitney or Wilcoxon Rank-Sum test. Performing this test on the data results in a sum of the ranks for the data from the non-steam generator welds of 47. Using the Mann-Whitney tables with n=9 (nine welds) and m=3 (three steam generator welds), the data is significant at the 2.5 percent level for a one-sided test and at the 5 percent level for a two-sided test. Since the data has such low significance, the null hypothesis that the steam generator and other welds come from the same population should be rejected. This suggests that there can be significant differences in the copper content of welds made with different coils of weld wire, even if the weld wire are from the same heat of material.

The above conclusion is further supported by the standard deviation of 0.070 percent for the coil to coil variation in the mean copper values for W-5214 material. This relatively large standard deviation probably results from the variability of the copper plate that surrounds the wire. There are two sources of copper in a weld. They are the amount of copper in the wire itself and the amount of copper in the plating that surrounds the wire. The variability of the copper within the wire from a specific heat is expected to be small because the copper should be relatively uniformly distributed in the wire after processing from an ingot. However, the amount of copper plated on the wire could be highly variable because the amount depends on the concentration of the plate bath, the temperature of the plate bath and the length of time that the coil is immersed in the bath. Since these parameters could vary between coils from a specific heat of weld wire, the copper plating could vary significantly from coil to coil.

The mean value from the simple average of the welds in the W-5214 weld database is an acceptable method of determining the best-estimate percent nickel in accordance with the PTS rule. The data has a standard deviation of 0.1275 percent nickel. This relatively large standard deviation results from the method of weld fabrication, in which nickel is added to the weld through cold nickel wire. The rate of feed of cold nickel wire could vary and could result in a relatively large variability in nickel.

The above observations have significant implications with respect to the adequacy of the margin term used in calculating the $RT_{PTS}$ value. This issue is discussed further in Section 4.0.

## 4.0 MARGIN TERM

As discussed in Section 1.0, the PTS rule contains a margin term to be added to the mean value of the adjustment in reference temperature. The margin term is intended to account for the uncertainty in the percent copper and nickel as well as the uncertainty in the initial reference temperature and the neutron fluence. The amount of margin is calculated following the methodology in RG 1.99, Revision 2. The margin term is determined based upon the variability in the initial reference temperature ($s_I$) and the variability in the adjustment in reference temperature ($s_\Delta$).

In accordance with RG 1.99, the margin term is given by

$$M = 2*[(s_I)^2 + (s_\Delta)^2]^{1/2}$$

where $s_I$ equals 17°F and $s_\Delta$ equals 28°F for the Palisades welds, since the initial reference temperatures were generic values. This results in a margin value of 66°F, the margin value in the PTS rule.

As discussed in Section 2.4, an assessment of the available drop weight and Charpy data for the W-5214 material indicates that the 17°F contribution to the margin term is adequate to account for the variability in the initial reference temperature of the W-5214 material. However, the staff noted that there is significant variability in the reported copper and nickel data for the W-5214 material. The 28°F contribution to the margin term corresponds to one standard deviation of the differences between the measured increase in reference temperature from surveillance data and the predicted increase in reference temperature for surveillance data using the methodology in RG 1.99, Revision 2. The measured minus predicted value from the surveillance data are referred to as residuals. The variability in these residuals includes variability in neutron fluence, copper, nickel, test and measurement techniques, and calculational procedures. The magnitude of the contribution from each of these variables to the overall variability in the residuals is difficult to determine. However, the staff was concerned that the variability of copper of 0.07 percent and nickel of 0.1275 percent that was observed for the W-5214 material could potentially result in a greater overall variability than accounted for by the margin term.

## 5.0 RPV FAILURE PROBABILITY

As discussed in SECY-82-465, the PTS screening criteria were selected based on generic studies of the expected frequency and character of a wide spectrum of transients and accidents that could cause pressurized overcooling of the reactor vessel (PTS events). The risk due to PTS events was assessed in terms of probabilistic fracture mechanics calculations coupled with the frequency of postulated PTS events to yield an expected frequency of through-wall crack penetration of the pressure vessel due to PTS events. The generic studies indicate that for mean values of $RT_{PTS}$ in the range of interest (below about 225°F), the failure frequency would be dominated by a transient involving extended high pressure safety injection (HPSI) following a postulated small-break loss-of-coolant accident. The generic studies indicated that at a mean surface reference temperature ($RT_{NDT}$) of 210°F the through-wall crack frequency would be about 6 x $10^{-6}$ (see Figure 8-3 in SECY-82-465). A mean $RT_{NDT}$ value of 210°F corresponds to the 270°F PTS screening criteria for axial welds and plates. The 60°F difference was the margin value assumed to account for uncertainties in the initial reference temperature and uncertainties in the increase in reference temperature resulting from neutron radiation.

The staff performed sensitivity studies using Monte Carlo simulation methods to assess the impact of the variability in percent copper and nickel for the W-5214 axial welds in the Palisades reactor vessel beltline on the frequency of through-wall crack penetration for postulated PTS events. The sensitivity studies were performed using a modified version of the VISA-IID Code. The capability of the current VISA-IID Code was enhanced by the staff to allow evaluations using the Palisades plant-specific discrete distributions of copper and nickel. To allow direct comparison of the frequency of through-wall crack penetration of the Palisades vessel with that from the generic study in SECY-82-465, the staff used the same flaw density and size distribution as those used in the 1982 study. If the staff used the flaw density and size distribution employed in the PTS evaluations conducted after the issuance of SECY-82-465, the failure frequencies would be significantly lower than reported here. With this modified Code, the staff calculated the conditional failure probabilities for the Palisades RPV using the same input parameters used in SECY-82-465 with the exception of incorporating the Palisades specific copper, nickel, and fluence distributions.

The initial reference temperature was sampled from a normal distribution with a mean value of -56°F and a standard deviation ($\sigma_I$) of 17°F. The mean value for the shift in reference temperature resulting from neutron irradiation and its standard deviation ($\sigma_\Delta$) were determined by using randomly sampled values of copper, nickel, and neutron fluence. Each simulation calculated a "simulated" shift in reference temperature using the methodology in the PTS rule. The copper and nickel values were sampled from histograms constructed from the available chemistry data for welds with Heat W-5214. The histogram for copper was derived from the copper values reported in Table 4 and was constructed from the following data (a) three values (0.249 percent, 0.271 percent and 0.348 percent) representing the three tandem copper values from the retired steam generators, (b) one value (0.310 percent) from the average of the two single arc welds in the W-5214 weld copper database, and (c) eight values (0.15 percent, 0.15 percent, 0.158 percent, 0.159 percent, 0.16 percent, 0.19 percent, 0.20 percent and 0.215 percent) representing the data from the remaining welds in the W-5214 weld copper database. The amount of copper in the two single arc welds were averaged to represent a tandem arc weld. The three values for the retired steam generators were the averages for the three combinations of tandem electrodes discussed in Section 3.2.1. The histogram for nickel was the fifteen W-5214 weld data values reported in Table 5.

The neutron fluence values were sampled from a normal distribution with the prescribed mean value from the plant-specific fluence map corresponding to values at the end of cycle 14 (4th quarter 1999) and a standard deviation of 20 percent of the mean value. This estimated fluence map was developed and submitted by the licensee for the Palisades RPV in a letter dated March 31, 1995. The map provides fluence values for every 3 degrees of arc (including the peak) and every 6 inches of active core height. These azimuthal and axial values are the product of relative fluence ratios and a peak fluence value at the end of cycle 14. The peak fluence value at the end of cycle (EOC) 14 was calculated using the EOC 10 fluence value, and assuming cycle 11 fluence rates for cycles 11 through 14. In the computer simulations, it is impractical to model the fluence map at this level of detail. Hence, the staff modelled the fluence values for every 15 degrees of arc and every 12 inches of active core height.

The staff considered two cases of transients. First, to provide a direct comparison with the SECY-82-465 evaluation, the extended HPSI transient from SECY-82-465 was used. For the second case, three plant-specific transients provided by the licensee were used. The staff reviewed these transients and concluded that the SECY-82-465 HPSI transient is much more severe than the three plant-specific transients [Ref. 6]. Based on the extended HPSI transient used in the 1982 study, the staff obtained a frequency of through-wall crack penetration of $3.93 \times 10^{-6}$ for all beltline welds of the Palisades vessel. The contribution of the circumferential weld to the overall frequency was insignificant. This failure frequency is less than the value of $6 \times 10^{-6}$ from SECY-82-465, in which only axial welds were considered. To perform a more comprehensive evaluation, the staff included all beltline plates of the Palisades vessel in this study. With the plant-specific chemical composition, initial $RT_{NDT}$, and fluence map unique to each of the six plates, and using a flaw density of one tenth of the welds, the staff arrived at a frequency of $3.68 \times 10^{-6}$ for the beltline plates for the extended HPSI transient.

To assure a valid comparison between the current calculations and those performed in SECY-82-465, the staff benchmarked the revised VISA-IID Code against a reference case analyzed in the SECY paper. The revised code resulted in a lower failure probability than that reported in SECY-82-465 (Figure H-8) for the reference case using the RANCHO SECO transient. Therefore, the frequencies calculated by the staff have been increased by 85.5 percent to reflect the difference between the results for the reference case and those obtained by using the revised VISA-IID Code.

The combined values of $7.61 \times 10^{-6}$ for the Palisades vessel using the extended HPSI is comparable to the frequency of $6 \times 10^{-6}$ from the generic study of 1982. For the plant-specific transients, the staff found that the Feed and Bleed (no operator action) transient is most limiting and has a much lower frequency of $1.06 \times 10^{-6}$. The combined failure frequency for all three transients is $2.11 \times 10^{-6}$.

## 6.0 RESULTS AND CONCLUSIONS

The licensee has concluded that the critical weld in the Palisades reactor vessel would reach the PTS screening criteria at a neutron fluence of 1.55E19 which is expected to occur in the year 2000. This value was determined using an initial reference temperature of -56°F, an increase in reference temperature resulting from radiation of 260°F and a margin value of 66°F. The initial reference temperature is the generic value for Combustion Engineering welds that is required by the PTS rule when credible values are not available. The margin value is the amount required by the PTS rule for welds when the initial reference temperature is a generic value. The increase in reference temperature is based on a chemistry factor of 232°F, which is an interpolated value from Table 1 in the PTS rule that corresponds to 0.212 percent copper and 1.02 percent nickel.

The staff has evaluated the industry data for thermal embrittlement and concludes that there is no conclusive evidence that thermal embrittlement at steam generator operating temperatures should have contributed to the embrittlement of the Palisades W-5214 steam generator material. Since the NDTT and the Charpy impact test data from unirradiated surveillance data and the retired steam generators indicate that welds fabricated from W-5214 could have initial reference temperatures ranging from -20°F to -93°F, the staff concluded that using the single data point from the retired steam generator to determine the initial reference temperature of W-5214 weld material is not appropriate. Hence, the staff concludes that the generic value of initial reference temperature of -56°F and its standard deviation of 17°F is acceptable to determine the $RT_{PTS}$ value for the Palisades reactor vessel welds.

The staff has concluded that the licensee's method of determining the best-estimate percent copper and nickel from the weld data is acceptable since it accounts for differences in coil to coil and single/tandem electrode variations in chemical composition.

As discussed in Section 3.2.2, the large variability in the weld W-5214 chemistry data used in calculating the shift in $RT_{NDT}$ raised concerns regarding the adequacy of the margin term in the evaluation. As indicated in Section 5.0, the staff performed analyses to assess this concern. The NRC staff employed the Palisades plant-specific chemistry and fluence data and performed RPV failure frequency calculations similar to those in SECY-82-465 which established the basis for the PTS screening criteria. These analyses demonstrated that the margins of safety intended by the PTS rule will be satisfied through the 14th refueling outage, even considering the variability observed in the Palisades chemistry data. The 14th refueling outage is currently scheduled for late 1999.

Based on the above, the staff has concluded that the Palisades RPV can be operated to the end of the 14th refueling outage, scheduled for late 1999, in compliance with and consistent with the margins of safety intended by 10 CFR 50.61.

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Date: April 12, 1995

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## TABLE 1
## CHEMICAL ANALYSES OF PALISADES WELD SEAM MATERIAL W-5214

| Location of Measurement | Analysis Method | Percent Cu | Percent Ni |
|---|---|---|---|
| **Results from Weld "A"** | | | |
| X (24mm from ID) | ICP-1 | 0.341 | 1.093 |
| | ICP-2 | 0.328 | 1.116 |
| | ICP-3 | 0.345 | 0.831 |
| | OES | 0.33 | 1.09 |
| | **AVERAGE** | **0.336** | **1.03** |
| Y (48mm from OD) | ICP-1 | 0.310 | 1.003 |
| | ICP-2 | 0.310 | 1.006 |
| | ICP-3 | 0.256 | 1.101 |
| | OES | 0.30 | 1.05 |
| | **AVERAGE** | **0.294** | **1.04** |
| Z (24mm from OD) | ICP-1 | 0.266 | 1.090 |
| | ICP-2 | 0.266 | 1.104 |
| | ICP-3 | 0.260 | 1.093 |
| | OES | 0.25 | 1.10 |
| | **AVERAGE** | **0.260** | **1.10** |
| **Results from Weld "B"** | | | |
| X (24mm from ID) | ICP-1 | 0.367 | 1.154 |
| | ICP-2 | 0.365 | 1.193 |
| | ICP-3 | 0.350 | 1.232 |
| | OES+15 | 0.37 | 1.23 |
| | OES+35 | 0.37 | 1.29 |
| | **AVERAGE** | **0.364** | **1.22** |
| Y (48mm from OD) | ICP-1 | 0.291 | 1.156 |
| | ICP-2 | 0.292 | 1.127 |
| | ICP-3 | 0.310 | 0.983 |
| | OES | 0.29 | 1.18 |
| | **AVERAGE** | **0.296** | **1.11** |
| Z (24mm from OD) | ICP-1 | 0.278 | 1.059 |
| | ICP-2 | 0.281 | 1.066 |
| | ICP-3 | 0.206 | 1.031 |
| | OES | 0.27 | 1.16 |
| | **AVERAGE** | **0.259** | **1.08** |
| **Results from Weld "C"** | | | |
| X (24mm from ID) | ICP-1 | 0.353 | 1.203 |
| | ICP-2 | 0.359 | 1.204 |
| | ICP-3 | 0.322 | 1.040 |
| | OES+17 | 0.34 | 1.15 |
| | OES+36 | 0.35 | 1.29 |
| | **AVERAGE** | **0.345** | **1.18** |
| Y (48mm from OD) | ICP-1 | 0.233 | 1.149 |
| | ICP-2 | 0.239 | 0.960 |
| | ICP-3 | 0.202 | 1.051 |
| | OES | 0.22 | 1.22 |
| | **AVERAGE** | **0.224** | **1.09** |
| Z (24mm from OD) | ICP-1 | 0.237 | 1.024 |
| | ICP-2 | 0.228 | 1.107 |
| | ICP-3 | 0.228 | 1.002 |
| | OES-34 | 0.22 | 1.18 |
| | OES-10 | 0.22 | 1.11 |
| | **AVERAGE** | **0.227** | **1.08** |

Notes for Analysis Methods:

- ICP-1 and ICP-2: Inductively Coupled Plasma Source Emmission Spectroscopy, performed by AEA-Harwell, UK.
- ICP-3: Inductively Coupled Plasma Source Emmission Spectroscopy, performed by Combustion Engineering.
- OES: Optical Emmission Spectroscopy, performed by Combustion Engineering. Numbers following OES indicate distance (mm) from the original sample site.

## TABLE 2
## CHEMICAL ANALYSES OF PALISADES WELD SEAM MATERIAL 34B009

| Location of Measurement | Analysis Method | Percent Cu | Percent Ni |
|---|---|---|---|
| **Results from Weld "A"** | | | |
| X (24mm from ID) | ICP-1 | 0.235 | 1.215 |
| | ICP-2 | 0.198 | 1.092 |
| | **AVERAGE** | **0.217** | **1.154** |
| Y (48mm from OD) | ICP-1 | 0.189 | 1.010 |
| | ICP-2 | 0.198 | 0.906 |
| | **AVERAGE** | **0.194** | **0.958** |
| Z (24mm from OD) | ICP-1 | 0.196 | 1.098 |
| | ICP-2 | 0.196 | 1.057 |
| | **AVERAGE** | **0.196** | **1.078** |
| **Results from Weld "B"** | | | |
| X (24mm from ID) | ICP-1 | 0.195 | 1.272 |
| | ICP-2 | 0.191 | 1.256 |
| | **AVERAGE** | **0.193** | **1.264** |
| Y (48mm from OD) | ICP-1 | 0.195 | 1.331 |
| | ICP-2 | 0.192 | 1.292 |
| | **AVERAGE** | **0.194** | **1.312** |
| Z (24mm from OD) | ICP-1 | 0.206 | 1.138 |
| | ICP-2 | 0.204 | 0.998 |
| | **AVERAGE** | **0.205** | **1.068** |
| **Results from Weld "C"** | | | |
| X (24mm from ID) | ICP-1 | 0.162 | 1.126 |
| | ICP-2 | 0.165 | 1.117 |
| | **AVERAGE** | **0.164** | **1.122** |
| Y (48mm from OD) | ICP-1 | 0.208 | 1.136 |
| | ICP-2 | 0.203 | 1.088 |
| | **AVERAGE** | **0.206** | **1.112** |
| Z (24mm from OD) | ICP-1 | 0.209 | 1.307 |
| | ICP-2 | 0.209 | 1.292 |
| | **AVERAGE** | **0.209** | **1.300** |

<u>Notes for Analysis Methods:</u>
- ICP-1 and ICP-2: Inductively Coupled Plasma Source Emmission Spectroscopy, performed by AEA-Harwell, UK.

## TABLE 3

### Weld Data for Determining Percent Copper for Heat Number W5214-- Sources Other Than Steam Generator Data

| Identification | Number of Primary Elecrodes | Percent Cu | Location | Number of Weld Wire Combinations | Est. # of Coils in Weld |
|---|---|---|---|---|---|
| D4463 IP2 1-042B | tandem | 0.20 | within weld | considered part of IP2 surveillance weld | 8-12 |
| HBR2 torus-flange weld | tandem | 0.154<br>0.163<br>0.152<br>0.166 | 4 locations around the flange OD surface | 1 tandem arc location | 10-12 |
| IP2 surveillance weld | tandem | 0.23<br>0.20<br>0.20<br>0.19<br>0.22<br>0.20 | Charpy W-13<br>Charpy W-12<br>Tensile W-6<br>Tensile W-4<br>Charpy W-17<br>Charpy W-19<br>(all test specimens machined at locations through the weld) | 3 tandem arc locations | 8-12 |
| IP3 surveillance weld | tandem | 0.15<br>0.166 | heat analysis<br>Charpy W-15 | 1 tandem arc location | 2 |
| IP3 nozzle cutout | tandem | 0.16<br>0.15<br>0.15 | outside surf.<br>3/4 thickness<br>weld center | 3 tandem arc locations | 8-12 |
| HBR2 surveillance weld | single | 0.32<br>0.34<br>0.33<br>0.35 | heat analysis<br>heat analysis<br>Charpy W-1<br>Charpy W-20 | 1 single arc location | 1 |
| Oyster Creek 1 surveillance weld | single | 0.282<br>0.290<br>0.285 | Charpy 1E2A<br>Charpy 1E2B<br>Charpy 1E3 | 1 single arc location | 1 |

## TABLE 4

### Weight Percent Copper in Heat W-5214 Welds

| Sample Description | Cu % | Weight | Cu% * Weight |
|---|---|---|---|
| IP3 nozzle cutout | 0.15 | 2 | 0.3 |
| IP3 nozzle cutout | 0.15 | 2 | 0.3 |
| IP3 surv. | 0.158 | 2 | 0.316 |
| HBR2 torus-flange | 0.159 | 2 | 0.318 |
| IP3 nozzle cutout | 0.16 | 2 | 0.32 |
| IP2 surv., region 3 | 0.19 | 2 | 0.38 |
| IP2 surv., region 1 | 0.20 | 2 | 0.40 |
| IP2 surv., region 2 | 0.215 | 2 | 0.43 |
| PAL SG, region 3 | 0.226 | 2 | 0.452 |
| PAL SG, region 2 | 0.277 | 2 | 0.554 |
| Oyster Creek 1 surv. | 0.285 | 1 | 0.285 |
| HBR2 surv. | 0.335 | 1 | 0.335 |
| PAL SG, region 1 | 0.348 | 2 | 0.696 |
| | Sum = | 24 | 5.086 |
| | MEAN | 0.212 | |
| | MEDIAN | 0.19 | |

## TABLE 5

### Weight Percent Nickel in Heat W-5214 Welds

| Identification | Average % Ni |
|---|---|
| D4494 IP2 1-042 | 0.94 |
| D4541 | 1.20 |
| D4577 IP2 | 1.00 |
| D4673 Millstone seam C | 1.05 |
| D4674 IP2 3-042B weld | 1.12 |
| D4686 MLI 2-072A | 0.97 |
| D4687 IP2 1-042A weld | 0.92 |
| D4688 PAL SG 5-943 | 0.99 |
| D4690 | 1.13 |
| HBR2 torus-flange weld | 0.99 |
| IP2 surv. weld | 1.03 |
| IP3 surv. weld | 1.12 |
| IP3 nozzle cutout | 1.09 |
| HBR2 surv. weld | 0.66 |
| Palisades SG | 1.10 |
| Mean Value | 1.02 |

Figure 1 HISTOGRAM OF COPPER CONTENT FOR HEAT W5214 (all welds are tandem electrode except for the weld identified in the 0.300-0.339 copper range. The weld in the 0.300-339 copper range is the average of two single electrode welds with 0.285 percent copper and 0.335 percent copper, respectively.)