SIEMENS

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Summary*)

On April 4, 1996, Consumers Energy submitted a reevaluation of the Palisades reactor pressure vessel fluence data in docket 50-255 to the United States Nuclear Regulatory Commission. Best estimate fluences were presented and discussed. SIEMENS-KWU in Erlangen (Germany) was charged with the task of appraising, commenting, and comparing with the SIEMENS method the analytical approach and the results.

Fluence calculations were performed and compared with measurements. The comparison showed that the calculated reaction rates are larger than the measurements. This was to be expected since the Westinghouse calculational model contains several conservative aspects. The spectrum adjustment with the FERRET code using least squares leads to results which predict that the PTS screening criteria will be exceeded in 2012 (Westinghouse figure 2011.9).

Should the Westinghouse calculated fluences and flux densities be subjected to the usual SIEMENS procedure then the PTS screening criteria will be reached in 2011.

Both results are almost identical and both approaches are suitable state-of-the-art evaluation alternatives.

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1. Introduction

On April 4, 1996, Consumers Energy submitted a reevaluation of the Palisades reactor pressure vessel fluence data in docket 50-255 to the United States Nuclear Regulatory Commission. Best estimate fluences were presented and discussed. SIEMENS-KWU in Erlangen (Germany) was charged with the task of appraising, commenting, and comparing with the SIEMENS method the analytical approach and the results.

2. Comment on the fluence determination by Consumers Energy

The determination of RPV fluence for the Palisades nuclear plant was performed by Westinghouse and documented in report No. WCAP-14557, revision 1 from March,1996. This report and the following discussions in the text form a basis for ajudging the quality of the Westinghouse work.

2.1 Fluence Calculation

The fluence calculations were performed for one core quadrant using the deterministic DORT code in (R-θ)-geometry covering the first eleven operating cycles of the Palisades plant. The calculations were performed cycle for cycle using S16 quadrature and scatter anisotropy upto P3. The BUGLE-93 cross-section database as based on ENDF/B-VI was used.

After the conclusion of the eleventh cycle the calculations showed a total fluence at the most highly irradiated position on the inner RPV surface of $\Phi = 1.59E19\ cm^{-2}$ for E>1 MeV. The maximum fluence for E>1 MeV at the axial RPV weld at an azimuthal angle of 60° showed $\Phi = 1.18E19\ cm^{-2}$ for the eleventh cycle end.

The time averaged flux density for E>1Mev and the eleventh cycle for the most highly neutron irradiated position on the axial RPV weld at 60° is $\varphi = 1.556E10\ cm^{-2}s^{-1}$.

Now these values are approx. 10% smaller than those obtained previously. This is explained by the fact that modifications to the latest calculations were made. Examples of this are the new determination of the neutron source strength distribution from the program SIMULATE, the lower water temperatures and a larger RPV radius.

The latest calculations are to be regarded as being conservative where the RPV fluence is concerned since the determination of the axial peaking factor neglected the core shroud former plates in the calculation: furthermore the bypass temperature represents an upper value. The calculations also did not consider that the power plant was operated at only 98% of its rated power.

The fluence calculations did not consider the axial position change of the RPV flux density maximum when going from a non-low leakage core to a low leakage core. The maximum moves axially upwards. Thus the simple addition of maximum RPV fluences for each cycle leads to an overestimate of the accumulated maximum fluence.

The calculations are of current state-of-the-art. The results were confirmed by comparison calculations performed by Brookhaven National Laboratory using the same technique and by AEA Technology using the Monte Carlo program of MCBEND.

2.2 Measured Reaction Rates

Activation and fission detectors were used for experimental reaction rate determination. Some of these detectors were placed in four capsules of the RPV material surveillance program which were installed inside the RPV, and others in encapsulated form at various positions on the exterior of the RPV. The reactions used were Cu63(n,α)Co60, Ti46(n,p)Sc46, Fe54(n,p)Mn54, Ni58(n,p)Co58, U238(n,f)Cs137 and Np237(n,f)Cs137.

The reaction rate determination considered the irradiation history and transient flux density changes at the detector positions. The fission products produced by photo-fission were taken into account for the fission detectors.

The results were compared with those reaction rates determined by the calculated neutron spectrum at the irradiation position. Averaging of the 96 M/C values (M/C is the ratio of measured reaction rate with that calculated) for the core mid-plane produced a bias factor of K_r=0.879 for the reaction rates. This means that the measured core mid-plane reaction rates are on average 12% below those calculated.

2.3 Least Squares Adjustment Procedure

The FERRET adjustment code was used to fit the neutron spectra at the detector positions until a minimum was obtained for the sum of the quadratic deviations from calculated to measured reaction rates. This spectrum adjustment for each detector capsule allows the determination of a quasi measured time-averaged flux density for E> 1 MeV. Averaging the 17 M/C values from the core mid-plane (here M/C is the ratio of the measured flux density with E>1 MeV with the calculated value) gives a bias factor of K_φ=0.831. This means that the flux density measured for the core mid-plane is smaller on average by 17% than that calculated.

A comparison of the bias factors for the flux density and reaction rate shows that spectrum adjustment increases the bias factor by 5%.

2.4 Best Estimate Fluence E>1 MeV

The calculational fluences were multiplied by the bias factor for E>1 MeV to determine the best estimate fluence.

$$\Phi_{\text{Best. Est.}} = K_\varphi \, \Phi_{\text{Calc}}$$

This algorithmus produces a best estimate of the fluence with E>1 MeV for the position most highly irradiated by neutrons on the inner RPV surface of $\Phi_{\text{Best Est.}}$ = 1.32E19 cm^{-2} at the end of the eleventh cycle. Likewise a best estimate for E>1 MeV on the axial RPV weld at 60° of $\Phi_{\text{Best Est.}}$ = 9.82E18 cm^{-2} is obtained at the end of the eleventh cycle.

The time averaged best estimate flux density for the eleventh cycle with E>1 MeV at the most highly neutron irradiated position of the axial RPV weld at 60° is $\varphi_{Best\ Est} = 1.30E10\ cm^{-2}s^{-1}$.

In the case where the M/C values for flux densities with E>1 MeV vary for the various detectors, the bias factor K, used to determine the best estimate fluence, is highly dependant on the selection of detector data for its determination. Since the M/C values for flux densities with E>1 MeV for Palisades (WCAP-14557, revision 1, tab. 7.2-1) are in a range of 0.713 to 0.992 then the determination of best estimate fluence is subject to a degree of randomness.

2.5 PTS Screening Criteria Date

The limiting fluences for E>1MeV for the shell plate and the welds are determined with PTS screening criteria by using input data which are partly RPV steel specific.

The limit for the axial RPV weld is $\Phi = 1.55E19\ cm^{-2}$. By taking the maximal best estimate fluence for E>1 MeV for the weld at the end of the eleventh cycle together with the best estimate of the maximal flux density at the weld, averaged over the eleventh cycle, then the date on which the limit will be exceeded is obtained.

The limit for the 60° axial weld will be exceeded in 2012 with the data given in section 2.4 if a capacity factor of 0.85 is assumed.

However, the fluence has been extrapolated using the flux density for the eleventh cycle. The axial flux density maximum occurs at a different position than the axial fluence maximum at the end of the eleventh cycle. Thus the fluence extrapolation is a conservative procedure.

3. Corresponding SIEMENS approach

The fluence determination by SIEMENS is performed according to the rules of KTA 3203. These rules state that the complete neutron spectrum for the surveillance capsules and at the inner surface of the RPV at the position of maximum flux density shall be determined by calculation for each reactor. The calculation has to use codes based on transport theory. The calculations are to be checked by measurements with neutron detectors.

These rules are met by determining the fluences at the RPV inner surface and for the surveillance capsules by using the deterministic DOT code in (R-θ) geometry. This fluence caculation is done in a more realistic manner without the conservatism in section 2.1. The calculated fluence for the surveillance capsules is then compared with the experimental fluence. Any deviations are analysed in more detail and discussed. The experimental fluence is calculated from the measured detector activities using the neutron spectrum from DOT and the irradiation history. As the neutron transport calculation has been performed in a realistic manner, the theoretical and experimental fluences are generally very close to one another.

The reactions Fe54(n,p)Mn54 and Nb93(n,n')Nb93m are used as fluence detectors. Formerly the reaction Th232(n,f) was used, but the results were uncertain due to photo-fission. These detectors are no longer used by SIEMENS.

The calculated fluence for neutrons with E>1 MeV using realistic non-conservative input data is decisive for predicting RPV steel and sample behaviour under neutron irradiation. This fluence is not adjusted with some sort of procedure. Decisive is the ratio between the surveillance capsule fluence and the fluence at the most highly irradiated RPV inner surface position over the same period. This ratio is the lead factor.

Additional detectors on the exterior of the RPV will only confirm the calc[illegible]ated fluences.

Should the RPV fluence approach the licenced limit then the theoretical results are supported by experimental RPV fluence determination, such as scraping samples from the RPV cladding.

Adjustment of the calculated fluence via the experimental fluence, as determined from the surveillance capsules, does not affect the lead factor. A fluence adjustment by comparing the measured and calculated reaction rates of the detectors in the surveillance capsules would simply result in the same lead factor.

In the USA the 10CFR 50.61 guide is used for damage prediction. Since the damage trend curve in 10 CFR 50.61 is mainly based on measurements, a fit of calculated fluences with the measurements makes sense.

However only such activation reactions should be used for this fit which have activation cross-sections which cover most of the range E>1 MeV. The half-life of the nuclide for evaluation should be not too short on comparison with the irradiation period. Furthermore we would dispense with the use of fission detectors.

4. Use of SIEMENS approach for the Palisades calculations

If the method described in section 3 is applied to Palisades, then that bias factor derived from a comparison of the reaction rates shall be used for the determination of the best estimate fluence. As described in section 3 only such reaction rates shall be used which are part of the RPV irradiation surveillance program. These are the internal capsules A240, W290, W290-9 und W110.

Only activation detectors of all types of detectors shall be taken and only those whose spectral response covers the entire energy regime above 1 MeV. This leaves over only two activation reactions, namely Fe54(n,p)Mn54 und Ni58(n,p)Co58. Using WCAP-14557,revision 1, Tab 7.2-1 average bias factors of 0.856 and 0.867 are obtained for iron detectors and nickel detectors, respectively, as taken from the RPV surveillance capsules. Since the daughter nuclide of Co58 in the Ni detector has a short half life (70.78 days) in comparison with the irradiation then the best estimate fluence determination should utilise an average bias factor based on the Fe54(n,p)Mn54 reaction rate.

Use of the bias factor of 0.856 produces a best estimate fluence E>1 MeV of $\Phi_{Best\ Est}$ = 1.01E19 cm^{-2} for the most highly neutron irradiated axial weld position at 60° at the end of the eleventh cycle. The best estimate flux density for E>1 MeV as averaged over the eleventh cycle for the same position is then $\varphi_{Best\ Est.}$ = 1.33E10 $cm^{-2}s^{-1}$.

Extrapolation of the fluence using the average flux density from the eleventh cycle shows that the axial weld fluence limit according to the PTS screening criteria will be reached in 2011.

Also at this point it must be indicated that the axial flux density maximum in the eleventh cycle occurs at a different position than the axial fluence maximum at the end of the same cycle. The fluence extrapolation is therefore conservative.

5. Résumé

Fluence calculations were performed by Westinghouse for the Palisades RPV and compared with measurements. The comparison showed that the calculated reaction rates are larger than the measurements. This was to be expected since the Westinghouse calculational model, described in section 2.1, contains several conservative aspects. The spectrum adjustment with the FERRET code using least squares leads to results which predict that the PTS screening criteria will be exceeded in 2012 (Westinghouse figure 2011 9).

Should the Westinghouse calculated fluences and flux densities be subjected to the usual SIEMENS procedure then the PTS screening criteria will be reached in 2011.

Both results are almost identical and both approaches are suitable state-of-the-art evaluation alternatives.