Monte Carlo Analysis

Question:

Provide the distributions used in the Monte Carlo analysis and explain why they are considered to be conservative.

Answer:

In order to estimate the risk of Indian Point Unit 2 U-bend tube failures during Cycle 14, a probabilistic evaluation was performed by applying a Monte Carlo analysis to the individual events that progress to a tube failure with a particular leakage rate. The probability distributions for each event are attached and are based on the IP2 specific situation in 1997 as we now know it. The final distributions were compared with the actual year 2000 detected U-bend flaw distributions at IP2 in order to assure that conservative estimates were used in the analysis. The distributions used in the calculation represents the end of Cycle 14 conditions. Therefore the results are very conservative with respect to the condition of the steam generators during the last operating cycle.

One hundred tubes with undetected axial cracks in the U-bend region were assumed to exist at the completion of the 1997 Steam Generator inspection. A higher likelihood of shallow cracks caused by the lower probability of detecting shallow cracks is reflected in the estimation that 50% of the cracks are less than 30% through wall deep. It is presumed that there is a lower likelihood of deeper cracks due to the higher likelihood of them being detected. Because this analysis evaluates ligament tearing failures rather than low leakage rate penetrations through the tube wall, the crack depths are considered to be the average measured depth of a given crack.

Based on the year 2000 inspections, the maximum average crack depth in each cracked U-bend is compared to what was used in the Monte Carlo Analysis. This comparison is based on the depth detected in the 2000 inspection, after nearly a full cycle of crack growth. The crack depth in 1997 would clearly be smaller. The "70 – 90%" actual data includes R2C5.

Depth of Crack (% through wall)	Depth presumed in the Monte Carlo Analysis to represent the beginning of Cycle 14	IP2 Crack Depths in 2000 (based on 2000 800 KHz Data)
0-30%	50% (50 tubes)	0 tubes
30-50%	31% (31 tubes)	3 tubes
50-70%	15% (15 tubes)	3 tubes
70-90%	4% (4 tubes)	2 tubes

The cracks in each of the 100 tubes became deeper during Cycle 14. A crack growth rate was selected for each tube. The growth rate probabilities applied are shown below with a comparison of the IP2 growth rates that were provided in the CMOA. These growth rates were derived from the U-bend cracks that had inspection data from both 1997 and 2000.

Crack Growth (% through wall per EFPY)	Crack Growth Rates presumed in the Monte Carlo Analysis during Cycle 14	IP2 Crack Growth Rates during Cycle 14 (based on comparison of 1997 and 2000 data)
0-4%	0%	20%
4-8%	58%	40%
8-12%	30%	40%
12-16%	10%	0%
16-20%	2%	0%

The crack depth at any time during Cycle 14 was calculated by adding the growth rate times the time duration to the initial flaw depth.

It was then determined whether the crack would have penetrated the wall. The likelihood that the crack would penetrate the tube wall was calculated based on the crack depth at a given time and the stress that would exist in the remaining ligament. The lowest CMTR reported tensile strength for any IP2 row 2 tube was used with a ΔP of 1,600 psig for the spontaneous rupture during normal operation condition. Using this tensile stress and ΔP, the calculated tube failure wall thickness based on pressure hoop stress results in a calculated ligament failure at 15% wall thickness, or an 85% crack depth. A 100% probability of through wall penetration is conservatively assumed for an 80% to 100% through wall crack and a 10 % probability of through wall penetration is assumed for crack depths between 70% and 80% through wall.

For each tube that is predicted to have a crack penetrate the wall, the total axial length of the final penetration was determined based on a crack length probability distribution. In the "IP2" data comparison provided below, all U-bend apex cracks detected in a given tube at IP2 were assumed to link together to form a single longer crack representing the length reported.

Length of Crack (inches)	Crack Length presumed in the Monte Carlo Analysis at the time that a crack penetrated the tube wall	IP2 Crack Lengths in 2000 (based on 2000 800 KHz Data)
0-0.5	4% (4 tubes)	4 tubes
0.5-1.0	7% (7 tubes)	0 tubes
1.0-1.5	12% (12 tubes)	1 tubes
1.5-2.0	18% (18 tubes)	0 tubes
2.0-2.5	22% (22 tubes)	3 tubes
2.5-3.0	18% (18 tubes)	0 tubes
3.0-3.5	10% (10 tubes)	0 tubes
3.5-4.0	6% (6 tubes)	0 tubes
4.0-4.5	3% (3 tubes)	0 tubes

Using the resulting crack lengths, a flow rate was determined from the flow rate to crack length trends reported for U-bend failures in NUREG 6365. The curve that was used was based on the NUREG data with the curve shifted from the mean of the IP2, Doel, and Surry 2 data to the upper bound (including the IP2 and Surry 2 data).

Figures representing these distributions are attached.

Question:

From the Monte Carlo analysis results, what is the time distribution of the "through-wall" spontaneous leakage events relative to the first and second year of Cycle 14.

Answer:

The Monte Carlo model predicted through wall penetration during the first year of Cycle 14 in 99% of the trials.

In order to prepare this answer, the Monte Carlo analysis was augmented to provide additional results data. The distributions for each "event" and the methods of analysis were not modified. The analysis was performed to track through tube wall events on a quarterly basis, i.e., every three months. The Monte Carlo analysis showed that approximately 90% of the through wall events occurred in the first quarter of operation. This means that of the 100 tubes in a trial that were presumed to have undetected cracks, that in 90% of the trials one of the tubes had a crack, that with crack growth, would satisfy the criteria for through-wall penetration during the first quarter of operation.

This high percentage occurred because very conservative crack depth and crack growth rate assumptions were used. The representation of the condition at the beginning of Cycle 14 was more conservative than the condition in the Steam Generators at the end of Cycle 14. Four percent of the tubes (out of 100 tubes) had beginning-of-cycle crack

depths between 70 and 90% of the wall thickness. The threshold for through wall penetration was conservatively set at 80%. As a result, many cracks went through wall right after or soon after the trial period began. This is considered unrealistic and very conservative. Due to the assumptions used in model, the calculations are not appropriate to be compared to industry events. Instead, the Monte Carlo calculations determine the upper range of the probability of a leakage event greater than a specified value.

Question:

What percentage of the Monte Carlo trials resulted in zero leakage?

Answer:

The through-wall leakage rates between 0 and 0.1 gpm were tracked in the analysis. Only a small percentage of the 10,000 trials resulted in leakage below 0.1 gpm. Specifically, in the case analyzed, only eighteen trials (<1%) had leakage in this range. The leakage was this low not because the crack length distribution allowed very short axial lengths to occur that were converted into leakage below 0.1 gpm.

Question:

What percentage of the Monte Carlo trials resulted in leakage between 0 and 75 gpm?

Answer:

Of the 10,000 trials, 37.2% resulted in leakage rates between 0.1 gpm and 75 gpm for Cycle 14. This correlates to a frequency of 0.186 per year.

The frequency per cycle and per year for each of the leakage categories are provided below:

Leak Rate Range	Frequency per Reactor Year	Frequency per Cycle
<0.1 gpm	<0.1%	<0.1%
0.1 gpm – 75 gpm	18.6%	37.2%
75 gpm - 225 gpm	27.5%	55.0%
> 225 gpm	3.9%	7.8%