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Risk Assessment for IP2 SG Tube Degradation

For the SDP, ΔCDF and ΔLERF are assessed for the *condition* of the tubes over the time that degradation exceeded allowable levels.

This is *different* from the licensee's assessment of the conditional core damage probability for the very specific features of the event that actually occurred on Febrauary 15, 2000.

The degraded condition of the tube made it vulnerable to several potential causes for failure:

spontaneous failure (with potential flows ranging from tenths to hundreds of gpm)

steam system depressurization transients

reactor coolant system over-pressurization transients

core damage accidents (with steam system dry and depressurized but RCS not fully depressurized)

Each of these sequences would add to the frequency of core damage accidents with containment bypass (treated as LERF).

The risk assessment process considers the frequency of each of these challenges, the probability that the tube would fail given each, and the probability that the challenge with tube failure would lead to core damage.

Of these, the spontaneous rupture dominates the risk estimate at about 1×10^{-4}/RY averaged over the last year.

The steam system depressurization transients and the core damage accidents could add about 1×10^{-5}/RY each if the tubes were susceptible for a whole year, but it is not clear whether they were.

Although the frequency of each of these accident sequences could be subjected to more detailed analysis, it is not expected that the result would be to reduce the total core damage frequency increment to a value below 1×10^{-5}/RY.

Because the numerical threshold between "red" and "yellow" is 1×10^{-5}/RY for core damage accidents that would create large releases, it does not appear that more detailed analysis would change the "color" assignment.

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Spontaneous Rupture

ΔLERF Contribution = [Tube Rupture Frequency] x [Probability of Not Preventing Core Damage]

<u>Tube Rupture Frequency</u>:

The condition of the tubes was allowed to deteriorate to the point that a substantial failure occurred before the end of the planned period of operation.

The flaw that failed was long enough to cause a full SGTR flow rate if remaining ligaments had failed.

Experience indicates that about half of the in-service tube failures are gross failures and half are leaks that result in shutdown before gross failure occurs.

So, probability of rupture is about 0.5.

The period of time to be used to make this a "frequency" is not determinate, because the failure occurs as soon as the tube is unable to withstand normal operating conditions. The practice is to average core damage frequency increments over a 1 year period.

So, frequency is estimated as about 0.5/RY.

<u>Probability of Not Preventing Core Damage</u>:

The net probability can be derived from a PRA by dividing the core damage frequency contribution from tube ruptures by the tube rupture frequency used in the PRA.

Results vary with the PRA used:

> The IP2 IPE gives 7.7×10^{-5}
> The NRC's SPAR model for IP2 gives 3.3×10^{-4}
> The NUREG-1150 model for Surry gives 1.8×10^{-4}

Review of cutsets indicates that the dominant contributions are human errors, which are very uncertain.

Conclusion is that the non-mitigation probability is about 10^{-4}

<u>Contribution to SDP ΔCDF and ΔLERF</u>:

Products of the above estimates range from 1.7×10^{-4}/RY to 3.9×10^{-5}/RY

Geometric mean is about 8×10^{-5}/RY

Tube Ruptures Induced by Steam System Depressurization Events

ΔLERF Contribution = [Frequency of Steam System Depressurization]
x [Conditional Probability of Tube Rupture]
x [Probability of Not Preventing Core Damage]

Frequency of Steam System Depressurization:

This frequency is estimated from experience to be in the mid-10^{-3}/RY for Westinghouse plants.

Estimates have ranged from 7 x 10^{-3}/RY to 1 x 10^{-3}/RY.

Assume value is 5 x 10^{-3}/RY for IP2

Conditional Probability of Tube Rupture:

It is clear that the tube at R2C5 in SG 24 would have failed earlier if theΔP increased.

It is not clear for what period of time the tube was susceptible to rupture at the increased ΔP that would result from a steam system depressurization event.

Most steam system depressurization events affect only one SG, so divide probability by 4 to account for number of SGs at IP2. (Assumes frequency per plant is independent of the number of SGs in the plant.)

Applying the increased probability to a default period of one year would give a conditional rupture probability of 0.25.

Probability of Not Preventing Core Damage:

The probability of not preventing core damage for this sequence was estimated in NUREG-1570 at 10^{-2}, based on extensive modeling of the thermal-hydraulic conditions and human error probabilities.

Contribution to SDP ΔCDF and ΔLERF :

The product of these factors is about 1 x 10^{-5}/RY.

Increased LERF Due to Tube Ruptures Induced by Core Damage

ΔLERF Contribution = ["Hi/Dry" Part of the Core Damage Frequency]
x [Probability that Tube Rupture Will Be Induced by Physical Phenomena]

<u>"High/Dry" Part of Core Damage Frequency</u>:

Some core damage accident sequences involve increased ΔPs across some or all SGs, which can induce rupture of flawed tubes, as discussed in the previous slide.

In addition, studies documented in NUREGs 1150 and 1570 demonstrated that, if the SGs were dry, core damage accidents could increase temperatures in SG tubes to the point that flawed tubes would fail by creep before other parts of the RCS pressure boundary, creating a large early release of radioactive materials for what would otherwise be a "contained" accident.

This part of the CDF is estimated to be between 1 and 2 x 10^{-5}/RY from other PRAs for Westinghouse plants

<u>Probability that Tube Rupture Will Be Induced by Physical Phenomena</u>:

Challenges to the tubes during core damage accident conditions can arise from increased pressure differentials across the tubes caused by steam side depressurization, from increased tube temperatures that weaken the Inconel tube material, and from combinations of these effects.

There are a number of core damage sequences that present different levels of challenge to the tubes.

It is clear that, just before the tube failure on February 15th, any slight combination of these effects would have induced tube failure.

But it is not clear how long the periods of susceptibility lasted for each of the various challenging sequences.

<u>Contribution to SDP ΔLERF</u>:

It is not possible without further detailed analysis to realistically estimate the contribution from this type of sequence.

If temperature effects alone would have induced tube failure during the last year, then the ΔLERF would be in the range of the "high/dry" frequency, about 10^{-5}/RY.

If a depressurized SG was necessary to induce the flawed tube to rupture during most of the year, then the ΔLERF would depend on the probability of SG depressurization. (IP2 has some history of SG leakage while "isolated.")

It would be necessary to perform extensive analyses before concluding whether this contribution to ΔLERF is sufficient to make the total ΔLERF for the condition exceed 1 x 10^{-5}/RY.

Staff Knowledge of Licensee's Risk Analysis

The staff has reviewed an analysis by the licensee that calculates a *conditional core damage probability* given the specifics of the event that actually occurred on February 15, 2000.

That analysis used the less-than-maximum potential flow rate to re-estimate the time available for operators to take mitigative actions and the human error probabilities associated with those actions.

This greatly reduced the estimated probability that core damage would occur, because the dominant cutsets in the risk analysis are those containing human errors.

The staff has three criticisms of the licensee's analysis:

> Some of the human errors considered would result in the flawed tube experiencing high stress for an extended period or even experiencing higher stresses than actually encountered during the event. The staff does not believe that the flow rate can be assumed not to increase over extended exposures to such conditions, given the size of the flaw and the incomplete state of its failure.
>
> The analysis does not take into account the potential for the flaw to have been initially revealed by a different degree of failure with a different flow rate.
>
> The analysis does not take into account the risk associated with the exposure to other potential events that would have been complicated by induced tube rupture.