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Appendix 4B Pool Performance Guideline

Introduction

The purpose of this appendix is to present the rationale for the pool performance guideline (PPG), and to illustrate how the PPG can be used to assure that spent fuel pool risk in decommissioning plants will continue to meet the Commission's quantitative health objectives (QHOs).

Regulatory Guide (RG) 1.174 contains general guidance for application of PRA insights to the regulation of nuclear reactors. The same concepts can also be applied in the regulation of spent fuel pools. The guidelines in RG 1.174 pertain to the frequency of core damage accidents (CDF) and large early releases (LERF). For both CDF and LERF, RG 1.174 contains guidance on acceptable values for the changes that can be allowed as a function of the baseline frequencies. For example, if the baseline CDF for a plant is below $1\text{E-}4$ per year, plant changes can be approved that increase CDF by up to $1\text{E-}5$ per year. If the baseline LERF is less than $1\text{E-}5$ per year, plant changes can be approved that increase LERF by up to $1\text{E-}6$ per year.

For decommissioning plants, the risk is primarily due to the possibility of a zirconium fire associated with the spent fuel cladding. The consequences of such an event do not equate directly to either a core damage accident or a large early release as modeled for an operating reactor. Zirconium fires in spent fuel pools potentially have more long term consequences than an operating reactor core damage accident because: there may be multiple cores involved; the relevant clad/fuel degradation mechanisms could lead to increased releases of certain isotopes (e.g., short-lived isotopes such as iodine will have decayed, but the release of longer-lived isotopes such as ruthenium could be increased due to air-cladding reactions); and there is no containment surrounding the SFP to mitigate the consequences. On the other hand, they are different from a large early release because the postulated accidents progress very slowly, allowing time for protective actions to be taken to significantly reduce early and latent fatalities. In effect, a spent fuel pool fire would result in a "large" release, but this release would not generally be considered "early" due to the significant time delay before fission products are released.

Even though the event progresses more slowly than an operating reactor large early release event and the isotopic make-up is somewhat different, the consequence calculations performed by the staff show that large inventories of radioisotopes could be released that could have significant health effects on par with the most severe releases in a reactor accident. These calculations considered the effects of different source terms, evacuation assumptions, and plume-related parameters on offsite consequences. Since an SFP fire scenario would involve a direct release to the environment with significant consequences, the staff has decided that the RG 1.174 LERF baseline guideline of $1\text{E-}5$ per year (the value of baseline risk above which the staff will only consider very small increases in risk) provides an appropriate threshold for controlling the risk from a decommissioning plant SFP, and has established $1\text{E-}5$ per year as the recommended pool performance guideline (PPG) for this purpose. The PPG provides a useful tool to be used in combination with other factors such as accident progression timing, to assess features, systems, and operator performance needs for a spent fuel pool in a decommissioning plant. Maintaining the frequency of events leading to uncover of the spent fuel at a value less

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than the PPG, will assure that zirconium fires remain highly unlikely and that the risk in a decommissioning plant will continue to meet the Commission's quantitative health objectives, as discussed below.

Our conclusion in the draft final report was that, even though there are some differences in source term and timing, scenarios involving a spent fuel pool zirconium fire would result in population doses that are generally comparable to those expected from accident scenarios at operating reactors, and therefore a PPG of $1\text{E-}5$ based on LERF was appropriate. The staff reassessed these conclusions following the performance of additional consequence calculations in Appendix 4A that took into account the possibility of significant ruthenium release fractions. This assessment was undertaken to address concerns raised during review of the draft final report that large ruthenium releases from a spent fuel fire could substantially increase both early and latent fatalities, as well as shift the controlling decision criteria from early fatalities to latent health effects due to the longer ruthenium half life.

In assessing the appropriateness of the 1×10^{-5} /year PPG, the staff contrasted the range of SFP accident consequences (early and latent health effects) reported in Appendices 4 and 4A with the consequences of the most risk-significant accidents evaluated in the NUREG-1150 study for Surry. The staff also compared the SFP risk for a licensee maintaining its facility at the PPG with the level of risk associated with reactor operation at the Surry site, and with the Commission's QHOs.

Comparison of Health Consequences

For internally-initiated, at-power reactor accidents, the sequences that dominate early fatalities also tend to dominate latent cancer fatalities and population dose. These sequences generally involve early containment failure or containment bypass. Based on a survey of consequence results for the NUREG-1150 plants, early containment failure and containment bypass accident progression bins account for 80 to 100 percent of early fatalities and 60 to 80 percent of the latent cancer fatalities and population dose.

Using NUREG-1150 results for Surry as a basis for comparison, early fatalities are dominated by interfacing system LOCA ("V") sequences. Steam generator tube rupture sequences with a stuck open secondary safety relief valve ("H" SGTR) also lead to large releases but these releases occur after evacuation is complete and cause relatively few early fatalities. Consequence measures that depend on the total amount of radioactivity released (latent cancer fatalities and population dose) are dominated by V and SGTR "H" sequences.

The mean consequence results reported in NUREG-4551 for the most probable wet and dry V sequence and SGTR "H" sequence for Surry are provided in Table 1. (These are identified as source terms SUR-03-3, SUR-05-3, and SUR-14-1, respectively, in NUREG-4551.) The "wet" V sequence represents sequences in which the break location is low enough in the auxiliary building that water escaping through the break would form a pool which would cover the break and scrub a significant portion of the release. The "dry" V sequence represents sequences in which this pool will not occur. Also provided in Table 1 are the reported consequences for the (less probable) source terms which produced the greatest early fatalities and latent health effects. (These are identified as source terms SUR-10-3 and SUR-10-1, respectively, in

NUREG-4551.) For the above source terms, the conditional number of early fatalities varied from essentially zero to approximately 12, the population dose ranged from 1E6 to 5E6 person-rem, and the number of latent cancer fatalities ranged from 800 to 5000.

Appendices 4 and 4A provide the results of offsite consequence calculations for a SFP fire occurring one year following reactor shutdown at a hypothetical 3441 MWth BWR spent fuel pool located at the Surry site. The calculations address the sensitivity of early and latent health effects to source terms, time of evacuation, population distribution, number of cores participating, and plume-related parameters.

The baseline calculation reported in Appendix 4 assumes the release fractions from NUREG/CR-4982 (including a ruthenium release fraction of $2E-5$), the release of no additional "fuel fines", and the participation of essentially 3.5 cores. The baseline calculation assumed late evacuation (i.e., an evacuation start time of 1.4 hours after the beginning of the release), however, additional cases assuming earlier evacuation are also provided (i.e., an evacuation start time of 3 hours before the beginning of the release). The consequences for the baseline calculation with early and late evacuation of 99.5% of the population are provided in Table 1. Given the long delays to the onset of fission product release in SFP accidents combined with the Industry Decommissioning Commitments (IDCs) and Staff Decommissioning Assumptions (SDAs), the staff considers the cases with early evacuation to be most representative. The consequences for the baseline calculation are well within the range of consequences predicted for large releases in an operating reactor accident for either evacuation time.

The consequence calculations presented in Appendix 4A show that when the ruthenium release fraction is increased from the original value of $2E-5$ to a level equivalent to that for volatile fission products (cesium and iodine), the early and latent health effects increase considerably. Sensitivity cases with a 0.75 release of cesium, iodine and ruthenium and a 0.01 release of fuel fines were used for comparison, to reflect the expectation that rubbing of the fuel would limit the release of ruthenium and volatile fission products to a value less than 1.0. The consequences for the large ruthenium release case with early and late evacuation of 95% of the population are provided in Table 1. (These are identified as cases 46b and 45b respectively in Appendix 4A.) The number of early fatalities increases by approximately two orders of magnitude, population dose increases by a factor of 2 to 3, and latent cancer fatalities increase by about a factor of 4 relative to the corresponding baseline calculations. For the case with early evacuation, early fatalities remain within the range considered in NUREG-1150, but population dose and latent cancer fatalities exceed the maximum values considered in NUREG-1150 by about 50%. For the case with late evacuation, the early fatalities are about a factor of 5 higher than the maximum values considered in NUREG-1150, and long term risk measures are about a factor of 2 higher than the maximum values considered in NUREG-1150.

Consequences for the worst case reported in Appendix 4A are also included in Table 1. This case, identified as case 45a, corresponds to a 1.0 release of the volatiles and ruthenium, a 0.01 release of fuel fines, and late evacuation of 95% of the population. The early fatalities are about a factor of 8 higher than the maximum values considered in NUREG-1150, and long term risk measures are about a factor of 2 higher than the maximum values considered in NUREG-1150.

In interpreting these comparisons it is important to note that the consequences for the SFP

accident are for a 3441MWth reactor whereas the NUREG-1150 results for Surry are for a power level of 2441 MWth. Also, the population doses for the SFP accident are for a 100 mile radius rather than the 50 mile radius reported for NUREG-1150. As a result, the reported consequences for the SFP accident tend to be overstated in these comparisons. It should also be acknowledged that these long term health impacts are sensitive to public policy decisions such as land interdiction criteria for returning populations.

Comparison of Risk

The previous discussion provides a comparison of reactor and SFP accident consequences but does not address the relative frequency of these events. The quantitative assessment of risk involves combining severe accident sequence frequency data with corresponding offsite consequence effects. To provide insights into the relative levels of risk for reactor accidents versus SFP accidents, the staff compared the level of risk associated with reactor operation at Surry with the level of risk associated with a SFP fire in the hypothetical BWR spent fuel pool located at the Surry site. The aforementioned caveats regarding the differences in power level and population dose distances apply here as well.

The mean risk associated with power operation of the Surry plant, as estimated in the NUREG-1150 study, is reported in Table 2. These risk results reflect a frequency-weighted sum of the consequences of all releases -- severe as well as benign. Also included in Table 2 are estimates of the risk of a SFP fire. These estimates were developed by assuming that the licensee maintains its facility at the PPG, and that the SFP fire results in one of previously discussed release cases. Three different release cases were considered, corresponding to: (1) the baseline releases with early evacuation, (2) a 0.75 release of cesium, iodine and ruthenium, 0.01 release of fuel fines, and early evacuation, and (3) a 1.0 release of cesium, iodine and ruthenium, 0.01 release of fuel fines, and late evacuation.

For the baseline release from a SFP accident, early fatalities are about two orders of magnitude lower than for a reactor accident. However, population dose is a factor of 7 higher and latent cancer fatalities are a factor of 4 higher for the SFP accident. The lower risk from latent health effects at Surry can be attributed to a substantially lower frequency of severe releases (by about a factor of 10) than the $1\text{E-}5$ value assumed for the SFP accident.

For the case with 0.75 release of cesium, iodine and ruthenium, 0.01 release of fuel fines, and early evacuation, early fatalities are comparable to those for a reactor accident. However, population dose and latent cancer fatalities are a factor of 14 higher for the SFP accident.

For the case with 1.0 release of cesium, iodine and ruthenium, 0.01 release of fuel fines, and late evacuation, early fatalities are about 3 orders of magnitude greater than those for a reactor accident. Population dose and latent cancer fatalities are about a factor of 20 higher for the SFP accident.

The individual early fatality risk reported in NUREG-4551 for internally-initiated events at Surry is $1.6\text{E-}8$ per year, or a factor of 30 lower than the Commission's QHO of $5\text{E-}7$ per year. The individual latent cancer fatality risk for internally-initiated events at Surry is $1.7\text{E-}9$ per year, or about 3 orders of magnitude lower than the Commission's QHO of $2\text{E-}6$ per year. Thus, even

though the risk associated with a fire in the hypothetical SFP at Surry would be an order of magnitude greater than the risk of power operation at Surry, the individual health effect risks for a SFP accident would not exceed the Commission's QHOs. Comparisons of individual health effect risks with the QHOs are presented below.

Comparison with Quantitative Health Objectives

The Safety Goal Policy Statement expressed the Commission's policy regarding the acceptable level of radiological risk from nuclear power plant operation as follows:

- Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life and health
- Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks.

The following quantitative health objectives (QHOs) are used in determining achievement of the safety goals:

- The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed.
- The risk to the population in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes.

These QHOs have been translated into two numerical objectives as follows:

- The individual risk of a prompt fatality from all "other accidents to which members of the U.S. population are generally exposed," such as fatal automobile accidents, is about $5E-4$ per year. One-tenth of one percent of this figure implies that the individual risk of prompt fatality from a reactor accident should be less than $5E-7$ per reactor year.
- "The sum of cancer fatality risks resulting from all other causes" is taken to be the cancer fatality rate in the U.S. which is about 1 in 500 or $2E-3$ per year. One-tenth of one percent of this implies that the risk of cancer to the population in the area near a nuclear power plant due to its operation should be limited to $2E-6$ per reactor year.

Although the Policy Statement and related numerical objectives were developed to address the risk associated with power operation, is it reasonable to require that these objectives continue to be met for as long as nuclear materials remain on the plant site. Accordingly, the staff has compared the risks to an individual with the QHOs, assuming the licensee maintains the facility at the recommended PPG of $1E-5$ per reactor year.

The risk measures corresponding to the above numerical objectives were calculated by MACCS2 for each of the cases reported in Appendix 4 and 4A. The relevant risk measures are the early fatality risk to an average individual within 1 mile of the plant, and the latent cancer fatality risk to an average individual within 10 miles of the plant. These measures would not be significantly impacted by population density since they are determined on the basis of the risk to the average individual. The risk results are reported in Table 3 for the previously mentioned cases involving a 0.75 release of cesium, iodine and ruthenium and a 0.01 release of fuel fines (with early and late evacuation), and a 1.0 release of cesium, iodine and ruthenium and a 0.01 release of fuel fines with late evacuation (i.e., the worst case reported in Appendix 4A). For comparison with the numerical objectives, the staff assumed that the licensee maintains the facility at the recommended PPG of $1\text{E-}5$ per reactor year.

The risk results indicate that at a PPG of $1\text{E-}5$ per year, the QHOs would continue to be met for even the worst case considered in Appendix 4A. The margins to both QHOs are substantial (about two orders of magnitude) for the case with early evacuation even with the large ruthenium release. The margins are considerably reduced in the late evacuation cases, but sufficient to conclude that the QHOs would be met given the conservatism inherent in these calculations.

The margin to the QHO is smallest for early fatality risk. Thus, similar to severe accidents in operating reactors, acceptable levels of risk for a SFP accident would be controlled by the early fatality risk measure. The margins to the QHO observed in these calculations suggest that the recommended PPG of $1\text{E-}5$ provides an appropriate level of safety.

Conclusions

Based upon the above comparisons, the staff believes that the LERF-based pool performance criteria of $1\text{E-}5$ per year is reasonable and appropriate. This is supported by the comparisons that show that the conditional health effects for SFP fires are generally in the range of health effects considered for severe accidents in operating reactors, and that the Commission's QHOs continue to be met for SFP fires even if the ruthenium release fraction is substantially increased.

However, since the potential does exist for several thousand latent cancer deaths regardless of ruthenium release fraction, an appropriate low frequency performance guideline should still be maintained even though the early fatalities estimates are below operating reactor LERF estimates. Given these observations, there does not appear to be sufficient justification to revise the proposed pool performance guideline of $1\text{E-}5$ which was developed from the RG 1.174 LERF considerations.

Table 1 - Comparison of Health Consequences for Reactor and Spent Fuel Pool Accidents

Consequence Measure	Consequence Results for Operating Reactor Accidents (from NUREG-1150 Study for Surry)					Consequence Results for Spent Fuel Pool Accidents (from Appendix 4)				
						Baseline Source Term		Release of 0.75 Ru and 0.01 Fuel Fines		Worst Case
	"H" SGTR (SUR-14-1)	"V" - Wet (SUR-03-3)	"V" - Dry (SUR-05-3)	Worst EF (SUR-10-3)	Worst LCF (SUR-10-1)	Early Evac of 99.5% (Case 13)	Late Evac of 99.5% (Base)	Early Evac of 95% (Case 46b)	Late Evac of 95% (Case 45b)	Late Evac of 95% (Case 45a)
Early fatalities	0.013	0.16	1.8	12	0.84	0.005	1.0	0.54	55	103
Population dose (person-rem)	1.9E6	1.1E6	2.6E6	3.3E6	4.8E6	4.2E6	4.5E6	7.9E6	1.2E7	1.3E7
Latent cancer fatalities	2650	794	2560	3670	4780	1990	2320	6880	10300	11700

Table 2 - Comparison of Risk Results for Reactor and Spent Fuel Pool Accidents

Risk Measure	Internal Event Risk for Surry (from NUREG-1150)	Risk for Spent Fuel Pool Accident SFP (conditional on SFP source term and 1E-5 PPG)		
		Base Case Release, Early Evac of 99.5% (Case 13)	Release of 0.75 Ru and 0.01 Fuel Fines, Early Evac of 95% (Case 46b)	Release of 1.0 Ru and 0.01 Fuel Fines, Late Evac of 95% (Case 45a)
Early fatalities per year	2E-6	5E-8	5E-6	1E-3
Population dose (person-rem per year)	5.8	42	79	130
Latent cancer fatalities per year	0.0052	0.020	0.069	0.12

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Table 3 - Comparison of Spent Fuel Pool Accident Risk with Quantitative Health Objectives

Case	QHO for Individual Risk of Prompt Fatalities					QHO for Societal Risk of Latent Cancer Fatalities				
	Ind. Early Fatality Risk	PPG	Prob of Early Fatality	QHO	% of QHO	Ind. Latent C. Fatality Risk	PPG	Prob of Latent C. Fatality	QHO	% of QHO
0.75 Ru w/ fuel fines, early evac of 95% (Case 46b)	1.40E-3	1E-5	1.40E-8	5E-7	3	2.55E-3	1E-5	2.55E-8	2E-6	1
0.75 Ru w/ fuel fines, late evac of 95% (Case 45b)	3.23E-2	1E-5	3.23E-7	5E-7	65	4.98E-2	1E-5	4.98E-7	2E-6	25
1.0 Ru w/ fuel fines, late evac of 95% (Case 45a)	3.66E-2	1E-5	3.66E-7	5E-7	73	5.16E-2	1E-5	5.16E-7	2E-6	26

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