From: Robert Palla , RPR
To: Jason Schaperow
Date: Mon, Aug 21, 2000 12:50 PM
Subject: Updated PPG Appendix

FYI - includes additional info on the seismic risk for Surry.

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Appendix 4B Pool Performance Guideline

Introduction

The Pool Performance Guideline (PPG) provides a threshold for controlling the risk from a decommissioning plant spent fuel pool (SFP). By maintaining the frequency of events leading to uncovery of the spent fuel at a value less than the recommended PPG value of 1E-5 per year, zirconium fires will remain highly unlikely, the risk will continue to meet the Commission's Quantitative Health Objectives [1], and changes to the plant licensing basis that result in very small increases in LERF may be permitted consistent with the logic in Regulatory Guide 1.174 [2]. The purpose of this appendix is to present the rationale for the PPG, and to illustrate how conformance with the recommended PPG will 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, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," 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 1E-4 per year, plant changes can be approved that increase CDF by up to 1E-5 per year. If the baseline LERF is less than 1E-5 per year, plant changes can be approved that increase LERF by up to 1E-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-fuel 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 more slowly, allowing time for protective actions to be taken to significantly reduce early fatalities (and to a lesser extent 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 (reported in Appendix 4) show that spent fuel pool fires 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 1E-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 1E-5 per year as the recommended 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 uncovery of the spent fuel at a value less 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 QHOs, as discussed below. Conformance with the PPG is also essential if the staff is to permit changes to the licensing basis that result in increases in LERF (or an equivalent increase in health effects), such as relaxations in Emergency Preparedness requirements.

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 1E-5 per year based on LERF was appropriate. The staff has 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 combined effect of longer times for evacuation and longer ruthenium half life.

In reassessing the appropriateness of the 1E-5 per year PPG as discussed below, the staff contrasts 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 compares 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 (documented in NUREG/CR-4551 [3]) as a basis for comparison, early fatalities are dominated by interfacing system LOCA ("V") sequences. Steam generator tube rupture (SGTR) sequences with a stuck open secondary safety relief valve 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 sequences with a stuck open secondary safety relief valve.

Mean source terms for the frequency-dominant accident progression bins for each plant damage state are reported in Section 3.3 of NUREG/CR-4551. The source terms for the most probable wet and dry V sequence and SGTR sequence with a stuck open secondary safety relief valve are also identified. 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 that 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. These source terms were compared to the source terms resulting from the binning/partitioning process (Table 3.4-4 of NUREG/CR-4551) to identify the closest match. (This was done since consequence results are only reported in NUREG/CR-4551 for the source terms produced through the partitioning process.) The source terms for the most probable wet and dry V sequence and SGTR sequence with a stuck open secondary safety relief valve correspond closely with source terms SUR-03-3, SUR-05-3, and SUR-14-1, respectively, in NUREG/CR-4551. The mean consequence results for these source terms are provided in Table 1. Also provided in Table 1 are the reported consequences for the source terms that produced the greatest early fatalities and latent health effects in the internal events analysis (identified as source terms SUR-10-3 and SUR-10-1, respectively), and the source term that produced the greatest health effects in the seismic analysis (SRH-10-3). It should be noted that the NUREG-1150 latent cancer fatality results are based on an earlier cancer risk model than used in the SFP consequence calculations. The model used in the SFP calculations, described in NUREG/CR-6059 [4], results in about a factor of two to three increase in latent cancer fatalities relative to the earlier model. To provide a more meaningful comparison, the latent cancer fatality results from NUREG-1150 were adjusted by a factor of three as noted in the table.

In summary, the conditional number of early fatalities considered in NUREG-1150 study for the Surry plant varied from essentially zero to approximately 250, the population dose within 50 miles ranged from 1E6 to 1.1E7 person-rem, and the number of latent cancer fatalities ranged from about 2400 to 22000. Radiological consequences of seismic events are subbstantially greater than for internal events due largely to the ineffectiveness of emergency response in high acceleration earthquakes.

Appendices 4 and 4A of this report 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. The consequences for the baseline source term are well within the range of consequences predicted for large releases in an operating reactor accident for either evacuation time.

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 consequence cases with early evacuation to be most representative for internally-initiated events. For the large seismic events that dominate the frequency of SFP fires, it is expected that there would be extensive damage to the infrastructure essential for effective emergency response. As a result, evacuation would be ineffective regardless of radiological emergency planning, and the case with late evacuation would be more representative.

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. A release fraction of 0.75 is considered realistic for volatile isotopes and reflects the expectation that the combined effect of rubbling of the fuel, incomplete fission product release from parts of the assemblies, and fission product deposition would limit the release fraction of volatile fission products to less than 1.0. Rubbling of the fuel may limit the ruthenium to much less than 1.0. Thus, the 0.75 release of ruthenium is considered conservative.

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, 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 and population dose within 50 miles remain within the range considered in NUREG-1150, but latent cancer fatalities exceed the maximum values considered in NUREG-1150 by about 30%. For the case with late evacuation, the early fatalities and population dose within 50 miles are comparable to those for the worst seismic event considered in NUREG-1150. Long term risk measures are about a factor of 2 higher than the maximum values considered in NUREG-1150.

Consequences for the worst case SFP accident 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. Even with these high release fractions the early fatalities and population dose are comparable to 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.

Although the latent cancer fatality values mentioned above may appear large, they must be considered in perspective. The calculated latent fatalities occur throughout the entire region around the plant (1000 miles) and over several decades. About 500,000 deaths due to cancer occur every year in the U.S. The population within 1000 miles of the plant is about 160 million. When spread over two or three decades, even tens of thousands of additional latent cancer fatalities are statistically indistinguishable from the background morbidity due to cancer fatalities from other causes (several hundred thousand per year).

It is important to note that the consequences for the SFP accident are based on a 3441MWth reactor whereas the NUREG-1150 results for Surry are for a power level of 2441 MWth. Results for a case with a SFP decay heat level corresponding to a reactor power of 2440 MWth (values in brackets in Table 2) indicate that the early fatalities would be a factor or 3 lower and the latent health consequences would be about 20 percent lower than those based on 3441 MWth. Thus, the reported consequences for the SFP accident are overstated somewhat 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 contribution to reactor risk from both internal and seismic events were considered since these contributors were important in the SFP study. The aforementioned caveats regarding the differences in power level 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. The SFP estimates were developed by assuming that the licensee maintains its facility consistent with the assumptions in the SFP study (i.e., the frequency of events leading to uncovery of the spent fuel is 3.4E-6 per year), and that the SFP fire results in one of the previously discussed release cases. Three different releases 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 an internally-initiated reactor accident, due primarily to lower inventories of cesium and iodine in the SFP source term. Population dose is a factor of 2 higher for the SFP accident but latent cancer fatalities are comparable.

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 an internally-initiated reactor accident. Population dose and latent cancer fatalities for the SFP accident are about a factor of 4 higher than for internally-initiated events, due primarily to the larger quantities of long-lived radionuclides released, but are comparable to the results for seismic events which assume no evacuation.

For the case with 1.0 release of cesium, iodine and ruthenium, 0.01 release of fuel fines, and late evacuation, early fatalities, population doses, and latent fatalities are generally comparable to those for the worst seismically-initiated reactor accident. Although the source term for the

SFP accident is larger than the reactor accident, this effect is partly offset by the late evacuation in the SFP case.

Even though the risk associated with a fire in the hypothetical SFP at Surry could 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.

<u>Comparison with Quantitative Health Objectives</u>

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 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 1E-5 per year.

The risk results indicate that at a PPG of 1E-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 bounding nature of these calculations.

The margin to the QHO is smallest (i.e., the percent of QHO is the largest) 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 1E-5 per year provides an appropriate level of safety.

Conclusions

Based upon the above comparisons, the staff believes that the LERF-based pool performance criteria of 1E-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. Given these observations, there does not appear to be sufficient justification to revise the proposed pool performance guideline of 1E-5 per year which was developed from the RG 1.174 LERF considerations.

References

1. Safety Goals for the Operations of Nuclear Power; Policy Statement, 51 Federal Register 28044, August 4, 1986.

2. Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," July 1998.

3. U.S. Nuclear Regulatory Commission, *Evaluation of Severe Accident Risks: Surry Unit 1*, NUREG/CR-4551, Vol. 3, Rev. 1, Part 1, Sandia National Laboratory, October 1990.

4. U.S. Nuclear Regulatory Commission, *MACCS Version 1.5.11.1: A Maintenance Release of the Code*, NUREG/CR-6059, Sandia National Laboratory, October 1993.

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

Consequence Measure	Consequences for Operating Reactor Accident (Surry, NUREG-1150)						Consequences for SFP Accident One Year After Shutdown				
	Internal Events					Seismic Events	Baseline Source Term		Release of 0.75 Ru and 0.01 Fuel Fines		Worst Case
	SGTR (SUR-14-1)	"V" - Wet (SUR-03-3)	"V" - Dry (SUR-05-3)	Worst EF (SUR-10-3)	Worst LCF (SUR-10-1)	Worst EF and LCF (SRH-10-3)	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 (EF)	0.013	0.16	1.8	12	0.84	249	0.005	1.0	0.54 [0.17]	55	103
Population dose within 50 miles (person-rem)	1.9E6	1.1E6	2.6E6	3.3E6	4.8E6	1.1E7	2.8E6	3.2E6	6.3E6 [5.1E6]	1.0E7	1.1E7
Latent cancer fatalities (LCF) [2]	2650 (7950)	794 (2380)	2560 (7680)	3670 (11000)	4780 (14300)	7240 (21700)	1370	1700	5860 [4420]	9320	10600

1 - Except where noted in brackets, consequence results for spent fuel pool accidents are based on a reactor power of 3441 MWth. Values in brackets are for a 2440 MWth reactor, equivalent to Surry.

2 - Numbers in parentheses reflect an adjustment to account for differences in the cancer risk model in the MACCS code used for NUREG-1150 and the MACCS2 code used for the SFP accident calculations

Table 2 - Comparison of Risk Results for Reactor and Spent Fuel Pool Accidents [1]

Risk Measure	Risk for Operating Reactor Accident (Surry, NUREG-1150)			Risk for SFP Accident One Year After Shutdown (conditional on SFP source term and 3.4E-6 per year fire frequency)		
	Internal Events	Seismic Events [3]	Internal and Seismic	Baseline 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)	2.0E-6	9.3E-5	9.5E-5	1.6E-8	1.8E-6 [5.8E-7]	3.5E-4
Population dose within 50 miles (person-rem per year)	5.8	45	61	10	21 [17]	39
Latent cancer fatalities (per year) [2]	0.0052 (0.016)	0.039 (0.12)	0.044 (0.13)	0.0047	0.020 [0.015]	0.036

1 - Except where noted in brackets, consequence results for spent fuel pool accidents are based on a reactor power of 3441 MWth. Values in brackets are for a 2440 MWth reactor, equivalent to Surry.

2 - Numbers in parentheses reflect an adjustment to account for differences in the cancer risk model in the MACCS code used for NUREG-1150 and the MACCS2 code used for the SFP accident calculations

3 - Based on Lawrence Livermore National Laboratory (LLNL) seismic hazard distributions

Table 3 - Comparison of Spent Fuel Pool Accident Risk One Year After Shutdown with Quantitative Health Objectives

Case	QHO for Individual Risk of Prompt Fatalities					QHO for Societal Risk of Latent Cancer Fatalities				
	Ind. Early Fatality Risk (per event)	PPG (events per year)	Prob of Early Fatality (per year)	QHO (per year)	% of QHO	Ind. Latent C. Fatality Risk (per event)	PPG (events per year)	Prob of Latent C. Fatality (per year)	QHO (per year)	% 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