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To: Gareth Parry, Timothy Collins
Date: Thu, Aug 31, 2000 8:01 AM
Subject: Writeups on SFP Risk Comparisons

Attached are updated writeups on the risk comparisons. The second attachment addresses comparisons based on translating the delta LERF concept in RG 1.174 to delta risk, and is new ground.

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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 those for a severe 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. 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 small increases in risk, 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 involving a large early release at operating reactors, and therefore a PPG of 1E-5 per year 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 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). The NUREG-1150 study assumed that 99.5% of the population would be evacuated. However, for large earthquakes (greater than 0.5g) it was assumed that there would be no effective evacuation until 24 hours, at which time the population in the emergency response zone would be relocated.

It should be noted that the latent cancer fatality results reported in NUREG-1150 and NUREG/CR-4551 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 three increase in latent cancer fatalities relative to the earlier model. The other risk measures (early fatalities, and population dose) are also slightly higher. More recent calculations based on the later version of the MACCS code are reported in NUREG/CR-6349 for most of the NUREG-1150 reference plant source terms (for internal events). The results from these later calculations are cited where available. Otherwise, the latent cancer fatality results from NUREG-1150 were increased by a factor of three to provide a more meaningful comparison.

Briefly stated, 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 substantially 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, percent of population participating in the evacuation, population distribution, number of cores participating in the SFP fire, and plume-related parameters.

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) related to SFP instrumentation and offsite communication, the staff considers the

consequence cases with early evacuation to be most representative for internally-initiated SFP accidents. Although 99.5% of the population was assumed to evacuate in NUREG-1150, this value may be somewhat optimistic, especially if existing EP requirements are relaxed, such as the requirement for notification systems. Accordingly, cases assuming reduced participation (i.e., 95% of the population) are considered more representative of an evacuation carried out on an ad hoc basis without the benefit of current radiological preplanning. For the large seismic events that dominate the frequency of SFP fires, it is expected that there would be extensive damage to the infrastructure needed 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 for these events.

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.

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 judged to be 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 from a nuclear accident occur throughout the entire region around the plant (1000 miles) and over several decades. The population within 1000 miles of the plant is about 160 million. Given the cancer fatality rate in the U.S. of about 1 in 500 per year, there would be about 300,000 deaths per year and 6 million deaths over a 2 decade period within the region from all other cancers. 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.

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. The long term protective assumption used in both the NUREG-1150 and SFP studies was to interdict land which could give a projected dose to an individual via the groundshine and resuspension inhalation pathways of more than 4 rem in 5 years (2 rem in the first year and 0.5 rem per year for the next 4 years, for an average of 800 mrem per year). Comparisons of consequence results at various distances for each of the NUREG-1150 reference plants are provided in NUREG/CR-6349, and clearly show that the increase in population dose with distance is due to a large number of people receiving very small doses, below the assumed long-term interdiction limit of 4 rem in 5 years, since the offsite consequences due to land condemnation, etc., remain essentially the same over the range of distances. The effect of varying long-term interdiction dose limits on latent fatalities, populations doses, and offsite costs was estimated in NUREG/CR-6349 by recalculating the consequences for each of the NUREG-1150 plants for various lower limits. The results show that as the interdiction limit is reduced, the latent cancers and population dose decrease and the offsite costs progressively increase. For a reduction in the interdiction limit from 800 mrem per year to 300 mrem per year the risk measures decreased by typically 20 to 30 percent, and offsite costs increased by about a factor of two. Thus, changes in risk results on this order can be expected as a result of public policy decisions.

Finally, in comparing the SFP consequences with those for a reactor accident at Surry it should be kept in mind that the NUREG-1150 results for Surry are for a power level of 2441 MWth, and that the SFP consequences will be overstated slightly due to the different power levels. Results for one case with a SFP decay heat level corresponding to a reactor power of 2440 MWth (values in brackets in Table 2) indicate that the latent health consequences would be about 30 percent lower than those based on 3441 MWth.

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, the early fatality risk results 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, the early fatality risk results 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

The frequency of events leading to uncovery of the spent fuel must be less than 1E-5 per year in order to consider risk-informed changes that could result in the equivalent of a 1E-6 per year increase in LERF. 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.

In the above comparisons the SFP accident is assumed to occur one year following shutdown. The consequences of the accident would be markedly lower if it were to occur at a later time due to fission product decay. Specifically, after about 5 years the contribution from ruthenium would be virtually eliminated, and consequences would be dominated by cesium. Accordingly, the results reported for the baseline source term would be most representative for events occurring 5 years or beyond.

Although the above comparisons focus on the Surry site, the results are expected to be generally applicable to other sites as well. At higher population sites the SFP accident consequences would be higher, but the risk associated with reactor accidents would be proportionally higher as well. Thus, the results of the relative comparisons should remain valid. Similarly, the QHOs represent risk to the average individual within 1 mile and 10 miles of the plant, and should be relatively insensitive to the site-specific population.

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 [2] (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[3] (SUR-14-1)	"V" - Wet[3] (SUR-03-3)	"V" - Dry[3] (SUR-05-3)	Worst EF[3] (SUR-10-3)	Worst LCF[4] (SUR-10-1)	Worst EF[4] 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)	0.017	0.23	2.7	15 13	0.84	249	0.005	1.0	0.54 [0.17]	55	103
Population dose within 50 miles (person-rem)	2.1E6	1.3E6	2.9E6	3.6E6 3.5E6	4.8E6	1.1E7	2.8E6	3.2E6	6.3E6 [5.1E6]	1.0E7	1.1E7
Latent cancer fatalities (LCF)	7850	2460	7930	11300 11300	14300	21700	**1990**	**2320**	**6880 [4420]**	**10300**	**11700**

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 - NUREG-1150 study assumed that 99.5% of the population would be evacuated. However, for large seismic events it was assumed that there would be no effective evacuation until 24 hours, at which time the population in the emergency response zone would be relocated.

3 - Based on results reported in NUREG/CR-6349.

4 - Based on results reported in NUREG/CR-4551. Values shown for latent cancer fatalities include a factor of three adjustment to account for differences in the cancer risk model used for NUREG-1150 and 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 5E-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	2.4E-8	2.7E-6 [8.5E-7]	5.2E-4
Population dose within 50 miles (person-rem per year)	5.8	45	51	14	31 [25]	57
Latent cancer fatalities (per year) [2]	0.016	0.12	0.13	**0.010**	**0.034 [0.022]**	**0.059**

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 - Values shown for operating reactor accident include a factor of three adjustment to account for differences in the cancer risk model used for NUREG-1150 and 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

Allowable Level of Risk Increase In Accordance With RG 1.174

RG 1.174 provides guidance on the allowable increase in the frequency of large early release associated with a proposed change to the licensing basis. In accordance with RG 1.174, 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. Relaxations in EP requirements do not impact the frequency of events involving a large early release (i.e., SFP fire frequency) but instead could increase the consequences associated with the large release. Hence, in applying the ΔLERF concept to plant changes that impact consequences it is necessary to translate the allowable increase in LERF into an allowable increase in risk.

The risk increase associated with a ΔLERF of 1E-6 per year at Surry can be bounded by considering the consequences for a worst case large early release sequence at Surry, in conjunction with the maximum allowable frequency increase (i.e., 1E-6 per year). This approach provides an upper limit on the increase in risk that might be approved at Surry, in accordance with RG 1.174 principle of permitting only small increases in risk. The consequences associated with the source term that produced the greatest number of early fatalities in the NUREG-1150 study for Surry are provided in Table 1 below. The consequences are reported separately for internal events and seismic events and are discussed in more detail in the appendix regarding the PPG. The risk measures reported for seismic events are based on the LLNL hazard curve and are about an order or magnitude more severe than those based on the EPRI hazard curve. The maximum allowable level of risk increase is the product of the consequences (in this case, the consequences for the worst seismic event since it is bounding) and the allowable frequency increase of 1E-6 per year. This risk increase is provided in the last column of Table 1.

It should be noted that the Commission's Quantitative Health Objectives (QHOs) correspond to an individual early fatality risk of 5E-7 per year and an individual latent cancer fatality risk of 2E-6 per year. Thus, the risk increase values inferred from RG 1.174 for individual early fatality risk (8.7E-8 per year) and individual latent cancer fatality risk (6.9E-8 per year) represent only about 17 percent and 4 percent of these QHOs, respectively. This margin reflects the strategy taken in establishing the acceptance guidelines for risk increase in RG 1.174. Specifically, in RG 1.174 the NRC adopted more restrictive acceptance guidelines than might be derived directly from the Commission's Safety Goal Policy Statement. This policy was adopted to account for uncertainties and for the fact that safety issues continue to emerge regarding design, construction, and operational matters.

Table 2 summarizes the bases for evacuation modeling for each of the major contributors to SFP fires. The effectiveness of EP was characterized is such a way to maximize the value of formal EP in the "full EP" case and minimize the value of ad hoc EP in the "no radiological preplanning" case. As such, the resulting estimates of the risk increase associated with EP relaxations represent an upper bound on the potential risk increase.

The consequences associated with each of the events leading to SFP fires are provided in Table 3 for the "full EP" case and "no radiological preplanning" case. The consequences are based on results of calculations reported in Appendix 4A. In several cases where MACCS2 runs were not available, the results for the closest corresponding calculation were used as an

approximation. The risk increase associated with the EP relaxation is the product of the event frequency and the change in consequences, summed over all contributors.

The sensitivity of the risk increase estimates is strongly dependent on the assumptions regarding the effectiveness of emergency evacuation in seismic events, since these events dominate the SFP fire frequency. In NUREG-1150, evacuation in seismic events was treated either of two ways depending on the peak ground acceleration (PGA) of the earthquake:

- for low PGA earthquakes (<0.6g), 99.5% of the population was assumed to evacuate however the evacuation was assumed to start later and proceed more slowly than evacuation for internally-initiated events. A delay time of 1.5 x the normal delay time and an evacuation speed of 0.5 x the normal evacuation speed was assumed for this case.

- for high PGA earthquakes (>0.6g), it was assumed that there would be no effective evacuation and that many structures would be uninhabitable. The population in the emergency response zone was modeled as being outdoors for the first 24 hours, and then relocating at 24 hours. The assumption that there would be no effective evacuation in high g earthquakes is consistent with previous Commission rulings on San Onofre and Diablo Canyon in which the Commission found that for those risk-dominant earthquakes which cause very severe damage to both the plant and the offsite area, emergency response would have marginal benefit because of its impairment by offsite damage.

Since the large majority of the SFP fire frequency involves large seismic events with PGA exceeding 0.6g, the baseline estimate of the risk increase associated with EP relaxation assumes no effective evacuation for the first 24 hours, consistent with the NUREG-1150 model. However, two additional cases were also considered to explore the sensitivity of the risk increase to evacuation assumptions. In both cases the seismic event was assumed to only partially degrade the emergency response.

In the first sensitivity case, it was assumed that evacuation would be carried out consistent with the NUREG-1150 model for low g earthquakes if current EP requirements are maintained, i.e., 99.5% of the population evacuates, the evacuation delay time is increased by 50 percent, and the time to complete the evacuation is doubled. This is extremely optimistic given the damage to communication and notification systems, buildings and structures, and roads that would accompany any seismic event severe enough to fail the SFP. With no preplanning for radiological accidents, the population evacuating was reduced to 95% and the evacuation delay time was further increased to three times the normal delay time. The second sensitivity case assumed the same delays but evacuation of only 50% of the population.

For purposes of assigning consequences in the seismic sensitivity cases, the "full EP" cases were represented by the results from the early evacuation case (i.e., evacuation is started and completed prior to the release) and the "no preplanning for radiological accidents" cases were represented by the results from the late evacuation case (i.e., evacuation is not started until after the release has occurred). By maximizing the effectiveness of evacuation in the full EP case and minimizing its effectiveness in the no preplanning case, the risk increase associated with EP relaxations would tend to be maximized.

The estimated risk increases associated with the EP relaxation are summarized in Table 4. The results indicate that relaxation of the requirements for radiological preplanning would result in an increase of about 1E-5 early fatalities per year, which is about a factor of 20 below the allowable increase inferred from the RG 1.174 LERF criteria. The relaxation would result in an increase of about 1 person-rem per year, which is about a factor of 10 below the maximum allowable from RG 1.174. The other risk measures are also about a factor of 10 or more lower than the allowables from RG 1.174. Since the SFP fire frequency for the reference plant is about a factor of 2 lower than the PPG of 1E-5 per year, a plant operating nominally at the PPG would have a smaller margin to the allowable risk limits but would still be at or below the limits under the above assumptions.

The results of the sensitivity studies indicate that even under the most optimistic assumptions regarding the value of EP in seismic events, the change in risk associated with relaxation of the requirements for radiological preplanning is still relatively small. The EP relaxation would result in an increase of about 2.5E-4 early fatalities per year, which is at the maximum allowable, and an increase of about 17 person-rem per year, which is slightly higher than the maximum allowable increase. The increase in the individual early and latent fatality risks are about 60 percent and a factor of three higher than the allowable values inferred from RG 1.174. It must be kept in mind that the evacuation effectiveness assumed in the "Full EP" sensitivity cases is unrealistic for high g earthquakes, and that the risk increase associated with the EP relaxations would be closer to the baseline value. Also, because the allowable increase in individual early and latent fatality risks inferred from the RG 1.174 LERF criteria represent only 17 percent and 4 percent of the QHO values, considerable margins to the QHOs would still remain.

Finally, the above comparisons are based on the risk levels one year after shutdown. The risk impact will decrease in later years due to (1) reduced consequences as fission products decay further, and (2) increased time available for ad hoc measures. This additional time will render the bounding assumptions regarding the effectiveness of ad hoc measures unduly conservative for the out years.

Table 1 - Allowable Level of Risk Increase In Accordance With RG 1.174 ΔLERF Criterion

Risk Measure	Consequences -- conditional upon source term that produces greatest early fatalities (per event)		Allowable frequency increase in accordance with RG 1.174 (events per year)	Allowable risk increase (per year)
	Internal Events	Seismic Events		
Early fatalities	15	250	1E-6	2.5E-4
Population dose (p-rem within 50 miles)	3.6E6	1.1E7	1E-6	11
Latent cancer fatalities	11300	22000 [1]	1E-6	0.022
Individual early fatality risk at 1 mile	2.9E-2	8.7E-2	1E-6	8.7E-8
Individual latent cancer fatality risk at 10 mile [1]	5.5E-3	6.9E-2	1E-6	6.9E-8

1 - Values shown include a factor of three adjustment to account for differences in the cancer risk model used for NUREG-1150 and SFP accident calculations

Table 2 - Evacuation Modeling for Major Contributors to SFP Fires

Event Type	Major Contributor	Freq (per year)	Minimum Time to Release (h)	Intact Infrastructure for Emergency Response?	Full EP		No Preplanning for Radiological Accidents	
					% Evac	Evacuation Model	% Evac	Evacuation Model
Boildown	LOOP (severe weather)	1.8E-7	>200	Yes	99.5	Early	95	Early
Rapid Draindown	Cask Drop	2.0E-7	~10	Yes	99.5	Early	95	Late
	Seismic [1]	4.5E-6	~10	No	0	No evacuation Relocation at 24 h	0	No evacuation Relocation at 24 h
	Sensitivity Case 1 [2]				99.5	1.5x normal delay 0.5x normal speed (Model as Early)	95	3x normal delay 0.5x normal speed (Model as Late)
	Sensitivity Case 2				50	1.5x normal delay 0.5x normal speed (Model as Early)	50	3x normal delay 0.5x normal speed (Model as Late)

1 - Evacuation model for full EP case is consistent with NUREG-1150 assumptions for high acceleration earthquakes

2 - Evacuation model for full EP case is consistent with NUREG-1150 assumptions for low acceleration earthquakes

Table 3 - Estimated Risk Increase Associated With Relaxing EP Requirements

Event Type Major Contributor	Freq (per year)	Consequences Per Event with Full EP					Consequences Per Event with No Preplanning for Radiological Accidents					Δ Risk per year from EP reduction				
		EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF	EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF	EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF
Boildown	1.8E-7	0.05	6.3E6	~5860	~1.4E-3	~2.5E-3	0.54	6.3E6	5860	1.40E-3	2.55E-3	9E-8	0	0	~0	~0
Cask Drop	2.0E-7	0.05	6.3E6	~5860	~1.4E-3	~2.5E-3	55	1.0E7	9320	3.23E-2	4.98E-2	1E-5	0.7	~7E-4	~6E-9	~9E-9
Seismic [1]	4.5E-6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0	0	0	0
Total	~5E-6											1E-5	0.7	7E-4	6E-9	9E-9
Sensitivity Case 1		0.05	6.3E6	~5860	~1.4E-3	~2.5E-3	55	1.0E7	9320	3.23E-2	4.98E-2	2.5E-4	16.7	~0.016	~1.4E-7	~2.1E-7
Sensitivity Case 2		5	6.3E6	~5860	NA	NA	55	1.0E7	~9320	NA	NA	2.3E-4	16.7	~0.016	NA	NA

1 - Risk results with and without EP would be comparable for large seismic events since emergency response would have marginal benefit because of its impairment by offsite damage

NA = not available

Table 4 - Comparison of Risk Increase with RG 1.174 Allowable

Risk Measure	Risk Increase due to EP Reduction (per year)			RG 1.174 Allowable Risk Increase (per year)
	Baseline	Sensitivity Case 1	Sensitivity Case 2	
Early Fatalities	1E-5	2.6E-4	2.4E-4	2.5E-4
Population Dose	0.7	17	17	11
Latent Cancer Fatalities	7E-4	0.016	0.016	0.022
Individual Early Fatality Risk	6E-9	1.4E-7	NA	8.7E-8
Individual Latent Cancer Fatality Risk	9E-9	2.1E-7	NA	6.9E-8