UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 26, 2004

~~OFFICIAL USE ONLY~~

MEMORANDUM TO: Glenn Tracy, Director
Division of Nuclear Security
Office of Nuclear Security and Incident Response

FROM: Farouk Eltawila, Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: SCOPING ANALYSIS OF A NON-DRAINDOWN SPENT FUEL POOL ACCIDENT

Work has been undertaken by the Office of Nuclear Regulatory Research to study certain non-draindown accidents in Spent Fuel Pools (SFPs). This work has been broken down into two phases. Phase 1 (which has been completed and is described in Attachment 1) deals with use of the design-basis Fuel Handling Accident (FHA) and the associated Regulatory Guide (RG) methodolog for estimating the consequences of an accident involving damage to spent fuel located in the spent fuel pool. Of particular interest is the level of conservatism inherent in this Design-Basis Accident (DBA) analysis. To this end, work has been performed to analyze the FHA and its conservatisms. Further work has been performed to apply more realistic assumptions to some of the key parameters of this analysis, through the use of a Monte Carlo simulation. Phase 2 will deal with the extension of this analysis to include[ ]already taken in to account by the Phase 1 analysis. Ex. 2

CONTACT: Donald Helton, RES:DSARE:SMSAB
301-415-7558

OFFICIAL USE ONLY
May be exempt from public release under the Freedom of Information Act (5 U.S.C. 552)

Exemption number 2
Nuclear Regulatory Commission review required before public release.

Farouk Eltawila, Director, DSARE:RES
Name and organization of person making determination.

Date of Determination 02/ /04

Portions withheld - Ex 2

~~OFFICIAL USE ONLY~~

~~Ex 2 entirety~~

8/10
10

~~OFFICIAL USE ONLY~~

As indicated above, Attachment 1 outlines the work performed during Phase 1. First, background on the accident of concern is provided. Next, the accident progression is outlined. This is followed by a description of the design-basis analysis, as set forth in the appropriate Regulatory Guides. As an extension of this analysis, a Monte Carlo simulation is performed which provides insight into the conservatism of the design-basis analysis. Finally, conclusions are drawn from the analysis. Two appendices are included which provide further detail of the analysis that has been performed.

Through the use of Monte Carlo simulation, it has been demonstrated that [ ] Sensitivity studies on [ ] have been performed which exhibit that under more realistic conditions, the offsite dose due to this accident [ ] These results are extended, to estimate [ ] assemblies would need to be ruptured before offsite doses would approach the regulatory [ ] With DBA conservatisms, [ ] With more realistic [ ] Ex. 2

Future work in this area will involve the use of [ ] Like the present work, this future work will investigate sensitivities in the solution via Monte Carlo simulation. Ex. 2

Attachments: As stated

cc: A. Thadani/J. Strosnider

Distribution w/att.: SMSAB R/F DSARE R/F JStarefos J. Schaperow
A.Ramey-Smith, DRAA B. Tegeler, DET
Al. Tardiff, NSIR W. Orders, NSIR J. Shea, NSIR

C:\MyFiles\Checkout\Feb04-memo-to-NSIR-concur.wpd
OAR in ADAMS? (Y or N) Y ADAMS ACCESSION NO.: ML040610114 TEMPLATE NO. RES-006
Publicly Available? (Y or N) N DATE OF RELEASE TO PUBLIC SENSITIVE? Y
To receive a copy of this document, indicate in the box: "C" = Copy without enclosures "E" = Copy with enclosures "N" = No copy

OFFICE	SMSAB		SMSAB		SMSAB		C:SMSAB		D:DSARE	
NAME	DHelton:mb		CTinkler		RHogan		JRosenthal		FEltawila	
DATE	02/26/04*		02/26/04*		02/26/04*		02/26/04*		02/26/04*	

Attachment 1

1. Introduction

During normal operation, certain fission products accumulate in the fuel rod gap, which is defined to be the volume between the fuel pellets and the fuel cladding. If the fuel cladding is breached for any reason, the fission products in the gap have the potential to escape from the fuel rod. Since these fission products are radioactive, their escape to their surrounding environment can cause a radioactive exposure. For this reason, it is important to characterize events which could lead to the release of the gap inventory.

[redacted] Fuel fines are "particulate material composed of fuel compounds and are produced as a result of mechanical stresses at both the fuel-cladding interface and the fuel pellet-fuel pellet interface" [NUREG/CR-6487]. Like the gap effluents, the fuel fines are radioactive, and their release from the SFP building could cause an off-site exposure. Ex. 2

As a starting point, one can look at the Fuel Handling Accident (FHA) which is a Design-Basis Accident (DBA) for nuclear power plants. This accident looks at the release of radioactivity due to the dropping of a fuel assembly in the SFP. It is typically assumed that all of the rods in one fuel assembly release their entire gap inventory. Two important points of interest are (1) the FHA methodology is intended as a bounding calculation, not a realistic calculation, and (2) the FHA source term is comprised of iodine and noble gasses, and does not include contribution from fuel fines, or other gap particulates (such as Cesium).

In this study, it has been assumed that [redacted] Ex. 2

2. Accident Basics

As described above, the basis for this work will be the Fuel Handling Accident, which is considered as a Design-Basis Accident, and is therefore covered in plant Final Safety Analysis Reports (FSARs). This accident evaluates the potential consequences of radioactive release from the Spent Fuel Pool building due to damage of a fuel assembly during fuel handling operations. Even if the initiator is different for a particular case of interest, the progression of the accident following initiation may be very similar to the FHA.

The FHA can be broken up into several discrete stages:

- accident initiation
- release of the gap inventory to the surrounding pool water
- transport of the release through the pool water
- transport of the release through the building atmosphere (building holdup)
- transport of the release through ventilation system filters (if present)
- transport of the release to the environment

- exposure of individuals to the release at the Exclusion Area Boundary (EAB)

Ex. 2

Dose limits for the FHA are given in Regulatory Guide 1.183 and the Standard Review Plan (SRP) to be 25% of the 10CFR limits. For plants which utilize the TID-14844 source term, the 10CFR100 limits are 25 rem whole-body and 300 rem thyroid dose. For plants which have adopted the Alternative Source Term (AST), the 10CFR50.67 limit is 25 rem Total Effective Dose Equivalent (TEDE).

3. Conservative Calculation (Regulatory Guide 1.183 and 1.195)

Calculation of the consequences of a Fuel Handling Accident is covered in Regulatory Guides 1.183 and 1.195. These Regulatory Guides give appropriate assumptions to be made when performing a conservative licensing calculation. Regulatory Guide 1.183 deals with the use of the Alternative Source Term and 1.195 deals with the use of the TID-14844 source term. In terms of the methodologies for the FHA, the two guides are very similar.

The starting point of the analysis is the inventory of radioactive iodine and noble gasses present in the fuel at the initiation of the event. For the purpose of this work, the source term will be taken from the FSAR analysis for the FHA of a representative Pressurized Water Reactor (PWR). Ex. 2 A detailed description of the Regulatory Guide 1.183 methodology is provided in Appendix A. This methodology is intended to produce a conservative result, based on a number of conservative assumptions regarding source term transport. These conservatisms are outlined in the table below, along with an estimate of their level of conservatism, if available.

Conservatism	Estimate of Importance
CsI is assumed to disassociate and produce elemental (vapor) Iodine	This could cause the conservative result to be approximately three times higher than a more realistic approach (see discussion on DFs in Appendix A)
Ex 2	
Peaking Factor (highest rated assembly)	This will cause the result to be times higher than the result for an average assembly (Ex. 2)
Gap Release Fractions	At SFP temperatures, the fraction of Iodine in vapor form could be substantially lower - this could cause a decrease in offsite doses
Pool Decontamination Factors	Not estimated

Conservatism	Estimate of Importance
No Credit for Building Holdup	
No Credit for Filtering	Not estimated; depends on the design of the ventilation system
Release timing	Not estimated
Weather Assumption (Stability Class F, 1 m/s wind speed)	This will have a substantial impact because this is a very conservative weather scenario.
Exposure timing	Not estimated; based on unsheltered 2-hour respiration

Table 1: Conservatisms in the Regulatory Calculation

The calculation described in Appendix A resulted in an offsite dose at the Exclusion Area Boundary of The FSAR of the plant whose source term was used gives a value of The dose limit for the FHA is specified in the Standard Review Plan (and the Regulatory Guides) to be 25% of the 10CFR50.67 limit of 25 rem (i.e., 6.25 rem). Hence, the values calculated here are than the 10CFR50.67 limits, and the SRP limits. Extrapolation of the results indicates that

Keep in mind, this calculation has many conservatisms (Table 1) and one potentially important non-conservatism (exclusion of fuel fines and particulates), which could be important for certain scenarios different from the DBA.

4. More-Realistic Calculation Using Monte Carlo Sampling

For a less conservative calculation (as opposed to the bounding calculation described above), one can simply use less conservative inputs and assumptions. However, this result will not speak at all to the probabilities of a proposed exposure. For this, Monte Carlo sampling can be used to sample from a range of inputs, to obtain a probability distribution of the predicted outcome. The methodology described in Regulatory Guide 1.183 will be employed as before, with the exception that some input parameters will now be sampled rather than set as constants.

In a typical once-through calculation, each input parameter (gap inventory, pool decontamination factor, etc.) is assigned a value and a calculation is performed to arrive at one answer. In Monte Carlo sampling, some inputs are assigned a range of values, and the calculation is performed numerous times. Each time the calculation is performed, the range of each input value is randomly sampled. The end result is a large number of answers, which can be viewed as a probability distribution. From these answers, one can obtain a mean (average) dose. In addition, one can produce a more conservative estimate by taking the 95th percentile (i.e., a value which is larger than 95% of the results).

The first parameter sampled is plant weather data, which is used to provide a distribution of χ/Q values. There are 8,640 values of weather data that are sampled (24 hours x 365 days). Once weather data has been sampled, it is transformed into χ/Q values, per the procedure described in Appendix B. The Regulatory Guide 1.145 methodology is more recent than the Regulatory Guide 1.4 methodology used by the plant to calculate the DBA value used in the FHA calculation.

Ex. 2

Ex. 2

Ex. 2

Ex. 2

(see Appendix B for more

The CDFs [redacted] are shown in Figure 2 and Figure 3. Ex. 2

[redacted]

Ex. 2

[redacted] This is accomplished by simply using the decay constants for each isotope, [redacted] Ex. 2 as given in the Chart of the Nuclides. Whenever isomeric states exist, the ground state half-life is used. Secondary decay is not considered, with one exception: the inventories of Xenon taken from the FSAR include contribution from Iodine precursors accumulated in the gap.

The results from all of the cases are provided in Table 2. Sampling weather resulted in

Ex. 2

Ex. 2

Ex. 2

Ex. 2

Ex. 2

Although results are given for the results can be extended to estimate other scenarios. One example of this is the case where it is felt that the accident For this case, one can take the results presented above, and remove the assumption This can be done because the dose is linearly related to As an example, take the case where real weather data is sampled, and the accident is assumed to happen The If one divides by the average fraction of will represent the case where the accident happens

Ex. 2

5. Conclusions

Sampling from both variable weather data resulted in

Ex. 2

If one uses mean values, Ex. 2

Again, these estimates do not take into account Ex. 2

On the other hand, these estimates also don't consider other conservatisms (outlined in Table 1), which would cause a decrease in the obtained doses. Both of these issues are currently being studied.

Appendix A

Regulatory Guide 1.183 Methodology

The starting place will be the inventory of the core prior to the accident. This inventory should take into account fuel enrichment, burnup, and reactor power (including an adjustment for ECCS evaluation uncertainty). Radial peaking factors are used to determine the maximum power for a particular fuel assembly. For this calculation, the FSAR source term for the fuel handling accident will be used. In this calculation, it will be assumed that all of the rods in one fuel assembly are perforated and give up their gap inventory. The source term used here is formulated by taking the total core inventory and adjusting for the number of fuel assemblies the radial peaking factor and the decay time Ex. 2

$$A_i = \left(\qquad e^{-\lambda_i T} \right. \qquad (A.1)$$

Where i represents individual nuclides, and λ_i is the decay constant. The decay time (T) is the time following shutdown Ex. 2

The source term used here is one given in the FSAR of a typical PWR. The source term is the total core inventory Hence, it already incorporates the radionuclide decay, and only needs to be adjusted to represent the highest inventory in a single fuel assembly (via the radial peaking factor and the number of fuel assemblies). Table A.1 lists the inventory for each isotope.

Ex. 2

RG 1.183 specifies that the gap contains 8% I-131, 10% Kr-85, 5% of other noble gasses and halogens, and 12% of alkali metals. Using this information, one can obtain the gap inventory.

It is assumed that all of the gap inventory is instantaneously released when the fuel assembly is damaged.

For transport of the source term through the pool water, RG 1.183 and RG 1.195 give a reference pool decontamination factor for removal of Iodine of 200. This value is based on the assumed percentages of organic versus inorganic iodine, and the assumption that 23 feet of water are present above the fuel. If it is assumed that CsI does not disassociate and produce elemental (vapor) Iodine, the corresponding effective decontamination factor for removal of Iodine would be approximately 600.

The radioactive release from the pool is given by:

$$A_{\text{escaping pool}} = \frac{A_{\text{gap inventory}}}{DF_{\text{pool}}} \qquad \text{(A.2)}$$

This applies only for the Iodine inventories. The noble gas inventories leaving the pool are identical to the noble gas gap inventories (Noble Gas Decontamination Factor = 1). This is because noble gasses are insoluble, and will pass through the pool without a decrease in inventory.

No generic credit is given for mixing in the Spent Fuel Pool building atmosphere. It is assumed that the radionuclides leaving the pool immediately enter the ventilation system without dilution. [Plants which have an ESF ventilation system can take credit for these systems.] Ex. 2

Once the radionuclides have been released from the spent fuel pool building, further progression of the accident is highly dependent upon meteorological conditions and site characteristics. Parameters such as meteorological stability class, wind speed, distance to the site boundary, and release height can have a substantial impact upon public exposure. Atmospheric dispersion factors (χ/Q) can either be obtained from the initial site licensing calculations, or via methodologies approved by the NRC. In general, approved methodologies include Regulatory Guides 1.3, 1.4, and 1.145. RG 1.145 should be used if the FSAR values are to be revised, or if new release points or receptor distances are to be employed. For the fuel handling accident calculation, a bounding atmospheric stability class of F, and wind speed of 1 m/s are used. The FSAR value for χ/Q calculated by the licensee is [ ] Ex. 2

Whereas RG 1.195 employs the concept of a thyroid dose and a whole-body dose, RG 1.183 employs the use of the Total Effective Dose Equivalent (TEDE). The TEDE is a combination of the Committed Effective Dose Equivalent (CEDE) and the Deep Dose Equivalent (DDE). The DDE is nominally equivalent to the Effective Dose Equivalent (EDE) for external exposure (if the whole body is irradiated uniformly), and this value can be used in place of the DDE.

Dose Conversion Factors (DCFs) needed to calculate the CEDE can be obtained from Table 2.1 of EPA-520/1-88-020, under the column headed 'effective'. The appropriate calculation is:

$$\text{CEDE} = \sum_{i=1}^{N} A_i^{\text{escaping building}} \cdot B \cdot DCF_i \cdot (\chi / Q) \qquad \text{(A.3)}$$

A breathing factor (B) of $3.5 \cdot 10^{-4}$ m^3/s is appropriate. External EDE conversion factors can be obtained from Table III.1 of EPA-402-R-93-081, also under the column headed 'effective'. In this case, the pertinent equation is:

$$\text{EDE} = \sum_{i=1}^{N} A_i^{\text{escaping building}} \cdot DCF_i \cdot (\chi / Q) \qquad \text{(A.4)}$$

These quantities are then summed:

$$\text{TEDE} = \text{CEDE} + \text{EDE} \qquad \text{(A.5)}$$

to give the TEDE. These equations represent a simplified, conservative approach, where time integration has been avoided by assuming that the receptor is exposed to the entire release.

Appendix B

Monte Carlo Input Parameter Distributions

For the χ/Q values, real plant weather data is used in conjunction with the equations given in Regulatory Guide 1.145. There are three pertinent equations for calculating the atmospheric dispersion values for a ground level release. These are:

$$\chi/Q = \frac{1}{u\left(\pi\sigma_y\sigma_z + A/2\right)} \qquad (B.1)$$

$$\chi/Q = \frac{1}{u\left(3\pi\sigma_y\sigma_z\right)} \qquad (B.2)$$

$$\chi/Q = \frac{1}{u\left(\pi M\sigma_y\sigma_z\right)} \qquad (B.3)$$

where χ/Q is the atmospheric dispersion or relative concentration (s/m^3), u is the wind speed (m/s), σ_y is the lateral plume spread (m), σ_z is the vertical plume spread (m), M is a wake-effect and plume-meander correction factor given in Figure 3 of Reg Guide 1.145, and A is the smallest vertical-plane cross-section of the reactor building (m^2). Values for σ_y and σ_z are given in Appendix C of NUREG/CR-6613, Volume 1. This source also gives a correction factor of 1.27 for σ_z, due to terrain considerations. A value of [redacted]s used for the building cross-sectional area. Ex. 2

The procedure given in Regulatory Guide 1.145 for determining which value of χ/Q to use follows. For stability classes of D, E, F, or G and u < 10 m/s, the higher value of equations B.1 and B.2 should be compared to the value from B.3, and the lower of these two values should be used. For all other conditions, one should use the higher of the two values obtained from equations B.1 and B.2.

The cumulative distribution function for the χ/Q distribution is given in Figure B.1.

Ex. 2

The weather data sampled here is for the same PWR whose FSAR value of χ/Q was used in the conservative Regulatory Guide 1.183 calculation. Ex. 2

Ex. 2

Ex. 2

Ex. 2

This distribution is demonstrated in Figure B.2.