Attachment 3

Alternate Source Term Dose Analysis: An Estimate of Risk Attributed to GSI-191

STP-RIGSI191-RAI.1

South Texas Project Risk-Informed GSI-191 Evaluation

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An Estimate of Risk Attributed to GSI-191

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Abstract

We estimate the rate, in terms of events per calendar year, of an alternate source term acceptance criteria exceedance (AST ACE) event, which is attributable to GSI-191. To do so, we use output from the CASA Grande simulation model to estimate the rate at which a sump failure occurs as a function of time since a loss of coolant accident. At the time the first sump fails, we assume all containment sprays are lost. We couple this estimation with a dose calculation as a function of the time at which containment sprays are lost, at the Technical Support Center (TSC) and the Control Room (CR). If the dose exceeds 5.0 rem when containment sprays are lost at the TSC or the CR then an AST ACE event is said to occur.

1 Sump Failure Frequency for a Given Time Threshold

The dose at the Technical Support Center (TSC) and the Control Room (CR) depends on how long the containment spray system (CSS) operates after a loss of coolant accident (LOCA). We refer to [4] for such doses including a detailed description of how they are calculated and their applicability to an AST evaluation. If required to operate following a LOCA, each CSS pump train would pull water through its sump that may fail due to filter plugging. At the time the first sump fails, we assume all other trains of CSS fail. And, we define an alternate source term acceptance criteria exceedance (AST ACE) event as a sump failure that occurs before the dose drops below 5.0 rem. For each size of a LOCA—small, medium, and large—and each pump state, we use output from the CASA Grande simulation model to estimate the conditional probability of a sump failure up to a given point in time, conditioned on that LOCA size and pump state. Then, the frequency of a sump failure event, as a function of time, can be calculated using the frequency of a LOCA of that size, multiplied by the joint probability of being in a pump state and having a sump failure occur by that time, summed over all pump states and LOCA sizes. Note that we only attribute the AST ACE event to GSI-191 if the pump state has at least two containment spray pumps initially available.

In this section we restrict attention to estimating the frequency with which we observe GSI-191 sump failures as a function of time after a LOCA. In Section 2 we estimate dose as a function of the time at which the CSS is lost. Section 3 combines these two calculations to estimate: (i) the frequency with which AST ACE events occur that are attributable to GSI-191, and (ii) the fraction of GSI-191 sump failures that lead to an AST ACE event. We begin formalizing our calculations as follows.

Indices and Sets:

$k = 1, \ldots, N$	index for set of pump states
$K \subset \{1, ..., N\}$	subset of pump states for which at least two containment sprays are available; i.e., K consists of pump state cases from Table 2.2.11 of Volume 3 [2] in which the "Working CS Pumps" column entry is at least 2

Events:

SL	small LOCA
ML	medium LOCA
LL	large LOCA
PS_k	pumps in state k
$\mathcal{S}$	sump failure

Parameters:

f_{LOCA}	frequency of a LOCA event, LOCA = LL, ML, SL (events/CY)
t	index of time elapsed from LOCA event (minutes)
$f_S(t)$	frequency of sump failure, by time t, for pump states indexed by K (events/CY)

Random Variable:

T	time elapsed between LOCA and sump failure

We calculate the frequency of a sump failure by time t for pump states in which at least two containment sprays are initially available, $f_S(t)$, by equation (1):

$$f_S(t) = \left[f_{LL} \cdot \sum_{k \in K} \mathbb{P}(PS_k) \cdot \mathbb{P}(T \leq t | PS_k, LL) + \right. \quad (1a)$$

$$f_{ML} \cdot \sum_{k \in K} \mathbb{P}(PS_k) \cdot \mathbb{P}(T \leq t | PS_k, ML) + \quad (1b)$$

$$\left. f_{SL} \cdot \sum_{k \in K} \mathbb{P}(PS_k) \cdot \mathbb{P}(T \leq t | PS_k, SL) \right]. \quad (1c)$$

We obtain f_{LL}, f_{ML}, and f_{SL} from the "GSI-191 PRA" column of Table 4-1 of Volume 2 [1]. We derive $\mathbb{P}(PS_k)$ from Table 2.2.11 of Volume 3 [2]. Simulation output from CASA Grande yields estimates of $\mathbb{P}(T \leq t|PS_k, LL)$, $\mathbb{P}(T \leq t|PS_k, ML)$, and $\mathbb{P}(T \leq t|PS_k, SL)$ for each LOCA category. Figure 1 displays the conditional cumulative distribution function (cdf), $\mathbb{P}(T \leq t|PS_k, LL)$, for several pump states, including the bounding pump states used in the analysis of Volumes 2 and 3 (see [1, 2]). However, for the analysis we report here, we do not use bounding pump states. Rather, we use output from CASA Grande for *all* pump states in which at least two containment sprays are available. For the simulation results we have from CASA Grande, we observe no sump failures after a small or medium LOCA event; i.e., $\mathbb{P}(T \leq t|PS_k, SL) = \mathbb{P}(T \leq t|PS_k, ML) = 0 \ \forall t, k \in K$. Hence, the only contribution to $f_S(t)$ in equation (1) is from the large LOCA term in equation (1a).

By estimating the conditional cdf for each pump state in which a sump failure would be attributable to GSI-191 (i.e., those pump states indexed by K, in which at least two containment sprays are available), we can apply equation (1) to estimate the frequency of a sump failure, for each time threshold t. The results are shown in Figure 2.

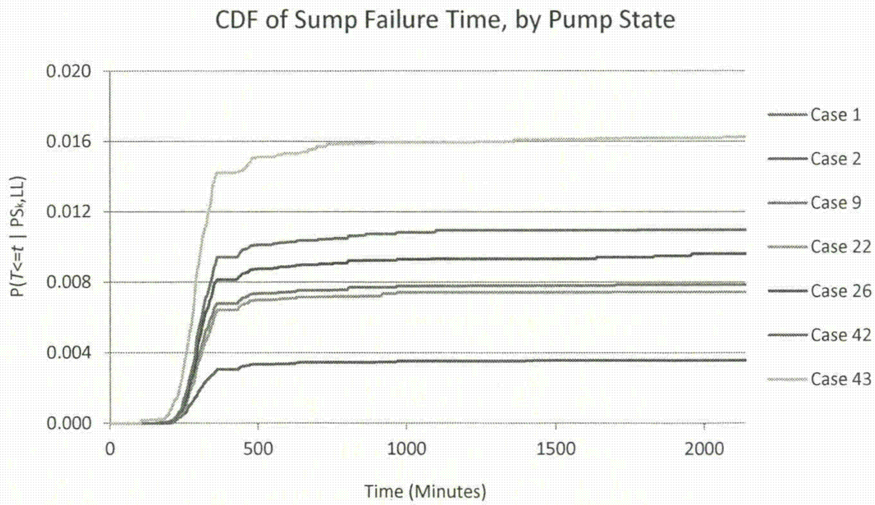

Figure 1: Conditional cumulative distribution function of sump failure for time elapsed from a large LOCA event, for seven example pump states. No sump failures occur after a small or medium LOCA event in CASA Grande output.

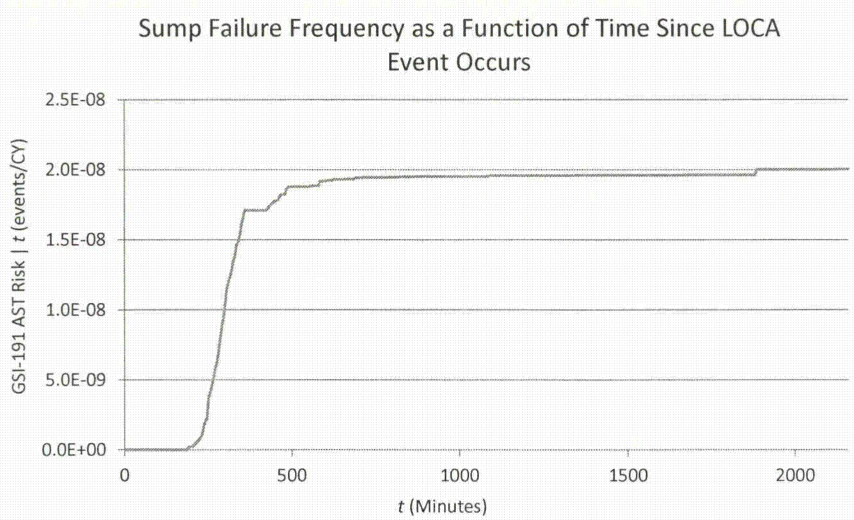

Figure 2: Estimated frequency (events/CY) of a sump failure for time threshold t.

2 Determining the Time Threshold for an AST ACE Event

We find an appropriate time threshold t for operation of the CSS after which the dose drops below 5.0 rem. By using conservative engineering calculations for dose data as a function of time at the TSC and the CR from [4], we fit an exponential function to dose with respect to CSS operation time, where our exponential function has the following form:

$$D(t) = Ae^{-Bt} + C. \tag{2}$$

Table 1: The first three columns contain CR and TSC dose data from engineering calculations [4]. The first column indicates the time (hours) since the LOCA event occurred. The second and third columns indicate the CR dose and the TSC dose (rem). Thus, if the spray pumps fail at time 4.000 hours, the CR dose is 4.760 rem and the TSC dose is 5.040 rem, according to these data. Columns four and five give the same values according to the fitted exponential functions. The final two columns indicate the squared error, with the bold values at the bottom indicating the sum of squared errors (SSE).

Time	CR Dose	TSC Dose	CR Fit	TSC Fit	CR SSE	TSC SSE
2.185	6.700	6.330	6.699	6.330	1.82E-07	1.00E-09
4.000	4.760	5.040	4.761	5.040	8.82E-07	1.80E-07
4.250	4.620	4.950	4.622	4.950	3.81E-06	2.49E-08
5.000	4.310	4.750	4.309	4.749	1.14E-06	1.46E-06
6.500	3.980	4.540	3.978	4.540	4.43E-06	6.18E-08
7.600	3.870	4.470	3.866	4.472	1.23E-05	3.80E-06
10.000	3.770	4.420	3.774	4.417	1.48E-05	9.83E-06
15.000	3.750	4.400	3.746	4.401	2.00E-05	9.58E-07
16.000	3.740	4.400	3.745	4.401	2.33E-05	3.78E-07
					8.08E-05	**1.67E-05**

We determine the unknown parameters A, B, and C in equation (2) by minimizing the sum of squared deviations between the given data points and the estimates of those data points provided by the fit exponential curves. The first three columns of Table 1 present the dose data used for the fitting procedure. In order to determine the best parameter values, we fit the exponential function given in equation (3) to all nine data points for both time series. Equation (3) gives the fit equation for the Control Room, and equation (4) gives the fit equation for the Technical Support Center:

$$D_{CR}(t) = 10.676655 \cdot e^{-0.5878029t} + 3.744 \tag{3}$$

$$D_{TSC}(t) = 7.283738 \cdot e^{-0.6078874t} + 4.400. \tag{4}$$

The fourth and fifth columns in Table 1 give the values of equations (3) and (4) at the times in the first column, and the final two columns give the squared deviations between each data point and the fit equation. Figure 3 displays the dose as a function of the time the CSS operates (in hours).

An AST ACE event is said to occur if a sump failure occurs, and hence we lose containment sprays, at a time when dose is 5.0 rem or more in either the CR or the TSC. We can use equation (2) to solve

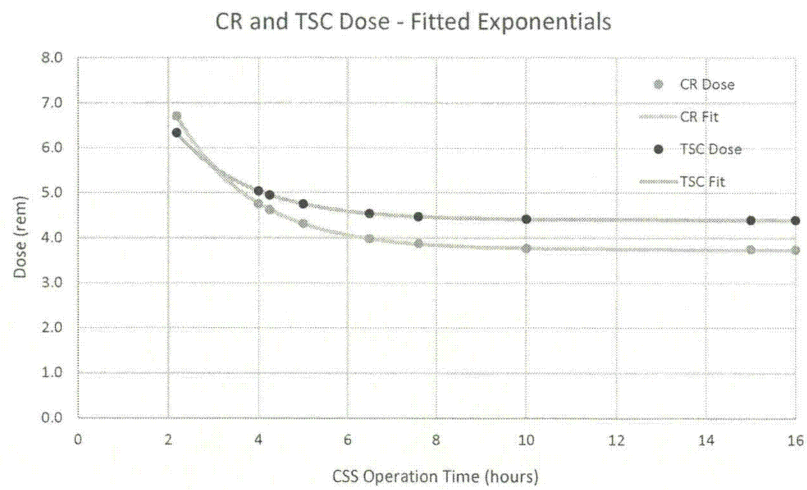

Figure 3: Fit exponential curves for the dose as a function of the time the CSS operates in the Control Room and the Technical Support Center.

for the time at which the CR and TSC curves reach a dose of 5.0 rem as shown in equation (5):

$$t = B^{-1} \cdot \ln\left(\frac{5.0 - C}{A}\right) \tag{5a}$$

$$t_{CR} = -0.5878029^{-1} \cdot \ln\left(\frac{5.0 - 3.744}{10.676655}\right) = 3.641 \text{ hours} = 218.4 \text{ minutes} \tag{5b}$$

$$t_{TSC} = -0.6078874^{-1} \cdot \ln\left(\frac{5.0 - 4.400}{7.283738}\right) = 4.107 \text{ hours} = 246.4 \text{ minutes.} \tag{5c}$$

Thus, an AST ACE event is said to occur in the Control Room if the sump fails at 218.4 minutes or earlier after a LOCA, and an AST ACE event is said to occur in the Technical Support Center if the sump fails at 246.4 minutes or earlier after a LOCA. Because we require both the CR and the TSC to have dose levels below 5.0 rem, we record an AST ACE event in the simulation model if we observe a sump failure by 246.4 minutes after a LOCA event.

3 Estimate of AST ACE Event Frequency

We see from Figure 2 that if the threshold t is large (i.e., we assume that the dose exceeds 5.0 rem for large values of t), that the asymptote of $f_S(t)$ approaches 2.004E-8 sump failure events per calendar year. However, because the CSS is operational for the requisite 246.4 minutes in most cases for the dose to drop below the 5.0 rem limit in both the Control Room and Technical Support Center, we can see from Figure 2 that the frequency (value of the y-axis at an x-axis value of 246.4 minutes) is instead $f_S(246.4)$ =3.724E-9 events per calendar year. Thus, the Emergency Core Cooling System works well

enough that $\frac{3.724E-9}{2.004E-8} \approx 18.6\%$ of the GSI-191 sump failures, when at least two containment sprays are initially available, lead to an AST ACE event.

4 Estimate of Initial Dose

In order to gain perspective for the values reported in Table 1, which are based on the engineering calculations in [4], we review historical leakage data from STPNOC. The total containment leakage is continually updated per the STPNOC Local Leakage Program [3], and results from containment penetration test measurements are recorded. A query of the results for both STPNOC Units from September 2002 to December 2013 (approximately 700 values) was analyzed to understand the variability and magnitude of the values, and the results are summarized in the box plots of Figure 4. The maximum measured value between both units in that time frame was 106,800 sccm (standard cubic centimeters per minute), approximately the same as two standard deviations above the mean rate of the data set. The containment leak rate used in the calculations discussed in Section 2 is 199,633 sccm, a factor of 1.87 larger than this maximum historical value. We note that this value of 199,633 sccm is STP's Technical Specification limit (see page A2 of [4]).

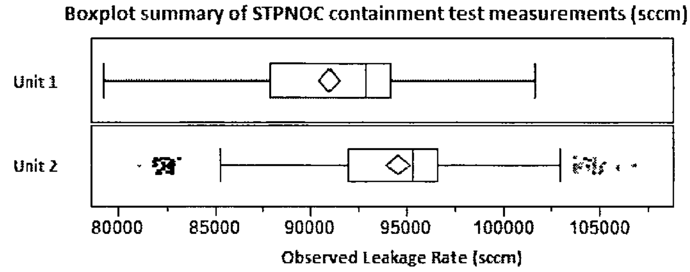

Figure 4: Boxplots of containment penetration test measurements from both STPNOC units. The threshold for an AST ACE event is a factor of 1.87 larger than the maximum observation across both units.

References

[1] Wakefield, D. and D. Johnson (2013, October). South Texas Project Risk-Informed GSI-191 Evaluation, Volume 2, Probabilistic Risk Analysis: Determination of Change in Core Damage Frequency and Large Early Release Frequency Due to GSI-191 Issues. Technical report, STPRIGSI191-VO2, Revision 2, ABSG Consulting Inc.

[2] Letellier, B., T. Sande, and G. Zigler (2013, October). South Texas Project Risk-Informed GSI-191 Evaluation, Volume 3, CASA Grande Analysis. Technical report, STP-RIGSI191-V03, Revision 2.

[3] C. Bradshaw and R. Stark, "Local Leakage Rate Test Calculations, Guidelines, and Program," STPNOC Procedure 0PSP11-ZA-0005, Revision 20, October 11, 2011.

[4] "Control Room, TSC, and Offsite LOCA Radiation Doses", STPNOC Engineering Calculation NC6013, Revision 17, 2014.