SPENT FUEL POOL
PSA

Reference: PSA-R-T15-01
Alternative Reference: FA-0072
Revision: 9

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GLOSSARY

Abbreviation	Description
AMAD	Activity Median Aerodynamic Diameter
ASME	American Society of Mechanical Engineers
BE	Basic Event
BNL	Brookhaven National Laboratory
CC	Cask Component
CCF	Common Cause Failure
CNS	Council for Nuclear Safety
EDG	Emergency Diesel Generator
EPRI	Electric Power Research Institute
FA	Fuel Assembly
FC	Fractional Contribution
FD	Fuel Damage
FV	Fussel-Vesely Importance
HD	High Dependency
HEP	Human Error Probability
HRA	Human Reliability Analysis
IEC	Conditional Initiating Event Frequency
IEF	Initiating Event Frequency
ISLOCA	Interconnected System Loss of Coolant Accident
JPD	Fire Fighting Water Distribution System
JPI	Nuclear Island Fire Protection
JPP	Fire Fighting Water Supply
JPS	Mobile Fire Fighting System
LD	Low Dependency
LERF	Large Early Release Fraction
LOCA	Loss of Cooling Accident
LOSP	Loss of Off-Site Power
MCS	Minimal Cut Set
MD	Medium Dependency
NAAS	Nuclear Accident Analysis Section
NM	Normal Mode
NNR	National Nuclear Regulator
NPSH	Net Possitive Suction Head
OBE	Operating Base Earthquake
OM	Outage Mode
OTS	Operating Technical Specifications
PAZ	Precautionary Action Zone
POS	Plant Operating State
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PTR	Reactor Cavity and Spent Fuel Pit Cooling System
PWRs	Pressurised Water Reactors
RDF	Risk Decrease Factor
RIF	Risk Increase Factor
RRA	Residual Heat Removal

RRI	Component Cooling System
RTD	Resistance Temperature Detector
RWST	Refuelling Water Storage Tank
SAMG	Severe Accident Management Guideline
SAR	Instrument Compressed Air Distribution System
SBO	Station Blackout
SEC	Essential Service Water System
SED	Demineralised Water Distribution System
SFD	Spent Fuel Damage
SFP	Spent Fuel Pool
SSE	Safe Shutdown Earthquake
TC	Transfer Compartment
TPU	Thermal Power Uprate
UPZ	Urgent Protective Action Planning Zone
USQ	Unresolved Safety Question

1 INTRODUCTION

1.1 OBJECTIVE

The objective of this analysis is, firstly, to determine the frequency of Spent Fuel Damage (SFD) of the Koeberg Spent Fuel Pool (SFP) using Probabilistic Safety Assessment (PSA) techniques and considering the impact of the Steam Generator Replacement (SGR) project. In this analysis initiating events that lead to spent fuel damage were identified and the frequency of SFD quantified using detailed event trees developed from fault trees. The fault trees in turn were developed through component data analysis and Human Reliability Analysis (HRA).

The acceptance criterion for Spent Fuel Damage is 1.00E-07 per year [Ref. 31] as this is similar to the Large Early Release (LERF) criteria used for reactor accidents.

Secondly, the site personnel and public radiological risk associated with the initiating events is determined and compared against the National Nuclear Regulator (NNR) Licensing Criteria [Ref. 2], presented in Table 1.1.

Table 1.1: NNR Licensing Criteria For Plant Personnel And Public Risk

PERSONNEL RISK	ACCIDENTS
Average	1.00E-05 Fatalities /Person/ Year
Peak	5.00E-05 Fatalities / Year
PUBLIC RISK	**ACCIDENTS**
Average	1.00E-08 Fatalities / Person/Year
Peak	5.00E-06 Fatalities / Year

1.2 SCOPE

In this study, initiating events that lead to SFD were identified and their frequencies quantified. These initiating events include loss of SFP cooling events, loss of inventory from the SFP and criticality accidents.

Event tree sequences were grouped into consequence states. A consequence state groups together event tree sequences with the same end state, thereby defining a top event level in the model. The following consequence states arising from the initiating events are defined:

- OK – Accident successfully mitigated. This consequence state comprises all states where spent fuel damage has not occurred and either Reactor Cavity and Spent Fuel Pit Cooling System (PTR) cooling has been re-established or make-up to the SFP has been established.
- BOIL – Heat-up of SFP to 100°C. No Fuel Damage has occurred. Off site radiological releases are minor and not considered in the determination of

public doses since the doses will be below 1 mSv and no health impact is envisaged.

- BLACKOUT – SFP Blackout. This consequence state was created in order to provide the transfer from the Loss of Off-Site Power (LOSP) event tree to the BLACKOUT event tree.
- FD – spent fuel damage due to fuel uncovery, which is assumed to occur when the level of the spent fuel pool is 9.85 m, and loss of cooling. Fuel Damage (FD) is the only consequence state considered for quantification.

It should be noted that external events such as seismic activity and aircraft crash are not considered in this document.

The scope of this PSA also includes an analysis of fission product inventory and release. This includes an analysis of the public and site personnel risks associated with the operation of the SFP.

1.3 IDENTIFICATION OF INITIATING EVENTS

Accident sequence initiating events are those events that disrupt normal SFP conditions. Numerous initiating events have been catalogued in previous PSAs and analyses. A systematic screening of the initiating events has been performed [Ref. 3]. A number of initiating events leading to spent fuel damage were identified and selected for further analysis. These initiating events fall into two main categories: loss of SFP cooling and loss of SFP inventory. The initiating events categories are listed below with corresponding initiating events:

Loss of PTR cooling:

- Loss of Component Cooling System (RRI) / Essential Service Water System (SEC) cooling
- PTR system failures
- Loss of Off-Site Power (LOSP) and BLACKOUT

Loss of SFP inventory:

- PTR pipe ruptures
- Door seal failure
- Failure of valves interfacing with the PTR system (flow diversions)

SFP Criticality:

- Boron Dilution
- Multiple misplacement of fresh assemblies

Criticality events leading to spent fuel damage have been analysed [Ref. 32], and this was after the installation of the 3rd train of PTR and therefore do not require revision.

Loss of PTR inventory due to a cask drop and subsequent SFP liner failure has been analysed in the Risk Assessment of Additional Metal Casks [Ref. 27]. This accident has not been included in this report as cask drops in the spent fuel building can only occur during cask movements. Normally cask movements occur when old fuel is loaded into the cask. The only other time casks are moved to and from the spent fuel building is in the case of a seal leak on a cask, when the seal requires replacement. However, this event rarely occurs and therefore any FD frequency attributed to this event would be an instantaneous frequency and not valid outside of a cask movement.

2 METHODOLOGY

2.1 STANDARDS USED

The requirements of NNR RD-0024 shall be met. Where NNR RD-0024 does not give instruction, the American Society of Mechanical Engineers (ASME) Probabilistic Risk Assessment (PRA) standards will be used as guides in the development of the PRA with the intent that the PRA should meet "Capability Category II" in areas impacting risk informed decisions.

The applicable ASME standards are:

- ASME/ANS RA-Sa–2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications" [Ref. 48];
- ANSI/ANS-58.22 (2009), "Low Power and Shutdown PRA Methodology, Draft" [Ref. 49];
- ANS/ASME-58.24 (2010), "Severe Accident Progression and Radiological Release (Level 2) PRA Methodology to Support Nuclear Installation Applications, Draft" [Ref. 50]; and
- ANS/ASME-58.25 (2010), "Radiological Accident Offsite Consequence Analysis (Level 3 PRA) to Support Nuclear Installation Applications, Draft" [Ref. 51].

2.2 ANALYSIS STEPS

This PSA study is comprised of several steps:

1. **Obtain Plant Specific SFP Information:** Plant specific information is necessary in order to develop the SFP model. Information was gathered for the SFP and its supporting systems regarding their operation, interfaces, maintenance requirements and design. Information was also needed regarding the radioactive inventory in the SFP. This information was obtained from various documents including system descriptions, operating and incident procedures, technical specifications as well as previous SFP PSA's. Additional information was obtained from discussions with plant personnel.

2. **Initiating Event Frequencies:** In this step initiating event frequencies were obtained for each initiating event. These initiating event frequencies were used both to determine the public and site personnel risk and to determine the frequency of fuel damage in the pool.

3. **Accident Sequence Modelling:** Accident sequence event trees identify the accident sequence paths resulting in spent fuel damage for each initiating

event. An accident sequence is the unique set of systemic responses, either successful or unsuccessful, to an initiating event. To calculate the frequency of each accident sequence a systematic method was used to identify and quantify all the ways that each accident sequence event can fail. Event tree models were constructed using the ***RISKSPECTRUM*** software.

4. **Data Analysis:** In order to construct event tree models data is required for basic events in each fault tree. These basic events involve hardware failures and component unavailability. Dependant failures (Common Cause Failures (CCFs)) of components and systems must be quantified. Failure probabilities for each mode of hardware failure and for test and maintenance failures were developed from the collection and analysis of plant-specific and industry wide data.

5. **Calculation of System and Operator Action Probabilities:** One of the assumptions of a PSA is that sufficiently accurate quantitative estimates of human performance can be made. However, since it is difficult to predict human behaviour and since no large collections of data quantifying human behaviour exist, these human error estimates have a substantial uncertainty. Consequently, the estimates for Human Error Probabilities (HEPs) and response times tend to be conservative.

   Only human actions related to erroneous performance of assigned steps were considered. Deliberate acts of sabotage were not modelled. It is assumed that all plant personnel are licensed, qualified and experienced. HEPs were calculated by using the Electric Power Research Institute (EPRI) HRA Calculator, following SPAR-H methodology. The HEPs together with the component reliability data was used to quantify the fault trees required to develop the necessary event trees for accurate accident sequence modelling.

   The time to diagnose accident scenario and time to perform operator actions for the new accident sequences was determined by expert opinion.

6. **Accident Sequence Quantification:** In this step the frequencies of the accident sequences leading to the consequence states given in Section 1.2 were quantified using the ***RISKSPECTRUM*** generated model. The dominant contributors in terms of initiating event frequencies, operator action failures or component failures were identified. The frequency of the fuel damage consequence state was determined and compared against the acceptance criteria. Additionally, importance and sensitivity analyses were performed on the spent fuel damage consequence state. Uncertainties were not calculated.

7. **Public and Site Personnel Risks:** The peak and average public and site personnel risks were assessed using the methodology outlined in Chapter 2. The site personnel and public risks were analysed using ***PC COSYMA***, as outlined in the procedure described in Site Personnel Risk Methodology [Ref. 6].

2.3 EVENT TIMING

A SFP loss of cooling accident can result in the SFP water boiling and hence the loss of SFP inventory through evaporation. Should boiling continue it would lead to the eventual uncovery of the fuel assemblies. However, as the SFP contains a large volume of water, which has a large thermal inertia, a long time interval can be expected prior to the onset of boiling and subsequent fuel uncovery. This extensive margin allows for conservative assumptions to be made in the analysis and still demonstrates that the results are within licensing criteria. In this section the time to boil and the time to fuel uncovery are determined using maximum pool heat loads (for normal and outage modes).

2.3.1 Assumptions

The following assumptions have been made to simplify the calculations required for event timing:

- The thermal properties of borated water correspond closely with that of pure water, therefore, the thermal properties of pure water are used in these calculations;
- The specific heat capacity for water and the other pool elements remains constant over the range of temperatures considered (50°C to 100°C); and
- Ideal mixing takes place in the water in the pool and in the atmospheres of the room.

2.3.2 Times to Heat-Up

The calculations determined the time to heat the SFP inventory from 50°C (I-PTR starting temperature) to 100°C . Also determined is the time to boil off the SFP inventory at a temperature of 100°C from various different levels to the 17 m level (loss of PTR suction) and to the 9.85 m level (it is assumed that Spent Fuel Damage (SFD) occurs when the SFP inventory level is 9.85 m, covering only ½ of the fuel assemblies). Results for timing calculations are summarised in Table 2.2. These times are used in the HRA to determine the HEP values for the various mitigating actions required by the operators.

The following reference data was used in the calculations:

- Density of water = 986 kg/m^3;
- Heat Capacity of 1 Fuel Element = 162.4 kJ/°C;
- Heat Capacity of Racks = 3830 kJ/m^3°C;
- Heat Capacity of water = 4.179 kJ/kg.K;
- Heat of Evaporation = 2 257 kJ/kg;
- Number of spent fuel assemblies in the pool = 1538;
- Pool water volume at 19.3 m level = 1077 m^3;
- Volume of one rack = 20 m^3; and
- Volume of fuel + racks + equipment = 166 m^3.

Although fuel storage rack uncovery occurs at 12.96 m (as depicted on system flow diagram KBA 0117 PTR 500) it should be noted that the spent fuel pool level at the top of the assemblies is lower than 12.96 m (12.2 m, according to KGG-SPT [Ref. 59].

The HEPs were calculated with SFD occurring when the level of water in the pool is 9.85 m, covering only ½ of the fuel assemblies. This assumption is based on the presentation in Appendix B (see slide 19). Damage will only occur once a considerable amount of the pellets are relying on steam cooling.

The times were calculated for the following two modes of operation:

- Normal Mode (NM) – This mode represents the maximum SFP conditions during normal plant operation. The heat load used was a maximum value – 4.06 MW (after implementation of PTR 3rd train). During an 18 month fuel cycle, the plant is expected to be in this mode for 17.0 months (94.2% of the fuel cycle [Ref. 45]).
- Outage Mode (OM) – This mode represents the situation where fuel unloading has just been completed. The heat load is assumed to take its maximum value of 11.5 MW (after implementation of PTR 3rd train). During an 18 month fuel cycle the plant is expected to be in this mode for 1.04 month (5.80% of the fuel cycle [Ref. 45]).

Apart from heat loads, other differences between NM and OM exist and are detailed in Table 2.1.

Given the heat removal capabilities of the PTR system and its additional cooling loop, the decay heat load during OM will not change following implementation of SGR. However, the decay heat load in the SFP during NM will decrease, mainly because the heat load calculated in the Siemens report [Ref. 57] for the pre-SGR configuration used a conservative enrichment of 5%, while the calculation for the SGR equilibrium core [Ref. 58] used the actual enrichment of 4.6%.

The post-SGR decay heat load in the SFP for NM is 3.45 MW [Ref. 58]. For the Level 1 and 2 PSA aspects of this study the post-SGR heat load is bounded by the 4.06 MW heat load of the pre-SGR configuration. This change will thus not have any negative effect on the SFP heat-up rate or heat-up and boil-off times. The results of SFP heat-up and boil-off times are presented in Figure 2.1 and Table 2.2. As discussed, these results remained unchanged when compared to the pre-SGR case.

Table 2.1: Differences Between Normal and Outage Modes

Normal Mode	Outage Mode
4.06 MW heat load	11.5 MW heat load
1 PTR, RRI, SEC pump in service	2 PTR, 2 RRI and 2 SEC pumps in service
1 PTR heat exchanger in service	3 PTR heat exchangers in service
Train A and B electrical boards available.	Train A (or B) electrical board not in service. Train A (or B) PTR pump supplied by other Unit Train B electrical board.

The SFP heat load is presented in the figure below [Ref. 9].

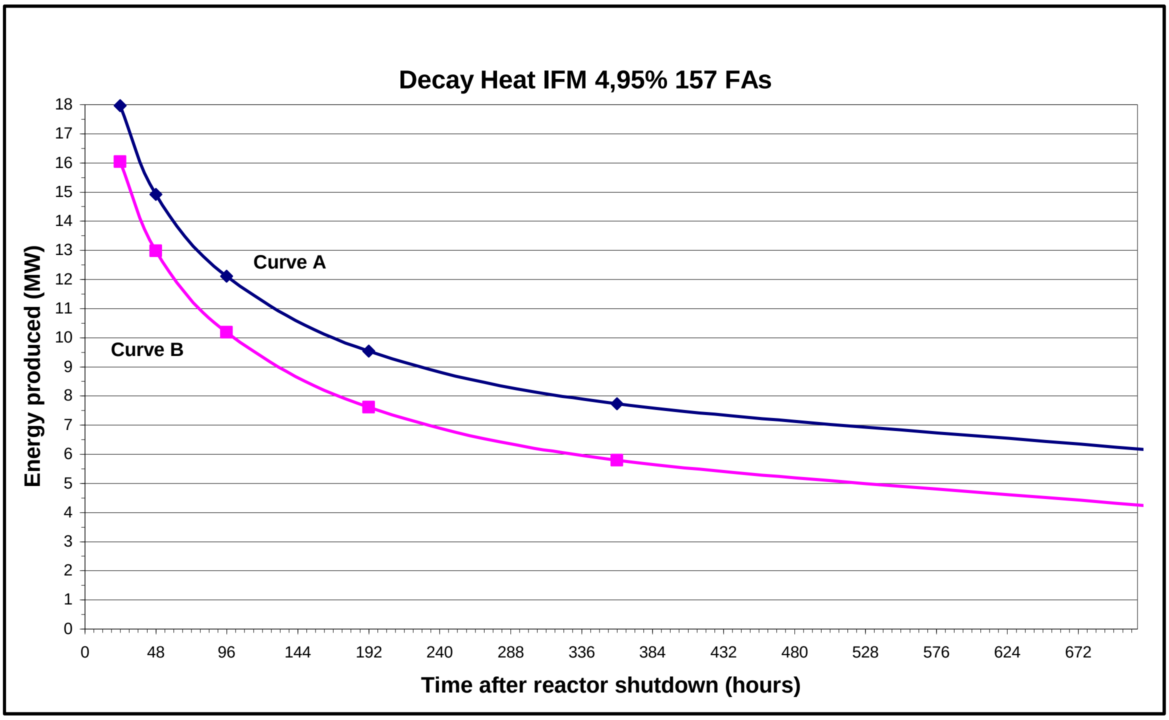


Figure 2.1: Reactor core decay heat (157 Fuel Assemblies (FAs)) as a function of time after reactor shutdown (curve B). Note that curve A represents the total heat in the pool due to the unloaded core (157 FAs) and the fuel assemblies already present in the pool. It is assumed that the pool is filled with fuel.

Table 2.2: SFP Heat-up and Boil-off Times

1.97 MW									
SFP level [m]	**Total SFP heat capacity [kJ/°C]**	**HUR for 1.97 MW [°C/h]**	**Time from 50°C to 100°C [h]**	**BOR [kg/h]**	**Boil-off Time to 17m [h]**	**Boil-off Time to 15.5m [h]**	**Boil-off Time to 13.25m [h]**	**Boil-off Time to 12.2m [h] (Fuel Uncovery)**	**Boil-off Time to 9.85m [h] (Fuel Damage)**
19.3	4902023	1.45	34.6	3142.2	77.2	127.6	203.1	231.1	291.2
17	3887970	1.82	27.4			50.4	125.9	153.9	214.0
15.5	3226630	2.20	22.7				75.5	103.5	163.7
13.25	2234621	3.17	15.8					28.0	88.1
12.2	1802272	3.94	12.7						52.9
9.85	860755	8.24	6.1						
4.06 MW									
SFP level [m]	**Total SFP heat capacity [kJ/°C]**	**HUR for 4.06 MW [°C/h]**	**Time from 50°C to 100°C [h]**	**BOR [kg/h]**	**Boil-off Time to 17m [h]**	**Boil-off Time to 15.5m [h]**	**Boil-off Time to 13.25m [h]**	**Boil-off Time to 12.2m [h] (Fuel Uncovery)**	**Boil-off Time to 9.85m [h] (Fuel Damage)**
19.3	4902023	2.98	16.8	6475.9	37.5	61.9	98.6	112.2	141.3
17	3887970	3.76	13.3			24.4	61.1	74.7	103.8
15.5	3226630	4.53	11.0				36.7	50.2	79.4
13.25	2234621	6.54	7.6					13.6	42.8
12.2	1802272	8.11	6.2						25.6
9.85	860755	16.98	2.9						

8.25 MW									
SFP level [m]	**Total SFP heat capacity [kJ/°C]**	**HUR for 8.25 MW [°C/h]**	**Time from 50°C to 100°C [h]**	**BOR [kg/h]**	**Boil-off Time to 17m [h]**	**Boil-off Time to 15.5m [h]**	**Boil-off Time to 13.25m [h]**	**Boil-off Time to 12.2m [h] (Fuel Uncovery)**	**Boil-off Time to 9.85m [h] (Fuel Damage)**
19.3	4902023	6.06	8.3	13159.1	18.4	30.5	48.5	55.2	69.5
17	3887970	7.64	6.5			12.0	30.1	36.8	51.1
15.5	3226630	9.20	5.4				18.0	24.7	39.1
13.25	2234621	13.29	3.8					6.7	21.0
12.2	1802272	16.48	3.0						12.6
9.85	860755	34.50	1.4						

11.5 MW									
SFP level [m]	**Total SFP heat capacity [kJ/°C]**	**HUR for 11.5 MW [°C/h]**	**Time from 50°C to 100°C [h]**	**BOR [kg/h]**	**Boil-off Time to 17m [h]**	**Boil-off Time to 15.5m [h]**	**Boil-off Time to 13.25m [h]**	**Boil-off Time to 12.2m [h] (Fuel Uncovery)**	**Boil-off Time to 9.85m [h] (Fuel Damage)**
19.3	4902023	8.45	5.9	18342.9	13.2	21.9	34.8	39.6	49.9
17	3887970	10.65	4.7			8.6	21.6	26.4	36.7
15.5	3226630	12.83	3.9				12.9	17.7	28.0
13.25	2234621	18.53	2.7					4.8	15.1
12.2	1802272	22.97	2.2						9.1
9.85	860755	48.10	1.0						

2.4 IMPORTANCE MEASURES

The importance measures used in this analysis are:

Fussel-Vesely Importance (FV)

The FV importance for basic events is calculated as follows:

For each basic event, the top event unavailability is calculated using only those Minimal Cut Sets (MCS) where the basic event is included. FV importance is the ratio between this unavailability and the nominal top event unavailability and is calculated as:

$$I^{FV}{}_{i} = \frac{Q_{TOP}\ (MCS\ including\ i)}{Q_{TOP}}$$

Risk Decrease Factor (RDF)

The unavailability of each basic event is set to Q = 0, i.e., the events are perfectly reliable. A new top event is calculated. This new, lower, result is identified as Q_{TOP} (Q_i = 0). RDF is calculated as:

$$I^{R}{}_{i} = \frac{Q_{TOP}}{Q_{TOP}\ (Qi = 0)}$$

Fractional Contribution (RC)

The Fractional Contribution is:

$$I^{F}{}_{i} = 1 - \frac{1}{I^{R}{}_{i}}$$

Risk Increase Factor (RIF)

The unavailability for each basic event is set to Q = 1, i.e., events are definitely failed.

For each basic event, a new top event result is calculated. This new, higher result is identified as Q_{TOP} (Q_i = 1). RIF is calculated as:

$$I^{I}{}_{i} = \frac{Q_{TOP}(Q_i = 1)}{Q_{TOP}}$$

2.5 ASSUMPTIONS

2.5.1 Main Modelling Assumptions

The following assumptions were used in the SFP PSA model:

- For the purposes of ascertaining milestone times for the SFP from the onset of the initiating event to the point of fuel uncovery, the initial temperature of the SFP was assumed to be 50°C (I-PTR starting temperature).
- Make-up from the PTR system to SFP was not considered due to its limited capacity and because of Operating Technical Specifications (OTS) limitations.
- The initiating event frequency of door seal failure was quantified historically using only catastrophic pneumatic failure. Partial drain-downs following door seal failure with the cask-loading or transfer canal isolated leads to an equilibrium water level above the 15.5 m level and as such, were not considered.
- With respect to the cask loading and transfer canal, the KAA-721 [Ref. 44] state that both compartments must be full at least 70% of the time. There is an administrative prohibition that prevents having both compartments empty. Therefore, overheating and subsequent seal failure will not lead to a SFP level lower than the level of PTR suction.
- Although the seals are qualified for an operating temperature of 80°C [Ref. 1], it has been shown that the seals are able to withstand a temperature of 100°C [Ref. 10].
- The SFP heat removal capacity was increased by the modification of the PTR 3rd train. With the PTR 3rd train and one PTR pump and both heat exchangers in service, 11.5 MW of heat will be removed from the SFP during outage operation. Separately, the 3rd train will be able to remove 6 MW of heat load from the SFP. During normal operation, one pump and one heat exchanger are in service. This will aid in removing 4.06 MW of heat from the SFP. The design allows the 3rd train to replace an existing PTR train and thus perform a nuclear safety function. This modification also will provide the ability to re-supply PTR 001 PO and PTR 002 PO motors from the other unit.
- For the purposes of this Level 1 PSA analysis it is assumed that the decay heat in the SFP during normal operation is 4.06 MW. This is the maximum decay heat during the 17.0 months (94.2% of an 18 month fuel cycle). For the Level 3 PSA analysis the maximum decay heat of 4.06 MW was used in order to determine radioactive releases.
- The maximum heat to be removed during refuelling outage operation is 11.5 MW. In this case two pumps and three heat exchangers (PTR 001 PO or PTR 002 PO through PTR 001 RF and PTR 002 RF in parallel and PTR 006 PO through PTR 004 RF) are operated (SFP temperature < 50°C). However during outage operation, one pump and one heat exchanger are sufficient to prevent boiling when the decay heat in the pool is 11.5 MW. Thus the accident analysis success criterion is operation of one pump and one heat exchanger. See Appendix C.
- As the pump installed for the 3rd train is identical to PTR 001 and 002 PO, it was assumed that this pump and its motor are exposed to CCF modes.

- During normal plant operation:
  - PTR Train A is assumed to be in service with Train B on standby.
  - RRI Train A is assumed to be in service with Train B on standby.
  - SEC Train A is assumed to be in service with Train B on standby.
  - 48 VDC Train A and common relaying is supplied by LCA.
  - 48 VDC Train B relaying is supplied by LCB.
- Note that recovery of the four diesels and recovery of Acacia is not modelled in order to be consistent with the Level 1 PSA model. However, due to the long times available for recovery for SFP cooling these recoveries could be considered if deemed appropriate at a later stage.
- It should be noted that, due to limited data on grid recoveries, the existing data cannot be used to predict non-recovery probabilities for extrapolated times. Therefore, for those milestone times over 24 hours, the non-recovery probability is cut off at 3.9E-05. This assumption however should be noted as being conservative.

3 INITIATING EVENT ANALYSIS

In this section each initiating event is analysed and explained and an initiating event frequency determined. A time fraction is applied to the frequencies according to the time the SFP is in NM (17.0 months, i.e., 94.2% of a 18 month fuel cycle) or OM (1.04 month, i.e., 5.80% of a 18 month fuel cycle).

3.1 LOSS OF PTR COOLING EVENTS

The value of loss of PTR cooling (due to a PTR System Failure) conditional initiating event frequency for OM and NM was calculated as:

$$\mathbf{F_{PTRC} = F_{RRI/SEC} + F_{PTR}}$$

Where:

F_{PTRC} = Overall loss of PTR cooling due to a PTR system failure,
F_{PTR} = PTR System failures (including power supply failures),
$F_{RRI/SEC}$ = Failure of RRI and/or SEC.

Using the **3PTRREP2.RSD** ***RISKSPECTRUM*** model, Conditional Initiating Event Frequencies of 9.52E-04 per year for NM and 1.17E-02 per year for OM were obtained. IEFs for NM and OM were calculated as 8.97E-04 per year and 6.79E-04 per year, respectively. The Conditional Initiating Event Frequencies (IECs) and Initiating Event Frequencies (IEFs) for the Loss of SFP Cooling initiatng event are sumarised in Table 3.1.

Table 3.1: Loss of SFP Cooling

Initiator	Time Fraction	IEC (/y)	IEF (/y)
Loss of RRI/SEC (NM)	9.42E-01	2.31E-05	2.18E-05
PTR System Failure (NM)	9.42E-01	9.29E-04	8.75E-04
Loss of SFP Cooling (NM)	**9.42E-01**	**9.52E-04**	**8.97E-04**
Loss of RRI/SEC (OM)	5.80E-02	1.08E-02	6.26E-04
PTR System Failure (OM)	5.80E-02	9.35E-04	5.42E-05
Loss of SFP Cooling (OM)	**5.80E-02**	**1.17E-02**	**6.79E-04**

3.1.1 Loss of RRI/SEC Cooling

The total failure of RRI (on the affected and unaffected units) would fail the cooling function of PTR and cause the temperature of the SFP to increase, accelerating evaporation from the SFP and resulting in inventory loss. A loss of SEC will fail RRI, with the same result. It should be noted that the Residual Heat Removal (RRA) system is not considered in the Instrument Compressed Air Distribution System (SAR) as back-up to PTR and will therefore not be modelled in this analysis.

The conditional frequency of total loss of RRI/SEC, as obtained from “Koeberg Level 1 PSA Model” [Ref. 28] is 1.83E-04 per year. This gives an IEF of 1.72E-04 per year for NM and 1.06E-05 per year for OM.

A second method to obtain IEFs for loss of RRI/SEC has been performed [Ref. 12]. This method involved using the ***RISKSPECTRUM*** model, **3PTRREP2.RSD**, to quantify loss of RRI/SEC and mechanical failure of the PTR pumps. Separate fault trees were created for NM and OM. Using this model, Conditional Initiating Event Frequencies of 2.31E-05 per year for NM and 1.08E-02 per year for OM were obtained. IEFs for NM and OM were calculated as 2.18E-05 per year and 6.26E-04 per year, respectively.

Since the values calculated using the **3PTRREP2.RSD** ***RISKSPECTRUM*** model take into account the different plant configurations in the different modes, these values are more realistic and plant specific and therefore will be used in this analysis.

3.1.2 PTR System Failures

This initiating event considers a loss of cooling due to the loss of PTR flow if both pumps fail. Previous SFP analyses have considered loss of PTR cooling due to a PTR System Failure to include both loss of RRI/SEC and PTR system failures to be one event. In order to align the SFP PSA with the main model, these two events have been dealt with separately.

No plant specific failures have been reported for PTR system failures. However, in “A Probabilistic Risk Assessment of Spent Fuel Pool Boron Dilution Events at Koeberg Nuclear Power Station”, [Ref. 4], PTR system failure is estimated to be 1.51E-03 per year. This results in an IEF of 1.42E-03 per year for NM and 8.76E-05 per year for OM.

Comparatively, by using the **3PTRREP2.RSD** ***RISKSPECTRUM*** model, Conditional IEFs of 9.29E-04 and 9.35E-04 were obtained for NM and OM respectively. IEFs for NM and OM were calculated as 8.75E-04 per year and 5.42E-05 per year, respectively.

Again, since the **3PTRREP2.RSD** ***RISKSPECTRUM*** model was specifically designed to take into account plant configurations in the different modes the values obtained from the model will be used in this analysis.

3.2 LOSS OF SFP INVENTORY

3.2.1 PTR Pipe Ruptures

The PTR system pipes range from 12” to 4”. Random failures of PTR system pipes are rare events as it is a seismically qualified system and its operating temperature and pressure are relatively low.

The conditional initiating event frequency for PTR pipe ruptures for both OM and NM is 1.30E-08 per year [Refs. 29 and 30].

3.2.2 PTR Flow Diversion

During normal PTR cooling, the SFP inventory can be inadvertently diverted to the following interfacing systems:

- RRA – Residual Heat Removal System;
- RPE – Nuclear Island Vent and Drain System;
- SED – Demineralised Water Distribution System; and
- TES – Solid Waste Treatment System.

These diversions may occur through the misalignment of interfacing valves or their failure.

Two plant specific events from Table B.2-1 (events 17 and 18) given in [Ref. 4] are associated with valve mis-positioning. Using these events the conditional initiating event frequency of this initiator was calculated as:

$$F_{FD} = 2/(2 \times 28) = 3.57E\text{-}02 \text{ / year}$$

The IEF is therefore 3.36E-02 for NM and 2.07E-03 for OM.

3.2.3 Cask Drop Accidents

Cask drop accidents leading to Loss of SFP inventory and consequently SFD is analysed in the Risk Assessment of Additional Metal Casks [Ref. 27].

3.3 GATE SEAL FAILURE

The SFP has two pneumatically sealed gates that allow communication between the SFP and the transfer and cask-loading compartments. A failure of these gates would not result in fuel assembly uncovery as the top of the fuel assemblies is at a lower elevation than the bottom of the gates. Door failure could, however, uncover the PTR suction if the Cask Compartment (CC) is empty and the canal is open resulting in a loss of SFP cooling. This scenario could occur during normal operation and dry transfer runs, and therefore this initiating event is only valid in NM. There is no back-up for restoring the seals once they have failed, i.e., water loss to the CC or Transfer Compartment (TC) will follow and make-up to the SFP would be required.

There is actuarial data for SFP seal failures, leading to loss of SFP inventory [Ref. 4]. With one catastrophic event in 28 years of total operation of the two units a point estimate for the initiating event frequency of the TC seal (one of two seals) was calculated as:

$$F_{DSF} = 1/(2 \times 28) = 1.79E\text{-}02 \text{ / year}$$

This is included in fault tree IE_CDSF_\PTR_NM\1 as the basic event for historical failure with an "AND" gate for operator error leaving TC and CC empty or the drain valves open. From this fault tree a Conditional Initiating Event Frequency of 5.37E-03 per year was calculated. This results in an IEF of 5.06E-03 per year for NM.

3.4 LOSS OF OFF-SITE POWER (LOSP)

A loss of off-site power can lead to a loss of PTR cooling due to the failure of both the PTR and RRI/SEC pumps and motors. Following a LOSP with the failure of the unit to house load, the PTR and SAR are load shed prior to EDG (Emergency Diesel Generator) start. Operator action is required to connect the PTR to the on-site power supplies. On-site power supplies support the piston driven SAP compressors. In the short term the seals for the two doors from SFP to the transfer and SF cask compartments will remain inflated, as they are isolated from the SAP system.

The main action required would be to re-establish PTR cooling prior to reaching the door seal failure temperature or boiling. Should PTR cooling not be re-established, SFP make-up would be required. The Conditional Initiating Event Frequency of LOSP has been calculated to 4.50E-01 per year for NM and 1.54E+00 per year for OM [Ref. 13].

A loss of power followed by the failure to house load along with the failures of Acacia and the diesel generators to start and run results in a station blackout. In this scenario the focus lies with the recovery of power in order to re-establish PTR cooling and/or make-up prior to door seal failure, boiling or fuel uncovery. Blackout frequencies were calculated by quantifying the relevant LOSP event tree sequence.

3.5 SUMMARY OF INITIATING EVENT FREQUENCIES

Table 3.2 below gives a summary of the initiating event frequencies that are used in the SFP PSA model.

PAIA section 44 (2)a. Redacted information could jepoardise effectiveness of testing procedure if disclosed

PAIA section 44 (2)a.Redacted information could jepoardise effectiveness of testing procedure if disclosed

Table 3.2: Initiating Event Frequencies

Initiator	Time Fraction	IEC (/y)	IEF (/y)
Catastrophic Gate Failure (NM)	9.42E-01	5.37E-03	5.06E-03
Loss of SFP Cooling (NM)	9.42E-01	9.52E-04	8.97E-04
Loss of SFP Cooling (OM)	5.80E-02	1.17E-02	6.79E-04
Loss of SFP Inventory due to diversion (NM)	9.42E-01	3.57E-02	3.36E-02
Loss of SFP Inventory due to diversion (OM)	5.80E-02	3.57E-02	2.07E-03
Loss of SFP Inventory due to PTR Pipe Rupture (NM)	9.42E-01	1.30E-08	1.22E-08
Loss of SFP Inventory due to PTR Pipe Rupture (OM)	5.80E-02	1.30E-08	7.54E-10
LOSP (NM)	9.42E-01	4.50E-01	4.24E-01
LOSP (OM)	5.80E-02	1.54E+00	8.93E-02
Local Boron Dilution (NM) [Ref. 32]	9.42E-01	1.36E-04	1.28E-04
Local Boron Dilution (OM) [Ref. 32]	5.80E-02	2.30E-03	1.33E-04
Global Boron Dilution (NM) [Ref. 32]	9.42E-01	1.82E-05	1.71E-05
Global Boron Dilution (OM) [Ref. 32]	5.80E-02	3.09E-04	1.79E-05
Multiple misplacement of fresh assemblies (NM) [Ref. 46]	9.42E-01	4.52E-08	4.26E-08

4 ACCIDENT SEQUENCE MODELING (EVENT TREES)

In this section, event tree models developed for each initiating event are described. The event trees start with an initiating event. The BLACKOUT event trees start with a consequence which is transferred from the relevant LOSP event trees.

Event trees model the systems and operator actions required to mitigate the initiating event. The outcome of the event trees' accident sequence paths are consequence states. These consequence states are given in Chapter 1.2.

It should be noted that in previous SFP PSAs it was assumed that the gate seals had a 50% chance of failing if the SFP temperature exceeded 100°C. This required the function event "No gate seal failure at 100°C" for relevant events in Normal mode. As already discussed, it is now assumed that no seal failure occurs at above 100°C and therefore this function event has been removed.

A modification is now in place which allows operators to provide make-up from SED remotely. Previously make-up via SED was not considered above 80°C as it was assumed that the SFP was inaccessible for local activities. Similarly, following the onset of boiling it was assumed that make-up could only be achieved via JPP. Due to the modification, make-up can now also be provided via SED.

Note that criticality accidents are not described in detail in this study, but included in the results. Criticality accidents are discussed in [Ref. 32].

All the selected initiating events lead to a loss of SFP cooling, a loss of SFP inventory or both. The success criteria for a loss of cooling or inventory are generally:
- Recover PTR cooling prior to boiling or PTR suction uncovery;
- Make-up inventory prior to PTR suction uncovery; and
- Make-up inventory prior to fuel uncovery.

Initiating events that are further described in this report have been grouped into the following categories:
- Loss of PTR cooling;
- Loss of PTR inventory;
- LOSP; and
- Catastrophic Gate Seal Failure.

These categories are described in the following sections (Note that in the model, SFP event trees are denoted with "Y" as a prefix to their ID names. This is for ease of indentification).

4.1 LOSS OF SFP COOLING EVENT TREES

In this initiating event:

- RRI/SEC cooling is lost; or
- The running PTR train fails and one of the following occur:
  - the standby PTR train fails to start and run;
  - the standby PTR train is unavailable due to maintenance; or
  - the standby PTR train is being used as the RRA back-up during shutdown operations.

Event trees were created for NM and OM and consist of the following function events:

1. Loss of SFP Cooling Due to a PTR System Failure in NM and OM (YLOPC_\PTR\NM and YLOPC\RRI\PTR\OM)

The initiating event is the failure of the PTR system, whereby all trains are unavailable for SFP cooling.

2. Recovery of PTR System Before Boiling at 19.3 m (PTR\REC_BB_NM and PTR\REC_BB_OM)

It is desirable to recover PTR cooling prior to the onset of SFP boiling with the pneumatic seals intact. Success for this function event is that one PTR train is recovered along with RRI cooling to the recovered train's heat exchanger.

This function event is present to distinguish the consequence state BOIL. Boiling would not lead to significant spent fuel assembly damage and so any radioactive releases to the environment would be minor.

Success for this function event is defined as the recovery of PTR cooling to the SFP before SFP boiling.

3. No Gate Seal Failure During SFP Boiling (GATE SEAL)

This functional event is only used in the Normal Mode Event Tree. If the CC and the TC are full there is no loss of SFP inventory following seal failure. Seal failure is considered if the SFP temperature is above 100°C [Ref. 10] and the CC and TC are empty. If gate seal failure occurs it is assumed to be catastrophic with a consequent level drop to 13.25 m.

4. Recovery of PTR Cooling Before Loss of PTR Suction at 17 m
(PTR\REC_BS_NM and PTR\REC_BS_OM)

The PTR pumps must not be re-started with a level of less than 17.0 m in the SFP. With the suction of the PTR pumps located at the 15.5 m level in the SFP, the minimum level for starting a PTR pump will reduce the possibility of vortexing in the SFP and cavitation at the pump suction [Ref. 14].

Below this level PTR cooling cannot be restarted, therefore make-up is the only remaining option. The loss of inventory due to boiling causes the SFP level to drop from the 19.3m level to the 17m level in 37.5 hours in NM and 13.2 hours in OM, from the time cooling is lost.

Success for this function event is defined as the recovery of PTR cooling to the SFP before the 17 m level is reached.

5. Establish SED Make-up Before Fuel Damage
(SED\MU_BD_17_NM and SED\MU_BD_17_OM)

This event is initiated after boiling when the level in the SFP starts to drop.

The current plant design requires local actions at the SFP to line-up SED [Refs. 14 and 15] and local actions inside and outside the fuel building to line up the alternative JPP make-up paths [Refs. 14, 15 and 16]. These line-ups must be performed prior to the start of boiling.

If the SED line-up is established, demineralised water from this system is used for make-up to the spent fuel pit using the SED inlet (provided at level +20.00 m for washing the spent fuel storage cask). The flow rate from this system is via the 2½" connection on the SFP floor at 98 m^3/hr. SED is the preferred source for SFP make-up in the procedure [Refs. 14 and 15].

The source of SED water is from a single storage tank of 500 m^3 capacity. However, should the tank be drained to its low level, make-up is automatically provided to the tank and terminated on a high level.

Available time to establish SED make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of SED make-up to the SFP prior to fuel damage.

6. Establish JPP Make-up Before Fuel Damage from 17 m (JPP\MU_BD_17_NM and JPP\MU_BD_17_ OM)

Should SED be unavailable for make-up to the SFP, the operator is instructed to use the JPI/JPD/JPP systems [Refs. 14, 15 and 16]. The fire protection system draws from various other back-up systems such that an essentially infinite water supply is available. The path to the SFP via the fire hose station outside the spent fuel pit area can provide approximately 100 m^3/hr. At this flow rate it would take 15 minutes to increase the SFP level from its low to its high alarm setpoints.

Available time to establish JPP make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPP make-up to the SFP prior to fuel uncovery.

7. Establish JPS Make-up Before Fuel Damage from 17 m
(JPS\MU_BD_17_NM and JPS\MU_BD_17_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16]. This event is considered from the time the 17 m level is reached.

Available time to establish JPS make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

4.2 LOSS OF PTR INVENTORY DUE TO PTR PIPE RUPTURE EVENT TREES

This initiating event considers the loss of SFP inventory due to pipe breaks in the PTR system.

Pipe breaks in PTR will result in the loss of SFP inventory which must be made up once the low SFP level alarm setpoint is reached. The pipe break size may range anywhere from 30 cm to 10 cm and may be even smaller. The break may or may not be isolatable and it may render one or both PTR trains inoperable. Finally, its location may be difficult to identify.

It was assumed that the rate of inventory loss is rapid enough that the operator will isolate the PTR system, thus rendering PTR/RWST mode of borated water make-up unavailable.

SFP water level may be anywhere between the inlet of PTR, which is at the 15.5 m level, and the low SFP level alarm setpoint (19.3 m).

If SED is used as the SFP make-up source make-up must be initiated prior to the onset of SFP boiling.

The success criteria for a loss of SFP inventory are generally:

- Isolate the leak or diversion prior to loss of PTR suction uncovery;
- Make-up inventory prior to PTR suction uncovery; and
- Make-up inventory prior to fuel uncovery.

Event tree models for this initiating event were created for NM and OM and consist of the following function events:

1. Loss of PTR Inventory due to a PTR Pipe Rupture
(YLOPI\R\PTR\NM and YLOPI\R\PTR\OM)

This event is defined as a loss of SFP water due to a pipe break. This will cause low level in the SFP and trigger the low level alarm in the control room. If the SFP level drops to the 15.5 m level the PTR pump's suction head will be lost and the pump will trip.

2. PTR Pipe Isolated Before Loss of PTR Suction at 15.5 m
(PTR_ISO_RP)

This function event considers the operator actions required to isolate the break prior to the loss of the PTR pump's suction. Success for this function event is that the leak is isolated before this level is reached.

3. Establish SED Make-up Before SFP Boiling at 15.5 m
(SED\MU_BB_15_NM and SED\MU_BB_15_OM)

At the 15.5 m level (or slightly above due to vortex cavitation) PTR pump suction is lost. At this level PTR cannot be recovered and make-up via SED, JPP or JPS is the only remaining options. This event considers maintaining the level such that PTR repairs can continue even after boil-off has started.

The current plant design requires local actions inside the SFP building to line-up SED. These line-ups must be performed prior to the onset of SFP boiling.

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11.0 hours in NM and 3.9 hours in OM from the time cooling is lost.

Success for this function event is defined as the establishment of SED make-up to the SFP prior to SFP boiling.

4. Establish JPP Make-up Before SFP Boiling at 15.5 m
(JPP\MU_BB_15_NM and JPP\MU_BB_15_OM)

Should SED be unavailable for make-up to the SFP, the operator is instructed to use the JPI/JPD/JPP systems [Refs. 14, 15 and 16]. The fire protection system draws from various other back-up systems such that an essentially infinite water supply is available. The path to the SFP via the fire hose station outside the spent fuel pit area can provide approximately 100 m^3/hr. At this flow rate it would take 15 minutes to increase the SFP level from its low to its high alarm setpoints.

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11 hours in NM and 3.9 hours in OM from the time cooling is lost.

The success criterion is the establishment of JPP make-up to the SFP prior to fuel uncovery.

5. Establish JPS Make-up Before SFP Boiling at 15.5 m
(JPS\MU_BB_15_NM and JPS\MU_BB_15_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16].

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11 hours in NM and 3.9 hours in OM from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

6. No Gate Seal Failure during SPF Boiling at 15.5 m
(GATE SEAL 15.5)

This functional event is only used in the NM Event Tree. If the CC and the TC are full there is no loss of SFP inventory following seal failure. Seal failure is considered if the SFP temperature is above 100°C [Ref. 10] and the CC and TC are empty. If gate seal failure occurs it is assumed to be catastrophic with a consequent level drop to 13.25 m.

7. Establish SED Make-up Before Fuel Damage from 15.5 m
(SED\MU_BD_15_NM and SED\MU_BD_15_)

If make-up is not established and PTR cooling is not restored before PTR suction uncovery the SFP level will drop to the point where the fuel is uncovered. This event indicates that the water level is at the 15.5 m level after the failure of preceding function events and the SFP is boiling.

Available time to establish SED make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85m) in 79.4 hours in NM (No Gate Failure), 42.8 hours NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criterion is the establishment of SED make-up to the SFP prior to fuel damage.

8. Establish JPP Make-up Before Fuel Damage from 15.5 m
(JPP\MU_BD_15_NM and JPP\MU_BD_15_OM)

Should SED be unavailable for make-up to the SFP, the operator is instructed to use the JPI/JPD/JPP systems [Refs. 14, 15 and 16].

Available time to establish JPP make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up is not established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 79.4 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criteria are the establishment of JPP make-up to the SFP prior to fuel uncovery.

9. Establish JPS Make-up Before Fuel Damage from 15.5m
(JPS\MU_BD_15_NM and JPS\MU_BD_15_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16].

Available time to establish JPS make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up is not established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 79.4 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

4.3 LOSS OF PTR INVENTORY DUE TO A FLOW DIVERSION EVENT TREES

Numerous valves are present that interface between PTR and other systems. These valves are routinely manipulated for various operations. The random failure and mis-positioning of these valves would divert SFP water. In such a case the SFP level will drop and the low level alarm will actuate in the control room. The SFP level can drop down to the 17 meter level, at which the PTR pump will fail to start or to the 15.5 m level at which the SFP suction head will be lost and the PTR pump will trip.

The success criteria for a loss of SFP inventory are generally:

- Isolate the leak or diversion prior to loss of PTR suction uncovery;
- Make-up inventory prior to PTR suction uncovery; and

- Make-up inventory prior to fuel uncovery.

For NM and OM, the PTR flow diversion due to valve mis-positioning event trees consist of the following function events:

1. Loss of PTR Inventory due to a Flow Diversion

(YLOPI\D\PTR\NM and YLOPI\D\PTR\OM)

This event is defined as a loss of SFP inventory due to diversion through an interfacing system valve failing open or having been left open during PTR operation. This will result in SFP low level and trigger the SFP low level alarm in the control room. If the SFP level drops to the 15.5 meter level the PTR pump's suction head will be lost and the pump will trip or fail to run.

2. PTR Flow Diversion Isolated Before Loss of PTR Suction at 15.5 m

(PTR_FD\ISO)

This function event considers the operator actions required to close the flow diversion path. Success for this function event is that the flow diversion path is isolated before this level is reached.

3. Establish SED Make-up Before SFP Boiling at 15.5 m

(SED\MU_BB_15_NM and SED\MU_BB_15_OM)

At the 15.5 m level (or slightly above due to vortex cavitation) PTR pump suction is lost. At this level PTR cannot be recovered and make-up via SED, JPP or JPS is the only remaining options. This event considers maintaining the level such that PTR repairs can continue even after boil-off has started.

The current plant design requires local actions inside the SFP building to line-up SED. These line-ups must be performed prior to the onset of SFP boiling.

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11.0 hours in NM and 3.9 hours in OM from the time cooling is lost.

Success for this function event is defined as the establishment of SED make-up to the SFP prior to SFP boiling.

4. Establish JPP Make-up Before SFP Boiling at 15.5 m

(JPP\MU_BB_15_NM and JPP\MU_BB_15_OM)

Should SED be unavailable for make-up to the SFP, the operator is instructed to use the JPI/JPD/JPP systems [Refs. 14, 15 and 16]. The fire protection system draws from various other back-up systems such that an essentially infinite water supply is available. The path to the SFP via the fire hose station outside the spent fuel pit area can provide approximately 100 m^3/hr. At this flow rate it would take 15 minutes to increase the SFP level from its low to its high alarm setpoints.

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11 hours in NM and 3.9 hours in OM from the time cooling is lost.

The success criterion is the establishment of JPP make-up to the SFP prior to fuel uncovery.

5. Establish JPS Make-up Before SFP Boiling at 15.5 m

(JPS\MU_BB_15_NM and JPS\MU_BB_15_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16].

If make-up cannot be established and PTR cooling is not restored the SFP inventory will start to boil in 11 hours in NM and 3.9 hours in OM from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

6. No Gate Seal Failure During SFP Boiling at 15.5 m

(GATE SEAL 15.5)

This functional event is only used in the NM Event Tree. If the CC and the TC are full there is no loss of SFP inventory following seal failure. Seal failure is considered if the SFP temperature is above 100°C [Ref. 10] and the CC and TC are empty. If gate seal failure occurs it is assumed to be catastrophic with a consequent level drop to 13.25 m.

7. Establish SED Make-up Before Fuel Damage

(SED\MU_BD_15_NM and SED\MU_BD_15_OM)

If make-up is not established and PTR cooling is not restored before PTR suction uncovery the SFP level will drop to the point where the fuel is uncovered. This event indicates that the water level is at the 15.5 m level after the failure of preceding function events and the SFP is boiling.

Available time to establish SED make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 79.4 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criterion is the establishment of SED make-up to the SFP prior to fuel damage.

8. Establish JPP Make-up Before Fuel Damage

(JPP\MU_BD_15_NM and JPP\MU_BD_15_OM)

Should SED be unavailable for make-up to the SFP, the operator is instructed to use the JPI/JPD/JPP systems [Refs. 14, 15 and 16].

Available time to establish JPP make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up is not established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 79.4 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criteria are the establishment of JPP make-up to the SFP prior to fuel uncovery.

9. Establish JPS Make-up Before Fuel Damage

(JPS\MU_BD_15_NM and JPS\MU_BD_15_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16].

Available time to establish JPS make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up is not established and PTR cooling is not restored the SFP level will drop from the 15.5 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 79.4 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 39.1 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

4.4 LOSS OF OFF-SITE POWER (LOSP)

LOSP is defined in terms of opening of the 400 kV breaker 1 GEV 001 JA. The number of times over the plant history it tripped is used to determine the LOSP frequency. Supply from Acacia can be available within 4 minutes and is included in the determination of LOSP frequency. Supply from the fifth diesel generator is viewed as emergency supply. Power recovery and emergency supplies taking longer than 4 minutes are modelled in the Station Blackout (SBO) event tree. This definition is consistent with NUREG/CR-5032; Modelling Time to Recovery and Initiating Event Frequency for Loss of Off-Site Power Incidents at Nuclear Power Plants [Ref. 51].

Following a LOSP, PTR and compressed air systems (SAP/SAR) are load shed and subsequently supplied by the main emergency buses powered by EDGs. In the case of the PTR pumps, this is a manual operation. The SFP gate seals would not be affected as the isolation valves between the seals and SAR are normally closed.

As the SED pumps are not diesel backed they would not to be available following the start of the EDGs. In this case, only JPP would be available as the JPP pumps are diesel backed. However, if off-site power is recovered, both the SED and JPP pumps would be available.

The JPS pumps do not require off-site AC power or the EDGs.

Failure of the EDGs and Acacia results in a transfer to the SBO event trees. An SBO initiating event is defined as an event that leads to the de-energization of the essential electrical boards, LHA and LHB. The definition implies failure of both onsite and offsite AC power supplies for longer than 4 minutes. This event is relevant to all plant operational states.

Single-unit loss of AC power events are not considered, as it was assumed that the affected unit would get AC power by a cross connecting to the other unit. It has also been assumed that if the LOSP is prolonged (longer than 6 hours), then house loading is not optional.

The LOSP event tree consists of the following function events for NM and OM:

1. SFP LOSP in Normal and Outage Mode

(YLOSP\L___\NM and YLOSP\L___\OM)

This event is defined as the failure of off-site power supplies. Both units are tripped and the EDGs and Acacia are started. Off-site power restoration is attempted as soon as possible.

2. LHA/LHB Energised

(LHA/B_E)

EDGs will automatically actuate and supply power to the emergency AC buses. In terms of the mode, the emergency AC buses supply the JPP pumps only. The mission time for the EDGs to run is assumed to be 24 hours.

Supply of off-site power from Acacia was modeled, taking into consideration the time available for switching actions. There are three Acacia gas turbines, of which only one has to start and run for 24 hours.

3. Operator Starts PTR Cooling After LOSP Before SFP Boiling at 19.3 m

(PTR_C\L_BB_19_NM and PTR_C\L_BB_19_OM)

If the EDGs start and run and the operator starts a PTR pump, SFP cooling is re established.

Success for this function event is to recover one PTR train along with RRI cooling to the recovered train's heat exchanger following the re-establishment of the emergency AC power supply to the PTR system.

If it is assumed that the SFP level is initially at the 19.3m level, the time to boiling is 16.8 hours in NM and 5.9 hours in OM.

4. No Gate Seal Failure During SFP Boiling

(GATE SEAL)

This functional event is only used in the NM Event Tree. If the CC and the TC are full there is no loss of SFP inventory following seal failure. Seal failure is considered if the SFP temperature is above 100°C [Ref. 10] and the CC and TC are empty. If gate seal failure occurs it is assumed to be catastrophic with a consequent level drop to 13.25 m.

5. Start PTR Cooling After LOSP Before Loss of PTR Suction at 17 m

(PTR_C\L_BS_17_NM and PTR_C\L_BS_17_OM)

The PTR pumps must not be re-started with a level of less than 17.0 m in the SFP. With the suction of the PTR pumps located at the 15.5 m level in the SFP, the minimum level for starting a PTR pump will reduce the possibility of vortexing in the SFP and cavitation at the pump suction [Ref. 14].

Below this level PTR cooling cannot be restarted, therefore make-up is the only remaining option. The loss of inventory due to boiling causes the SFP level to drop from the 19.3 m level to the 17 m level in 37.5 hours in NM and 13.2 hours in OM, after a LOSP initiating event. As there is sufficient Net Possitive Suction Head (NPSH) for the pumps, it is expected that the PTR cooling function may be restored even if boiling occurs in the SFP.

Success for this function event is defined as the recovery of PTR cooling to the SFP before the 17 m level is reached.

6. Establish SED Make-up Before Fuel Damage

(SED\MU_BD_17_NM and SED\MU_BD_17_OM)

This event is initiated after boiling when the level in the SFP starts to drop.

The current plant design requires local actions at the SFP to line-up SED [Refs. 14 and 15] and local actions inside and outside the fuel building to line up the alternative JPP make-up paths [Refs. 14, 15 and 16]. These line-ups must be performed prior to the start of boiling.

If the SED line-up is established, demineralised water from this system is used for make-up to the spent fuel pit using the SED inlet (provided at level +20.00 m for washing the spent fuel storage cask). The flow rate from this system is via the 2½" connection on the SFP floor at 98 m^3/hr. SED is the preferred source for SFP make-up in the procedure [Refs. 14 and 15].

The source of SED water is from a single storage tank of 500 m^3 capacity. However, should the tank be drained to its low level, make-up is automatically provided to the tank and terminated on a high level.

Available time to establish SED make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of SED make-up to the SFP prior to fuel damage.

7. Establish JPP Make-up Before Fuel Damage from 17 m

(JPP\MU_BD_17_NM and JPP\MU_BD_17_OM)

If the Acacia successfully supplies LHA or LHB board or EDGs start and run and the operator fails to start a PTR pump, SFP cooling is lost. If the operator starts a JPP pump, SFP make-up is then established.

Available time to establish JPP make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If PTR cooling is not restored and make-up cannot be established, the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPP make-up to the SFP prior to fuel uncovery.

8. Establish JPS Make-up Before Fuel Damage

(JPS\MU_BD_17_NM and JPS\MU_BD_17_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16]. This event is considered from the time the 17m level is reached.

Available time to establish JPS make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If PTR cooling is not restored and make-up cannot be established the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

4.5 STATION BLACKOUT

The failure of the site EDGs as well as the dedicated 132 kV power supply facility at Acacia Power Station to receive automatic start order signals and to run leads to a station blackout event. The SFP SBO event trees consider this scenario. The focus of the operator actions is to recover off-site power and establish PTR cooling prior to the onset of SFP boiling or prior to the uncovery of PTR pumps' suction. If PTR is not recovered, establishment of make-up is attempted after off-site power recovery. Given that off-site power is recovered make-up can be from JPP or SED. In the event that power is not recovered, the only source of SFP make-up would be the mobile fire JPS fire pump.

The SFP SBO event trees for NM and OM consist of the following function events:

1. LOSP – ET for SPF SBO in Normal Operation Mode

(YLOSP\SBO\NM and YLOSP\SBO\OM)

The initiating event is the failure of the off-site power supplies, including emergency off-site power from Acacia. Both units are tripped, the EDGs fail to start or run for 24 hours and offsite sources are not recovered in accordance with the SBO definition given in NUREG/CR-5032; Modelling Time to Recovery and Initiating Event Frequency for Loss of Off-Site Power Incidents at Nuclear Power Plants [Ref. 51].

2. Manually Align 9 LHS to Either LHA or LHB Switchboard

(9LHS\SBO)

It is desirable to recover power prior to the onset of SFP boiling. This can be done in one of two ways: either the recovery of the grid or by aligning the fifth diesel to either LHA or LHB.

Success for this function event is that the fifth diesel is aligned and power restored to one of the two LHx switchboards. If it is assumed that the SFP level is initially at 19.3 m, the time to boiling is 16.8 hours in NM and 5.9 hours in OM.

3. Recovery of Grid Before SFP Boiling at 19.3 m

(GRID_BB_NM or GRID_BB_OM)

The success criterion for this function event is that the grid is recovered prior to SFP boiling. SFP boiling occurs after 16.8 hours in NM and 5.9 hours in OM.

Note that recovery of the four diesels and recovery of Acacia is not modelled in order to be consistent with the Level 1 PSA model. However, due to the long times available for recovery for SFP cooling these recoveries could be considered if deemed appropriate at a later stage.

4. Start PTR Cooling Before SFP Boiling at 19.3 m (PTR_C\SBO_BB_NM and PTR_C\SBO_BB_OM)

Success for this function event is defined as the recovery of PTR cooling to the SFP before SFP boiling. If it is assumed that the SFP level is initially at the 19.3 m level, the time to boiling is 16.8 hours in NM and 5.9 hours in OM.

5. No Gate Seal Failure During SFP Boiling

(GATE SEAL)

This functional event is only used in the NM Event Tree. If the CC and the TC are full there is no loss of SFP inventory following seal failure. Seal failure is considered if the SFP temperature is above 100°C [Ref. 10] and the CC and TC are empty. If gate seal failure occurs it is assumed to be catastrophic with a consequent level drop to 13.25 m.

6. Recovery of Grid Before Loss of PTR Suction at 17 m (GRID_BS_NM and GRID_BS_OM)

The loss of inventory due to boiling causes the SFP level to drop from the 19.3 m level to the 17 m level in 37.5 hours in NM and 13.2 hours in OM after a LOSP initiating event.

Success for this function event is defined as the recovery of the grid before the 17 m level is reached.

7. Start PTR Cooling Before SFP Loss of PTR Suction at 17 m

(PTR_C\SBO_BS_NM and PTR_C\SBO_OM)

The PTR pumps must not be re-started with a level of less than 17.0 m in the SFP. With the suction of the PTR pumps located at the 15.5 m level in the SFP, the minimum level for starting a PTR pump will reduce the possibility of vortexing in the SFP and cavitation at the pump suction [Ref. 14].

Below this level PTR cooling cannot be restarted, therefore make-up is the only remaining option. The loss of inventory due to boiling causes the SFP level to drop from the 19.3 m level to the 17 m level in 37.5 hours in NM and 13.2 hours in OM, after a LOSP initiating event. As there is sufficient NPSH for the pumps, it is expected that the PTR cooling function may be restored even if boiling occurs in the SFP.

If either the fifth diesel is aligned or the grid is recovered before SFP boiling then the PTR system can be started and cooling re-established to the SFP before the SFP starts to boil.

The success criterion for this function event is that one PTR train is started before the SFP starts to boil. The times available to recover power and start PTR cooling are 22 hours in NM and 11 hours in OM.

8. Recovery of grid before fuel damage from 17 m (GRID_BD_NM and GRID_BD_OM)

The success criterion for this function event is to recover the grid prior to SFD.

SFD occurs after 103.8 hours in NM and 36.7 hours in OM.

Note that recovery of the four diesels and recovery of Acacia is not modelled in order to be consistent with the Level 1 PSA model. However, due to the long times available for recovery for SFP cooling these recoveries could be considered if deemed necessary at a later stage.

9. Establish SED Make-up Before Fuel Damage from 17 m

(SED\MU_BD_17_NM and SED\MU_BD_17_OM)

The current plant design requires local actions at the SFP to line-up SED [Refs. 14 and 15] and local actions inside and outside the fuel building to line up the alternative JPP make-up paths [Refs. 14, 15 and 16]. These line-ups must be performed prior to the start of boiling.

If the SED line-up is established, demineralised water from this system is used for make-up to the spent fuel pit using the SED inlet (provided at level +20.00 m for washing the spent fuel storage cask). The flow rate from this system is via the 2½" connection on the SFP floor at 98 m^3/hr. SED is the preferred source for SFP make-up in the procedure [Refs. 14 and 14].

The source of SED water is from a single storage tank of 500 m^3 capacity. However, should the tank be drained to its low level, make-up is automatically provided to the tank and terminated on a high level.

Available time to establish SED make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If make-up cannot be established and PTR cooling is not restored the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

10. Establish JPP Make-up Before Fuel Damage from 17 m

(JPP\MU_BD_17_NM and JPP\MU_BD_17_OM)

Available time to establish JPP make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If PTR cooling is not restored and make-up cannot be established, the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPP make-up to the SFP prior to fuel uncovery.

11. Establish JPS Make-up Before Fuel Damage from 17 m

(JPS\MU_BD_17_NM and JPS\MU_BD_17_OM)

If make-up cannot be established via SED or JPP the operator is instructed to start the mobile fire pump (JPS) [Refs. 14 and 16]. This event is considered from the time the 17 m level is reached.

Available time to establish JPS make-up before fuel damage in NM is calculated separately for when there is no gate failure and when the gate failed.

If PTR cooling is not restored and make-up cannot be established the SFP level will drop from the 17 m level to the point where it is assumed that fuel damage occurs (at 9.85 m) in 103.8 hours in NM (No Gate Failure), 42.8 hours in NM (Gate Failed) and 36.7 hours in OM, from the time cooling is lost.

The success criterion is the establishment of JPS make-up to the SFP prior to fuel damage.

5 ACCIDENT SEQUENCE QUANTIFICATION (FAULT TREES)

In this section the various fault trees used to quantify the function events in the event trees are discussed. The focus is on how the relevant system is used and the failure modes.

Event trees start with an initiating event, (or consequence in the case of SBO), which were quantified Chapter 3.

Event trees model the systems and operator actions required to mitigate the initiating event. All operator actions were re-quantified in the EPRI HRA CALCULATOR following the SPAR-H methodology. HRAs are discussed in more detail in Chapter 6.

5.1 PTR SYSTEM FAULT TREES

The PTR system is used extensively in the function events that comprise the SFP event trees.

5.1.1 PTR System Description

The function of the PTR, as modelled in this analysis is SFP cooling. The components associated with this function are considered in this analysis.

The system is designed so that a single failure of any component will not impair the system's ability to perform its intended function. PTR and its RRI cooling systems, is classified as Safety Class 3 and Seismic Category 1.

Each of the three trains of the cooling system consists of a pump, a heat exchanger, valves, piping and instrumentation. The pumps take suction from the fuel pool at an inlet located below the pool water level (~15.5 m), transfer the pool water through a heat exchanger and return it back into the pool through an outlet typically located below the cooling system inlet and some large distance from it. The return line is designed to prevent siphoning. The flow rate is 360 m^3/h [Ref. 33]. The heat exchangers are cooled by component cooling water (RRI) system.

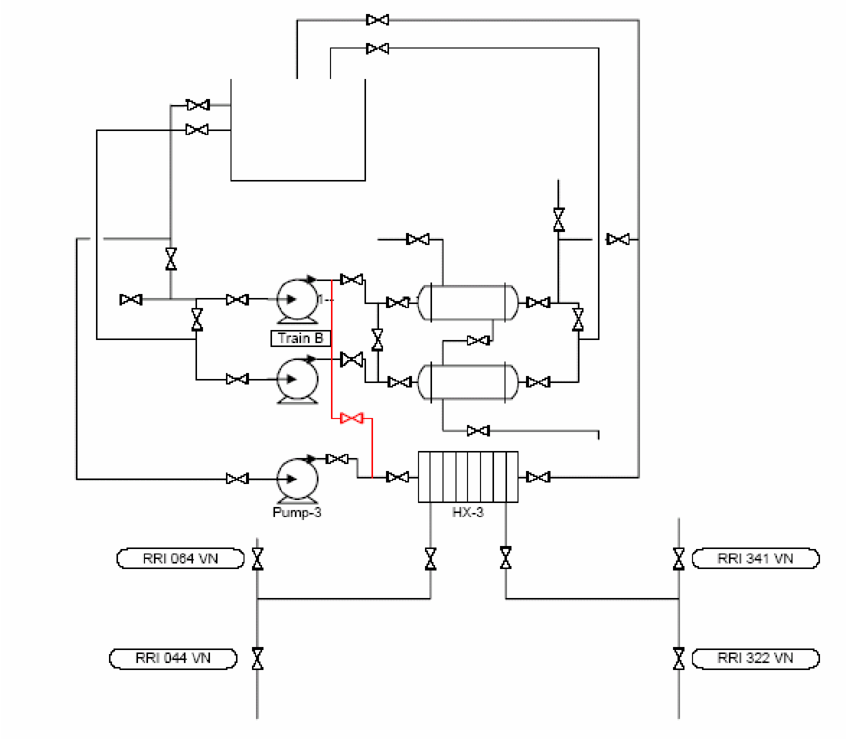


Figure 5.1: PTR System Configuration

The electrical power supply to the system has two independent supplies feeding the two trains.

The PTR 3rd Train modification introduced inter-unit power cabling that is used for backing-up the PTR pumps (PTR 001 PO and PTR 002 PO) from the other unit during outages. However, this equipment does not form part of the PTR 3rd Train modification. PTR pumps PTR 001 PO and PTR 002 PO are supplied from their normal supplies namely, PTR 001 PO from LLI 205 JA and PTR 002 PO from LLB 201 JA. The 3rd Train cooling pump, PTR 006 PO, is normally supplied from LLD 209 JA (Train B).

During electrical board maintenance of either LHA or LHB, PTR 001 PO and PTR 002 PO can be supplied from LLJ 205 JA (Train B) on the operating unit. During electrical board maintenance of LHB, PTR 006 PO on the outage unit can be supplied from LLD 209 JA (Train B) on the operating unit. In this case the electrical supply to PTR 006 PO on the operating unit is unavailable.

The PTR pumps are shed during EDG starting and permission to load is given at 40 seconds (Train A) and 15 seconds (Train B). The 3rd Train pump is permitted to restart (restarted manually) at 15 seconds in accordance with the Train B pumps. However, when PTR 001 PO and PTR 002 PO pumps are being supplied from the other unit, the reload permission will be at 0 seconds.

Make-up (2440 to 2700 ppm borated water) to replenish the spent fuel pit is provided by a PTR pump from the refuelling water storage tank (the inventory of this tank is maintained by REA). Assuming normal evaporation at the surface of the spent fuel pit (at the rate of about 50 mm/week), boron concentration in the spent fuel pit water will increase.

Pumps that perform filling or draining functions (PTR 001 PO, PTR 002 PO and PTR 005 PO) can be controlled from the operating deck of the pools thus permitting visual monitoring of operations. When these pumps are used for draining a compartment they are tripped automatically on detection of low level in the compartment. A low-pressure detection device at the pump suction also protects the pumps. When PTR 002 PO is backing up RRA, all automatic pump trips (low pressure or level) are inhibited but the alarm signals are maintained. One pump provides the flow rate required for cooling the spent fuel pit. The other pump backs up either the first pump or RRA.

The PTR heat exchangers are cooled using demineralised and treated, closed-loop RRI water to reduce the risk of contaminated water being released should the heat exchanger accidentally leak.

In the event of a loss of RRI cooling for the PTR heat exchanger of one unit, the PTR exchanger of this unit can be cooled by the RRI of the other unit. In the event of the total loss or of a long duration of inoperability of both PTR pumps and/or both PTR heat exchangers, cooling of SFP water would not take place. Evaporation and ultimately boiling of the water in the SFP would occur unless mitigating actions are taken.

Failure of the system includes failure of all pumps, all heat exchangers as well as the failure to line up the correct path. Failure of the PTR heat exchangers takes into account the loss of RRI, internal leakage and failure to valve in the standby train. It should be noted that PTR 001 PO can be used in conjunction with PTR 002 RF, and likewise for PTR 002 PO and PTR 001 RF. It should also be noted that in NM both trains of RRI/SEC can be used to cool the heat exchangers, as well as both trains from the second unit.

Table 5.1 contains the PTR Heat Exchanger Capability (calculated with PTR.exe) at different Sea Water Temperatures.

The assumptions from Appendix C are as follows:

- PTR Heat Exchanger Capability - Single Exchanger;
- RRI Flow Rate = 450 m^3/h;
- PTR Flow Rate = 300 m^3/h (throttled using one heat exchanger);
- PTR Inlet Temp = 100°C (PTR 001 and 002 PO ½ hour; PTR 006 PO permanent);
- Sea Water Temp = Case 1: 20°C; Case 2: 15°C; Case 3: 23.5°C;
- RRI/SEC B value = 2.66 MW/°C;
- RRI Base Load = 5.1 MW;
- Fouling Factor = 0.000086; and
- Exchange Area = 239 m^2.

Table 5.1: PTR Heat Exchanger Capability

Case	Sea Water Temp (°C)	Heat Removal Capacity (MW)
1	14	14.68
2	20	13.67
3	23.5	13.08

5.1.2 PTR System Success Criteria

PTR system success criteria, by initiating event, are given in the Table 5.2 below.

Table 5.2: PTR System Success Criteria

INITIATING EVENT	SUCCESS CRITERIA
Catastrophic Door Seal Failure	SPF Level is too low to run or restart PTR cooling
Loss of SFP Cooling due to a PTR System Failure	Recover Cooling before boiling at 19.3 m
	Recover Cooling before 17 m
Loss of PTR Inventory due to a Flow Diversion	PTR Flow Diversion Isolated before Loss of PTR suction at 15.5 m
Loss of PTR Inventory due to a PTR Pipe Rupture	PTR Pipe Isolated before Loss of PTR suction at 15.5 m
LOSP	Operator Starts PTR before boiling at 19.3 m
	Operator Starts PTR before 17 m
SBO	Start PTR Cooling before SFP boiling at 19.3 m
	Start PTR Cooling before 17 m

5.1.3 PTR System Recovery Following LOSP or SBO

PTR is normally in service. However, following a LOSP or station blackout, power must be restored and the pumps manually re-started. The fault trees for failure to start PTR consist of an "OR" gate with two inputs. One input is a transfer to the fault tree that models the PTR system failing to start and run, and the second input is to a basic event for the operator failing to start PTR cooling.

The function events dealing with the failure to start PTR cooling, together with the associated fault trees are listed in Table 5.3.

Table 5.3: Operator Actions to Start PTR Cooling in LOSP and SBO Scenarios

Event Tree	Function event	Fault Tree	Operator Action
YLOSP_\SFP\NMPTR_C SFP LOSP in Normal Mode	PTR_C\L_BB_19_NM Start PTR cooling after LOSP before Boiling at 19.3 m (NM)	HES-PTR-C\LOSP-NM Operator Fails to start PTR cooling after LOSP (NM)	HES-PTR-C\L-BB-19-NM Operator Fails to Start PTR Cooling after LOSP before Boiling at 19.3 m (NM)
	PTR_C\L_BS_17_NM Start PTR cooling after LOSP before loss of PTR suction at 17 m (NM)	HES-PTR-C\LOSP-NM Operator Fails to start PTR cooling after LOSP (NM)	HES-PTR-C\L-BS-17-NM Operator fails to start PTR cooling after LOSP before loss of PTR suction at 17 m (NM)
YLOSP_\SFP\OM SFP LOSP in Outage Mode	PTR_C\L_BB_19_OM Start PTR cooling after LOSP before SFP boiling at 19.3 m (OM)	HES-PTR-C\LOSP-OM Operator fails to start PTR cooling after LOSP (OM)	HES-PTR-C\L-BB-19-OM Operator fails to start PTR cooling after LOSP before SFP boiling at 19.3 m (OM)
	PTR_C\L_BS_17_OM Start PTR cooling after LOSP before loss of PTR suction at 17 m (OM)	HES-PTR-C\LOSP-OM Operator fails to start PTR cooling after LOSP (OM)	HES-PTR-C\L-BS-17-OM Operator fails to start PTR cooling after LOSP before loss of PTR suction at 17 m (OM)
YLOSP\SBO\NM LOSP – ET for SFP SBO in Normal Mode	PTR_C\SBO_BB_NM Start PTR cooling before SFP boiling at 19.3 m (NM)	HES-PTR-C\LOSP-NM Operator fails to start PTR cooling after LOSP (NM)	HES-PTR-C\L-BB-19-NM Operator fails to start PTR cooling after LOSP before SFP boiling at 19.3 m
	PTR_C\SBO_BS_NM Start PTR cooling before loss of PTR suction at 17 m (NM)	HES-PTR-C\LOSP-NM Operator fails to start PTR cooling after LOSP (NM)	HES-PTR-C\L-BS-17-NM Operator fails to start PTR cooling after LOSP before loss of PTR suction at 17 m (NM)
YLOSP\SBO\OM LOSP – ET for SFP SBO in Outage Mode	PTR_C\SBO_BB_OM Start PTR cooling before SFP boiling at 19.3 m (OM)	HES-PTR-C\LOSP-OM Operator fails to start PTR cooling after LOSP (OM)	HES-PTR-C\L-BB-19-OM Operator fails to start PTR cooling after LOSP before SFP boiling at 19.3 (OM)
	PTR_C\SBO_BS_OM Start PTR cooling before loss of PTR suction at 17 m (OM)	HES-PTR-C\LOSP-OM Operator fails to start PTR cooling after LOSP (OM)	HES-PTR-C\L-BS-17-OM Operator fails to start PTR cooling after LOSP before loss of PTR suction at 17 m (OM)

5.1.4 PTR System Recovery Probability Models

The fault tree for this function event consists of an “OR” gate with two inputs. One input is a transfer gate to the fault tree that models the failure of the PTR system to start and run from standby. The second input to this “OR” gate is a basic event that models the probability of failure to recover PTR cooling prior to either PTR boiling or the PTR level dropping to 17 m. These probabilities were determined from Figure 5.2.

Nuclear Engineering, Plant Engineering and Maintenance were approached independently; their timings are presented in Table 5.4 and corresponded well with the curve presented in Figure 5.2, giving confidence in the results.

Table 5.4: Recovery Times: Estimates (Nuclear Engineering, Plant Engineering & Maintenance)

Component	**Normal Failures**		**Normal Failures**	
	Type of Failure	**Mechanism**	**Repair Time (hours)**	**Replace Time (hours)**
Pumps	Impeller	Worn impeller / Worn wear rings	12	3-4
	Bearing	Vibration	24	3-4
	General Damage	Corrosion	12	
Motors	Insulation	Moisture	8-10	8-10
	Resistance	Moisture	8-10	8-10
	Insulation	Dirt	144	8-10
	Resistance	Dirt	144	8-10
	Bearing	Vibration	12	12
	General Damage	Corrosion	168	N/A
Heat exchangers	Structural failure	SCC	30	15
Piping	Structural failure	Damage / SCC	12 (clamp) 24 (weld)	N/A
Instrumentation	Incorrect readings	Drift	2	N/A
		Damage	1-6	3-6

The Best Estimate Repair Time is the time to sufficiently repair the component in order to re-establish cooling to the spent fuel pool. Therefore minor leaks, vibration etc were not considered. Also, PTW, Pre-job briefs etc will be largely suspended during a nuclear emergency (loss of cooling to the Spent Fuel Pool).

Notes:
The estimated times assume focused action possibly bypassing the normal processes to speed up the recovery.

a) Pump failure:

A normal (single) failure of a PTR pump will lead to replacement of the pump with the spare.

b) Motor failure:

When a motor fail due to moisture, there is a process to dry it and restart, but in the event of a motor failing due to dirt, the motor has to be sent off site to be fixed. This can take up to 6 days.

c) Pipe break:

Repair times for pipe breaks are dependent on the size and location of the break. The repair times for pipe breaks were estimated to be 12h for clamping and 24 h for welding.

The mean recovery time is based on the highest of the replacement times given to us from plant personnel. This is possibly a conservative approach but allows for optimistic feedback from maintenance personnel. Since the highest replacement time is used, an error factor of 2.5 is assigned based on expert judgement. The PTR system recovery probability curve presented in Figure 5.2 and Table 5.5 was obtained when assuming the repair time follows a log-normal curve with the following parameters:

EF	=	2.5	Error Factor
Mean	=	15 h	Pump Recovery Time
σ	=	0.56	
μ	=	2.6 h	

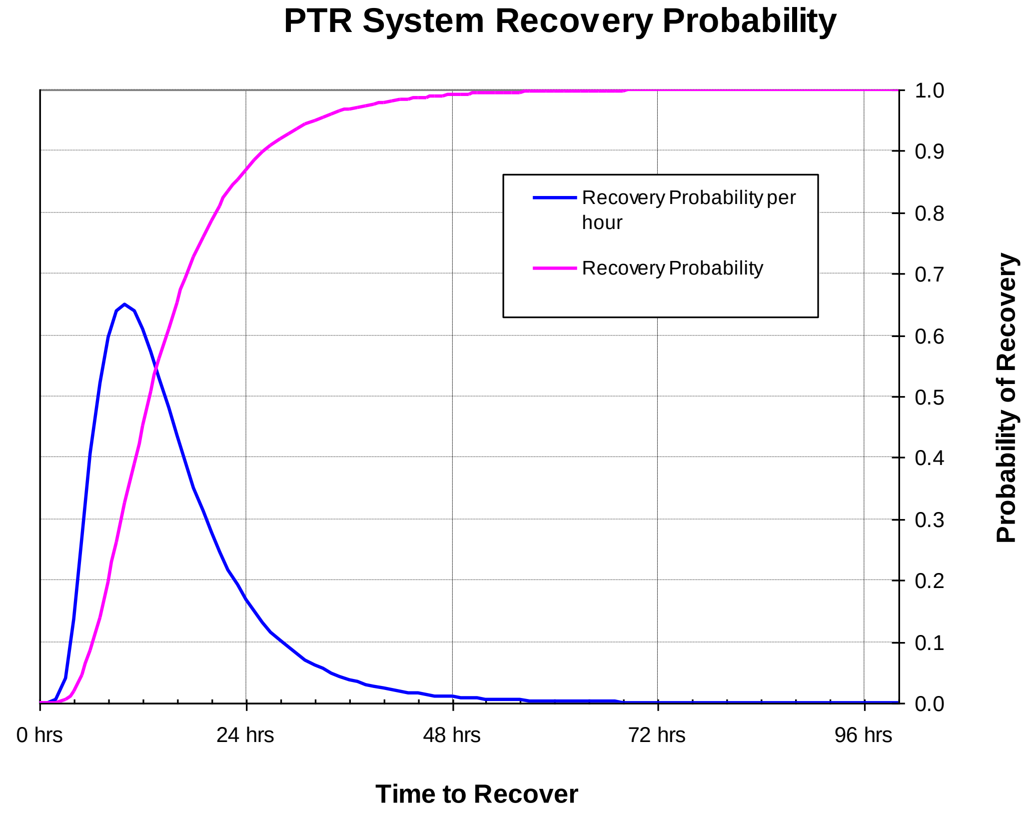


Figure 5.2: PTR System Recovery Probability

Table 5.5: PTR System Recovery Probability

Time (hours)	Recovery Probability	Recovery Probability per hour	Probability of Non Recovery
0	0.00E+00	0.00E+00	1.00E+00
1	2.29E-06	2.29E-06	1.00E+00
2	4.21E-04	4.18E-04	1.00E+00
3	4.52E-03	4.09E-03	9.95E-01
4	1.81E-02	1.36E-02	9.82E-01
5	4.52E-02	2.70E-02	9.55E-01
6	8.59E-02	4.07E-02	9.14E-01
7	1.38E-01	5.20E-02	8.62E-01
8	1.98E-01	5.97E-02	8.02E-01
9	2.62E-01	6.39E-02	7.38E-01
10	3.27E-01	6.50E-02	6.73E-01
11	3.90E-01	6.38E-02	6.10E-01
12	4.51E-01	6.10E-02	5.49E-01
13	5.09E-01	5.72E-02	4.91E-01
14	5.61E-01	5.28E-02	4.39E-01
15	6.10E-01	4.82E-02	3.90E-01
16	6.53E-01	4.37E-02	3.47E-01
17	6.93E-01	3.92E-02	3.07E-01
18	7.28E-01	3.51E-02	2.72E-01
19	7.59E-01	3.13E-02	2.41E-01
20	7.87E-01	2.77E-02	2.13E-01
21	8.11E-01	2.46E-02	1.89E-01
22	8.33E-01	2.17E-02	1.67E-01
23	8.52E-01	1.92E-02	1.48E-01
24	8.69E-01	1.69E-02	1.31E-01
25	8.84E-01	1.49E-02	1.16E-01
26	8.97E-01	1.32E-02	1.03E-01
27	9.09E-01	1.16E-02	9.11E-02
28	9.19E-01	1.02E-02	8.09E-02
29	9.28E-01	9.04E-03	7.19E-02
30	9.36E-01	7.97E-03	6.39E-02
31	9.43E-01	7.04E-03	5.69E-02
32	9.49E-01	6.22E-03	5.06E-02
33	9.55E-01	5.50E-03	4.51E-02
34	9.60E-01	4.87E-03	4.03E-02
35	9.64E-01	4.31E-03	3.60E-02
36	9.68E-01	3.82E-03	3.21E-02
37	9.71E-01	3.39E-03	2.88E-02
38	9.74E-01	3.01E-03	2.58E-02
39	9.77E-01	2.67E-03	2.31E-02
40	9.79E-01	2.37E-03	2.07E-02
41	9.81E-01	2.11E-03	1.86E-02
42	9.83E-01	1.88E-03	1.67E-02
43	9.85E-01	1.68E-03	1.50E-02
44	9.86E-01	1.50E-03	1.35E-02
45	9.88E-01	1.34E-03	1.22E-02
46	9.89E-01	1.20E-03	1.10E-02
47	9.90E-01	1.07E-03	9.93E-03
48	9.91E-01	9.58E-04	8.97E-03

From Figure 5.2 and Table 5.5, the pump non-recovery probabilities presented in Table 5.6 were obtained for certain milestone times.

Table 5.6: Probability of PTR Non-Repair

Milestone	Available Time (hours)	Probability
PTR not recovered before boiling – NM	16.8	3.47E-01
PTR not recovered before 17 m – NM	37.5	2.88E-02
PTR not recovered before boiling – OM	5.9	9.14E-01
PTR not recovered before 17 m – OM	13.2	4.91E-01

The event trees and function events dealing with the failure to recover PTR cooling, together with the associated fault trees and basic events are listed in Table 5.7.

Table 5.7: PTR System Recovery Fault Trees

Event Tree	Function Event	Fault Tree	Basic Event
YLOPC_\PTR\NM Loss of SFP cooling due to a PTR system failure in Normal mode	PTR\REC_BB_NM Recovery of PTR system before SFP boiling at 19.3 m (NM)	PTR\C_BB_NM PTR not repaired before boiling or fails to run (NM)	PTR-RECOV-BB-NM PTR system not recovered before boiling during normal operation mode
	PTR\REC_BS_NM Recovery of PTR cooling before loss of PTR suction at 17 m (NM)	PTR\C_BS_NM PTR not repaired before loss of PTR suction (17 m) or fails to run	PTR-RECOV-BS-NM PTR system not recovered before loss of PTR suction (17 m) during normal operation mode
YLOPC_\PTR\OM Loss of SFP cooling due to a PTR system failure in Outage Mode	PTR\REC_BB_OM Recovery of PTR system before SFP boiling at 19.3 m (OM)	PTR\C-BB-OM PTR not repaired before boiling or fails to run (OM)	PTR-RECOV-BB-OM PTR system not recovered before boiling during outage operation mode
	PTR\REC_BS_17_OM Recovery of PTR cooling before loss of PTR suction at 17 m (OM)	PTR\C-BS-OM PTR not repaired before loss of PTR suction at 17 m or fails to run (OM)	PTR-RECOV-BS-OM PTR system not recovered before loss of PTR suction at 17 m or fails to run (OM)

5.2 SED SYSTEM FAULT TREES

The SED system is used as a means to make-up the SFP level in the event that cooling to the SFP fails and cannot be re-established. Make-up to the SFP can be achieved via SED, JPP or JPS and therefore, in most cases, SED make-up events are modeled in conjunction with JPP and JPS make-up events.

SED electrical supply is from the 9 LKK switchboard which is not diesel backed therefore SED make-up cannot be established during a SBO.

5.2.1 SED System Description

The station's demineralisation plant includes two demineralisation process lines, each designed for a net production of 2450 m^3/day. The demineralised water production plant is supplied by gravity from the Station's two main potable water storage tanks of 9000 m^3 each. This supply, based on the requirements of the two demineralisation process lines operating in parallel, is designed for a flow of 250 m^3/h. Part of the demineralised water, produced at pH 7, is stored in a 500 m^3 tank from which it is drawn off by two 75 m^3/h pumps for supply to the nuclear island demineralised water distribution system (SED).

Operation of the demineralisation and the resin regeneration systems is of the sequential automatic type.

The demineralisation building and the demineralised water storage tanks (pH 7 and pH 9) are located in the northern area of the station site.

An SED pump train is always running and will supply at least 25 m^3/hr of water to SFP from a 2.5” manual valve 144 VD in the SFP room. If there are no other SED loads, the flow may be as high as 98 m^3/hr (rounded up to 100 m^3/hr for the purposes of this report).

Make-up to the SED tank is manual. The SED tanks have low-level alarms.

5.2.2 SED System Success Criteria

SED system success criteria, by initiating event, are given in Table 5.8. The success criterion for SED make-up is that at least one SED pump train delivers up to 600 m^3 unborated water to the SFP at the rate of 25 – 100 m^3/hr. Flow rates depend on other SED loads at the time SFP make-up is required. In the fault tree model both trains were assumed to be on standby.

Table 5.8: SED System Success Criteria

INITIATING EVENT	SUCCESS CRITERIA
Catastrophic Door Seal Failure	Establish SED make-up before SFP boiling at 13.25 m (NM)
	Establish SED make-up before fuel damage from 13.25 m (NM)
Loss of SFP Cooling due to a PTR System Failure	Establish SED make-up before fuel damage
Loss of PTR Inventory due to a Flow Diversion	Establish SED make-up before boiling at 15.5 m
	Establish SED make-up before fuel damage
Loss of PTR Inventory due to a PTR Pipe Rupture	Establish SED make-up before SFP boiling at 15.5 m
	Establish SED make-up before fuel damage
LOSP	Establish SED make-up before fuel damage
SBO	Establish SED make-up before fuel damage

5.2.3 SED System Failure Model

The SED system was modelled using the fault trees. Pump and motor failures, including electrical supplies, were considered. Maintenance unavailability and valve failures were also modelled. The SED system is not diesel backed and therefore in the case of SBO SED make-up cannot be established.

As with the PTR system, the SED system is used extensively in the function events that comprise the SFP event trees. The Event trees and Function events dealing with the failure to establish SED make-up, together with the associated Fault trees are listed in Table 5.9.

Table 5.9: SED Make-Up Fault Trees

Event Tree	Function Event	Fault Tree
YCDSF_\PTR\NM Catastrophic door seal failure in Normal Mode	SED\MU_BB_13_NM Establish SED make-up before SFP boiling at 13.25 m (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
	SED\MU_BD_13_NM Establish SED make-up before fuel damage from 13.25 m (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOPC_\PTR\NM Los of SFP cooling due to a PTR system failure in Normal Mode	SED\MU_BD_17_NM Establish SED make-up before fuel damage (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOPC_\PTR\OM Loss of SFP cooling due to a OTR system failure in Outage Mode	SED\MU_BD_17_OM Establish SED make-up before fuel damage from 17 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation mode
YLOPI\D\PTR\NM Loss of PTR inventory due to a flow diversion in Normal Mode	SED\MU_BB_15_NM Establish SED make-up before SFP boiling at 15.5 m (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
	SED\MU_BD_15_NM Establish SED make-up before fuel damage (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOPI\D\PTR\OM Loss of PTR inventory due to a flow diversion in Outage Mode	SED\MU_BB_15_OM Establish SED make-up before SFP boiling at 15.5 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation mode
	SED\MU_BD_15_OM Establish SED make-up before fuel damage from 15.5 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation mode
YLOPI\R\PTR\NM Loss of PTR inventory due to a PTR pipe rupture in Normal Mode	SED\MU_BB_15_NM Establish SED make-up before SFP boiling at 15.5 m (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
	SED\MU_BD_15_NM Establish SED make-up before fuel damage (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOPI\R\PTR\OM Loss of PTR inventory	SED\MU_BB_15_OM Establish SED make-up before	SED-MU_OM Establish SED make-up before

Event Tree	Function Event	Fault Tree
due to a PTR pipe rupture in Outage Mode	SFP boiling at 15.5 m (OM)	fuel damage during outage operation mode
	SED\MU_BD_15_OM Establish SED make-up before fuel damage from 15.5 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation mode
YLOSP_\SFP\NM SFP LOSP in Normal Operation	SED\MU_BD_17_NM Establish SED make-up before fuel damage (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOSP_\SFP\OM SFP LOSP in Outage Operation	SED\MU_BD_17_OM Establish SED make-up before fuel damage from 17 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation mode
YLOSP\SBO\NM LOSP – ET for SFP SBO in Normal Mode	SED\MU_BD_17_NM Establish SED make-up before fuel damage (NM)	SED-MU_NM Establish SED make-up before fuel damage during normal operation mode
YLOSP\SBO\OM LOSP – ET for SFP SBO in Outage Mode	SED\MU_BD_17_OM Establish SED make-up before fuel damage from 17 m (OM)	SED-MU_OM Establish SED make-up before fuel damage during outage operation

5.3 LOSP AND SBO FAULT TREES

The first function event after a LOSP is to re-energise LHA or LHB. This function event was taken directly from the main Level 1 PSA model and is explained in PSA-S-T06-31; Loss of Essential Electrical Voltages [Ref. 17].

The first action after a SBO is to manually align the fifth diesel. This function event was also taken from the main Level 1 PSA model and is explained in PSA-S-T08-16; Post SBO AC Power Recovery Fault Trees [Ref. 18].

If the fifth diesel cannot be aligned, recovery of the grid is considered. Recovery of the grid was examined in PSA-N-T09-07; Loss of Grid Power Supply Frequency and Recovery Times for Koeberg NPP [Ref. 19].

5.3.1 Grid Recovery

The probability of non-recovery of the grid was determined from the graph presented in Figure 5.3 below for certain milestone times and are presented in Table 5.10.

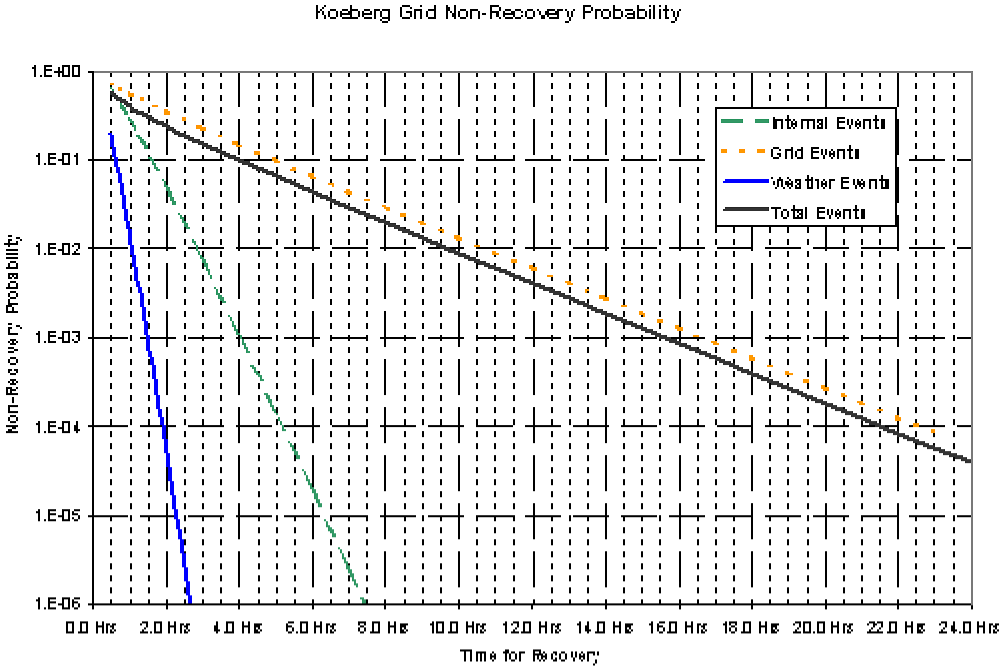


Figure 5.3: Grid Non-Recovery Probabilities

It should be noted that, due to limited data on grid recoveries, the above data cannot be used to predict non-recovery probabilities for extrapolated times. Therefore, for those milestone times over 24 hours, the non-recovery probability is cut off at 3.9E-05. This assumption however should be noted as being conservative.

Table 5.10: Non-Recovery of Grid Probabilities

Milestone	Available Time (hours)	Probability
Grid not recovered before boiling – NM	16.8	8.53E-04
Grid not recovered before 17 m – NM	37.5	3.98E-07
Grid not recovered before fuel damage – NM	103.8	4.06E-08
Grid not recovered before boiling – OM	5.9	6.60E-02
Grid not recovered before 17 m – OM	13.2	4.04E-03
Grid not recovered before fuel damage – OM	36.7	5.83E-07

The time to boil is calculated from an initial temperature of 50ºC in the SFP, the time to boil-off to a lower level in the SFP is also calculated from an initial temperature of 50ºC in the SFP. Therefore, in order to prevent “double counting” of times associated with these non-recovery probabilities, all cutsets including both failure to recover before boiling and failure to recover before 15.5 m were edited during post processing, during the quantification process in RiskSpectrum, to only include the latter event. Similarly, those cutsets including all three events, i.,e., failure to recover before boiling, failure to recover before 15.5 m and failure to recover before fuel uncovery, were edited during post processing to only include the failure to recover before fuel uncovery.

The event and fault trees associated with the recovery of the grid are listed in Table 5.11 together with the relevant function event.

Table 5.11: Grid Recovery Fault Trees

Event Tree	Function Event	Fault Tree
YLOSP\SBO\NM LOSP – ET for SFP SBO in Normal Mode	GRID_BB_NM Recovery of grid before SFP boiling at 19.3 m (NM)	GRID-NONREC-16H Probability of not recovering the Grid within 16 hours after a LOSP
	GRID_BS_NM Recovery of grid before loss of PTR suction at 17 m (NM)	GRID-NONREC-36H Probability of not recovering the Grid within 36 hours after a LOSP
	GRID_BD_NM Recovery of grid before fuel damage from 17 m	GRID-NONREC-42H Probability of not recovering the grid within 42 hours after a LOSP
YLOSP\SBO\OM LOSP – ET for SFP SBO in Outage Mode	GRID_BB_OM Recovery of grid before SFP boiling at 19.3 m (OM)	GRID-NONREC-05H Probability of not recovering the Grid within 05 hours after a LOSP
	GRID_BS_OM Recovery of grid before loss of PTR suction at 17 m (OM)	GRID-NONREC-12H Probability of not recovering the Grid within 12 hours after a LOSP
	GRID_BD_OM Recovery of grid before fuel damage from 17 m (OM)	GRID-NONREC-35H Probability of not recovering the Grid within 35 hours after a LOSP

5.4 JPP/JPS SYSTEM FAULT TREES

As with the PTR and SED systems, the JPP system is used extensively in the function events that comprise the SFP event trees.

5.4.1 JPP/JPS System Description

JPP, the fire fighting water production system, includes the fire fighting water distribution system (JPD) and the nuclear island fire protection system (JPI).

Fire Fighting Water Production System (JPP)

Each unit has two pumps (one pump per train). The capacity of each pump is 200 m^3/h and with a discharge pressure of 1.2 MPa. These pumps are located at the level 0.00 m of the SEC pump house. The discharge lines of the four pumps are interconnected by a connecting pipe fitted with two inter-unit valves in series.

The pumps are supplied by a fresh water reserve of two 1760 m^3 concrete tanks which are also located in the pumping station. This fresh water reserve is gravity fed from the two 9000 m^3 potable water tanks on the site. A volume of 1730 m^3 in each of these two tanks is reserved for fire fighting purposes.

If the freshwater reserve is exhausted, the fire protection pumps can be fed directly with seawater, filtered through the SEC filters, by opening a connection with the SEC system.

The pumps are started either manually from the control room, from the electrical supply switchboard or automatically on receiving a low-low level signal from the JPD pressurization tank.

Fire Fighting Water Distribution System (JPD, JPI)

In the conventional part of the station, the fire protection system is a closed loop. The main loop is divided into two half-loops, each of which can be isolated.

The closed loop is supplied by the fire protection pumps through two lines designed to ensure the protection of the nuclear island and the electrical rooms. These two lines can be isolated from the loop by normally open remotely controlled motor-operated valves. These valves can be manually closed.

In the nuclear part of the station, protection is provided by the nuclear island fire protection system (JPI) which branches off the two lines in various positions. JPD system provides an emergency water supply for ASG system.

The distribution system's inventory is maintained by a 40 m^3 tank pressurized by nitrogen. This tank is kept filled by two jockey pumps which take water from the SEP system. The tank is connected to the distribution system by a check valve, which only allows flow from the tank to the system. Water from the tank can be used for immediate fire fighting purposes prior to starting of the JPP pumps.

As the system is a closed loop, the vent and drain isolation valves are located in such a way as to enable maintenance operations on isolated sections without interruption of protection of areas representing the greatest hazard.

JPI flow to the SFP is 100 m^3/hr can be established via hydrant 9 JPD 817 BI.

5.4.2 JPP/JPS Success Criteria

The success criterion is to connect JPP to obtain 100 m^3/hr water flow into SFP for at least 6 hours. In the fault tree model both trains were assumed to be in standby. JPP and JPS system success criteria, by initiating event, are given in Table 5.12.

Table 5.12: JPP and JPS System Success Criteria

Initiating Event	Success Criteria
Catastrophic Door Seal Failure	Establish JPP/JPS make-up before SFP boiling at 13.25 m
	Establish JPP/JPS make-up before fuel damage from 13.25 m
Loss of SFP Cooling due to a PTR System Failure	Establish JPP/JPS make-up before fuel damage from 17 m

Initiating Event	Success Criteria
Loss of PTR Inventory due to a Flow Diversion	Establish JPP/JPS make-up before SFP boiling at 15.5 m
	Establish JPP/JPS make-up before fuel damage from 15.5 m
Loss of PTR Inventory due to a PTR Pipe Rupture	Establish JPP/JPS make-up before SFP boiling at 15.5 m
	Establish JPP/JPS make-up before fuel damage
LOSP	Establish JPP/JPS make-up before fuel damage from 17 m
SBO	Establish JPP/JPS make-up before fuel damage from 17 m

5.4.3 JPP/JPS System Failure Model

The JPP and JPS systems were modelled using fault trees. Pump and motor failures, including electrical supplies, were considered. Maintenance unavailability and valve failures were also modelled.

The function events dealing with the failure to establish JPP make up and JPS make up, together with the associated fault trees are listed in Table 5.13 and Table 5.14 respectively.

Table 5.13: JPP Make-Up Fault Trees

Event Tree	Function Event	Fault Tree
YCDSF_\PTR\NM Catastrophic door seal failure in Normal Mode	JPP\MU_BB_13_NM Establish JPP make-up before SFP boiling at 13.25 m (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
	JPP\MU_BD_13_NM Establish JPP make-up before fuel damage from 13.25 m (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
YLOPC_\PTR\NM Los of SFP cooling due to a PTR system failure in Normal Mode	JPP\MU_BD_17_NM Establish JPP make-up before fuel damage from 17 m	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
YLOPC_\PTR\OM Loss of SFP cooling due to a OTR system failure in Outage Mode	JPP\MU_BD_17_OM Establish JPP make-up before fuel damage from 17 m	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation
YLOPI\D\PTR\NM Loss of PTR inventory due to a flow diversion in Normal Mode	JPP\MU_BB_15_NM Establish JPP make-up before SFP boiling at 15.5 m level (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
	JPP\MU_BD_15_NM Establish JPP make-up before fuel damage from 15.5 m (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
YLOPI\D\PTR\OM Loss of PTR inventory due to a flow diversion in Outage Mode	JPP\MU_BB_15_OM Establish JPP make-up before SFP boiling at 15.5 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation
	JPP\MU_BD_15_OM Establish JPP make-up before fuel damage from 15.5 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during

Event Tree	Function Event	Fault Tree
		outage operation
YLOPI\R\PTR\NM Loss of PTR inventory due to a PTR pipe rupture in Normal Mode	JPP\MU_BB_15_NM Establish JPP make-up before SFP boiling at 15.5 m level (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
	JPP\MU_BD_15_NM Establish JPP make-up before fuel damage from 15.5 m (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
YLOPI\R\PTR\OM Loss of PTR inventory due to a PTR pipe rupture in Outage Mode	JPP\MU_BB_15_OM Establish JPP make-up before SFP boiling at 15.5 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation
	JPP\MU_BD_15_OM Establish JPP make-up before fuel damage from 15.5 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation
YLOSP_\SFP\NM SFP LOSP in Normal Operation	JPP\MU_BD_17_NM Establish JPP make-make before fuel damage from 17 m (NM)	JPP-MU_NM Establish JPP make-up before fuel damage during normal operation
YLOSP_\SFP\OM SFP LOSP in Outage Operation	JPP\MU_BD_17_OM Establish JPP make-up before fuel damage from 17 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation
YLOSP\SBO\NM LOSP – ET for SFP SBO in Normal Mode	JPP\MU_BD_17_NM Establish JPP make-up before fuel damage from 17 m (NM)	JPP-MU_NM Establish JPP make-up before fuel dmamge during normal operation
YLOSP\SBO\OM LOSP – ET for SFP SBO in Outage Mode	JPP\MU_BD_17_OM Establish JPP make-up before fuel damage from 17 m (OM)	JPP-MU_OM Establish JPP make-up before fuel damage during outage operation

Table 5.14: JPS Make-Up Fault Trees

Event Tree	Function Event	Fault Tree
YCDSF_\PTR\NM Catastrophic door seal failure in Normal Mode	JPS\MU_BB_13_NM Establish JPS make-up before SFP boiling at 13.25 m (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
	JPS\MU_BD_13_NM Establish JPS make-up before fuel damage from 13.25 m (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOPC_\PTR\NM Los of SFP cooling due to a PTR system failure in Normal Mode	JPS\MU_BD_17_NM Establish JPS make-up before fuel damage (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOPC_\PTR\OM Loss of SFP cooling due to a OTR system failure in Outage Mode	JPS\MU_BD_17_OM Establish JPS make-up before fuel damage from 17 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
YLOPI\D\PTR\NM Loss of PTR inventory due to a flow diversion in Normal Mode	JPS\MU_BB_15_NM Establish JPS make-up before SFP boiling at 15.5 m (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation

Event Tree	Function Event	Fault Tree
	JPS\MU_BD_15_NM Establish JPS make-up before fuel damage (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOPI\D\PTR\OM Loss of PTR inventory due to a flow diversion in Outage Mode	JPS\MU_BB_15_OM Establish JPS make-up before SFP boiling at 15.5 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
	JPS\MU_BD_15_OM Establish JPS make-up before fuel damage from 15.5 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
YLOPI\R\PTR\NM Loss of PTR inventory due to a PTR pipe rupture in Normal Mode	JPS\MU_BB_15_NM Establish JPS make-up before SFP boiling at 15.5 m level (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
	JPS\MU_BD_15_NM Establish JPS make-up before fuel damage (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOPI\R\PTR\OM Loss of PTR inventory due to a PTR pipe rupture in Outage Mode	JPS\MU_BB_15_OM Establish JPS make-up before SFP boiling at 15.5 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
	JPS\MU_BD_15_OM Establish JPS make-up before fuel damage from 15.5 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
YLOSP_\SFP\NM SFP LOSP in Normal Operation	JPS\MU_BD_17_NM Establish JPS make-up before fuel damage (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOSP_\SFP\OM SFP LOSP in Outage Operation	JPS\MU_BD_17_OM Establish JPS make-up before fuel damage (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation
YLOSP\SBO\NM LOSP – ET for SFP SBO in Normal Mode	JPS\MU_BD_17_NM Establish JPS make-up before fuel damage (NM)	JPS-MU_NM Establish JPS make-up before fuel damage during normal operation
YLOSP\SBO\OM LOSP – ET for SFP SBO in Outage Mode	JPS\MU_BD_17_OM Establish JPS make-up before fuel damage from 17 m (OM)	JPS-MU_OM Establish JPS make-up before fuel damage during outage operation

5.5 COMMON CAUSE FAILURE (CCF)

CCF probabilities were quantified for valves, heat exchangers, pumps and pump motors. The MGL model was used and the parameters were obtained from Guidelines on Modelling Common-Cause Failures in Probabilistic Risk Assessment [Ref. 20]. CCF probabilities of breakers and contactors were not quantified as the Level 1 PSA model already has these values, which were included without revision in the SFP model. A summary of each CCF evaluation that was performed is shown in Appendix A.

5.6 ALARMS, INSTRUMENTATION AND MONITORING

Instrumentation is available to monitor SFP water level and temperature and the radiation levels in the fuel storage building. Additional instrumentation is provided to monitor the pressure, flow, and temperature of the SFP cooling and cleanup system.

It should be noted that this instrumentation is generally non-redundant, apart from PTR 002 AA; PTR 002 PO pump fault, all sensors and alarms are supplied from Train A.

The pool water is sampled periodically to determine the boron concentration as well as the gross radioactivity. Chemical analyses are used to determine the SFP boron concentration. The instrumentation provided to monitor gamma radiation in the fuel storage building indicates locally and annunciates in the control room. Two activity measurements are continuously taken at the water surface of the spent fuel pit. An activity measurement is made at the water surface of the reactor cavity.

The instrumentation provided to monitor the SFP water temperature indicates locally and annunciates in the control room. The temperature of the fuel pool is measured by two train-related Resistance Temperature Detectors (RTDs): PTR 100 MT and PTR 101 MT. These detectors give an output to a recorder PTR 100 EN as well as PTR 101 ID. Apart from indication and trending, the sensors will trigger high and high-high temperature alarms in the 19 m control room if the temperature in the SFP exceeds 50°C and 80°C. If the SFP temperature reaches and exceeds 40°C then the SFP temperature must be monitored hourly.

SFP water level instrumentation and abnormal level alarms indicates locally and annunciates in the control room. The SFP level is normally at 19.50 m with the high and low SFP level alarm setpoints at 19.55 m and 19.3 m, respectively. The spent fuel pool level is detected by PTR 100 MN and PTR 101 MN. The level sensors are of the bubbler type and use compressed air (SAR) to measure the level. The train A level sensor PTR 101 MN gives indication of level on the KPR panel as well as the control room, but the train B sensor PTR 100 MN only gives an output to the control room. Each sensor has its own dedicated air reservoir located on the 0 m level in the fuel building next to the PTR 001 PO and PTR 002 PO. Two independent air supplies are used as the level sensors are train related. Each tank has been designed to supply its sensor for at least 100 hours in the event of a loss of air. This value can be extended to more than double the time if one sensor is used intermittently. The 100 hours is considered sufficient time for the repair of one compressor or finding other means to supply the compressed air.

The heat exchanger outlet temperature is measured by PTR 001 MT and PTR 002 MT. These sensors output is displayed on PTR 102 ID and PTR 100 EN in the control room. The sensors initiate a high temperature alarm if the heat exchanger outlet exceeds 44°C. Locally there are inlet as well as outlet temperature gauges for monitoring. Fouling of the heat exchanger tubes are detected by differential pressure gauges that measure the pressure drop across the PTR heat exchanger. Only local indication for the exchanger delta P is available.

The refuelling water storage tank is equipped with three level transmitters (PTR 018 MN, PTR 019 MN and PTR 020 MN), which provide level measurements for indication and protection. The PTR tank level can be monitored in the control room by the following means:

- Alarms – PTR 001 BA tank level low/abnormal, as measured by PTR 019 MN/PTR 18 MN (PTR 401 AA/PTR 402 AA). The setpoint is at the 15.3 m level;
- KIT - PTR 001BA level low/abnormal (PTR 401 EC/PTR 402 EC);
- Control Room IDs - PTR 401 ID/PTR 402 ID/PTR 404 ID.

Table 5.15, Table 5.16 and Table 5.17 list the PTR alarms, indications and controls available to monitor and control the PTR system.

Table 5.15: PTR Alarms

Train	Identifier	Setpoint	Description
A	PTR100AA	19.55 m	Spent Fuel Pool Level High
B	PTR101AA	19.55 m	Spent Fuel Pool Level High
A	PTR102AA	19.3 m	Spent Fuel Pool Level Low
B	PTR103AA	19.3 m	Spent Fuel Pool Level Low
A	PTR104AA	18.0 m	Spent Fuel Pool Level Low Low
B	PTR105AA	18.0 m	Spent Fuel Pool Level Low Low
A	PTR106AA	50°C	Spent Fuel Pool Temperature High
B	PTR107AA	50°C	Spent Fuel Pool Temperature High
A	PTR108AA	80°C	Spent Fuel Pool Temperature High High
B	PTR109AA	80°C	Spent Fuel Pool Temperature High High
A	PTR110AA	44°C	001RF Outlet Temperature High
B	PTR111AA	44°C	002RF Outlet Temperature High
A	PTR112AA		Mode Selection Fault
B	PTR113AA		Mode Selection Fault
A	PTR114AA		001PO Pump Fault
B	PTR115AA		002PO Pump Fault

To enable the operator to monitor the PTR system the indications presented in Table 5.16 are available.

Table 5.16: KSC and KPR Indications to Monitor PTR

Train A				
Transmitter	**Description**	**Indicator**	**KIT**	**Recorder**
PTR 101 MN	SFP level	PTR 100 ID1 PTR 104 ID1 (KPR)	PTR 101 MN	PTR 100 EN (1)

Train A				
Transmitter	**Description**	**Indicator**	**KIT**	**Recorder**
PTR 101 MT	SFP temp	PTR 101 ID1 PTR 104 ID2 (KPR)	PTR 101 MT	PTR 100 EN (3)
PTR 103 MT	HX outlet temp	PTR 102 ID1	PTR 103 MT	PTR 100 EN (5)
PTR 101 MD	upstream HX flow	PTR 103 ID1	PTR 101 MD	
DVK 101 MP	FB pressure	DVK 100 ID1	DVK 101MP	
Train B				
PTR 100 MN	SFP level	PTR 100 ID2 PTR 104 ID2 (KPR)	PTR 100 MN	PTR 100 EN (2)
PTR 100 MT	SFP temp	PTR 101 ID2	PTR 100 MT	PTR 100 EN (4)
PTR 102 MT	HX outlet temp	PTR 102 ID2	PTR 102 MT	PTR 100 EN (6)
PTR 100 MD	upstream HX flow	PTR 103 ID2	PTR 100 MD	
DVK 100 MP	FB pressure	DVK 100 ID2	DVK 100MP	

The Re-Racking project, S95168-1/2 (suite of SFP ANSI Phase 2 modifications), introduced a new set of requirements for Spent Fuel Storage, and Spent Fuel Pool Cooling in particular. These requirements are from ANSI/ANS 57.2-1983 [Ref. 60] and ANSI/ANS 51.1-1983 [Ref. 61]and allow for the two-region storage of spent fuel, taking credit for burn-up of fuel assemblies and fission products. To accommodate these requirements, certain PTR indications and controls are now located in the control room (KSC) and on the Emergency Control (KPR) panel. The controls presented in Table 5.17 are located on Panel T 02, or KPR.

Table 5.17: KSC and KPR Controls For PTR

Component	Label	Description
PTR 001 PO	PTR 001 TL	Pump start/stop TPL
PTR 002 PO	PTR 001 TL	Pump start/stop TPL
3 way switch	PTR 001 CV	PTR 001 PO - Start inhibit, or cooling, or non-cooling
3 way switch	PTR 002 CV	PTR 002 PO - Start inhibit, or cooling, or non-cooling
PTR 961 VD	PTR 005 TL	PTR 961 VD open/close TPL
PTR 961 VD	PTR 003 CC	PTR 961 VD Train A/B selector switch
SED 981 VD	SED 001 TL	SED 981 VD open/close TPL
PTR 001 PO	PTR 003 TL (KPR)	Pump start/stop TPL (KPR)
PTR 002 PO	PTR 004 TL (KPR)	Pump start/stop TPL (KPR)
2 way switch	PTR 001 CC (KPR)	PTR 001 PO - Remove control from KSC (KPR)
2 way switch	PTR 002 CC (KPR)	PTR 002 PO - Remove control from KSC (KPR)

6 HUMAN RELIABILITY ANALYSES

This section describes the HRA for those event tree function events containing operator actions.

The event sequences considered in this analysis are heavily dependent on operator actions. These actions typically have long diagnostic and action time periods. These time periods are in hours as opposed to the typical time windows in terms of fraction of hours as typically found in the at-power Level 1 PSA event sequences.

In a typical at-power core damage sequence quantification the total credit for operator actions may be limited to a total of 1.0E-05 for a given sequence. On the other hand, in shutdown operations, and the SFD sequences studied here, such a limitation may not be appropriate and even misleading. However, the dependence among actions in the same sequence must always be evaluated and factored in as appropriate.

It is recognised that the failure of operator actions to terminate SFP make-up from an unborated water source is calculated to have a very small probability. It actually consists of a product of multiple failures by different crew, even different shifts over time periods of many hours.

Each of the HEP Basic Events (BEs) listed in Table 6.1 were analysed in the EPRI HRA CALCULATOR in line with the SPAR-H methodology.

Actions are proceduralised in the following references:

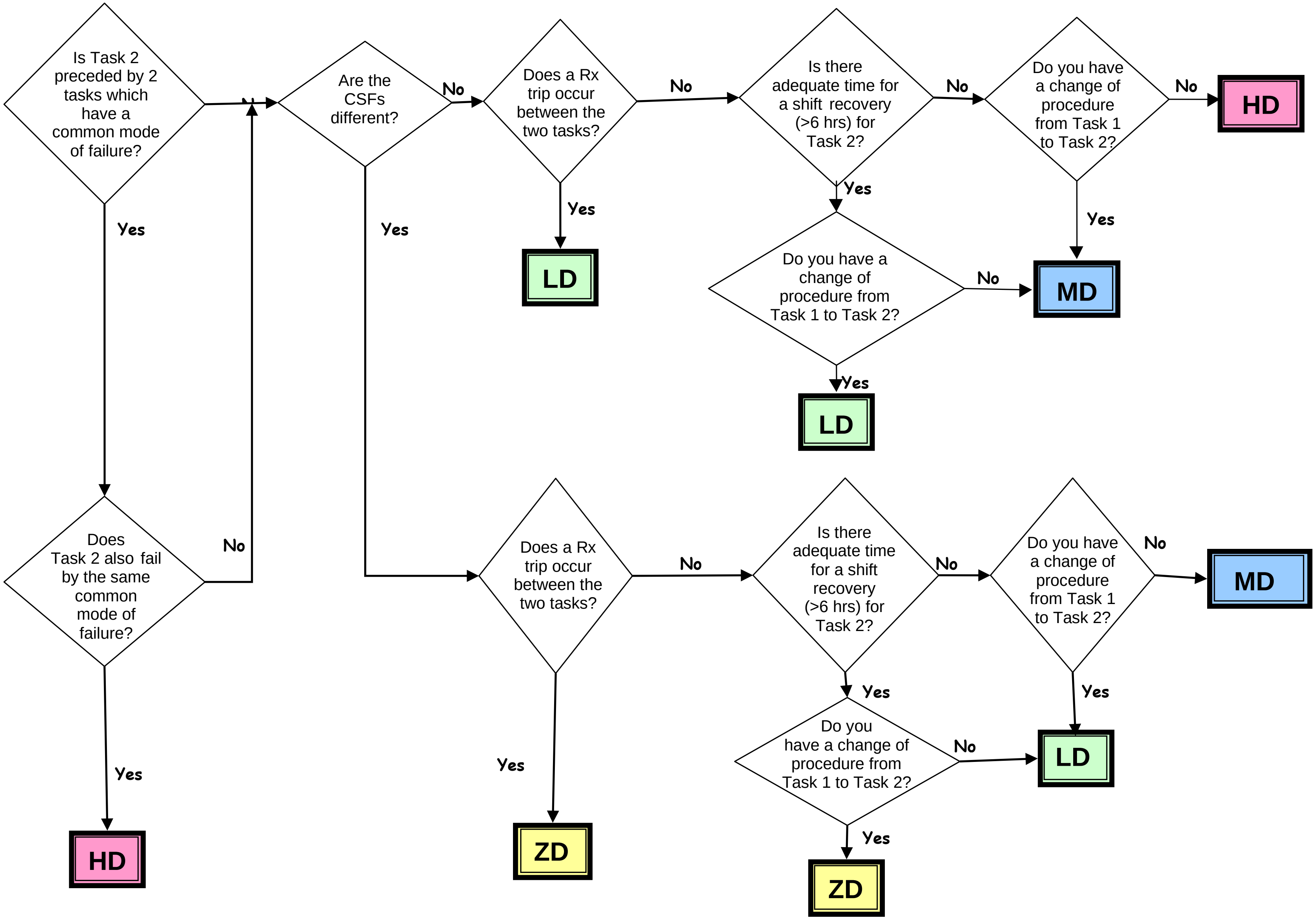
- KWB-OP-PTR-001; Spent Fuel Pit Cooling System Operation [Ref. 21];
- KWB-I.PTR; Total Loss of SFP Cooling [Ref. 22];
- KWB-1-LAS 055; Preparation of SFP Emergency Make-up from JPD [Ref. 23];
- KWB-1-LAS 046; Connect Mobile Fire Pump to JPD, [Ref. 24];
- KWB-I.RRI 7 / SEC; Loss of RRI and / or SEC [Ref. 25]; and
- KGB-ECA-0.0; Total Loss of All AC Power [Ref. 26].

Table 6.1: List of HRA HEPs Performed

BE ID	BE Description	HEP
HES-JPP-BB-13-NM	Establish JPP make-up before SFP boiling at 13.25m (normal operating mode)	1.10E-04
HES-JPP-BB-15-NM	Establish JPP make-up before SFP boiling at 15.5m (normal operation mode)	1.10E-04
HES-JPP-BB-15-OM	Establish JPP make-up before SFP boiling at 15.5m (outage operation mode)	1.10E-04
HES-JPP-BD-13-NM	Establish JPP make-up before SFP Level drains from 13.25 m to 9.85 m (normal operating mode)	4.50E-05
HES-JPP-BD-15-NM	Establish JPP make-up before SFP draining to 9.85m from 15.5m (normal operating mode)	9.00E-06

BE ID	BE Description	HEP
HES-JPP-BD-15-OM	Establish JPP make-up before SFP draining to 9.85m from 15.5m (outage operating mode)	9.00E-05
HES-JPP-BD-17-NM	Establish JPP make-up before SFP draining to 9.85m from 17m (normal operating mode)	9.00E-06
HES-JPP-BD-17-OM	Establish JPP make-up before SFP draining to 9.85 m from 17 m (outage operating mode)	8.50E-05
HES-JPS-BB-13-NM	Establish JPS make-up before SFP boiling at 13.25m (normal operating mode)	2.10E-03
HES-JPS-BB-15-NM	Establish JPS make-up before SFP boiling at 15.5m (normal operating mode)	2.80E-04
HES-JPS-BB-15-OM	Establish JPS make-up before SFP boiling at 15.5m (outage operation mode)	2.10E-03
HES-JPS-BD-13-NM	Establish JPS make-up before SFP Level drains from 13.25 m to 9.85 m (normal operating mode)	2.80E-04
HES-JPS-BD-15-NM	Establish JPS make-up before SFP draining to 9.85m from 15.5m (normal operating mode)	9.00E-05
HES-JPS-BD-15-OM	Establish JPS make-up before SFP draining to 9.85 m from 15.5 m (outage operating mode)	2.80E-04
HES-JPS-BD-17-NM	Establish JPS make-up before SFP draining to 9.85 m from 17 m (normal operating mode)	9.00E-05
HES-JPS-BD-17-OM	Establish JPS make-up before SFP draining to 9.85 m from 17 m (outage operating mode)	2.80E-04
HES-PTR-C\L-BB-19-NM	Start PTR cooling after LOSP before SFP boiling (normal operation mode)	2.30E-05
HES-PTR-C\L-BB-19-OM	Start PTR cooling after LOSP before SFP boiling at 19.3 m (outage operation mode)	1.10E-04
HES-PTR-C\L-BS-17-NM	Start PTR cooling after LOSP before loss of PTR suction at 17m level (normal operating mode)	4.30E-05
HES-PTR-C\L-BS-17-OM	Start PTR cooling after LOSP before loss of PTR suction at 17 m level (outage operation mode)	1.30E-04
HES-PTR-C\SBO-BB-NM	Start PTR cooling before SFP boiling at 19.3m (normal operation mode)	1.10E-04
HES-PTR-C\SBO-BB-OM	Start PTR cooling before SFP boiling at 19.3m (outage operation mode)	1.30E-03
HES-PTR-C\SBO-BS-NM	Start PTR cooling before loss of PTR suction at 17m (normal operation mode)	1.30E-04
HES-PTR-C\SBO-BS-OM	Start PTR cooling before loss of PTR suction at 17m (outage operation mode)	1.30E-04
HES-PTR-FD\ISO-15-NM	PTR flow diversion isolated before loss of PTR suction at 17m (normal operating mode)	4.30E-03
HES-PTR-FD\ISO-15-OM	PTR flow diversion isolated before loss of PTR suction at 17m (outage operation mode)	4.30E-03
HES-SED-BB-13-NM	Establish SED make-up before SFP boils at 13.25 m (normal operating mode)	5.40E-05
HES-SED-BB-15-NM	Establish SED make-up before SFP boiling at 15.5m (normal operation mode)	5.40E-05

BE ID	BE Description	HEP
HES-SED-BB-15-OM	Establish JPS make-up before SFP boiling at 15.5m (outage operation mode)	5.40E-05
HES-SED-BD-13-NM	Establish SED make-up before SFP Level drains from 13.25 m to 9.85 m (normal operating mode)	4.50E-05
HES-SED-BD-15-NM	Establish SED make-up before SFP draining to 9.85m from 15.5m (normal operating mode)	4.50E-06
HES-SED-BD-15-OM	Establish SED make-up before SFP draining to 9.85 m from 15.5 m (outage operating mode)	4.50E-05
HES-SED-BD-17-NM	Establish SED make-up before SFP Level drains from 17 m to 9.85 m (normal operating mode)	4.50E-06
HES-SED-BD-17-OM	Establish SED make-up before SFP draining to 9.85m from 17m (outage operating mode)	4.50E-05


Is Task 2 preceded by 2 tasks which have a common mode of failure?
Yes
No
Does Task 2 also fail by the same common mode of failure?
Yes
HD
Are the CSFs different?
No
Yes
Does a Rx trip occur between the two tasks?
Yes
LD
No
Is there adequate time for a shift recovery (>6 hrs) for Task 2?
Yes
Do you have a change of procedure from Task 1 to Task 2?
No
MD
Yes
LD
No
Do you have a change of procedure from Task 1 to Task 2?
Yes
MD
No
HD
Does a Rx trip occur between the two tasks?
Yes
ZD
No
Is there adequate time for a shift recovery (>6 hrs) for Task 2?
Yes
Do you have a change of procedure from Task 1 to Task 2?
No
LD
Yes
ZD
No
Do you have a change of procedure from Task 1 to Task 2?
Yes
LD
No
MD

The dependency between individual HEPs appearing in the same MCSs were evaluated and assigned according to the logic presented in the diagram above [Ref. 67]. In summary:

- Time < 6 hours = High Dependency (HD);
- 6 hours < Time < 24 hours = Medium Dependency (MD); and
- Time > 24 hours = Low Dependency (LD).

The HEP Group (HEG) probabilities are presented in Table 6.2. Most dependencies for post-initiator HEPs are low or medium as the probabilities of common mode of failure is low. This is only applicable where it is the same system being considered. Different systems are used for SFP make-up, e.g., SED, JPP and JPS.

Table 6.2: HEP Groups

HEP Groups	Fractional Contribution (Total)					FDF
HEP	Ind. HEP	LD	MD	HD	HEG	Contribution
HEG-ACACIA-OV/LD	5.33E-02				5.33E-02	2.68E-09
HES-PTR-FD\ISO-15-NM	1.27E-02				1.27E-02	6.39E-10
HES-JPP-BB-15-NM	0.00E+00		1.15E-02		1.15E-02	5.78E-10
HES-JPP-BD-15-NM	0.00E+00	1.14E-02			1.14E-02	5.73E-10
HES-SED-BB-15-NM	3.71E-07		1.11E-02		1.11E-02	5.58E-10
HES-SED-BD-15-NM	0.00E+00	1.11E-02			1.11E-02	5.58E-10
HES-SED-BD-17-OM	1.94E-03	7.76E-03			9.70E-03	4.88E-10
HES-PTR-FD\ISO-15-OM	9.46E-03				9.46E-03	4.76E-10
HES-JPP-BD-17-OM	5.78E-05	9.25E-03			9.31E-03	4.68E-10
HES-JPP-BB-15-OM	2.55E-11			9.17E-03	9.17E-03	4.61E-10
HES-JPP-BD-15-OM	0.00E+00	9.17E-03			9.17E-03	4.61E-10
HES-SED-BB-15-OM	2.79E-08			9.07E-03	9.07E-03	4.56E-10
HES-SED-BD-15-OM	0.00E+00	9.07E-03			9.07E-03	4.56E-10
HES-PTR-C\L-BB-19-NM	8.09E-03				8.09E-03	4.07E-10
HES-SED-BD-17-NM	2.40E-04	7.70E-03			7.94E-03	3.99E-10
HES-PTR-C\L-BB-19-OM	7.93E-03				7.93E-03	3.99E-10
HES-PTR-C\L-BS-17-OM	0.00E+00		7.93E-03		7.93E-03	3.99E-10
HES-PTR-C\L-BS-17-NM	0.00E+00		7.87E-03		7.87E-03	3.96E-10
HES-JPP-BD-17-NM	3.54E-07	7.76E-03			7.76E-03	3.90E-10
HES-JPS-BD-17-OM	9.59E-05	4.75E-03			4.85E-03	2.44E-10
HES-JPS-BD-17-NM	1.44E-04	3.88E-03			4.02E-03	2.02E-10
HES-JPS-BB-15-OM	1.44E-08			2.97E-03	2.97E-03	1.49E-10
HES-JPS-BD-15-OM	0.00E+00	2.97E-03			2.97E-03	1.49E-10
HES-JPS-BB-15-NM	3.13E-08		1.54E-03		1.54E-03	7.75E-11
HES-JPS-BD-15-NM	0.00E+00	1.53E-03			1.53E-03	7.70E-11
HES-JPP-BD-13-NM	1.34E-07	4.34E-04			4.34E-04	2.18E-11
HES-SED-BD-13-NM	1.61E-05	4.02E-04			4.18E-04	2.10E-11
HES-JPP-BB-13-NM	3.66E-05		1.26E-04		1.63E-04	8.18E-12
HES-JPS-BD-13-NM	1.89E-06	1.50E-04			1.52E-04	7.64E-12

HEP Groups HEP	Fractional Contribution (Total)					FDF Contribution
	Ind. HEP	LD	MD	HD	HEG	
HES-SED-BB-13-NM	1.40E-04				1.40E-04	7.04E-12
HES-JPS-BB-13-NM	9.07E-06		2.13E-05		3.04E-05	1.53E-12
HES-PTR-C\SBO-BB-OM	2.62E-07				2.62E-07	1.32E-14
HES-PTR-C\SBO-BS-OM	2.76E-10		2.62E-07		2.62E-07	1.32E-14
HES-PTR-C\SBO-BB-NM	3.82E-08				3.82E-08	1.92E-15
HES-PTR-C\SBO-BS-NM	1.16E-11	3.55E-08			1.79E-08	1.32E-15
HEG-LHS-ECA00-01H	8.47E-12				8.47E-12	4.26E-19

7 RESULTS

7.1 FUEL DAMAGE FREQUENCY

The primary focus of this analysis was to quantify the set of initiating events that were considered as precursors for those event sequences that lead to the spent fuel damage consequence state. The results from the post-SGR Koeberg PSA model – PSA13R11_L2_SFP_FIN.RPP show an estimated FDF of 5.03E-08 per year.

7.1.1 MCS Analysis

Table 7.1 presents a comparison of the FDF for NM and OM.

Table 7.1: Normal Mode and Outage Mode Spent Fuel Damage Frequencies

Mode	Conditional Fuel Damage Frequency	Normal Fuel Damage Frequency
Normal Mode	5.13E-08	4.83E-08
Outage Mode	3.40E-08	1.99E-09
TOTAL	**N/A**	**5.03E-08**

The initiating event contributions to FDF are presented in Table 7.2 and Figure 7.1.

Table 7.2: Consequence State Frequency For All Initiating Events

Initiating Event	**FC**		**FD**	**% of FD**
	(Fraction)		*(Events/Year)*	*(%)*
	2FD-NORMAL-ALL	**2FD-NORMAL-NM**	**2FD-NORMAL-ALL**	**2FD-NORMAL-ALL**
Multiple misplacement of fresh assemblies (NM)	8.46E-01	8.81E-01	4.26E-08	84.60
Catastrophic door seal failure (NM)	4.89E-03	5.09E-03	2.46E-10	0.49
SFP LOSP (NM)	9.56E-02	9.95E-02	4.81E-09	9.56
Loss of PTR inventory due to a flow diversion (NM)	1.28E-02	1.34E-02	6.46E-10	1.28
Local Dilution (NM)	1.09E-03	1.13E-03	5.48E-11	0.11
Global Boron Dilution (NM)	1.45E-04	1.51E-04	6.19E-12	0.01
Loss of Spent Fuel Pool cooling due to a PTR system failure (NM)	8.29E-05	8.63E-05	4.17E-12	0.01
Loss of SFP Inventory due to PTR Pipe Rupture (NM)	2.24E-13	2.34E-13	1.69E-21	0.00
		2FD-NORMAL-OM		
SFP LOSP in (OM)	2.69E-02	6.81E-01	1.35E-09	2.69
Loss of PTR inventory due to a flow diversion in (OM)	9.47E-03	2.40E-01	4.77E-10	0.95
Local Dilution (OM)	1.13E-03	2.87E-02	5.69E-11	0.11
Global Boron Dilution (OM)	1.52E-04	3.85E-03	7.65E-12	0.02
Loss of Spent Fuel Pool cooling due to a PTR system failure (OM)	1.82E-03	4.60E-02	9.16E-11	0.18
Loss of SFP Inventory due to PTR Pipe Rupture (OM)	3.38E-14	8.53E-13	1.69E-21	0.00
Overall Fuel Damage Frequency *			**5.03E-08**	**100.00**

PAIA section 44 (2)a.Redacted information could jepoardise effectiveness of testing procedure if disclosed

The most dominant contributors to the fuel damage frequency result from:

- Multiple misplacement of fresh assemblies (NM); and
- SFP LOSP (NM).

The above two dominant event tree groups contribute 94.16% (4.74E-08) to the overall FDF.

The HRA results show that the operator actions listed below now feature predominantly in the top minimal cutsets:

- HEC-ACACIA-OV/LD: Operator Overloaded Acacia PS;
- HES-PTR-FD\ISO-15-NM: Operator Fails to Isolate PTR flow Diversion Before 15.5 m (NM);
- HMD-JPP-BB-15-NM: Establish JPS make-up before SFP boiling at 15.5 m (NM); and
- HLD-JPP-BD-15-NM: Establish JPP make-up before SFP draining to 9.85 m from 15.5 m (NM).

7.1.2 Basic Event Fussel-Vesely (BE FV) Importance

The FV importance of the top 10 BEs are presented in Table 7.3 below.

Table 7.3: Basic Event Fussel-Vesely (BE FV) Importance

No	ID	Description	FV
1	9JPS001MO-FR	9 JPS 001 MO Fails whilst Running	1.35E-01
2	CC-BRK\AC\L6-SO-ALL	CCF Group for the Spurious Opening of the (380 V) LLx (DF2) Breakers	5.14E-02
3	SED981VD\P-FO	SED 981 VD Fails to Open	2.86E-02
4	CC-CTR\AC\M8-FC-ALL	CCF Group for the Failure to Close of the 380 V (Motor) Safeguard Contactors (CF5)	2.74E-02
5	CC-CHG\BATT4-FR-ALL	CCF Group for the Failure to Run of the LCx (48 V) Battery Chargers	1.70E-02
6	9LKK-LP	9 LKK 380 V de-energised	1.32E-02
7	PTR961VD\P-FO	PTR 961 VD Fails to Open	6.13E-03
8	CC-BAT\LEAD3-ST-ALL	CCF Group for the Failure due to Short Circuiting of the LCx (48 V) Batteries	3.91E-03
9	CC-APS\ENG-FS-ALL	CCF Group for the Failure to Start of the Acacia Gas Turbine Engines	3.56E-03
10	CC-CTR\ACM11-SO-ALL	CCF Group for the Spurious Opening of the 380 V (Motor) Safeguard Contactors (CF5)	2.97E-03

7.1.3 Basic Event Fractional Contribution (BE FC) Importance

The FC of the top 10 BEs are presented in Table 7.4 below.

Table 7.4: Basic Event Fractional Contribution (BE FC) Importance

No	ID	Description	FC
1	9JPS001MO-FR	9 JPS 001 MO Fails whilst Running	1.35E-01
2	CC-BRK\AC\L6-SO-ALL	CCF Group for the Spurious Opening of the (380 V) LLx (DF2) Breakers	5.14E-02
3	SED981VD\P-FO	SED 981 VD Fails to Open	2.86E-02
4	CC-CTR\AC\M8-FC-ALL	CCF Group for the Failure to Close of the 380 V (Motor) Safeguard Contactors (CF5)	2.74E-02
5	CC-CHG\BATT4-FR-ALL	CCF Group for the Failure to Run of the LCx (48 V) Battery Chargers	1.70E-02
6	9LKK-LP	9 LKK 380 V de-energised	1.32E-02
7	PTR961VD\P-FO	PTR 961 VD Fails to Open	6.13E-03
8	CC-BAT\LEAD3-ST-ALL	CCF Group for the Failure due to Short Circuiting of the LCx (48 V) Batteries	3.91E-03
9	CC-APS\ENG-FS-ALL	CCF Group for the Failure to Start of the Acacia Gas Turbine Engines	3.56E-03
10	CC-CTR\ACM11-SO-ALL	CCF Group for the Spurious Opening of the 380 V (Motor) Safeguard Contactors (CF5)	2.97E-03

7.1.4 Basic Event Risk Decrease Factor (BE RDF)

The RDF of the top 10 BEs are presented in Table 7.5 below.

Table 7.5: Basic Event Risk Decrease Factor (BE RDF)

No	ID	Description	RDF
1	9JPS001MO-FR	9 JPS 001 MO Fails whilst Running	1.16E+00
2	CC-BRK\AC\L6-SO-ALL	CCF Group for the Spurious Opening of the (380 V) LLx (DF2) Breakers	1.05E+00
3	SED981VD\P-FO	SED 981 VD Fails to Open	1.03E+00
4	CC-CTR\AC\M8-FC-ALL	CCF Group for the Failure to Close of the 380 V (Motor) Safeguard Contactors (CF5)	1.03E+00
5	CC-CHG\BATT4-FR-ALL	CCF Group for the Failure to Run of the LCx (48 V) Battery Chargers	1.02E+00
6	9LKK-LP	9 LKK 380 V de-energised	1.01E+00
7	PTR961VD\P-FO	PTR 961 VD Fails to Open	1.01E+00
8	CC-BAT\LEAD3-ST-ALL	CCF Group for the Failure due to Short Circuiting of the LCx (48 V) Batteries	1.00E+00
9	CC-APS\ENG-FS-ALL	CCF Group for the Failure to Start of the Acacia Gas Turbine Engines	1.00E+00
10	CC-CTR\ACM11-SO-ALL	CCF Group for the Spurious Opening of the 380 V (Motor) Safeguard Contactors (CF5)	1.00E+00

7.1.5 Basic Event Risk Increase Factor (BE RIF)

The RIF of the top 10 BEs are presented in Table 7.6 below.

Table 7.6: Basic Event Risk Increase Factor (BE RIF)

No	ID	Description	RIF
1	CC-CHG\BATT4-FR-ALL	CCF Group for the Failure to Run of the LCx (48 V) Battery Chargers	3.03E+04
2	CC-BAT\LEAD3-ST-ALL	CCF Group for the Failure due to Short Circuiting of the LCx (48 V) Batteries	3.03E+04
3	CC-BRK\AC\L6-SO-ALL	CCF Group for the Spurious Opening of the (380 V) LLx (DF2) Breakers	3.02E+04
4	MIS-L-FUEL	Misplacing leaker fuel assemblies	5.89E+03
5	MIS-SSF	Misplacing single old fuel assembly	5.89E+03
6	MIS-SNF	Misplacing single new fuel assembly	5.89E+03
7	CC-SBD\DC\C1-FR-ALL	CCF Group for the Failure whilst in Service of the LCx Switchboards	6.57E+02
8	CC-CHG\BATT2-FR-ALL	CCF Group for the Failure to Run of the LBx (125 V) Battery Chargers	6.48E+02
9	CC-BAT\LEAD2-ST-ALL	CCF Group for the Failure due to Short Circuiting of the LBx (125 V) Batteries	6.44E+02
10	CC-CTR\AC\M8-FC-ALL	CCF Group for the Failure to Close of the 380 V (Motor) Safeguard Contactors (CF5)	6.18E+02

7.1.6 Component Fractional Contribution Importance (Comp FC)

The Component Fractional Contribution (Comp FC) of the top 10 components are presented in Table 7.7 below.

Table 7.7: Component Fractional Contribution Importance (Comp FC)

No	ID	Description	FC
1	9JPS001PO	9 JPS 001 PO	1.38E-01
2	SED981VD\P	SED981VD	2.86E-02
3	9LKK001TB\L	9 LKK 380 V Switchboard	1.32E-02
4	PTR961VD\P	PTR 961 VD	6.13E-03
5	ACACIA-KBG-LINE	Acacia Line	2.91E-03
6	ACABRKR(APS)	Acacia Line Breaker @APS	1.42E-03
7	ACA2\BRKR	Acacia 2 Line Breaker @KBG	1.42E-03
8	132-CPL2-JABA	132 kV Breaker for Coupling Way No 2	1.16E-03
9	APSDISTRJABA	APS 132 kV Distribution Breaker	1.16E-03
10	132-CPL1-JABA	132 kV Breaker for Coupling Way No 1	1.16E-03

7.1.7 Component Risk Decrease Factor (Comp RDF)

The Component Risk Decrease Factor (Comp RDF) of the top 10 component are presented in Table 7.8 below.

Table 7.8: Component Risk Decrease Factor (Comp RDF)

No	ID	Description	RDF
1	9JPS001PO	9 JPS 001 PO	1.16E+00
2	SED981VD\P	SED981VD	1.03E+00
3	9LKK001TB\L	9 LKK 380 V Switchboard	1.01E+00
4	PTR961VD\P	PTR 961 VD	1.01E+00

*Note that this table is only limited to 4 components bcause the RDF of all othercomponents are 1.00.

7.1.8 Component Risk Increase Factor (Comp RIF)

The Component Risk Increase Factor (Comp RIF) of the top 10 components are presented in Table 7.9 below.

Table 7.9: Component Risk Increase Factor (Comp RIF)

No	ID	Description	RIF
1	9LKK001TB\L	9 LKK 380 V Switchboard	4.10E+01
2	SED981VD\P	SED981VD	4.07E+01
3	SED001BA\L	SED 001 BA	4.05E+01
4	9JPS001PO	9 JPS 001 PO	1.09E+01
5	PTR961VD\P	PTR 961 VD	9.50E+00
6	JPP001BA\L	JPP 001 BA\L	9.45E+00
7	LCA001BT\L	LCA 48 V Battery	5.95E+00
8	PTR005VB\C	PTR 005 VB	3.81E+00
9	PTR004VB\C	PTR 004 VB	3.81E+00
10	ACACIA-KBG-LINE	Acacia Line	3.66E+00

8 PUBLIC AND SITE PERSONNEL RISKS

This section presents the SFP public and site personnel risks. The main objective of this section is to assess the off-site radiological consequences of accidental releases of radioactive materials into the atmosphere from the SFP and to compare those consequences to the safety standards of the NNR to determine compliance. Specifically, only the health impact of such releases on the population in an area lying within 60.0 km of site will be evaluated. No attempt is made in this study to assess the economic or social consequences of accidents.

8.1 SAFETY CRITERIA OF THE NNR

All nuclear power installations require licenses in order to operate. The Koeberg license requires the licensee to demonstrate that its operation does not expose the public and site personnel to unacceptably high risks in the event of accidental releases of radioactivity into the environment. It must demonstrate its safety by meeting certain safety criteria set by the NNR in the document RD-0024 [Ref. 2]. This reference sets the safety criteria for normal and accident situations for both public and site personnel. Only the safety criteria for accidental releases of radioactivity will be stated here. The NNR compliance criteria for the public and site personnel in the event of a nuclear accident can be expressed in the following way:

1. Risk to members of the Public due to Accidents:

- The average annual mortality risk per person due to accidents must not exceed 1.00E-08 deaths per person per year; and
- The peak individual risk must not exceed 5.00E-06 deaths per year.

2. Risk to plant Personnel due to Accidents:

- The average annual mortality risk for site personnel must not exceed 1.00E-05 deaths per person per year; and
- The peak individual risk must not exceed 5.00E-05 deaths per year.

8.2 SCOPE

The scope of this section is limited to releases from the SFP associated with accidents. Normal operation events are outside the scope of this document; they are considered within the radiological protection programme and need to conform to different criteria laid down in RD-0024. Non-radiological accidents are also outside the scope of this report.

Fuel handling accidents, which involve fuel damage as a result of dropping a fuel assembly, are considered in a separate study [Ref. 6] and will therefore not be analysed in this report. Fuel handling accidents are expected to contribute a negligible amount to the public risk since at most only a few fuel assemblies are affected during the accident and then only the gaseous isotopes are released [Ref. 34].

Accidents associated with Dry Storage Casks are not considered in this report since they have been covered in [Ref. 27].

External events and post-accident events are beyond the scope of this report.

The analysis to determine the initial radioactive isotopic inventory of the SFP at various times during outages and normal power operation has been assessed in the report Radioactive Inventory in the Spent Fuel Pool [Ref. 36]. The results contained within Ref. 36 will be quoted and used in this report.

This report is limited to the assessment of the consequences of accidental releases to the atmosphere, and does not consider releases to the aquatic environment. This is because releases to the aquatic environment generally make only a small contribution to the overall public risk from nuclear power plants because it takes a much shorter time for releases into the atmosphere to reach humans than for aquatic releases. This is because the dispersion process will generally be slower in water than in the atmosphere. For this reason, historically the assessment of the release to the atmosphere has been the principle concern.

The scope of this analysis is limited to the analysis of the following endpoints in the absence of countermeasures:

- Number of early fatalities;
- Number of latent cancer fatalities;
- Individual risk of early effects; and
- Individual risk of late effects.

The above endpoints are calculated for the whole body and for several critical body organs. Specifically, mean health effects and risks due to irradiation of one or all of the following organs will be determined: lung, bone marrow and GI-tract. The health effects evaluated are divided into two categories, namely deterministic and stochastic health effects. Deterministic health effects comprise death from irradiation of bone marrow, lung and the GI-tract or from radiation effects on all of these organs. Stochastic health effects on the other hand, are largely cancers and consist of incidence of and death from cancer of the bone, lung and stomach. They also include death from leukaemia and the emergence of hereditary effects. The health effects of interest in this study are thus the numbers of fatalities due to exposure of the public to radiation. The risk will be presented in terms of mean individual or collective risks of early and late deaths.

8.3 OVERVIEW OF METHODOLOGY

The purpose of this section is to present the methodology for performing the necessary dose calculations in order to determine mortality risks for both the public and site personnel.

For a detailed description of the main elements of consequence modeling, the Koeberg Level 3 PSA Study [Ref. 37] should be consulted. It should be noted that this analysis follows the Koeberg Level 3 PSA Study for all inputs, modeling assumptions and methodology, except where explicitly stated otherwise.

PC COSYMA is a PC version of the original COSYMA (Code System from MARIA) code for mainframe computers. PC COSYMA describes consequences of accidental releases as endpoints. The major endpoints, which can be calculated by the system, are:

- Air concentration or deposition of particular nuclides;
- Doses received by members of the population;
- Individual or collective risks of health effects in the exposed population;
- The extent and duration of countermeasures which might be imposed to reduce health effects; and
- Economic costs of the countermeasures and health effects.

PC COSYMA will be used to calculate the peak and average mortality risks to site personnel and the public. The two endpoints required to determine site personnel and public risk are:

- The early and late individual risks of mortality; and
- The mean numbers of early and late health effects.

The "individual risk of mortality" results provided by PC COSYMA do not take into account the population at each distance band. The results provide the risk of mortality for an individual at a certain distance from the accident. The individual risks of mortality results are used in this analysis to approximate the risk to site personnel assumed to be located at 500 m. It is customary to refer to the individual risk of mortality as the "conditional individual mortality risk".

The PC COSYMA results that calculate the "mean numbers of early (or late) health effects vs. distance" do take into account the population at each distance band and are used to determine the public mortality risks. The mean numbers of health effects versus distance results are generally referred to as the "deaths per distance band".

It should be noted that it is customary to assume that no threshold dose exists below which any effects will be detectable. Therefore it is assumed that the mortality risk is proportional to the dose, even though there is little evidence that low doses of radiation cause harmful effects.

8.3.1 Calculation of Peak and Average Mortality Risks

The Peak Public Risk

The peak individual risk refers to the highest risk that a member of the public may be subjected to as a result of a nuclear accident. The risk will be greatest closest to the plant. In the case of Koeberg, the point closest to the site at which the public may be found is the site boundary. The site boundary at Koeberg extends from 1.3 km to 2.5 km from site. Therefore the peak public risk will be calculated at the distance band from 1 km to 2.5 km. Thus, the risk at 1.75 km, which is the most representative distance where dose consequences are calculated in PC COSYMA, is given as annual fatalities at 1.75 km divided by the number of people in that distance band.

The number of people in the 1.75 km distance band is determined as 2076 from the 2008 projected cumulative population data used in this study [Ref. 37].

If $D_{i(1.75\ km)}$ is the total mean number of fatalities at 1.75 km due to Release Category RC_i, f_i is the frequency of the Release Category (RC_i), n is the number of RCs and $P_{(1.75\ km)}$ is the total population at 1.75 km, then the peak public risk is given by:

$$\text{Peak public risk} = \frac{(\text{frequency of RC} \times \text{deaths at site boundary})_{\text{summed over all RCs}}}{\text{Population at site boundary}}$$

$$= \frac{\sum_{i=1}^{n}(D_{i(1.75\,km)} \times f_i)}{P_{(1.75\,km)}}$$

The Average Public Risk

The average public risk to an individual in the national population is defined as the number of annual fatalities divided by the total national population. The national population figure is 51.77 million from the 2011 census data [Ref. 35]. In accordance with the NNR accepted interim arrangement for addressing the use of outdated population data in PSA Level 3 studies discussed in Section 8.4.3, the average public risk result was adjusted further as follow:

- Firstly, scaled by a factor of 1.0633 to be representative of the year 2008, to ensure that the total national population and the small area projected cumulative population data (i.e. the number of people in the 1.75 km distance band) are both for the year 2008

- Then scaled further by a factor of 2.3 to be representative of the year 2025.

PC COSYMA only calculates consequences in an area described by a 60 km radius. Thus, we cannot calculate fatalities beyond 60 km from site using PC COSYMA. The NNR criteria is for the national population. In order to do this, we will require one additional band which will start from the 60 km mark and extend to the furthest point in the country. The annual fatalities for this band will be taken as zero since the major population areas (e.g., Gauteng, Natal, Free State, etc) are so far away from the Koeberg site.

Therefore, if D_i is the total mean number of fatalities summed over all distances due to Release Category RC_i, n is the number of RCs and f_i is the frequency of the Release Category (RC_i), then the average risk to the public is given by:

Average public risk = (frequency of RC × total number of fatalities)$_{\text{summed over all RCs}}$ / National Population

$$= \frac{\sum_{i=1}^{n} (D_i \times f_i)}{Total\ National\ Population}$$

The total number of fatalities is the mean numbers of early health effects (mortality) plus the mean numbers of late health effects (mortality) within 60 km from the site. Likewise, the deaths at the site boundary for peak public risk determination consider both the early and late deaths at the site boundary.

The Peak and Average Site Personnel Risk

The peak risk to personnel involved in an accident is calculated as:

Peak Risk = (Frequency of RC × Individual Risk of Mortality)$_{\text{summed over all RCs}}$

Since all the personnel on site are exposed to the risk from SFP accidents, the average personnel risk is the same as the peak personnel risk. As for the Koeberg Level 3 PSA [Ref. 37], the peak and average site personnel risks are regarded as those within a 1 km radius, i.e., in the 0.5 km mid-point distance band.

Using PC COSYMA to estimate doses on site (e.g., close to the site of the accident) can lead to considerable uncertainty. Therefore the site personnel risks from severe accidents can therefore only be regarded as a poor approximation but that this approximation is far from the allowable limits that a considerable factor of increase could be imposed without effecting the conclusions of the report.

In this regard Eskom acknowledges the NNR's acceptance communicated in letter k27997N [Ref. 65] of the proposed application of a scaling (or risk increase) factor of 10.0 derived in the report entitled "Comparison of PC Cosyma and ARCON2 Near-Field Atmospheric Dispersion Factors", Number: PSA-R-T18-03, Revision 2 [Ref. 66], to be applied to the PC Cosyma results at 500 m that are used to approximate the peak and average risks to site personnel from accidents related to releases from core damage, the spent fuel pool and casks accidents, in order to appropriately adjust the PC Cosyma results at 500 m to be more representative and bounding of the results expected at a distance of 100 m. Accordingly, the peak and average risks to site personnel from accidents related to releases from core damage, the spent fuel pool and casks accidents were adjusted / scaled by a factor of 10.

Further; by far the majority of severe accidents take several hours to develop into a release from the containment building. This will allow for the implementation of our Emergency Plan which involves the evacuation of non-essential personnel and the sheltering of the rest, including the administration of stable iodine tablets for sheltered personnel. Given these protective actions; the site personnel doses should be limited.

8.4 GENERAL ASSUMPTIONS

Several assumptions are made when carrying out this study [Ref. 37]. Some of the assumptions have to do with the PC COSYMA code in terms of the input data used in the analysis while others are general assumptions which would influence the overall results. This section deals only with the general assumptions. The assumptions related to the code can be found in relevant sections of this report. Three major assumptions have been made in this analysis, namely:

- Further irradiation of the exposed population through ingestion of foodstuffs is not considered.
- No emergency plan (countermeasures), other than the food ban, to mitigate the accident has been assumed.
- Cumulative population data (sum of the permanent resident and tourist populations) based on the 2001 population census projected for the year 2008 has been used. Population projections for the end of plant life are also not considered and is justified given that the Koeberg PSA is maintained as a living PSA and updated periodically.

8.4.1 Ingestion Pathway

With regards to the demonstration of compliance to the NNR fundamental safety standards (which includes the NNR public risk criteria prescribed in RD-0024), the NNR states the following in licensing guide LG-1041 [Ref. 53]:

"*Reliance may not be placed on highly uncertain factors or countermeasures. No credit may be given for off-site countermeasures involving the public (emergency plan). This is a matter of principle and does not only relate to the question of uncertainties. Credit may however be given for the implementation of a food ban provided the process has adequate procedures and is shown to be credible*."

Irradiation of people via the consumption of contaminated foodstuffs (i.e., the ingestion pathway) has not been considered for this study. This will, however, not influence significantly the predicted numbers of health effects, and in this case deaths, since if significant exposure were likely to arise from the consumption of irradiated foodstuffs, they could easily be controlled by instituting a total food ban. Obviously, such actions will carry an economic penalty associated with them. In the event that a food ban is imposed, the cost of such action is likely to be subsidised by ESKOM. Therefore, the ingestion pathway and associated dose is not included in this study for the following reasons:

- Food countermeasures are easy to implement following an accident if there is a well-developed infrastructure and supply system as it is here in South Africa. In addition, the implementation of a food ban and the control of foodstuffs is adequately procedurised in Section 5.7 of the Koeberg emergency planning procedure, KEP-024 [Ref. 54], and in the Integrated Koeberg Nuclear Emergency Plan, KAA-811 [Ref. 55];
- A significant fraction of the food consumed in the Western Cape is not grown locally;

- The ingestion dose from chronic exposure following an accident is generally a small contributor to total dose;
- The ingestion pathways models are inaccurate and calculations must rely on assumptions which are typically very conservative, and
- We are not aware of any country that does take the ingestion pathways into account for the calculation of accidental doses for regulatory purposes.

8.4.2 Emergency Plan

The primary contribution to the protection of the public from any risk associated with the operation of a nuclear installation comes from engineered safeguards, good design, quality in construction, competence of staff, effective maintenance and quality assurance. Despite these measures the occurrence of an accident cannot be entirely ruled out. Because of this, nuclear installations are required to have a credible and practical emergency plan that outlines the intervention criteria for implementation in the event of a severe accident. This is necessary in order to limit the radiological effects of the release on the exposed population and reduce the risk to individuals from such exposure based on pre-determined reference levels.

The main aim of an emergency plan is to prevent the occurrence of early fatalities in the event of the most severe accident. This is done by employing various relevant protective and corrective measures (countermeasures). The emergency plan will generally have pre-established intervention criteria to be followed after an accident has occurred. Some of the measures that may be applied after an accident include administration of stable iodine tablets, sheltering, evacuation, relocation, food control, decontamination of persons, decontamination of areas, body protection, respiratory protection and control of access.

There are generally three basic principles that guide emergency intervention in the event of a severe accident and these are:

- To avoid early (non-stochastic) health effects, by the introduction of countermeasures to limit the individual dose to levels below established threshold;
- To limit the risk from late health effects, and
- To limit the overall incidence of late health effects by reducing the collective dose equivalent.

The parameter of importance when deciding on the introduction or withdrawal of countermeasures is the level of individual dose.

In the present study it is assumed that no countermeasures are applied after or during the accident other than a ban on irradiated foodstuffs. This assumption is considered appropriate and justified given the following:

- With regards to the demonstration of compliance to the NNR fundamental safety standards (which includes the NNR public risk criteria prescribed in RD-0024), the NNR states the following in licensing guide LG-1041 [Ref. 53]:
  "*Reliance may not be placed on highly uncertain factors or countermeasures. No credit may be given for off-site countermeasures involving the public (emergency plan). This is a matter of principle and does not only relate to the question of uncertainties. Credit may however be given for the implementation of a food ban provided the process has adequate procedures and is shown to be credible*."
- The inclusion of countermeasures will result in very small public mortality risk values which is not compatible with the main objective of this study as

described in Section 1.1. The use of a more conservative approach provides an added level of confidence that the NNR public risk criteria prescribed in RD-0024 are indeed met given the uncertainties in the Koeberg PSA.
- Countermeasures (other than food ban as described in Section 8.4.1) are not credited to prevent the emergency plan being used to theoretically offset an unsafe plant from a public mortality risk perspective.

For a description of the countermeasures that can be applied, see the Koeberg Level 3 PSA Study [Ref. 37].

8.4.3 Transient Population and Population Growth

The population data used in this study is based on the 2001 population census projected for the year 2008 as documented in the latest demography section of the Duynefontein Site Safety Report and takes into account the transient/tourism figures within 60 km of site, i.e., it represents the 2008 projected cumulative population (sum of the permanent resident and tourist populations) [Ref. 38].

In letter k25004N dated 26 May 2020 [Ref. 62] the NNR has accepted the use of the 2001 population census data projected for the year 2008 in the Package 8 PSA deliverable L8.14 and stated the following:

"*Since there is margin to the current risk criteria available, the NNR conditionally and in the interim accepts the lack of updating the population input data in the PSA models for the SGR project only.*"

Additionally, the NNR has accepted in letter k27823N [Ref. 64] the following way forward proposed in Section 5 of the report titled: "Impact Evaluation of Outdated Population Data Used in PSA Studies", Number: PSA-R-T16-22, Revision 4 [Ref. 63], as an interim arrangement for all PSA applications and all projects, except the SGR project, while Section 5.4 of the Duynefontein Site Safety Report is being updated to consider the Census 2011 population data:

- For existing Koeberg Level 3 studies where the average public risk results have already been calculated using the total national population for Census 2011 value of 51770560, a scaling factor value of 1.0633 should be applied to the calculated average public risk results (i.e., multiply the average public risk results by 1.0633) to adjust the average public risk results to be representative of the year 2008.
- A further scaling factor value of 2.3 determined for the year 2025 should be applied to the calculated average public risk results (i.e., multiply the calculated average public risk results by 2.3) to adjust the average public risk results to be representative of the year 2025.

Lastly, population projections for the end of plant life are not considered. This is justified given that the Koeberg PSA is maintained as a living PSA and updated periodically.

8.5 INPUTS

The aim of this section is to specify the inputs used to calculate the risks. In PC COSYMA the calculations begin with a description of the characteristics of the radionuclide release, including the following:

- Quantity of each radionuclide released to the environment;
- The amount of energy associated with the release;
- The duration of the release;
- The time of the release after accident initiation;
- The warning time;
- The height of release;
- The frequency of occurrence predicted for the accident;
- A description of the population affected by the release; and
- Meteorological data.

The PC COSYMA summary files are included in Appendix F.

8.5.1 Release Category Frequencies

In order to calculate the risk due to an accident, the frequency of that accident must be known. Only the ZIRC-FIRE (zirconium fire) consequence are considered in the SFP Level 3 PSA, since the release associated with the BOIL-ALL (SFP boiling) consequence was shown to be insignificant in “Public Risk Assessment for Spent Fuel Pool Boiling” NSD – R98/018, SC-9.9 [Ref. 56], and is therefore screened out from the Level 3 PSA assessment.

Two release categories are defined for the ZIRC-FIRE consequence namely NM and OM. The frequencies for these release categories are summarized in Chapters 4 and 7.1 and reproduced in the Table 8.1 below.

Table 8.1: Normal Mode and Outage Mode Spent Fuel Damage Frequencies

Mode	Conditional Fuel Damage Frequency (/y)	Normal Fuel Damage Frequency (/y)
Normal Mode	5.13E-08	4.83E-08
Outage Mode	3.40E-08	1.99E-09
TOTAL	**N/A**	**5.03E-08**

8.5.2 Population Data

The spatial distribution of the population specified in this analysis is for an area within 60 km radius around the Koeberg Nuclear Power Station. The population data file **pop2008a.GR2** employed in this study is the same as the one used in the Koeberg Level 3 PSA [Ref. 37]. The population data is based on the 2001 population census projected for the year 2008 as documented in the latest demography section of the Duynefontein Site Safety Report and takes into account the transient / tourism figures within 60 km of site, i.e., it represents the 2008 projected cumulative population (sum of the permanent resident and tourist populations) [Ref 38].

The derivation of the content of the population data file **pop2008a.GR2** is documented in Ref. 38 and also presented in Appendix G.

Consequence analysis codes invariably require that population data be assigned to annuli, centered on the release site and segmented by radial lines (i.e. an r-θ grid). Therefore the population data used in the population data file **pop2008a.GR2** was organized into radial sectors and distance bands that form a radial grid. The radial grid comprises 25 distance bands and 72 sectors at 5 degree intervals.

The distance bands, in kilometers, used here are: 0 to 1 km, 1 to 2.5 km, 2.5 to 5 km, 5 to 7.5 km, 7.5 to 10 km, 10 to 12.5 km, 12.5 to 15 km, 15 to 17.5km, 17.5 to 20 km, 20 to 22.5 km, 22.5 to 25 km, 25 to 27.5 km, 27.5 to 30 km, 30 to 32.5 km, 32.5 to 35 km, 35 to 37.5 km, 37.5 to 40 km, 40 to 42.5 km, 42.5 to 45 km, 45 to 47.5 km, 47.5 to 50 km, 50 to 52.5 km, 52.5 to 55 km, 55 to 57.5 km, and 57.5 to 60 km.

The national population figure used is 51.77 million based on the 2011 census data [Ref. 35].

8.5.3 Meteorological Data

For probabilistic runs of PC COSYMA, it is not realistic to evaluate the consequences of an accident for each meteorological condition in the weather file as the process would be prohibitively long. It is thus sufficient to calculate the consequences for a representative sample of weather conditions. This sample must however enable adequate precision to be obtained when estimating the numbers of consequences over the entire range of interest. For this reason, the sampling of data is perhaps the most important input specification in any consequence assessment since the results will depend on the sample of conditions used.

The stratified sampling scheme, the scheme used for this analysis, is appropriate for conditions within tens of kilometers from site and not for large distances from site. In stratified sampling, the various atmospheric conditions that are similar to one another are grouped into a number of categories. When used these meteorological sequences would yield comparable magnitude of radiological consequences. In this way, even rarely occurring sequences that may give rise to high consequences can be identified and included explicitly. Sequences are then selected for analysis by randomly selecting one or more hours as starting points from each category. This way a full range of meteorological conditions is considered. The technique of stratified sampling is discussed in Methods for Assessing the Off-site Radiological Consequences of Nuclear Accidents [Ref. 39].

Probabilistic runs of PC COSYMA require a data file containing hourly atmospheric conditions for one or two years. The meteorological conditions attributed to the site were obtained from 2 years of hourly measurements taken at the meteorological station at Koeberg. Excel sheets containing these measurements (supplied by Koeberg Weather Station) must be converted to text files in the format used by PC COSYMA. The years for which the data is applicable are 2006 and 2007. The files containing the meteorological conditions used in this analysis are called **MET0607A.MH2** and **MET0607A.INP**. The two files should reside in the DATA folder under the PCCOSYM2 directory for use by PC Cosyma whenever performing off-site consequence calculations related to Koeberg SFP Level 3 PSA studies. The atmospheric conditions contained in these files are given in the Koeberg Level 3 PSA Study [Ref. 37], Appendix 5. The data represents hourly atmospheric conditions for a period of two years. This represents a total of 17520 hours. Each line in the data file represents one hour of weather conditions. The atmospheric conditions in each hour in the file are described by five numbers:

- Wind direction in degrees (clockwise from North). This is the direction from where the wind is blowing;
- A number representing the atmospheric stability category, 1 – 6 for A to F respectively based on the Pasquill-Gifford scheme. PC COSYMA does not consider stability category G;
- Rainfall rate (mm/hour) × 100;
- Wind speed (m/s) × 100; and
- The depth of the mixing layer (m).

The Koeberg Level 3 PSA Study gives more detail on each of the above five numbers. A copy of the weather data files “MET0607a.INP” and “MET0607a.MH2” are stored on the Koeberg G drive.

Since the SFP Level 3 PSA uses different values for parameters such as building dimensions (height and width), release heights and energy than those specified in the Koeberg Level 3 PSA Study for each release category, the meteorological sequences involved for each release category in the SFP and Koeberg Level 3 PSA studies are different. Therefore the meteorological sampling scheme files used for the SFP Level 3 PSA are included in Appendix E.

8.5.4 Source Term

For the SFP Level 3 PSA, it was demonstrated that the post-SGR without Thermal Power Uprate (TPU) source term is not significantly different from the pre-SGR SFP source term [Ref. 47]. It is therefore acceptable to continue using the pre-SGR SFP source term with associated decay heat for the post-SGR without TPU case.

Initial Inventory

The initial isotopic inventory in the Spent Fuel Pool was taken from the report titled “Spent Fuel Pool Accident Risks”, Number: NAAS-R01/005 [Ref. 40]. It is necessary to calculate releases both during normal operation and during outage times when the radioactive inventory in the Spent Fuel Pool is significantly higher. The inventory in the pool during both normal operation and during outage is presented below. The 5 Day case relates to a decay heat of 11.5 MW, the estimated decay heat during outage, while the 15 Day case relates to the decay heat of 4.06 MW present during normal operation.

Table 8.2: Initial Inventory in SFP

ISOTOPE	5 Days – Outage Mode (Bq)	15 Days – Normal Mode (Bq)
Kr-85	2.12E+17	1.93E+17
Xe-129m	1.48E+14	4.81E+13
Xe-131m	2.98E+16	8.05E+15
Xe-133m	5.68E+16	8.44E+14
Xe-133	3.49E+18	3.16E+17
Xe-135m	2.85E+12	1.11E+01
Xe-135	1.57E+15	5.95E+06
I-129	1.69E+12	1.63E+12
I-131	1.83E+18	2.72E+17
I-132	1.39E+18	5.73E+16
I-133	1.05E+17	1.17E+13
I-135	1.78E+13	6.95E+01
Mo-99	1.42E+18	3.83E+16
Sr-89	2.43E+18	5.39E+17
Sr-90	2.72E+18	2.57E+18
Te-132	1.35E+18	5.56E+16
Sb-127	1.09E+17	7.40E+15
Cs-134	1.31E+18	1.03E+18
Cs-137	4.12E+18	3.92E+18
Ba-140	3.65E+18	6.83E+17
La-140	4.14E+18	7.86E+17
Ce-141	4.17E+18	1.09E+18
Ce-144	3.91E+18	1.54E+18
Np-239	1.25E+19	2.76E+17
Pu-238	2.40E+17	2.36E+17
Cm-242	1.69E+17	1.09E+17
Cm-244	3.27E+17	3.24E+17

In principle, to fully define the source term, information on the physical and chemical form of the released radionuclides is also required. In practice, very detailed information on the physical and chemical form is seldom available. The physical size of the released aerosol and the chemical form of its constituents are important, particularly for determining the deposition of particulate material in both the environment and the respiratory tract. Given a lack of precise data on the physical and chemical form of the release, it is generally assumed that the radionuclides are released in a 1 μm Activity Median Aerodynamic Diameter (AMAD) aerosol with each chemical element in oxide form, apart from the noble gases and the fraction of iodine released in an organic form. Most current consequence modeling codes are limited in their treatment of the physical and chemical form released.

Radionuclide Selection Cut-off

Nuclear reactors contain some hundreds of radionuclides, which may be released in an accident. It is not practicable to consider all of the released nuclides in an accident consequence calculation. Many of the nuclides present make only a very small contribution to the overall dose from the release, for two possible reasons.

First, many of the nuclides which are released, particularly in a reactor accident, are of very short half life; radioactive decay reduces their dose contribution to a very low level. Second, many of the nuclides are not volatile and so the fraction of those nuclides released is much lower than that of other nuclides.

The data libraries used with PC COSYMA contain information on 197 nuclides which are likely to be the most important contributors to the doses and hence the risks of most accidents at nuclear facilities. However, it is not possible to consider all these 197 nuclides in PC COSYMA calculations, because of the CPU time and disk storage which would be needed. The PC COSYMA calculation programs are limited to considering not more than 60 nuclides in the source term. The user must first specify the inventories and release fractions of those nuclides which are to be considered for inclusion in the source term. This can be as many of the 197 nuclides considered by PC COSYMA as the user has information on the amount released. The program then calculates a quantity related to the dose from each of the nuclides specified for each of the exposure pathways of exposure considered in PC COSYMA, and sums these quantities. For example, for inhalation the quantity calculated is the product of the amount released and the dose per unit intake. For the external dose from deposited activity the quantity is the product of the amount released, the deposition velocity of the nuclide and the dose per unit deposit. The nuclides are then ranked in order of decreasing contribution to dose. The Input Interface also prompts the user for a cut-off value of dose. The source term is built up of those nuclides which together contribute more than the specified fraction of the dose. This procedure is carried out for each of the pathways of exposure separately, and those nuclides identified for any pathway are included in the source term. If the procedure identifies more than 60 nuclides for inclusion in the source term, then the program will stop with an appropriate error message. The user can then examine the ***.SRC** file produced by the source term program located in the **\PCCOSYM2\RESULTS\SRC** directory and must adjust the cut-off value specified for one or more of the routes of exposure considered and rerun the program.

The nuclides which are selected depend on the period over which the dose is to be integrated. Therefore the nuclides selected for inclusion in a source term for calculating early health effects would be different from those selected for calculating late health effects. The source term for early effects is based on the dose over a few days, while that for late effects is based on the dose over 50 years. Short lived nuclides are more likely to be important for early effects than for late effects. The source term program allows for radioactive decay, and the ingrowth of daughter paroducts, during the period between the shut-down of the reactor and the time at which the material is released.

In this study, the nuclide selection cut-off used for each of the exposure pathways is presented in the table below.

Table 8.3: Nuclide Selection Cut-off used in PC COSYMA Calculations

Pathway	Selection Cut-off in %	
	Normal Mode	Outage Mode
Cloudshine	0.01	0.01
Groundshine	0.01	0.01
Inhalation	0.01	0.01
Skin	0.01	0.01
Ingestion	99.99	99.99

Radionuclide Grouping Scheme

The purpose of the grouping scheme is simply to assign release fractions to radionuclides. Thus, the grouping scheme is only used to determine the amount of each relevant isotope released to the environment.

PC COSYMA groups together nuclides with similar characteristics in order to reduce calculation time. The source term calculation deals with this by grouping together elements with the same release fractions. The atmospheric dispersion calculation module places elements into groups having the same deposition characteristics. These two groupings are independent of one another so that the grouping by release fractions does not influence the grouping by deposition.

It was agreed with NNR that 11 grouping schemes be used for PC COSYMA calculations. The reason for using 11 nuclide groups rather than the 12 grouping schemes employed by MAAP is that MAAP schemes has two groups of the same element, Tellurium. The first Tellurium group is in oxide form (TeO_2) while the second is in elemental form (Te_2). The new grouping scheme combines the two Tellurium groups into one Te group for use in PC COSYMA. The release fraction for the new group is conservatively assumed to be the highest release fraction of the two groups.

PC COSYMA models 197 isotopes that make the largest contribution to doses from accidental releases from nuclear power stations. Unfortunately, MAAP does not directly model all these 197 isotopes. The new binning scheme is based on NUREG/CR-6119 [Ref. 41] and adapted to the MAAP grouping scheme, but with more isotopes. It was also agreed with the NNR that the elements Ag, Si, and P can be discounted from the PSA. Again Be should be included in the group containing Sr.

The following rules have been followed in assigning the isotopes modeled in the NUREG/CR-6119 grouping scheme to 11 groups:

- If MAAP models one element of a NUREG/CR-6119 group then the whole group will be given the release fraction of that one element.
- If MAAP models more than one element of a NUREG/CR-6119 group then, providing the elements have different release fractions, the group will be split and any remaining elements not directly modeled by MAAP will be assigned to the split group with the largest release fraction.

The resulting grouping scheme which is used for Koeberg Level 3 PSA is presented in Table 8.4 below.

Table 8.4: Nuclide Grouping Scheme for Use in PC COSYMA Calculations

Group Number	MAAP Grouping	NUREG/CR-6119 Grouping	New Grouping Scheme: 11 Groups
1	Xe, Kr	Kr, Xe, Ar	Kr, Xe, Ar
2	I	I, Br	I, Br
3	Te	Te, Se, Po	Te, Se, Po
4	Sr	Sr, Ba, Ra	Sr, Ra, Be
5	Mo	Mo, Fe, Co, Tc, V, Cr, Mn, Nb, Ta, W	Mo, Fe, Co, Tc, V, Cr, Mn, Nb, Ta, W, Ru, Rh, Re, Ni
6	Cs, Rb	Cs, Na, Rb, Cu	Cs, Na, Rb, Cu
7	Ba	Ag	Ba
8	La, Pr, Nd, Sm, Y	La, Sc, Y, Pr, Nd, Pm, Sm, Eu, Am, Cm	La, Sc, Y, Pr, Nd, Pm, Sm, Eu, Am, Cm
9	Ce	Ce, Hf, Np, Pu, Zr	Ce, Hf, Zr
10	Sb	Sb, Hg, Zn	Sb, Hg, Zn
11	U, Np, Pu	U	U, Np, Pu
		Si, P	
		Ru, Rh, Re, Ni	

Release Fractions

There is some uncertainty in the isotopic release fractions for spent fuel pool accidents and so two cases are presented. The NRC release fractions are considered conservative while the MAAP release fractions are considered to be “best estimate” [Ref. 40]. The release fractions are shown in Table 8.5 below.

Table 8.5: Release Fractions

Group Number	Release Group	Best Estimate (MAAP Release Fractions)	Upper bound (NRC Release Fractions)
1	Kr, Xe, Ar	9.93E-01	1.00E+00
2	I, Br	3.15E-02	1.00E+00
3	Te, Se, Po	9.29E-02	2.00E-02
4	Sr, Ra, Be	2.66E-03	2.00E-03
5	Mo, Fe, Co, Tc, V, Cr, Mn, Nb, Ta, W, Ru, Rh, Re, Ni	3.13E-04	2.00E-05
6	Cs, Na, Rb, Cu	3.72E-02	1.00E+00
7	Ba	1.32E-03	2.00E-03
8	La, Sc, Y, Pr, Nd, Pm, Sm, Eu, Am, Cm	1.86E-04	6.00E-06
9	Ce, Hf, Zr	2.07E-03	6.00E-06
10	Sb, Hg, Zn	7.55E-02	7.55E-02
11	U, Np, Pu	7.88E-06	7.88E-06

Fraction of Decay Heat Released

PC COSYMA requires the heat content of the release to be specified as this is responsible for initial rise of the plume. The energy content of the plume is determined from the fraction of decay heat in the release. The fraction of decay heat in the plume is part of the MAAP output. The energy content of the plume is the product of the decay heat and the fraction of the decay heat that is released with the plume. The release of this stored heat directly influences radiological consequences as it may cause the plume to rise substantially into the atmosphere before significant dispersion takes place. This will result in a reduction of exposure of the population located downwind.

For the Koeberg Level 3 PSA Study, the release was assumed to occur in six phases, but for the SFP Level 3 PSA, only one phase is assumed, with zero time delay. MAAP runs performed [Ref. 42] indicate that the fraction of energy released is 0.24, resulting in actual energy releases of:

- 2.758 MW (determined as 11.49 MW × 0.24) for the 5 day case; and
- 0.974 MW (determined as 4.06 MW × 0.24) for the 15 day case.

Building Dimensions

Current consequence analysis codes can readily model a point source release from a known height. If the containment response analysis predicts a release of this nature, then the height of release is provided. A release height of 0 m is conservative. A release height of 10 m is conservatively assumed[1] for releases during an outage and normal operation.

If the release does not emerge from a well-defined source, or if that source is on the side or roof of a reactor building, then it is generally assumed that mixing will occur throughout the building wake. For model mixing in the building wake, the building dimensions are generally required. According to the SAR, the SFP building has a height of 38.5 m and is 30 m long by 17 m wide. PC COSYMA requires the height and the width. Sensitivity analyses were performed which found that the most conservative building width option to use with the building height of 38.5 m is 30 m, which was selected.

8.5.5 Surface Roughness

PC COSYMA allows for two choices of surface roughness: smooth and rough surface. As for the Koeberg Level 3 PSA Study [Ref. 37], the smooth surface roughness is used in the present study.

8.5.6 The Breathing Rate

PC COSYMA requires the breathing rate to be specified for use in calculating both short and long term consequences. In this analysis we assume a breathing rate of 3.333E-04 m^3/s.

8.5.7 Short-Term Dose Integration Time

The dose integration time for short-term doses is assumed to be 30 days.

1. PC COSYMA automatically uses 10 m as the release height in calculations if the user attempts to select a lower value. Therefore, this is effectively the lowest release height that can be selected.

8.5.8 Countermeasures

The calculations assume a food ban. This means that ingestion as an exposure pathway is excluded. No other countermeasures are assumed.

8.5.9 Shielding Factors

The calculations are performed assuming no shielding for the duration of exposure, that is, people are outdoors naked and continue to occupy the same location for the duration of the dose integration time. So location factors used with the various exposure pathways are all 1 to indicate no dose protection from anything including clothes.

8.5.10 Cancer Risk Factors

The calculations will be performed using cancer risk factors from ICRP-60 [Ref. 43].

8.6 PUBLIC AND SITE PERSONNEL RISK RESULTS

This section presents the various results obtained from using PC COSYMA to evaluate the radiological consequences of a SFP accident resulting in the consequence Spent Fuel Damage.

The risk measures for both the public and site personnel will be presented in this section. These are:

- Organ doses;
- Numbers of fatalities; and
- Risks of mortality.

These consequences are for both short term and long term exposure to radiation. They are presented in terms of the mean (expectation value) of the magnitude of each consequence in each distance band.

8.6.1 Short Term and Long Term Doses

In the event of a SFP accident, it would be necessary to calculate the projection of doses that members of the public might receive in the event of a release of radioactivity. The organ dose generally plays a major role in the incidence of both early and late health effects. It is also one of the major considerations affecting the implementation and timing of countermeasures directly involving people (i.e., sheltering, evacuation and relocation).

Equivalent doses to various organs and effective dose to the whole body will be presented here for both short term and long term exposure. Short term doses were integrated over 30 days while 50 years is assumed to be the long term integration time. The organs considered for early dose calculations are the thyroid, eye lens, ovaries, skin, lung, bone marrow and GI-tract. For long term doses, the organs of interest are the bone marrow, skin, bone surface, breast, lung, stomach, colon, liver, pancreas, thyroid and gonads.

Short term and long term doses are presented in Appendix D, Tables D-01 to D-04 and Tables D-05 to D-08 for both MAAP and NRC release fractions respectively. These doses are given for the 5 day and 15 day inventories.

8.6.2 Number of Early and Late Fatalities

The fatalities calculated here are due to the irradiation of a single or multiple vital organs. They are split into two types, namely early and late fatalities. Early fatalities result from exposure from acute doses of radiation over a short period of time. The exposure time considered in this study is 30 days. Early fatalities include deaths from irradiation of the bone marrow (hematopoietic syndrome), lung (pulmonary syndrome), skin, GI-tract (GI syndrome) or from the effect of irradiation all these vital organs.

Late fatalities, on the other hand, generally appear several years after the accident has occurred. They are generally deaths from cancers of individual organs or multiplicity of organs. Fatalities from cancers of the bone, breast, lung, stomach, colon, liver, pancreas, thyroid and skin will be calculated. Also included in the late fatalities are deaths from hereditary effects.

The mean number of fatalities in each radial block is determined from the conditional mean individual risk in each block in the radial grid and the number of people within the block.

The mean short and long term individual risks of mortality as a function of distance for the 5 day and 15 day inventories are given in Appendix D, Tables D-09 to D-12 and D-13 to D-16 for MAAP and NRC release fractions respectively.

The mean numbers of early and late deaths resulting from irradiation of one or more organs as a function of distance for the 5 day and 15 day inventories are given in Appendix D, Tables D-17 to D-20 and D-21 to D-24 for MAAP and NRC release fractions respectively.

Table D-25, Appendix D, gives the total deaths per distance band (mean numbers of early and mean numbers of late deaths). This table was used to calculate the peak and average public risks.

Table D-26, Appendix D, gives the total conditional individual mortality risks per distance band (mean short term individual risks and mean long term individual risks). This table was used to calculate the peak and average site personnel risks.

8.6.3 Calculation of Peak and Average Mortality Risks

The Peak Public Risk

$$\text{Peak public risk} = \frac{(\text{frequency of RC} \times \text{deaths at site boundary})_{\text{summed over all RCs}}}{\text{Population at site boundary}}$$

From Table D-25, the peak individual public risk per unit is as follows:

Peak Public Risk (fatalities per year)	MAAP RF	NRC RF
	2.52E-09	4.18E-09

The Average Public Risk

$$\text{Average public risk} = \frac{(\text{frequency of RC} \times \text{total number of fatalities})_{\text{summed over all RCs}}}{\text{National Population}}$$

From Table D-25, the average public risk per unit is calculated to be equal to:

Average Public Risk (fatalities per person per year)	MAAP RF	NRC RF
Using 2011 national population	3.23E-11	1.48E-10
Representative of year 2008	3.43E-11	1.58E-10
Representative of year 2025	7.90E-11	3.63E-10

Peak and Average Site Personnel Risks

Peak Risk = RC Frequency $\times$ Mortality Consequence

Thus, from Table D-26, the peak and average site personnel risks per unit are as follows:

Peak Site Personnel Risk (fatalities per person per year)	**MAAP RF**	**NRC RF**
	4.20E-08	5.97E-08
Average Site Personnel Risk (fatalities per person per year)	**MAAP RF**	**NRC RF**
	4.20E-08	5.97E-08

As per the discussion in Section 8.3.1, scaling of the peak and average site personnel risks by a factor of 10 are included.

8.6.4 Risk Comparisons of Release Categories (per Unit)

MAAP RF							
Release Category	**Frequency**	**Average Public Conditional Risk**	**Average Public Risk**	**% Risk**	**Peak Public Conditional Risk**	**Peak Public Risk**	**% Risk**
MAAP (NM)	4.83E-08	6.42E-04	3.10E-11	96.08%	4.96E-02	2.40E-09	95.02%
MAAP (OM)	1.99E-09	6.36E-04	1.26E-12	3.92%	6.31E-02	1.26E-10	4.98%
TOTAL (2011)[1]		**1.28E-03**	**3.23E-11**	**100%**			
TOTAL (2008)[2]	**5.03E-08**	**-**	**3.43E-11**	**-**	**1.13E-01**	**2.52E-09**	**100%**
TOTAL (2025)[3]		**-**	**7.90E-11**	**-**			
NRC RF							
Release Category	**Frequency**	**Average Public Conditional Risk**	**Average Public Risk**	**% Risk**	**Peak Public Conditional Risk**	**Peak Public Risk**	**% Risk**
NRC (NM)	4.83E-08	2.95E-03	1.43E-10	96.23%	8.26E-02	3.99E-09	95.45%
NRC (OM)	1.99E-09	2.81E-03	5.59E-12	3.77%	9.56E-02	1.90E-10	4.55%
TOTAL (2011)[1]		**5.76E-03**	**1.48E-10**	**100%**			
TOTAL (2008)[2]	**5.03E-08**	**-**	**1.58E-10**	**-**	**1.78E-01**	**4.18E-09**	**100%**
TOTAL (2025)[3]		**-**	**3.63E-10**	**-**			
NNR Criteria			**1.00E-08**			**5.00E-06**	

[1] Average public risk based on 2011 national population.
[2] 2011 average public risk scaled by 1.0633 to be representative of the year 2008 (see Sections 8.3.1 and 8.4.3).
[3] 2008 average public risk scaled by 2.3 to be representative of the year 2025 (see Sections 8.3.1 and 8.4.3).

8.6.5 Risk Comparisons of Release Categories (Station)

Peak and Average Public and Site Personnel Risk for the Station

Risk Criteria	**MAAP RF**		**NRC RF**	
	Annual Risk	**% of NNR Criteria**	**Annual Risk**	**% of NNR Criteria**
Peak Public Risk (fatalities per year)	5.04E-09	0.10%	8.36E-09	0.17%
Average Public Risk (fatalities person^{-1} year^{-1}) (using 2011 national population)	6.46E-11	0.65%	2.96E-10	2.96%
Average Public Risk (fatalities person^{-1} year^{-1}) (representative of year 2008)	6.87E-11	0.69%	3.15E-10	3.15%
Average Public Risk (fatalities person^{-1} year^{-1}) (representative of year 2025)	1.58E-10	1.58%	7.25E-10	7.25%
Peak Site Personnel Risk (fatalities per year)	8.40E-08	0.17%	1.19E-07	0.24%
Average Site Personnel Risk (fatalities person^{-1} year^{-1})	8.40E-08	0.84%	1.19E-07	1.19%

As per the discussion in Section 8.3.1, scaling of the peak and average site personnel risks by a factor of 10 are included.

9 CONCLUSIONS

When using the more conservative NRC release fractions, the Koeberg SFP PSA study considering the impact of SGR results in a station average public risk representative of year 2025 of 7.25E-10 fatalities person^{-1} year^{-1} (7.25% of the NNR criterion) and a peak public risk of 8.36E-09 fatalities per year (0.17% of the NNR criterion) . Thus, the SFP risk remains within the NNR limit in the SGR configuration.

The most dominant contributions to the fuel damage frequency result from Multiple Misplacement of Fresh Assemblies (NM) and LOSP (NM & OM).

The accident Multiple Misplacement of Fresh Assemblies is essentially where the new assemblies are loaded into Region 2 racks side-by-side. It is assumed that this will lead to criticality occurring without any dilution of the boron in the spent fuel pool water. There are a number of measures taken to prevent this misplacement from occurring so it is an unlikely event but it remains one of the dominant spent fuel pool accidents.

In the case of LOSP leading to SBO the JPS pump and motor (JPS 001 PO and JPS 001 MO) and the SED valve (SED 981 VD\P) is essential to avoid Spent Fuel Damage. It is therefore important to maintain these systems and keep the equipment in a good, operable condition.

In the event of a Loss of 400 kV grid and Loss of Acacia, the 9 LKK board supplying the SED system, which is the preferred source for SFP make-up, is not available. JPP and JPS then becomes the only source of SFP make-up emphasising the importance of maintaining these systems in a good operable condition and having spares available.

The FDF from internal events is expected to be significantly lower than CDF since the decay heat in the SFP is much lower than the heat load in the reactor. Therefore, it is not surprising that the FDF is in the order of 100 times less than the estimated CDF. However, without a containment structure to prevent fission product releases, the consequences can be much worse making the overall public risks comparable.

In the present study it is conservatively assumed that no Emergency Plan countermeasures are applied after or during the accident other than a ban on irradiated foodstuffs. In practice it is required that the Precautionary Action Zone (PAZ) of 5 km and the Urgent Protective Action Planning Zone (UPZ) of 16 km are evacuated within 4 hours and 16 hours respectively. Both these evacuation times are less than the time to spent fuel uncovery and spent fuel damage in most sequences modeled.

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11 REVISION INFORMATION

Revision 3

Changes were made to include PTR 3rd Train modification in the SFP model.

Revision 4

Changes were made to align the SFP model with Level 1 and 3 PSA models, including the Level 1 PSA equipment failure data and the Level 3 PSA updated population and meteorological data.

Revision 5

Changes were made to align the SFP model with the Level 1 and 3 PSA models, including the Level 1 PSA equipment failure data and the Level 3 PSA updated population and meteorological data.

Revision 6

(This is a partial revision to address specific NNR comments on the previous revision. Certain other errors that were noticed during the revision process were corrected as noted, and minor improvements were made to enhance readability.)

To address NNR comments received in NNR Letter k20968N, the following changes were made:

- Updated the population data file to POP2008a.GR2, to line up with that used for the Koeberg Level 3 PSA, and text changes corresponding to this (NNR comment no. 3.1, 3.2 and 3.3);
- Provided additional justification for the exclusion of ingestion and for excluding countermeasures other than food-banning by reference to the Koeberg Level 3 PSA Study (NNR comment no. 3.1);
- Clarified the use of a 10 m release height (NNR comment no. 3.4); and
- Editorial changes (NNR comment no. 3.5).

Lastly, corrected the GSF cancer mortality risk fractions previously used (incorrectly, by accident) to the ICRP-60 cancer mortality fractions.

Revision 7

A minor typographical error was corrected in response to NNR comments received in NNR Letter k20968N as noted for Rev. 6 (see NNR comment no. 3.5).

Revision 8

The analysis was revised to take into account the following PSA modelling change due to the implementation of the Steam Generator Replacement (SGR) project:

- Following SGR there will be 60 new fuel assemblies loaded as opposed to the current fuel loading plan where 53 fresh fuel assemblies are loaded. This change affects the frequency of misplacement of multiple fresh fuel assemblies as detailed in Sections 3.5,the Fuel Damage Frequency detailed in Section 7.1, the Inputs detailed in Section 8.5, the Public and Site Personnel Risk Results in Section 8.6 and the references listed in Section 10.

Lastly, minor editorial changes and improvements resulting from the Eskom internal review were implemented.

Revision 9

Changes and additions were made in Sections 8.3.1, 8.4.3, 8.6.3 to 8.6.5, 9 and 10 to clarify the adjusments / scaling applied to the average public risk and the peak and average risks to site personnel from SFP accidents respectively.

APPENDIX A: COMMON CAUSE FAILURE ANALYSES

CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : JPD MSV FO

Q_{tot}	5.00E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

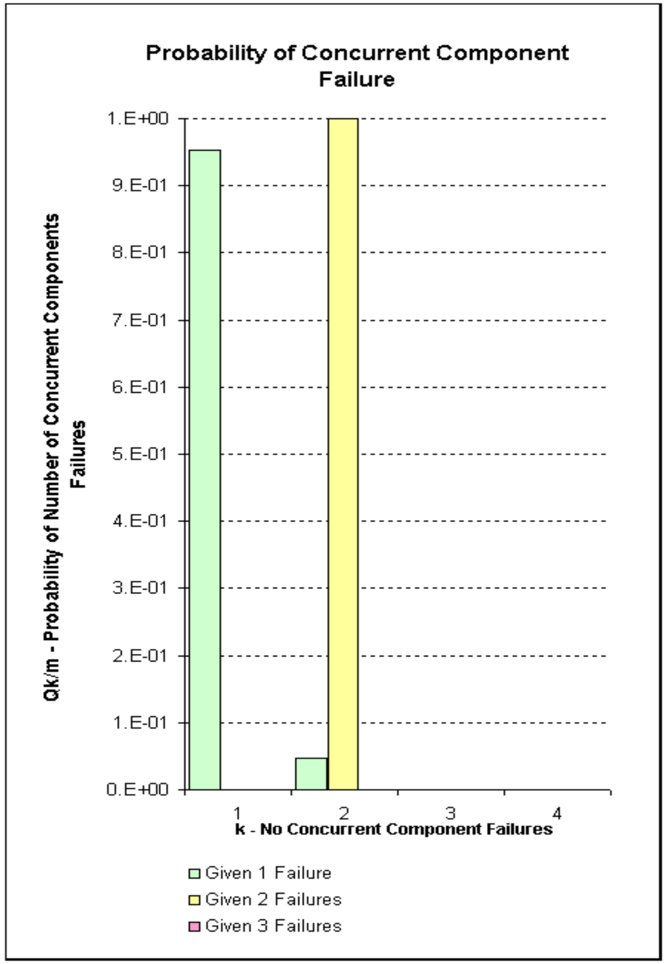
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k\|Q_{tot}$=Nom	$Q_k\|Q_{tot}$=1	$Q_k\|\beta$=1	$Q_k\|\beta\&\gamma$=1	
1	1	1.00E+00	9.53E-01	4.77E-05	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	2.35E-06	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	5.00E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : JPP MSV FC

Q_{tot}	5.00E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

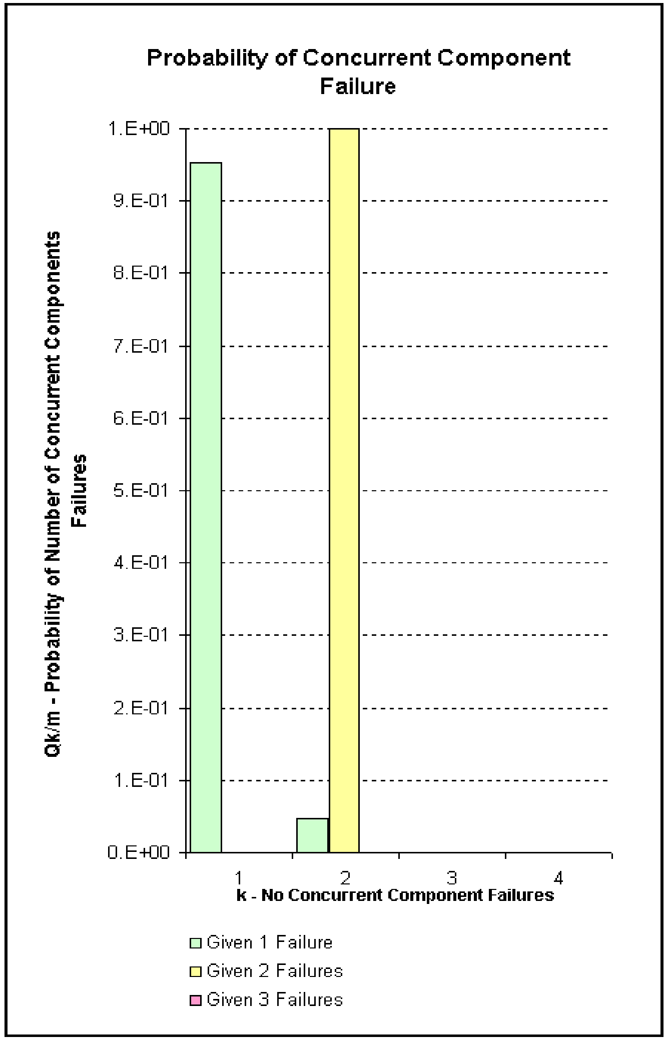
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1-\rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k\|Q_{tot}$=Nom (Q_{tot}=Nom)	$Q_k\|Q_{tot}=1$ ($Q_{tot}=1$)	$Q_k\|\beta=1$ ($Q_{tot}=1$)	$Q_k\|\beta\&\gamma=1$ ($Q_{tot}=1$)	
1	1	1.00E+00	9.53E-01	4.77E-05	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	2.35E-06	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	5.00E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR Heat Exchangers Clogged

Failure Rate	2.07E-05	/ hr
Mission Time	24	hrs

Q_{tot}	4.97E-04	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.40E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

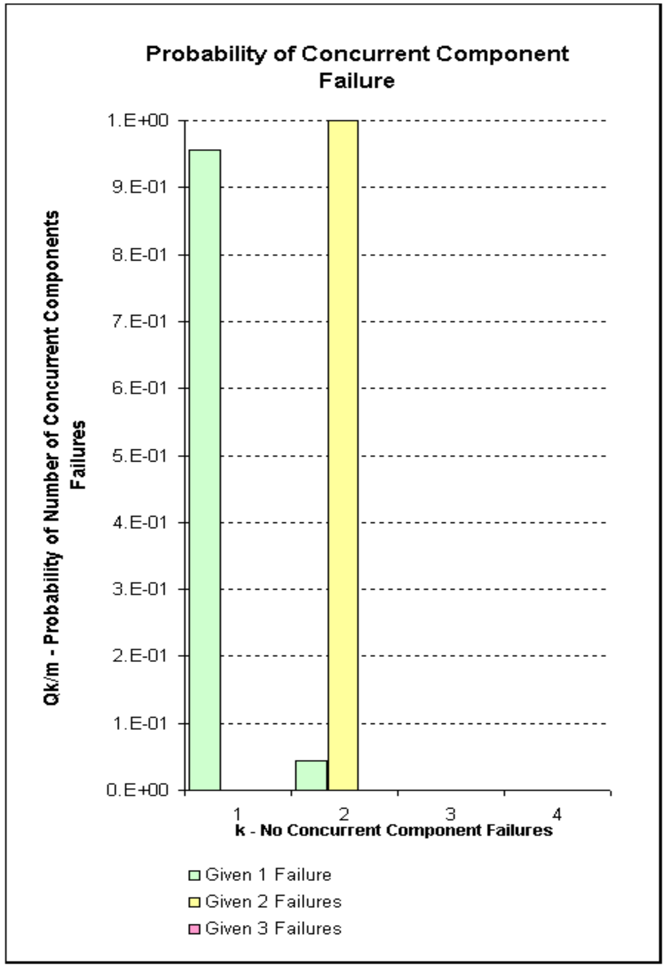
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.56E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.40E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	**Comb**	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}=1$	$Q_k \mid \beta=1$	$Q_k \mid \beta\&\gamma=1$	
1	1	1.00E+00	9.56E-01	**4.75E-04**	9.56E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.40E-02	1.00E+00	**2.19E-05**	4.40E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	4.97E-04	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR NRVs FC

Q_{tot}	1.35E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

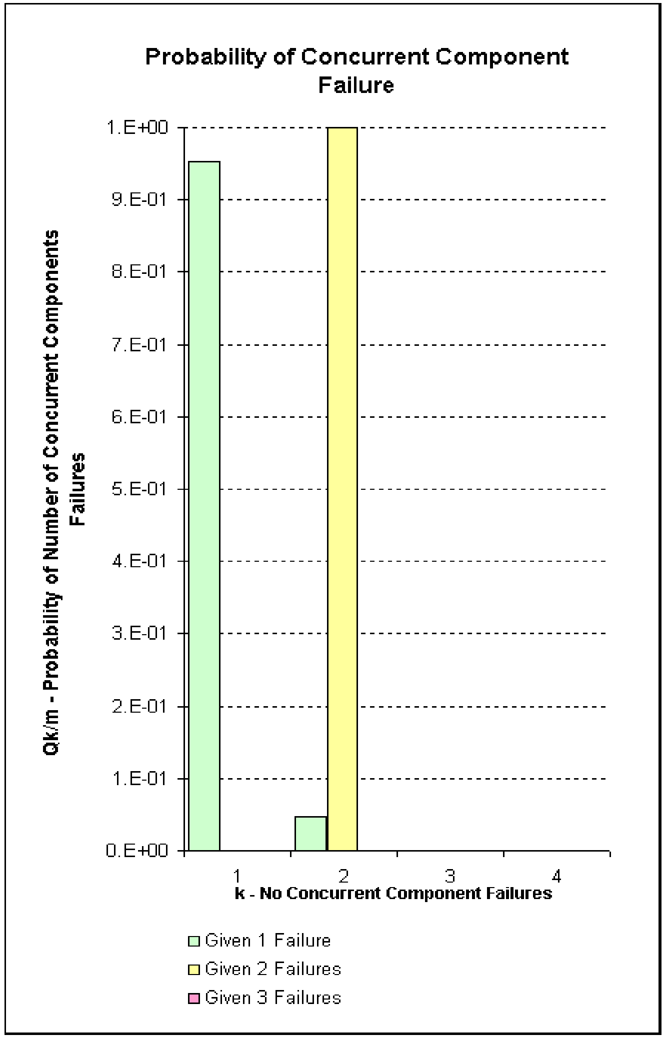
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}=1$	$Q_k \mid \beta=1$	$Q_k \mid \beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	**1.29E-05**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**6.35E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	1.35E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR NRVs FO

Q_{tot}	1.35E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

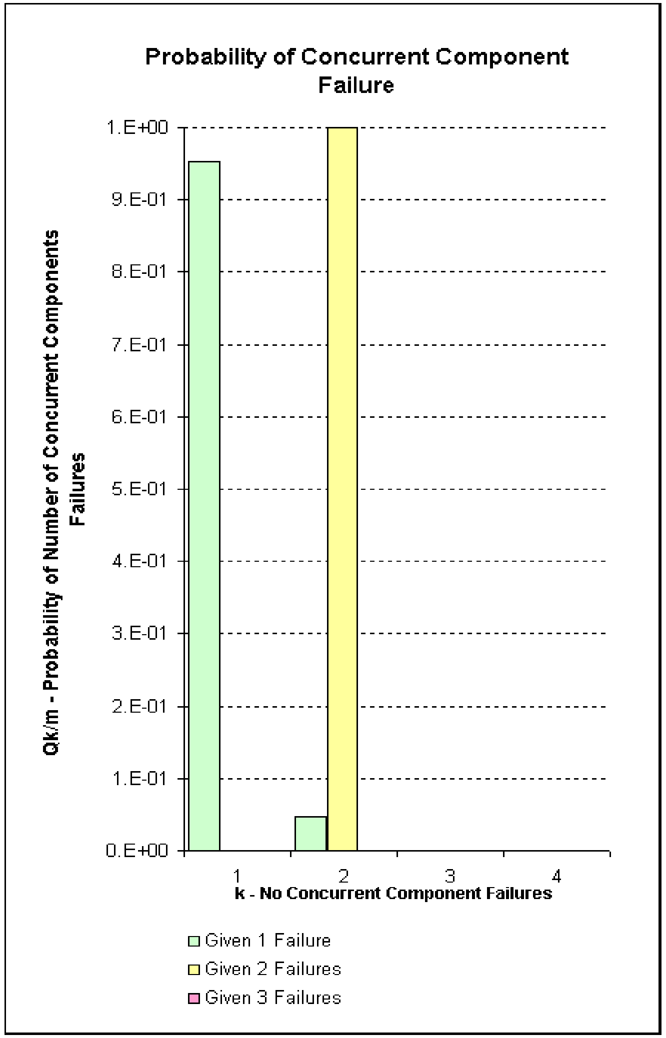
$$Q_K = \frac{1}{\binom{m-1}{k-1}}\left(\prod_{i=1}^{k}\rho_i\right)\left(1-\rho_{k+1}\right)Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \| Q_{tot}$=Nom	$Q_k \| Q_{tot}$=1	$Q_k \| \beta$=1	$Q_k \| \beta\&\gamma$=1	
1	1	1.00E+00	9.53E-01	**1.29E-05**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**6.35E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	1.35E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR Pump Motors FR

Failure Rate	3.30E-06	/ hr
Mission Time	24	hrs

Q_{tot}	7.92E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.40E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

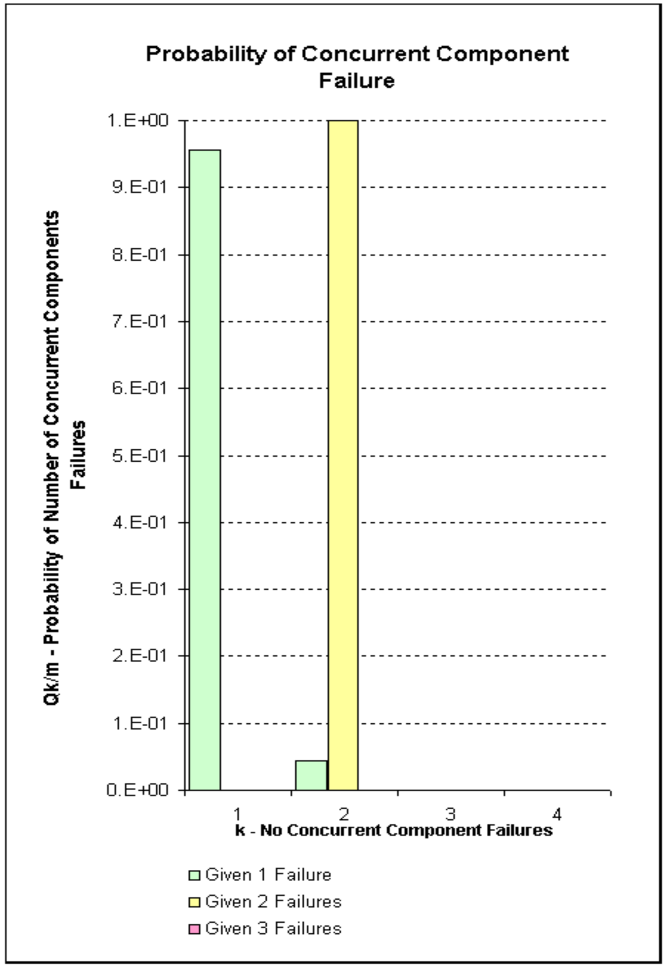
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.56E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.40E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}=1$	$Q_k \mid \beta=1$	$Q_k \mid \beta\&\gamma=1$	
1	1	1.00E+00	9.56E-01	**7.57E-05**	9.56E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.40E-02	1.00E+00	**3.48E-06**	4.40E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	7.92E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR Pumps Motor FS

Q_{tot}	9.00E-06	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

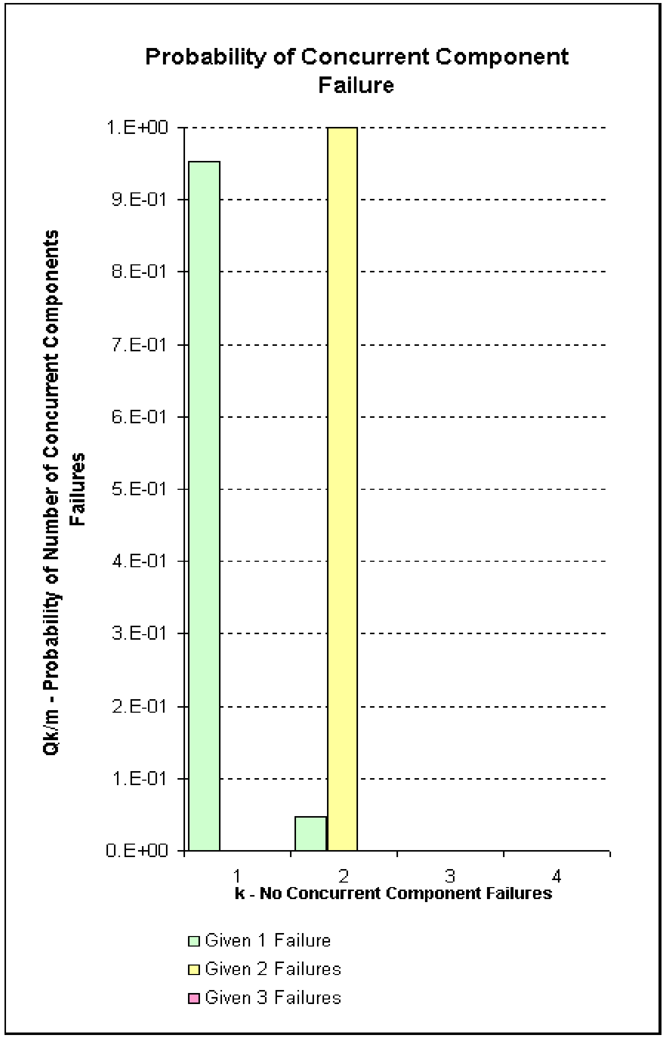
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}$=1	$Q_k \mid \beta$=1	$Q_k \mid \beta\&\gamma$=1	
1	1	1.00E+00	9.53E-01	**8.58E-06**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**4.23E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	9.00E-06	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR Pumps FR

Failure Rate	9.92E-06	/ hr
Mission Time	24	hrs

Q_{tot}	2.38E-04	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.40E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

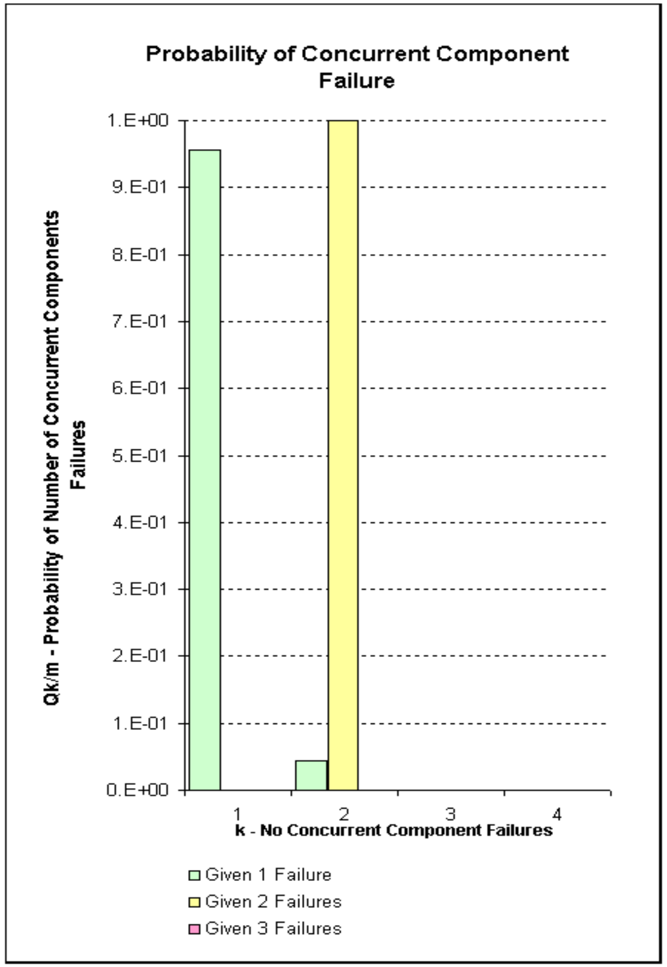
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.56E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.40E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	**Comb**	**$\Pi\rho_k$**	**$1-\rho_{k+1}$**	**$Q_k \mid Q_{tot}$=Nom**	**$Q_k \mid Q_{tot}$=1**	**$Q_k \mid \beta$=1**	**$Q_k \mid \beta\&\gamma$=1**	
1	1	1.00E+00	9.56E-01	**2.28E-04**	9.56E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.40E-02	1.00E+00	**1.05E-05**	4.40E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	2.38E-04	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : PTR Pumps FS

Q_{tot}	9.97E-06	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

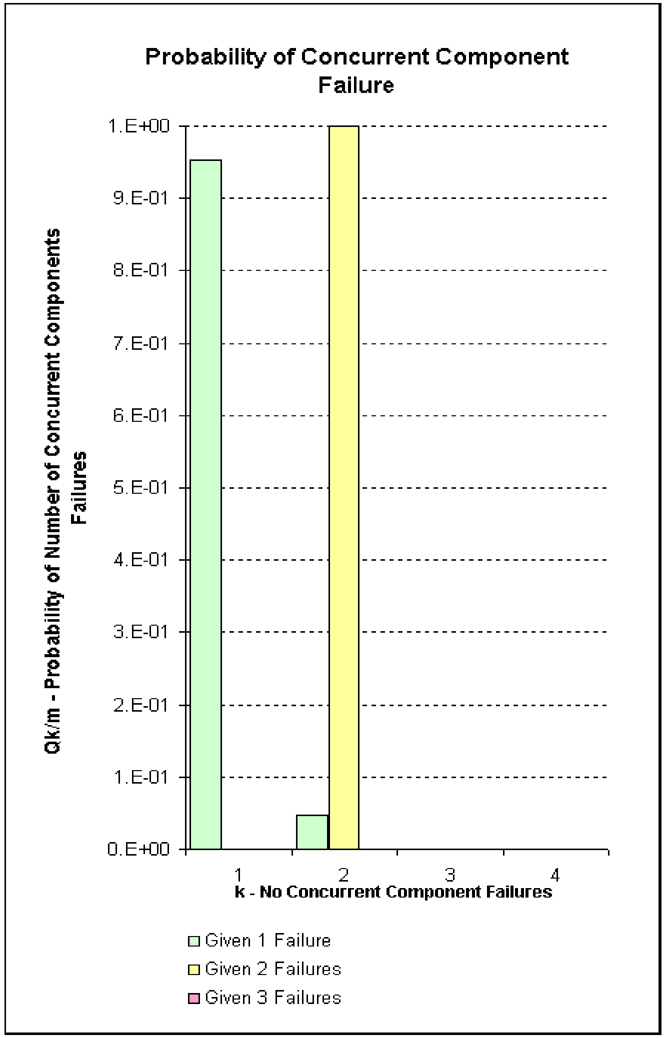
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \vert Q_{tot}$=Nom	$Q_k \vert Q_{tot}=1$	$Q_k \vert \beta=1$	$Q_k \vert \beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	**9.50E-06**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**4.69E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	9.97E-06	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : RRI MOV FO

Q_{tot}	5.00E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

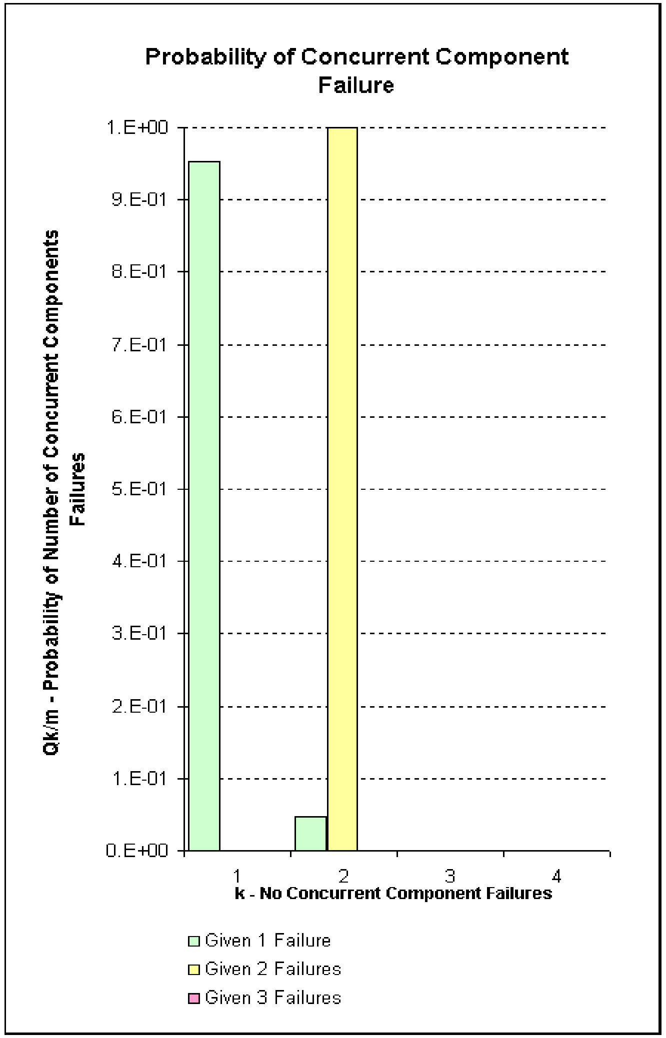
$$Q_K = \frac{1}{\binom{m-1}{k-1}}\left(\prod_{i=1}^{k}\rho_i\right)\left(1-\rho_{k+1}\right)Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k\|Q_{tot}$=Nom	$Q_k\|Q_{tot}=1$	$Q_k\|\beta=1$	$Q_k\|\beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	**4.77E-05**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**2.35E-06**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	5.00E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : RRI MSV FC

Q_{tot}	2.16E-04	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

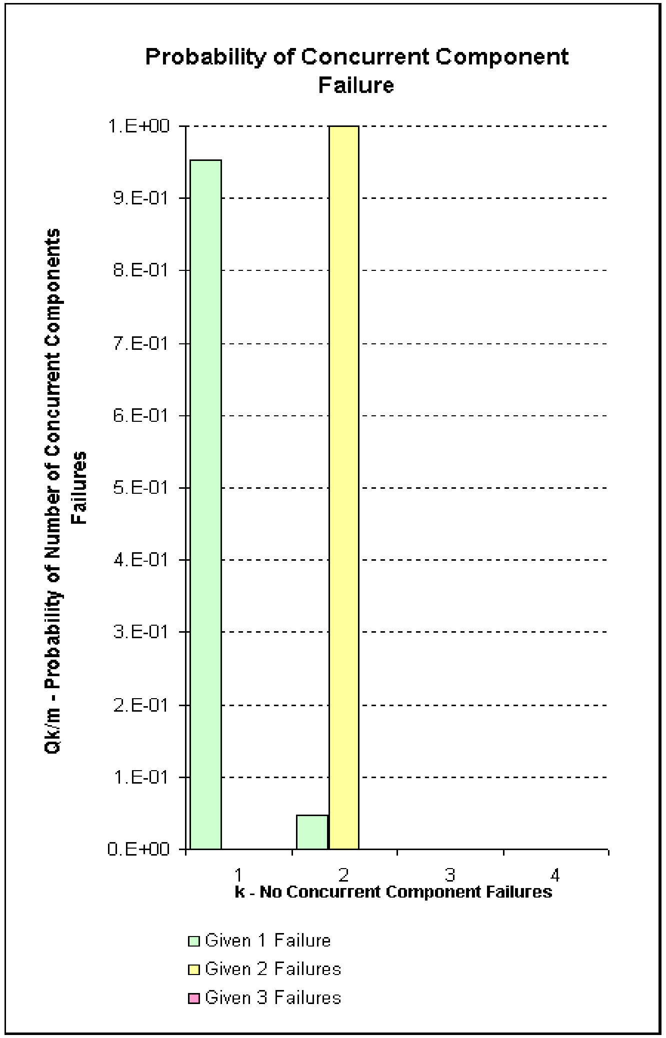
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}=1$	$Q_k \mid \beta=1$	$Q_k \mid \beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	**2.06E-04**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**1.02E-05**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	2.16E-04	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED NRV FC

Q_{tot}	1.50E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$=\rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$=\rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$=\rho_4$	Probability that more than three failures given the failure of three component

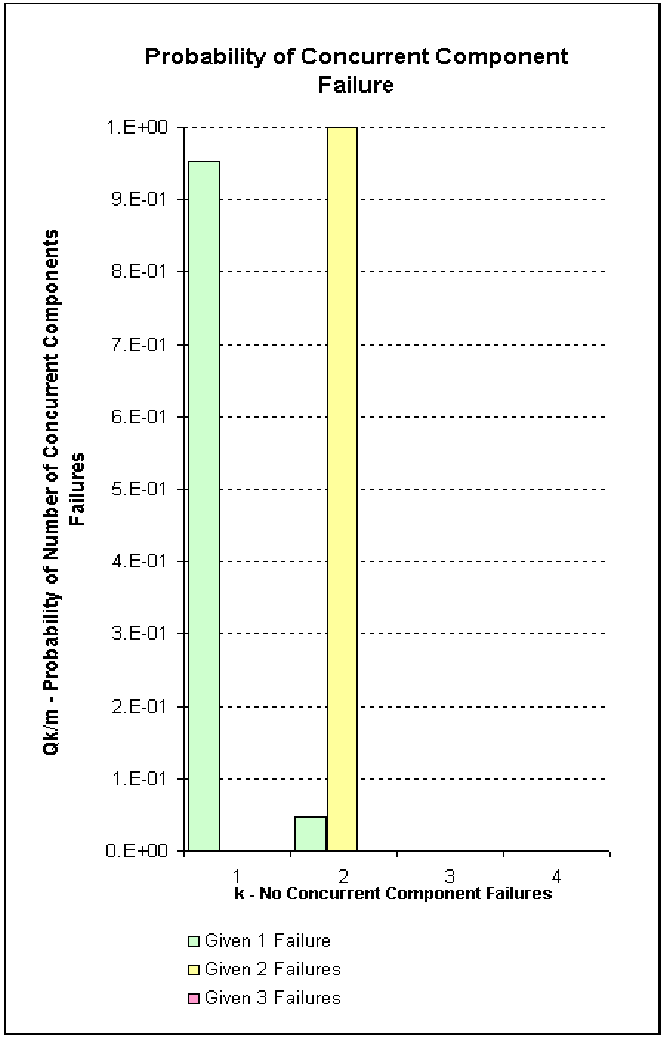
$$Q_K = \frac{1}{\binom{m-1}{k-1}}\left(\prod_{i=1}^{k}\rho_i\right)\left(1-\rho_{k+1}\right)Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k\|Q_{tot}$=Nom	$Q_k\|Q_{tot}$=1	$Q_k\|\beta$=1	$Q_k\|\beta\&\gamma$=1	
1	1	1.00E+00	9.53E-01	1.43E-05	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	7.05E-07	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	1.50E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED NRV FO

Q_{tot}	5.00E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

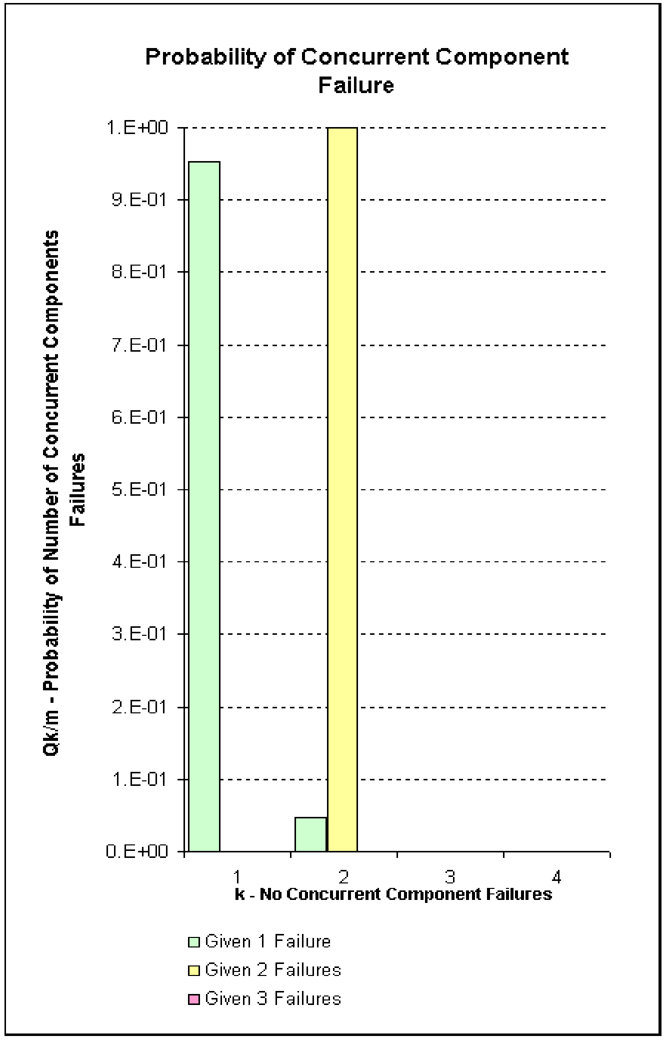
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) \left(1 - \rho_{k+1}\right) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	Q_{tot}=Nom: $Q_k \mid Q_{tot}$=Nom	Q_{tot}=1: $Q_k \mid Q_{tot}=1$	Q_{tot}=1: $Q_k \mid \beta=1$	Q_{tot}=1: $Q_k \mid \beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	4.77E-05	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	2.35E-06	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	5.00E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED Pump Motors FR

Failure Rate	3.35E-06	/ hr
Mission Time	24	hrs

Q_{tot}	8.04E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.40E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

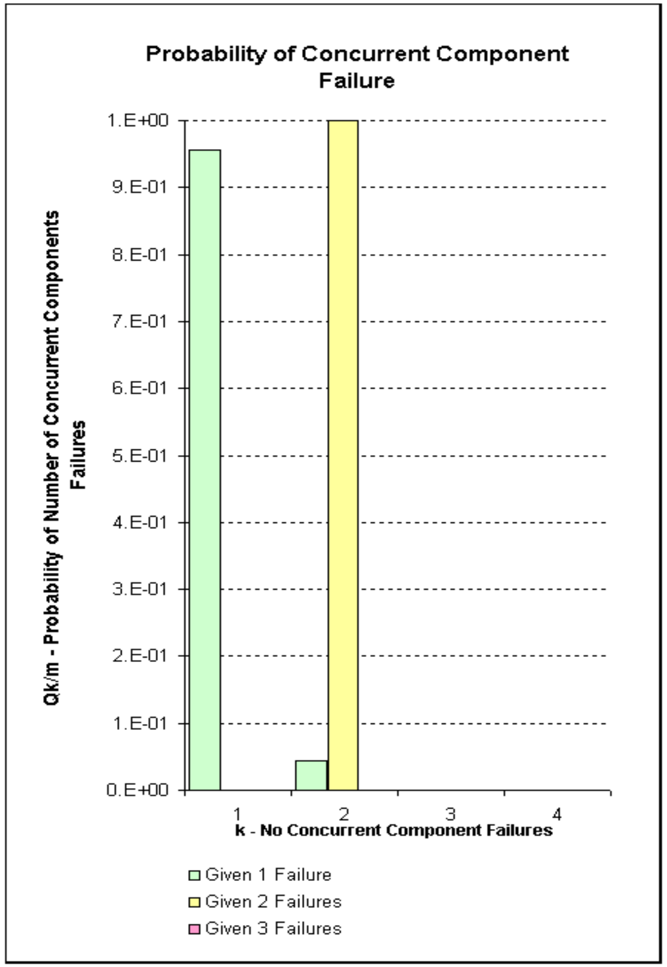
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.56E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.40E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	**Comb**	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \vert Q_{tot}$=Nom	$Q_k \vert Q_{tot}=1$	$Q_k \vert \beta=1$	$Q_k \vert \beta\&\gamma=1$	
1	**1**	1.00E+00	9.56E-01	**7.69E-05**	9.56E-01	0.00E+00	0.00E+00	1 Failure
2	**1**	4.40E-02	1.00E+00	**3.54E-06**	4.40E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	8.04E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED Pump Motors FS

Q_{tot}	9.00E-06	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2		No of Components
β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

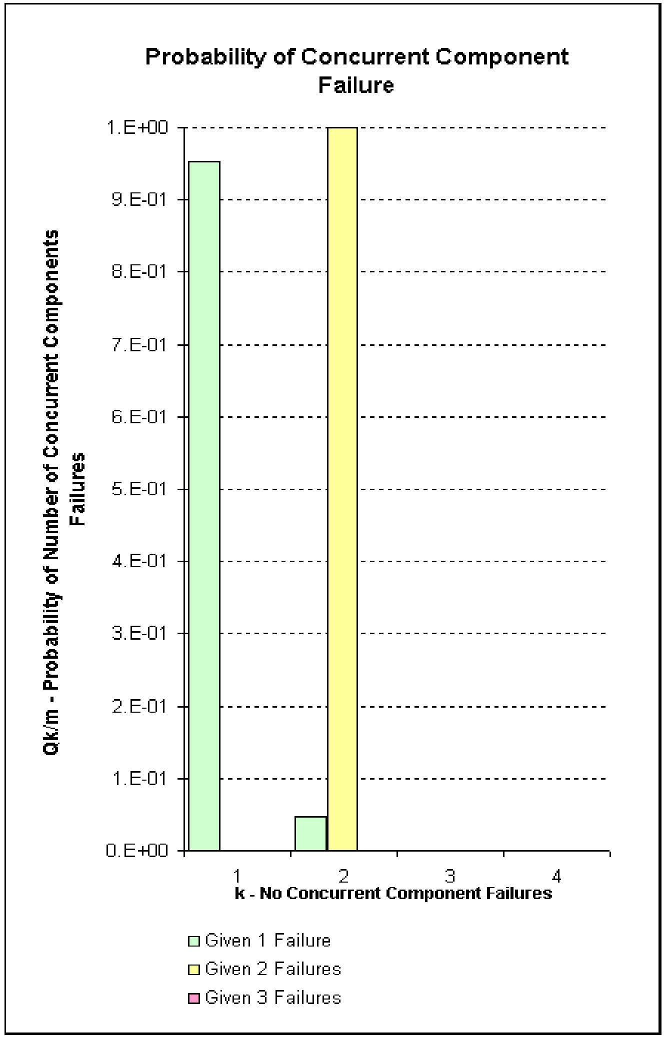
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \mid Q_{tot}$=Nom	$Q_k \mid Q_{tot}$=1	$Q_k \mid \beta$=1	$Q_k \mid \beta\&\gamma$=1	
1	1	1.00E+00	9.53E-01	**8.58E-06**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**4.23E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	9.00E-06	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED Pumps FR

Failure Rate	8.70E-06	/ hr
Mission Time	24	hrs

Q_{tot}	2.09E-04	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.40E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

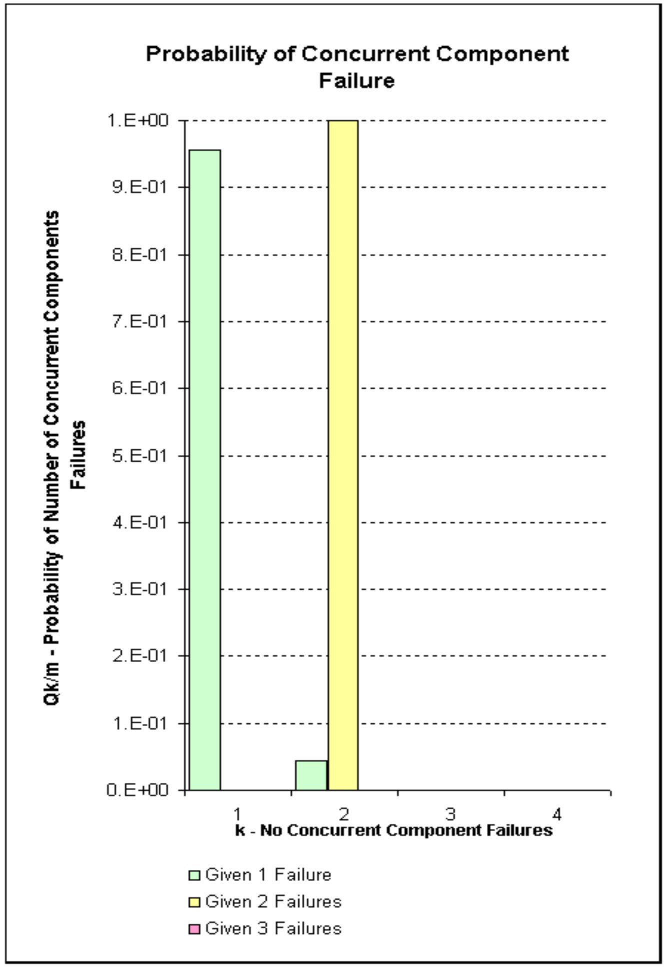
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

α_1	9.56E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.40E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \vert Q_{tot}$=Nom	$Q_k \vert Q_{tot}$=1	$Q_k \vert \beta$=1	$Q_k \vert \beta\&\gamma$=1	
1	1	1.00E+00	9.56E-01	**2.00E-04**	9.56E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.40E-02	1.00E+00	**9.19E-06**	4.40E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	2.09E-04	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



CCF Group Calculation Tool

MGL CCF MODEL

CCF Group : SED Pumps FS

Q_{tot}	1.50E-05	Component Failure Probability or Failure Rate

MGL Model Parameters for CCF Group

m	2	No of Components

β	4.70E-02	$= \rho_2$	Probability that more than one failure given a single failure
γ	1.00E+00	$= \rho_3$	Probability that more than two failures given the failure of two component
δ	1.00E+00	$= \rho_4$	Probability that more than three failures given the failure of three component

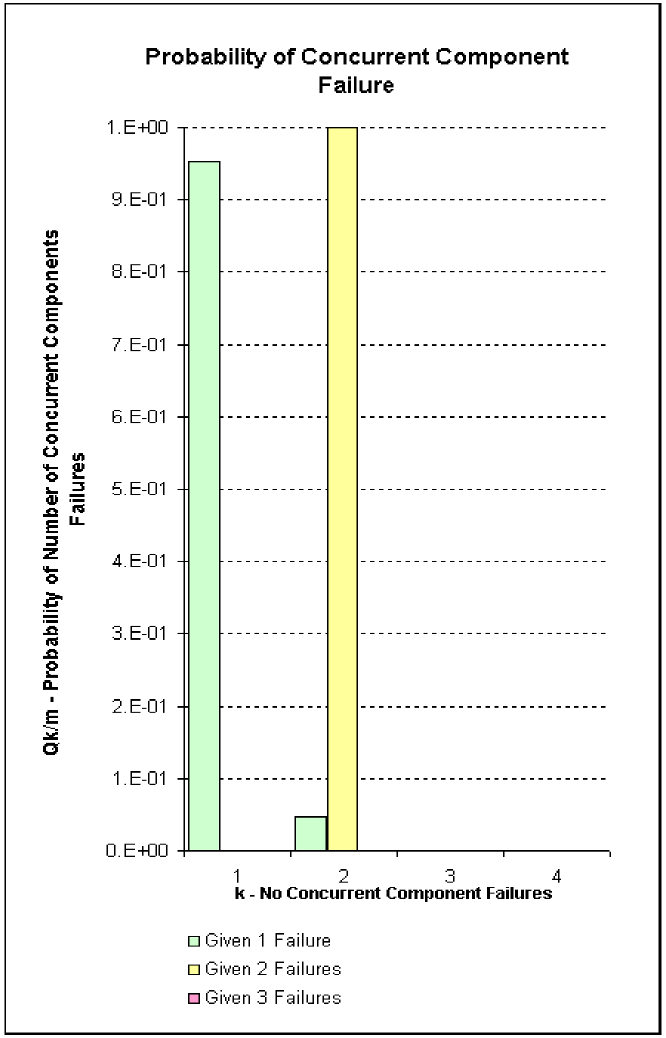
$$Q_K = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_i \right) (1 - \rho_{k+1}) Q_{tot}$$

Alpha Model Parameter for CCF Group (for staggered testing)

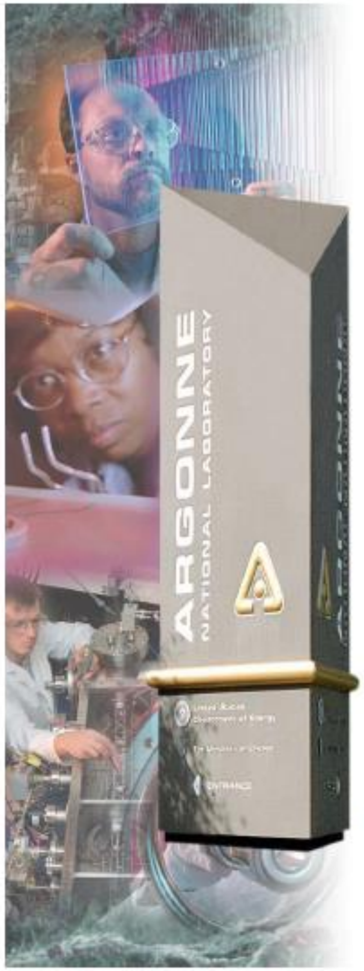
α_1	9.53E-01	Probabilty of a single failure given a single failure has occurred
α_2	4.70E-02	Probabilty of any two failures given a single failure has occurred
α_3	0.00E+00	Probabilty of any three failures given a single failure has occurred
α_4	0.00E+00	Probabilty of four or more failures given a single failure has occurred
Σ	1.00E+00	Sum of all α's [Should equal 1]

Probability of k CCF failures with different initial number of failures

				Q_{tot}=Nom	Q_{tot}=1			
k	Comb	$\Pi\rho_k$	$1-\rho_{k+1}$	$Q_k \vert Q_{tot}$=Nom	$Q_k \vert Q_{tot}=1$	$Q_k \vert \beta=1$	$Q_k \vert \beta\&\gamma=1$	
1	1	1.00E+00	9.53E-01	**1.43E-05**	9.53E-01	0.00E+00	0.00E+00	1 Failure
2	1	4.70E-02	1.00E+00	**7.05E-07**	4.70E-02	1.00E+00	0.00E+00	2 Failures
3								3 Failures
>=4								All Failures
			Σ	1.50E-05	1.00E+00	1.00E+00	0.00E+00	Should equal Q_{tot}



APPENDIX B: OPERATIONAL SAFETY OF SPENT NUCLEAR FUEL



Operational Safety of Spent Nuclear Fuel

Joseph C. Braun

Lecture 6.1b

2 December , 2010

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Expected Outcomes from this Lecture

As a result of this lecture,
the student will be able to:

- Identify the Decay Heat Standard ANSI/ANS-5.1 1979
- Be able to compute the decay heat as a function of time after shutdown for one or more fuel assemblies
- Recognize the various conditions where fuel assemblies may be at risk from overheating

Decay Heat Standard Reference:

Decay Heat Power in
Light Water Reactors

ANSI/ ANS – 5.1-1979

Published by the American Nuclear Society
555 N. Kensington Avenue
Lagrange Park, Illinois, 60525 USA

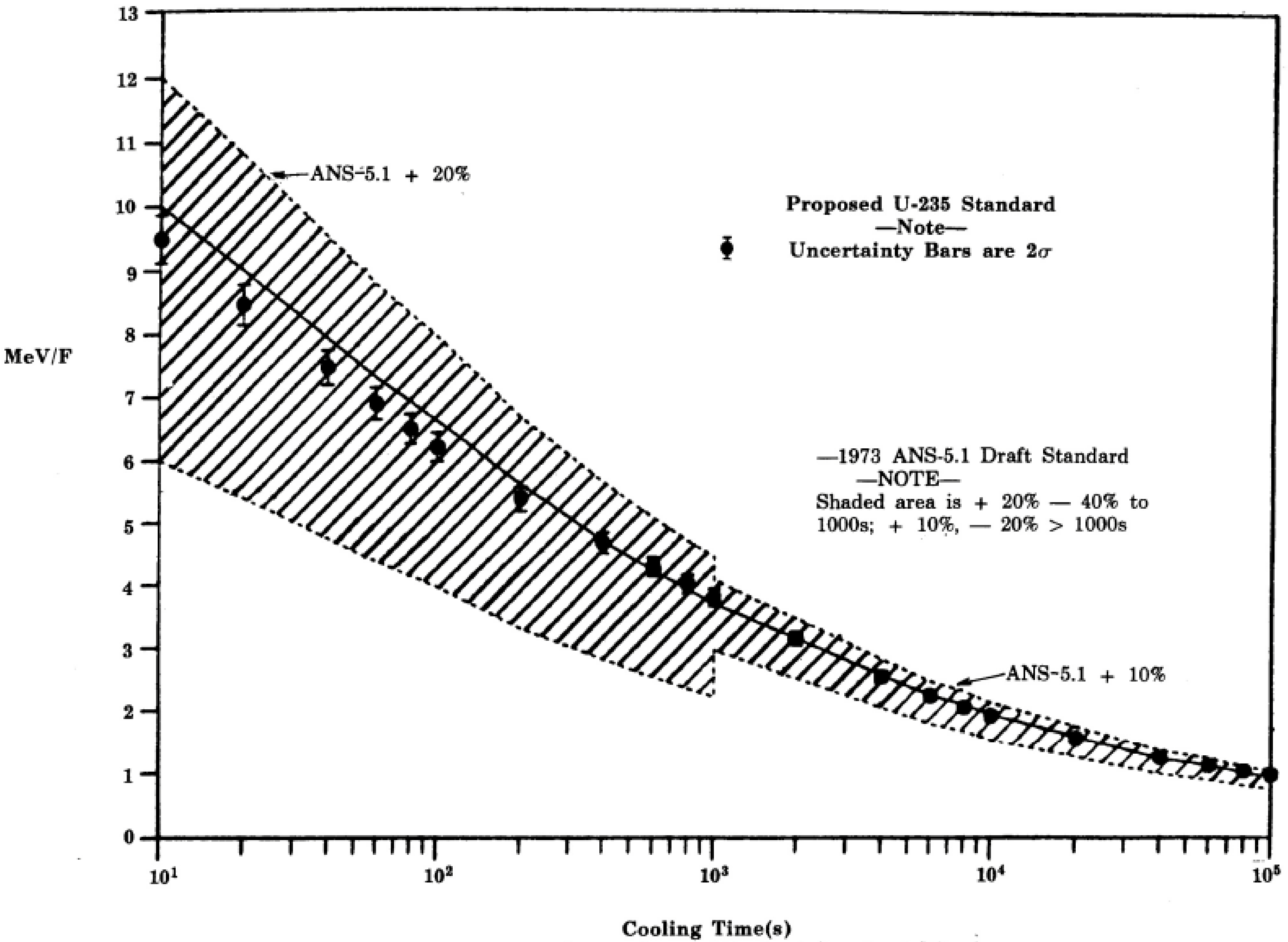


Figure F-1. Comparison of Revised Standard F(t,∞)

Decay Heat in Light Water Reactor Fuel

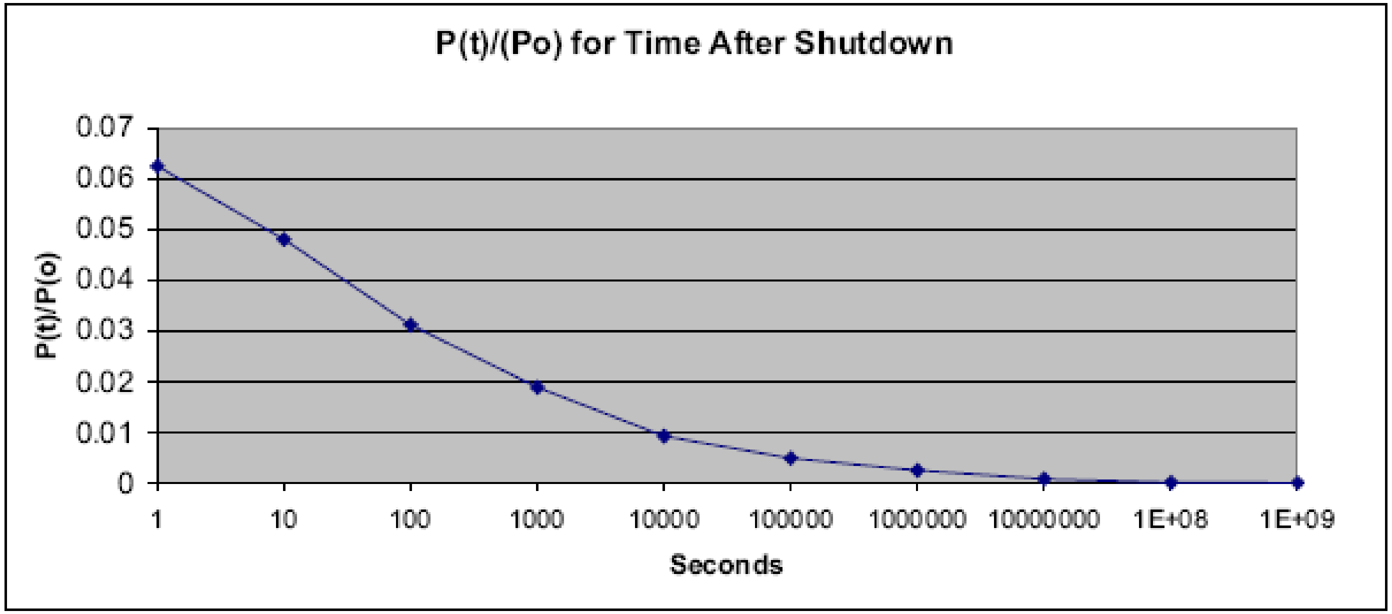
Measured From Time After Shutdown
(Irradiation time: 1020 days ~ three years)

Seconds after shutdown	P (t) /P(0)	Multiplier	Note(s)
1.00E+00	6.247	6.25E-02	
1.00E+01	4.804	4.80E-02	
1.00E+02	3.115	3.12E-02	
1.00E+03	1.886	1.89E-02	
1.00E+04	0.9237	9.24E-03	
1.00E+05	0.487	4.87E-03	1
1.00E+06	0.247	2.47E-03	2
1.00E+07	0.0775	7.75E-04	3,4
1.00E+08	0.00994	9.94E-05	5
1.00E+09	0.00174	1.74E-05	6

Notes:

- (1) 1.0E+5 seconds ~ 1 day (8.64E+4 sec)
- (2) 1.0E+6 seconds ~ 12 days (1.0368 E +6 sec)
- (3) 1.0E+7 seconds ~ 120 days (1.0368 E +7 sec)
- (4) 1 year = 365 days = 3.153 E +7 sec
- (5) 1.0E +8 seconds = 3.17 years
- (6) 1.0E +9 seconds = 31.7 years

1	0.06247
10	0.04804
100	0.03115
1000	0.01886
10000	0.009237
100000	0.00487
1000000	0.00247
10000000	0.000775
100000000	0.0000994
1000000000	0.00001736



Fuel Assembly Decay Heat Calculation:

Imagine a Hypothetical 1000 Mw(e) Power Reactor that has 300 fuel assemblies:

- If the thermal efficiency is 33% then the Thermal power is 3000 Mw(th)
- 3000 Mw(th) divided by 300 assemblies equals 10 MW(th) per assembly
- 10 Mw(th) per assembly is 10,000 kw per assembly.

Let 10,000 kw per assembly be identified as the assembly power at time zero.

- Hence P(0) = 10,000 kw.
- Using the decay heat table, we can obtain the thermal output as a function of time after shutdown.

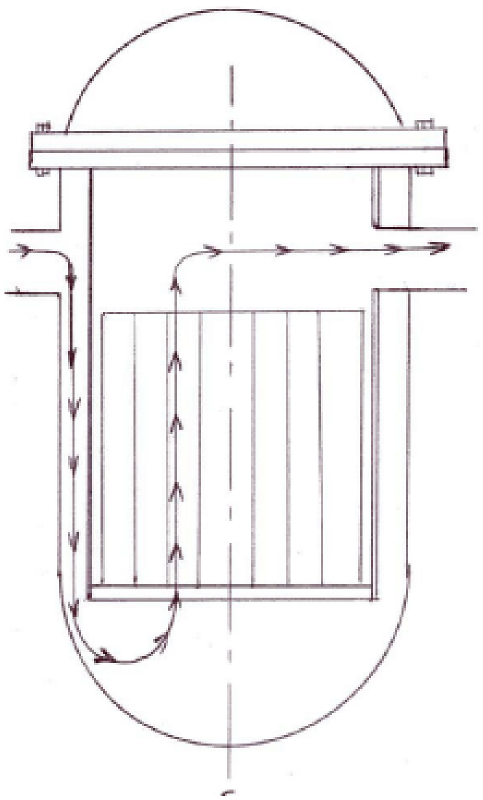
Fuel Assembly Decay Heat Calculation:

Thermal Power of a 10 Mw Fuel Assembly (in Seconds After Shutdown)

Seconds after Shutdown	Multiplier	Thermal Power P (t) (kw)
1.00E+00	6.25E-02	624.7
1.00E+01	4.80E-02	480.4
1.00E+02	3.12E-02	311.5
1.00E+03	1.89E-02	188.6
1.00E+04	9.24E-03	92.4
1.00E+05	4.87E-03	48.7
1.00E+06	2.47E-03	24.7
1.00E+07	7.75E-04	7.8
1.00E+08	9.94E-05	1.0
1.00E+09	1.74E-05	0.2

Six Cases Involving Shutdown Plants and Spent Fuel

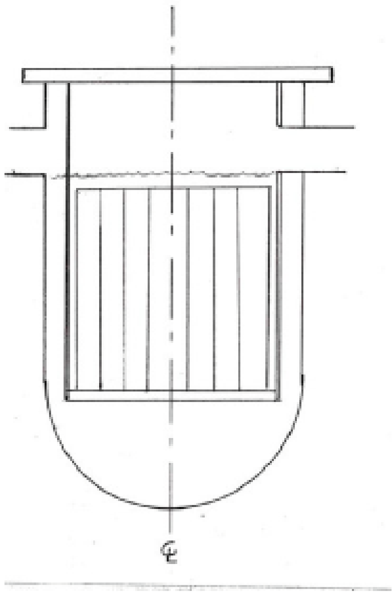
- Case #1: Fuel in Closed Reactor Vessel
- Case #2: Fuel in Open and Drained Reactor Vessel
- Case #3: Fuel in Spent Fuel Pool –Natural Circulation
- Case #4: Fuel in Completely Drained Spent Fuel Pool
- Case #5: Fuel in Partially Drained Spent Fuel Pool
- Case #6: Dry Fuel Movement and Storage



Case #1: Fuel in Closed Reactor Vessel

Decay Heat Regime: 1 to 30 days

- Important to keep fuel covered with water at all times.
- Important to have heat removal from reactor coolant system.
- Assure that control rods fully inserted, and/or soluble boron levels are adequate, and there are no reactivity issues.
- If water in reactor system is removed for any reason, this could lead to heat removal problems.
- If boiling occurs, this could lead to voiding and possible fuel damage.
- Need to be particularly careful when system is partially drained



Case #2: Fuel in Open and Drained Reactor Vessel

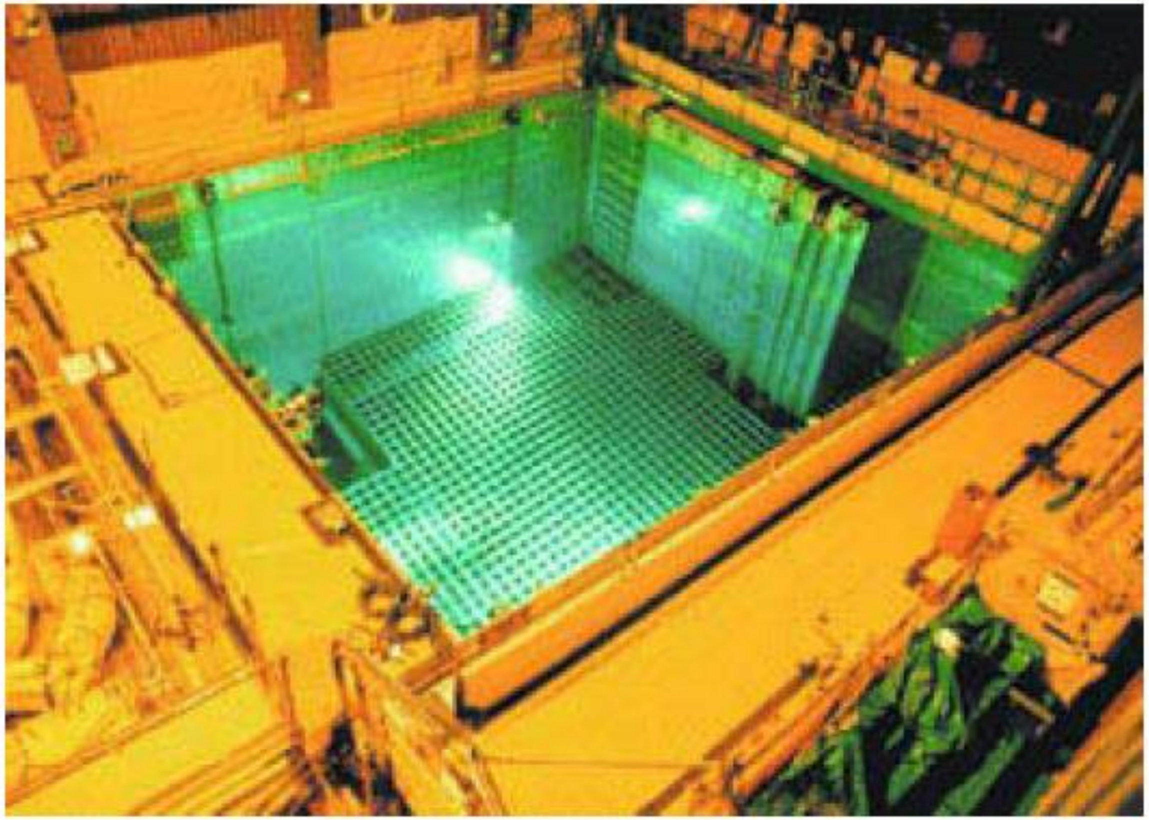
Decay Heat Regime: 3 to 50 days.

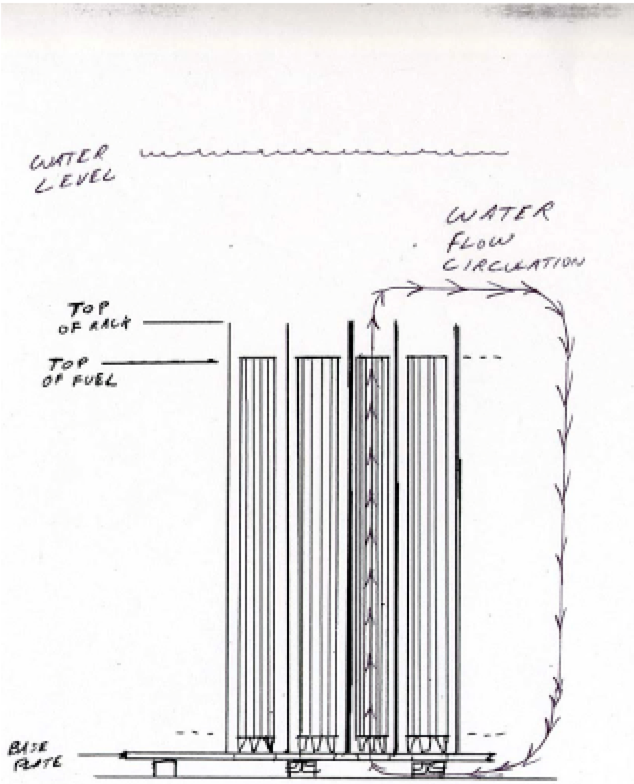
•An early industry practice was to drain loops for Steam Generator Maintenance. Mistakes in this practice have lead to dangerously low water levels in the reactor vessel.

•Classic case for “time to boil” calculations:
- -Estimated volume of water
- -Known heat rate –from decay heat curves.
- - Calculate time to boil, boil-off rate, time to uncover fuel, possibly fuel clad and centerline temperatures.

•This configuration is seldom used today in the U. S.

Spent Fuel Pool

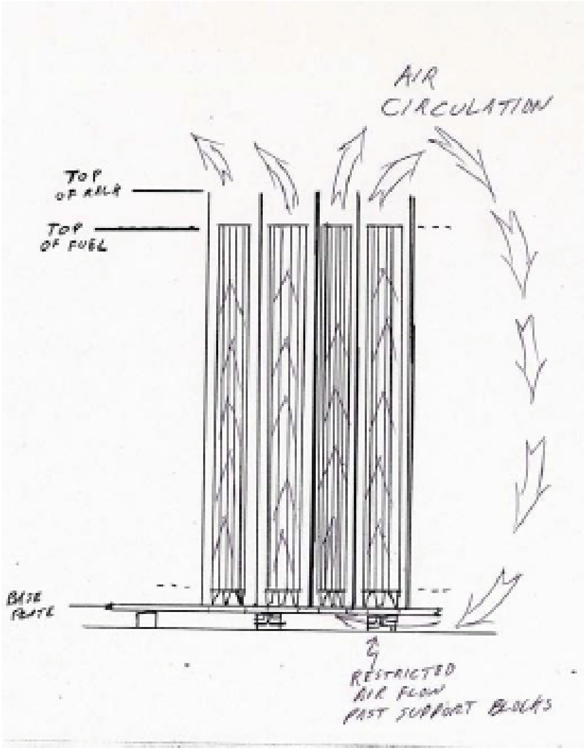




Case #3: Fuel in Spent Fuel Pool –Natural Circulation

Decay Heat Regime: 5 days to 40 years.

- •Water circulates through fuel assemblies in spent fuel pool. Cooler water sinks to bottom of pool and is heated by fuel assemblies. Water rises and a natural circulation process occurs.
- •Fuel pools have cooling systems to cool the water from the pool.
- •Failure of cooling system is not critical due to the large mass of water above the fuel. Rise in pool water temperature is easily detected.
- •Ample time available to repair or compensate for failed cooling systems.
- •Loss of pool water from leaks is an area of growing concern in aging plants and fuel storage facilities where corrosion may have advanced considerably.
- •This concern is augmented by concerns about sabotage or terrorist attack.

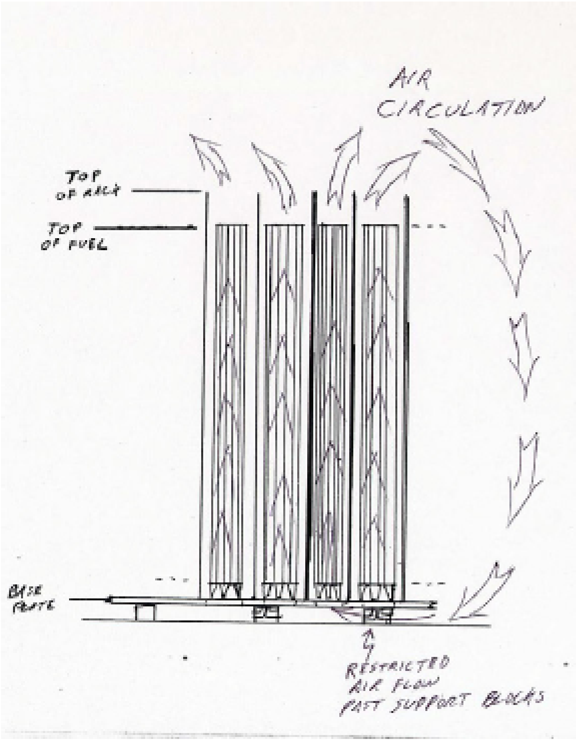


Case #4: Fuel in Completely Drained Spent Fuel Pool

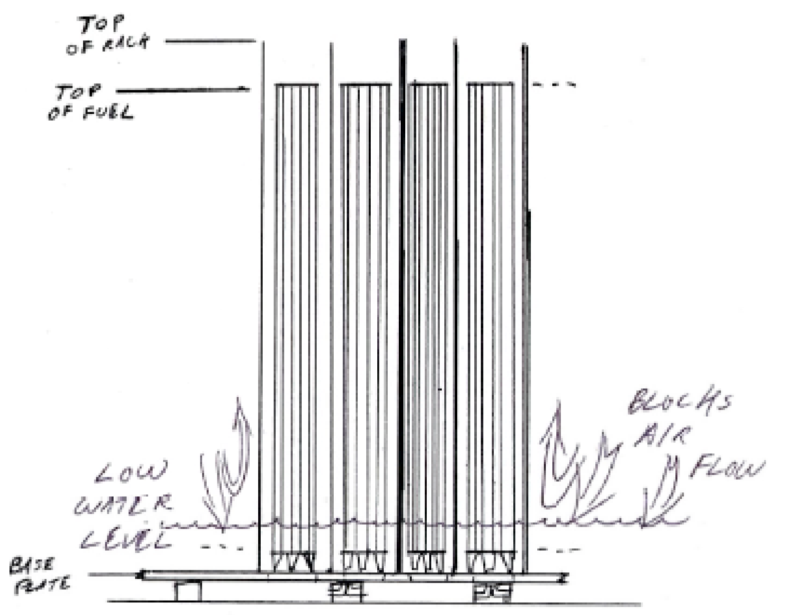
Decay Heat Regime: 5 days to 50 years.

•This case is of intellectual interest as an "end point" of the water loss problem in a spent fuel pool. Which fuel assemblies are safe, and which fuel assemblies are at risk?

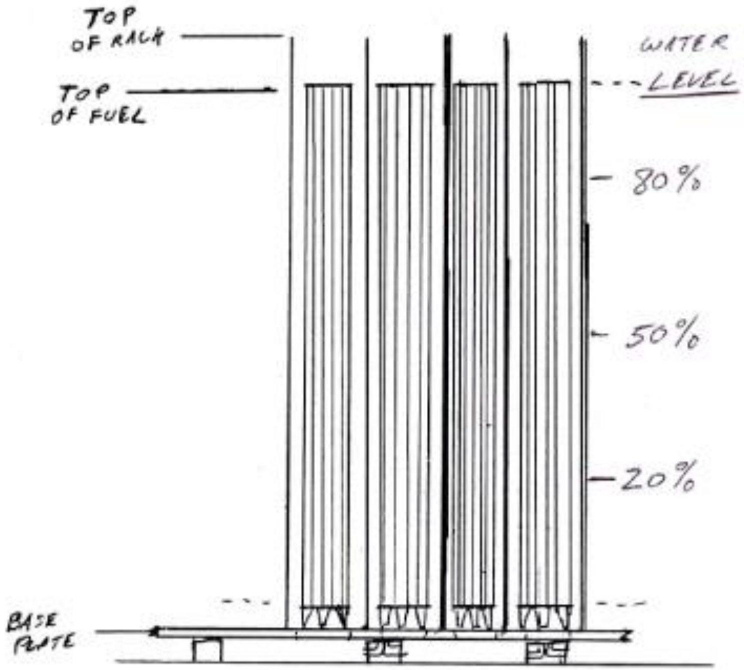
•The decay heat curves are used, with added heat rates to cover uncertainties, to calculate conductive, convective and radiative heat losses (i.e. thermal radiation) to structural components and fuel assemblies.



- The general view among the industry is that fuel assemblies that have aged for more than about 120 days will rise to an elevated temperature and achieve equilibrium with a circulating air environment. This stable temperature will have the cladding below the 1100-1200 C temperatures at which combustion of zirconium begins. This temperature is also below the melting temperature of commonly used steel alloys of around 1400 C.
- Substantial oxidation of zirconium may occur at these elevated temperatures.
- The elevated temperatures and loads may cause structural damage to the fuel pool or fuel racks. Detailed calculations are needed to model these effects.
- Heat rate at 120 days is about 7 kw per assembly.
- Assemblies with higher heat rates may reach "ignition" temperatures and eventually melt.



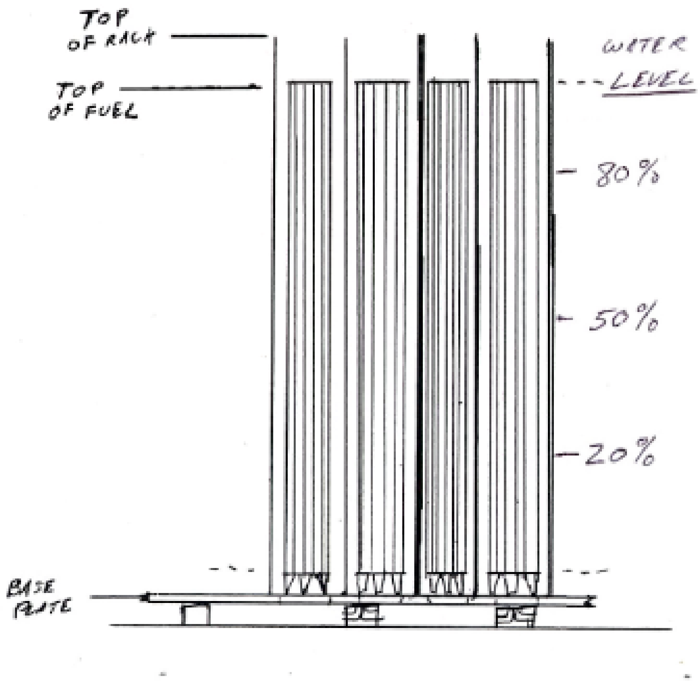
<u>Water addition:</u> adding water to the bottom of an empty spent fuel pool can damage an assembly with a heat rate of 7kw or less that has reached equilibrium in air! -- *The water can block the circulation of air and cause the fuel assembly to overheat. The heat removed by the low level of water is insufficient to cool the assembly.*



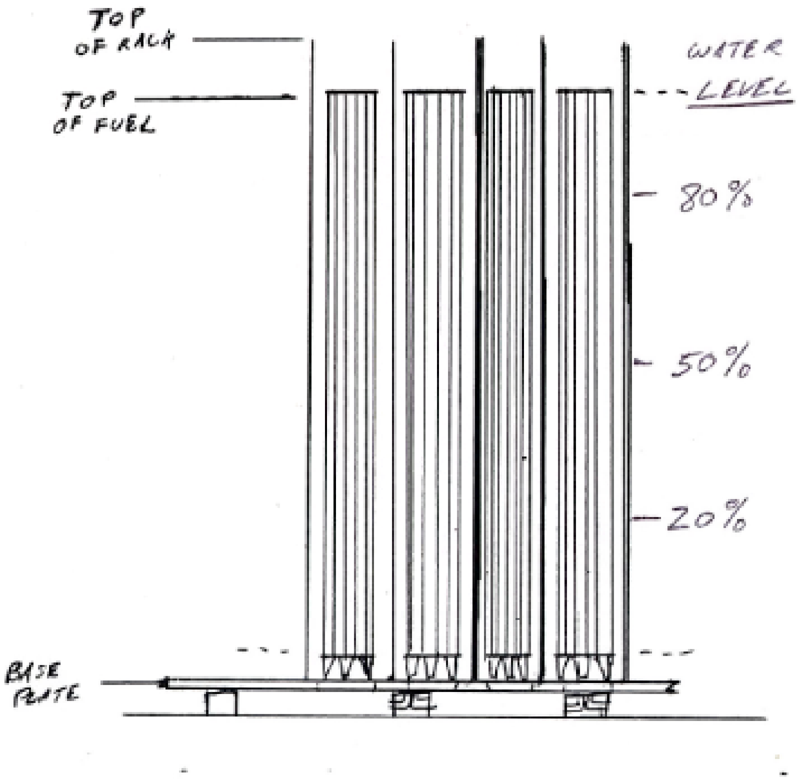
Case #5: Fuel in Partially Drained Spent Fuel Pool

Decay Heat Domain: 5 days to 50 years.

- What is the effect of water level on spent fuel in a rack in a pool?
- A water level above the top of the rack allows natural circulation of water to occur.
- When the water level falls to the top of the fuel racks, natural circulation stops and water heat-up begins.

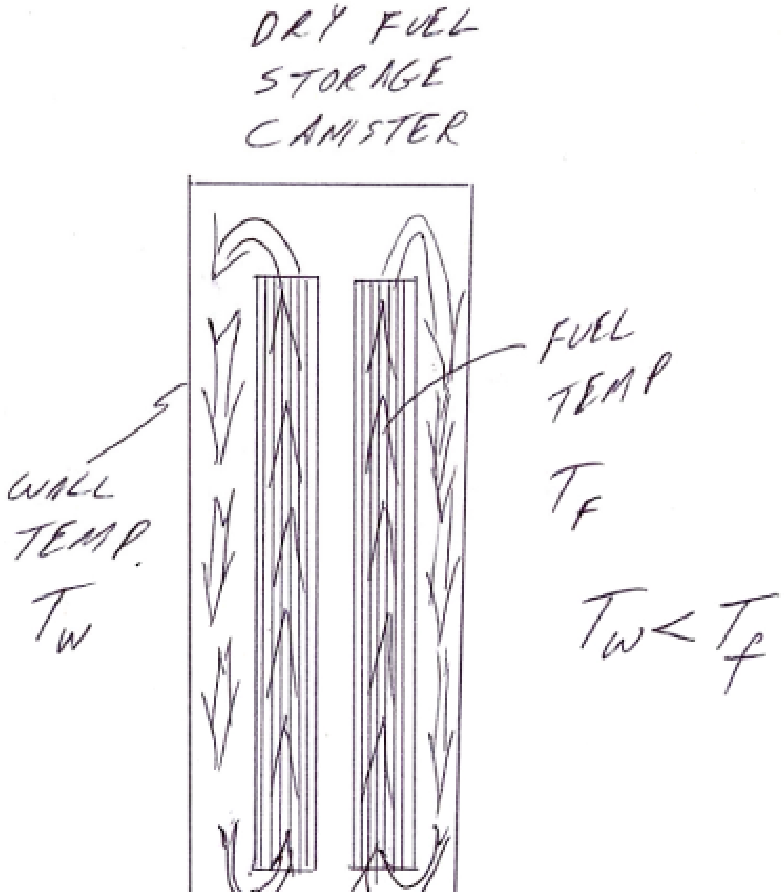


- Water temperatures will rise and boiling will eventually occur in the hotter assemblies.
- Water will flow along the bottom the pool from cooler assemblies to hotter assemblies.
- Boil-off will occur and water levels will drop—probably over the time scale of hours.
- As the levels drop, steam from the boil-off will cool the uncovered parts of the fuel.
- At some point, the rising steam will be insufficient to cool the uncovered fuel and clad temperatures will rise until they reach the "ignition" point.
- Where is this level? Detailed calculations are needed. Experts suggest that it is somewhere between 20 and 80% of assembly height, possibly around the mid-point.



- When the water is at the bottom of the fuel, say about the 20% level, the steaming rate is probably insufficient to cool the rest of the assembly, and air circulation is not possible. So fuel assemblies that may be safe in air are likely to melt with a low water level.

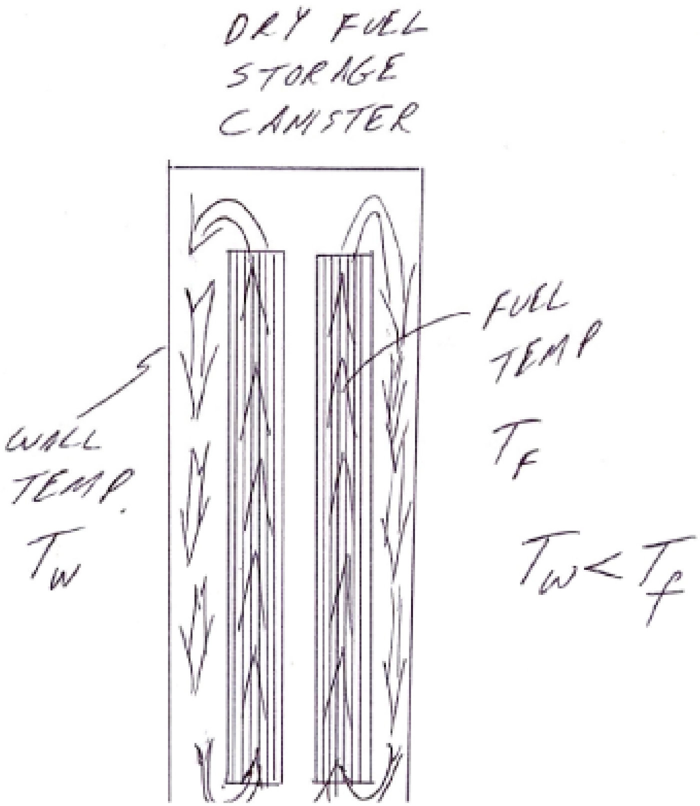
- Detailed calculations are needed to address specific issues of geometry and heat transfer.



Case #6: Dry Fuel Movement and Storage

Decay Heat Regime: 5+ years to 50 years

•We have seen that after about 120 days it is possible that an assembly can be cooled in air without melting. Heat rates are about 7 kw per assembly at that time. After about three years, the heat rate drops to about 1 kw per assembly, and although the risk of melting in air is clearly lower, corrosion is still an issue as fuel centerline and clad temperatures are still elevated.



- Remember that assemblies that may not melt in a good air flow, may melt if that air flow is blocked.
- The design of spent fuel storage canisters and casks considers these issues and a spectrum of possible accidents that can occur in dry storage and transport.
- Extensive testing is done on spent fuel shipping containers to account for crashes, drops, drops onto a penetrating object, fire, and flooding after a fire—remember that a small amount of water in the wrong place in a dry canister can block air flow and lead to possible fuel melting.

Summary and Conclusions

- Decay heat effects in spent nuclear fuel are well understood—the classic standard has existed since 1979.
- Spent nuclear fuel must be adequately cooled at all times.
- It is necessary to understand the physical circumstances for cooling spent nuclear fuel and to guard against conditions that could undermine this cooling.
- Computer analyses of spent nuclear fuel pools can provide detailed information that can help to provide strategies to manage and reduce risks of spent nuclear fuel handling, treatment and storage.

APPENDIX C: PTR HEAT EXCHANGER CAPABILITY

Danette Moller - Notes on Patrick's programme

From: Don Poliwoda <dpoliwoda@nci-sa.co.za>
To: Lindley Perryman <Lindley.Perryman@eskom.co.za>
Date: 2011/06/02 11:18 AM
Subject: Notes on Patrick's programme
CC: Joseph Haba <Joseph.Haba@eskom.co.za>, "danette.moller@eskom.co.za" <danette.moller@eskom.co.za>

Hi All

When using the PTR programme:

1. RRI flow is always 450 m^3/h regardless of whether one or two PTR heat exchangers are in service as the RRI flow to these heat exchangers is always in series (in theory, RRI flow to these heat exchangers can be supplied in parallel, but in practice this is not done).

2. With one PTR heat exchanger in service PTR flow per exchanger is 300 m^3/h and with two heat exchangers in service this flow is 150m^3/h.

3. Two PTR pumps in service is not permitted by the NNR.

4. Leave RRI base load, exchange area and fouling factor as is.

5. Regarding RRI/SEC capability factor:

   2.44 MW/^{o}C is for normal power operation

   2.66 MW/^{o}C is for outage operation with two RRI and two SEC pumps in service – normal outage RRI/SEC configuration

   2.80 MW/^{o}C is for normal power operation with one RRI and two SEC pumps in service

6. Heat exchanger configuration refers to the number of PTR heat exchangers in operation.

7. RRI configuration, as discussed above, is normally in series.

Should you have any questions, or require any further information, please advise.

Regards,

Don

Case 1: PTR Heat Exchanger Capability - Single Exchanger

RRI Flow Rate	450 m^3/h
PTR Flow Rate	300 m^3/h
PTR Inlet Temp	100°C
PTR Outlet Temp	56.808°C
RRI Inlet Temp	21.436°C
RRI Outlet Temp	49.762°C
Sea Water Temp	14°C
RRI/SEC B value	2.66 MW/°C
RRI Base Load	5.1 MW
Fouling Factor	0.000086
Exchange Area	239 m^2
Average RRI Temp	35.598°C
Average PTR Temp	78.406°C
hi	8243.5 $W/m^2.°C$
ho	5799.1 $W/m^2.°C$
Overall U	1661 $W/m^2.°C$
Log Mean Temp	36.98°C
HEAT REMOVAL CAPACITY	14.68 MW

Case 2: PTR Heat Exchanger Capability - Single Exchanger

RRI Flow Rate	450 m^3/h
PTR Flow Rate	300 m^3/h
PTR Inlet Temp	100°C
PTR Outlet Temp	59.75°C
RRI Inlet Temp	27.057°C
RRI Outlet Temp	53.477°C
Sea Water Temp	20°C
RRI/SEC B value	2.66 MW/°C
RRI Base Load	5.1 MW
Fouling Factor	0.000086
Exchange Area	239 m^2
Average RRI Temp	40.267°C
Average PTR Temp	79.877°C
hi	8303.3 $W/m^2.°C$
ho	5948.8 $W/m^2.°C$
Overall U	1676 $W/m^2.°C$
Log Mean Temp	34.13°C
HEAT REMOVAL CAPACITY	13.67 MW

Case 3: PTR Heat Exchanger Capability - Single Exchanger

RRI Flow Rate	450 m^3/h
PTR Flow Rate	300 m^3/h
PTR Inlet Temp	100°C
PTR Outlet Temp	61.48°C
RRI Inlet Temp	30.334°C
RRI Outlet Temp	55.631°C
Sea Water Temp	23.5°C
RRI/SEC B value	2.66 MW/°C
RRI Base Load	5.1 MW
Fouling Factor	0.000086
Exchange Area	239 m^2
Average RRI Temp	42.982°C
Average PTR Temp	80.742°C
hi	8337.8 $W/m^2.°C$
ho	6033.9 $W/m^2.°C$
Overall U	1684.3 $W/m^2.°C$
Log Mean Temp	32.48°C
HEAT REMOVAL CAPACITY	13.08 MW

APPENDIX D: PC COSYMA RESULTS

Table D-01: Mean short term individual dose (Sievert) for 5 day inventory using MAAP release fractions

Distance (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.50	1.92E+00	6.37E+00	1.36E+00	1.27E+00	6.02E+01	3.67E+00	1.36E+00	1.64E+00
1.75	3.81E-01	1.21E+00	2.76E-01	2.56E-01	1.14E+01	7.25E-01	2.74E-01	3.29E-01
3.75	1.61E-01	4.61E-01	1.20E-01	1.11E-01	4.47E+00	3.08E-01	1.18E-01	1.41E-01
6.25	6.85E-02	1.87E-01	5.19E-02	4.77E-02	1.83E+00	1.31E-01	5.10E-02	6.05E-02
8.75	3.03E-02	7.96E-02	2.34E-02	2.14E-02	7.68E-01	5.68E-02	2.29E-02	2.68E-02
11.25	1.95E-02	5.08E-02	1.53E-02	1.39E-02	4.80E-01	3.60E-02	1.49E-02	1.72E-02
13.75	1.47E-02	3.89E-02	1.13E-02	1.03E-02	3.80E-01	2.79E-02	1.11E-02	1.30E-02
16.25	1.18E-02	3.08E-02	8.98E-03	8.25E-03	3.07E-01	2.26E-02	8.83E-03	1.05E-02
18.75	1.21E-02	3.01E-02	9.46E-03	8.64E-03	2.96E-01	2.29E-02	9.24E-03	1.08E-02
21.25	9.95E-03	2.48E-02	7.68E-03	7.06E-03	2.49E-01	1.91E-02	7.55E-03	8.88E-03
23.75	8.77E-03	2.13E-02	6.75E-03	6.22E-03	2.19E-01	1.71E-02	6.65E-03	7.87E-03
26.25	1.12E-02	2.60E-02	8.50E-03	7.88E-03	2.83E-01	2.25E-02	8.43E-03	1.01E-02
28.75	9.01E-03	2.01E-02	7.35E-03	6.67E-03	1.94E-01	1.65E-02	7.12E-03	8.10E-03
31.25	7.85E-03	1.67E-02	6.56E-03	5.91E-03	1.57E-01	1.40E-02	6.31E-03	7.06E-03
33.75	7.40E-03	1.51E-02	6.20E-03	5.60E-03	1.45E-01	1.33E-02	5.97E-03	6.68E-03
36.25	7.63E-03	1.49E-02	6.43E-03	5.80E-03	1.45E-01	1.38E-02	6.19E-03	6.93E-03
38.75	6.83E-03	1.36E-02	5.56E-03	5.07E-03	1.44E-01	1.30E-02	5.41E-03	6.22E-03
41.25	5.63E-03	1.19E-02	4.43E-03	4.08E-03	1.30E-01	1.11E-02	4.36E-03	5.13E-03
43.75	4.69E-03	1.01E-02	3.74E-03	3.42E-03	1.06E-01	9.04E-03	3.66E-03	4.25E-03
46.25	3.86E-03	8.26E-03	3.09E-03	2.83E-03	8.56E-02	7.34E-03	3.02E-03	3.49E-03
48.75	3.53E-03	7.55E-03	2.82E-03	2.58E-03	7.90E-02	6.77E-03	2.76E-03	3.20E-03
51.25	3.25E-03	6.93E-03	2.57E-03	2.36E-03	7.43E-02	6.34E-03	2.53E-03	2.96E-03
53.75	3.09E-03	6.47E-03	2.44E-03	2.24E-03	7.06E-02	6.07E-03	2.40E-03	2.82E-03
56.25	3.10E-03	6.26E-03	2.47E-03	2.26E-03	6.88E-02	6.07E-03	2.42E-03	2.83E-03
58.75	3.19E-03	6.22E-03	2.55E-03	2.34E-03	6.98E-02	6.30E-03	2.50E-03	2.93E-03

Table D-02: Mean long term individual dose (Sievert) for 5 day inventory using MAAP release fractions

Distance (km)	EFFECTIVE	SKIN	B.MARROW	B.SURFACE	BREAST	LUNG	STOMACH	COLON	LIVER	PANCREAS	THYROID	GONADS	REMAINDER
0.50	2.81E+01	8.73E+00	2.89E+01	5.97E+01	2.60E+01	3.19E+01	2.43E+01	2.40E+01	3.06E+01	2.25E+01	3.53E+01	2.55E+01	2.69E+01
1.75	5.77E+00	1.67E+00	5.93E+00	1.20E+01	5.38E+00	6.53E+00	5.01E+00	4.94E+00	6.24E+00	4.64E+00	7.19E+00	5.25E+00	5.55E+00
3.75	2.58E+00	6.68E-01	2.65E+00	5.19E+00	2.42E+00	2.91E+00	2.25E+00	2.22E+00	2.77E+00	2.08E+00	3.15E+00	2.36E+00	2.50E+00
6.25	1.12E+00	2.76E-01	1.15E+00	2.23E+00	1.06E+00	1.27E+00	9.85E-01	9.68E-01	1.20E+00	9.10E-01	1.36E+00	1.03E+00	1.09E+00
8.75	5.13E-01	1.16E-01	5.25E-01	9.82E-01	4.84E-01	5.74E-01	4.51E-01	4.43E-01	5.43E-01	4.17E-01	6.18E-01	4.71E-01	5.00E-01
11.25	3.38E-01	7.24E-02	3.45E-01	6.29E-01	3.20E-01	3.76E-01	2.98E-01	2.92E-01	3.55E-01	2.75E-01	4.07E-01	3.11E-01	3.30E-01
13.75	2.47E-01	5.76E-02	2.53E-01	4.81E-01	2.33E-01	2.77E-01	2.17E-01	2.13E-01	2.63E-01	2.00E-01	2.98E-01	2.27E-01	2.40E-01
16.25	1.98E-01	4.67E-02	2.03E-01	3.89E-01	1.86E-01	2.22E-01	1.73E-01	1.70E-01	2.11E-01	1.60E-01	2.37E-01	1.81E-01	1.92E-01
18.75	2.12E-01	4.54E-02	2.17E-01	4.01E-01	2.00E-01	2.37E-01	1.87E-01	1.83E-01	2.24E-01	1.72E-01	2.53E-01	1.95E-01	2.07E-01
21.25	1.74E-01	3.83E-02	1.78E-01	3.35E-01	1.64E-01	1.95E-01	1.53E-01	1.50E-01	1.85E-01	1.41E-01	2.08E-01	1.60E-01	1.70E-01
23.75	1.54E-01	3.41E-02	1.58E-01	2.99E-01	1.45E-01	1.73E-01	1.35E-01	1.33E-01	1.64E-01	1.25E-01	1.83E-01	1.42E-01	1.50E-01
26.25	1.97E-01	4.46E-02	2.02E-01	3.93E-01	1.85E-01	2.22E-01	1.73E-01	1.70E-01	2.11E-01	1.59E-01	2.32E-01	1.80E-01	1.91E-01
28.75	1.72E-01	3.03E-02	1.75E-01	3.04E-01	1.64E-01	1.90E-01	1.52E-01	1.49E-01	1.78E-01	1.41E-01	2.02E-01	1.59E-01	1.69E-01
31.25	1.55E-01	2.46E-02	1.57E-01	2.63E-01	1.48E-01	1.70E-01	1.38E-01	1.35E-01	1.59E-01	1.27E-01	1.82E-01	1.44E-01	1.53E-01
33.75	1.48E-01	2.30E-02	1.50E-01	2.51E-01	1.41E-01	1.63E-01	1.32E-01	1.29E-01	1.52E-01	1.22E-01	1.73E-01	1.37E-01	1.46E-01
36.25	1.54E-01	2.33E-02	1.57E-01	2.63E-01	1.48E-01	1.70E-01	1.38E-01	1.35E-01	1.59E-01	1.27E-01	1.80E-01	1.44E-01	1.53E-01
38.75	1.33E-01	2.32E-02	1.36E-01	2.41E-01	1.27E-01	1.48E-01	1.18E-01	1.16E-01	1.39E-01	1.09E-01	1.55E-01	1.23E-01	1.31E-01
41.25	1.05E-01	2.09E-02	1.08E-01	2.01E-01	9.95E-02	1.18E-01	9.28E-02	9.10E-02	1.12E-01	8.57E-02	1.23E-01	9.69E-02	1.03E-01
43.75	8.81E-02	1.69E-02	9.02E-02	1.64E-01	8.36E-02	9.84E-02	7.79E-02	7.64E-02	9.28E-02	7.20E-02	1.03E-01	8.13E-02	8.63E-02
46.25	7.29E-02	1.36E-02	7.45E-02	1.34E-01	6.93E-02	8.12E-02	6.45E-02	6.32E-02	7.65E-02	5.96E-02	8.54E-02	6.73E-02	7.15E-02
48.75	6.65E-02	1.26E-02	6.80E-02	1.23E-01	6.32E-02	7.42E-02	5.89E-02	5.77E-02	7.00E-02	5.44E-02	7.79E-02	6.14E-02	6.52E-02
51.25	6.08E-02	1.19E-02	6.23E-02	1.15E-01	5.77E-02	6.80E-02	5.37E-02	5.27E-02	6.43E-02	4.96E-02	7.11E-02	5.61E-02	5.95E-02
53.75	5.80E-02	1.14E-02	5.94E-02	1.10E-01	5.49E-02	6.49E-02	5.12E-02	5.02E-02	6.14E-02	4.73E-02	6.77E-02	5.35E-02	5.67E-02
56.25	5.91E-02	1.11E-02	6.05E-02	1.11E-01	5.61E-02	6.61E-02	5.23E-02	5.13E-02	6.24E-02	4.83E-02	6.87E-02	5.46E-02	5.79E-02
58.75	6.16E-02	1.14E-02	6.31E-02	1.16E-01	5.85E-02	6.89E-02	5.45E-02	5.34E-02	6.51E-02	5.03E-02	7.14E-02	5.69E-02	6.04E-02

Table D-03: Mean short term individual dose (Sievert) for 15 day inventory using MAAP release fractions

Distance (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.50	1.22E+00	1.93E+00	9.57E-01	9.32E-01	3.56E+01	2.47E+00	9.91E-01	1.00E+00
1.75	2.29E-01	3.46E-01	1.85E-01	1.78E-01	6.20E+00	4.51E-01	1.89E-01	1.90E-01
3.75	8.14E-02	1.16E-01	6.80E-02	6.43E-02	1.99E+00	1.54E-01	6.84E-02	6.80E-02
6.25	4.20E-02	5.73E-02	3.47E-02	3.31E-02	1.05E+00	8.15E-02	3.52E-02	3.51E-02
8.75	2.36E-02	3.16E-02	1.94E-02	1.86E-02	6.02E-01	4.64E-02	1.98E-02	1.98E-02
11.25	1.23E-02	1.63E-02	1.05E-02	9.82E-03	2.75E-01	2.27E-02	1.05E-02	1.03E-02
13.75	8.08E-03	1.08E-02	6.77E-03	6.40E-03	1.94E-01	1.54E-02	6.82E-03	6.78E-03
16.25	6.70E-03	8.87E-03	5.70E-03	5.36E-03	1.53E-01	1.25E-02	5.70E-03	5.64E-03
18.75	6.95E-03	9.10E-03	6.07E-03	5.64E-03	1.45E-01	1.25E-02	6.00E-03	5.89E-03
21.25	6.20E-03	8.08E-03	5.33E-03	4.99E-03	1.37E-01	1.14E-02	5.30E-03	5.23E-03
23.75	5.18E-03	6.69E-03	4.43E-03	4.16E-03	1.16E-01	9.64E-03	4.42E-03	4.37E-03
26.25	4.13E-03	5.29E-03	3.54E-03	3.32E-03	9.24E-02	7.70E-03	3.53E-03	3.49E-03
28.75	3.25E-03	4.18E-03	2.72E-03	2.58E-03	7.85E-02	6.28E-03	2.75E-03	2.74E-03
31.25	2.73E-03	3.50E-03	2.27E-03	2.16E-03	6.70E-02	5.31E-03	2.30E-03	2.29E-03
33.75	2.84E-03	3.60E-03	2.46E-03	2.30E-03	6.13E-02	5.22E-03	2.44E-03	2.41E-03
36.25	3.34E-03	4.16E-03	3.07E-03	2.79E-03	5.65E-02	5.56E-03	2.96E-03	2.87E-03
38.75	2.98E-03	3.72E-03	2.70E-03	2.47E-03	5.35E-02	5.08E-03	2.62E-03	2.55E-03
41.25	2.54E-03	3.18E-03	2.24E-03	2.08E-03	5.02E-02	4.50E-03	2.21E-03	2.16E-03
43.75	2.29E-03	2.87E-03	2.00E-03	1.86E-03	4.77E-02	4.16E-03	1.98E-03	1.95E-03
46.25	2.11E-03	2.63E-03	1.82E-03	1.70E-03	4.56E-02	3.89E-03	1.81E-03	1.79E-03
48.75	2.08E-03	2.58E-03	1.79E-03	1.68E-03	4.57E-02	3.87E-03	1.78E-03	1.76E-03
51.25	1.97E-03	2.42E-03	1.68E-03	1.58E-03	4.37E-02	3.68E-03	1.68E-03	1.67E-03
53.75	1.81E-03	2.22E-03	1.53E-03	1.44E-03	4.21E-02	3.46E-03	1.54E-03	1.53E-03
56.25	1.71E-03	2.10E-03	1.42E-03	1.36E-03	4.24E-02	3.38E-03	1.44E-03	1.44E-03
58.75	1.68E-03	2.05E-03	1.36E-03	1.31E-03	4.37E-02	3.39E-03	1.40E-03	1.41E-03

Table D-04: Mean long term individual dose (Sievert) for 15 day inventory using MAAP release fractions

Distance (km)	EFFECTIVE	SKIN	B.MARROW	B.SURFACE	BREAST	LUNG	STOMACH	COLON	LIVER	PANCREAS	THYROID	GONADS	REMAINDER
0.50	3.35E+01	6.53E+00	3.52E+01	7.35E+01	3.16E+01	3.63E+01	2.95E+01	2.87E+01	3.73E+01	2.73E+01	3.75E+01	3.09E+01	3.26E+01
1.75	6.48E+00	1.14E+00	6.76E+00	1.35E+01	6.14E+00	6.98E+00	5.73E+00	5.57E+00	7.11E+00	5.29E+00	7.27E+00	6.00E+00	6.34E+00
3.75	2.37E+00	3.70E-01	2.46E+00	4.69E+00	2.27E+00	2.55E+00	2.11E+00	2.05E+00	2.56E+00	1.95E+00	2.67E+00	2.21E+00	2.34E+00
6.25	1.22E+00	1.98E-01	1.27E+00	2.47E+00	1.16E+00	1.31E+00	1.08E+00	1.05E+00	1.33E+00	1.00E+00	1.37E+00	1.13E+00	1.20E+00
8.75	6.83E-01	1.13E-01	7.12E-01	1.40E+00	6.50E-01	7.37E-01	6.06E-01	5.89E-01	7.46E-01	5.60E-01	7.64E-01	6.34E-01	6.71E-01
11.25	3.67E-01	5.16E-02	3.80E-01	6.96E-01	3.52E-01	3.94E-01	3.28E-01	3.18E-01	3.92E-01	3.03E-01	4.13E-01	3.42E-01	3.63E-01
13.75	2.37E-01	3.64E-02	2.46E-01	4.69E-01	2.27E-01	2.55E-01	2.11E-01	2.05E-01	2.56E-01	1.95E-01	2.66E-01	2.21E-01	2.34E-01
16.25	2.00E-01	2.87E-02	2.07E-01	3.83E-01	1.91E-01	2.15E-01	1.78E-01	1.73E-01	2.14E-01	1.65E-01	2.25E-01	1.86E-01	1.97E-01
18.75	2.13E-01	2.72E-02	2.19E-01	3.88E-01	2.05E-01	2.28E-01	1.91E-01	1.85E-01	2.25E-01	1.76E-01	2.40E-01	1.99E-01	2.11E-01
21.25	1.88E-01	2.58E-02	1.94E-01	3.53E-01	1.80E-01	2.02E-01	1.68E-01	1.63E-01	2.00E-01	1.55E-01	2.11E-01	1.75E-01	1.86E-01
23.75	1.57E-01	2.20E-02	1.62E-01	2.98E-01	1.50E-01	1.68E-01	1.40E-01	1.36E-01	1.67E-01	1.29E-01	1.76E-01	1.46E-01	1.55E-01
26.25	1.25E-01	1.75E-02	1.30E-01	2.38E-01	1.20E-01	1.34E-01	1.12E-01	1.09E-01	1.34E-01	1.03E-01	1.41E-01	1.17E-01	1.24E-01
28.75	9.65E-02	1.49E-02	1.00E-01	1.92E-01	9.21E-02	1.04E-01	8.58E-02	8.33E-02	1.04E-01	7.92E-02	1.08E-01	8.97E-02	9.50E-02
31.25	8.05E-02	1.27E-02	8.37E-02	1.62E-01	7.67E-02	8.66E-02	7.15E-02	6.94E-02	8.73E-02	6.60E-02	8.99E-02	7.48E-02	7.91E-02
33.75	8.69E-02	1.16E-02	8.97E-02	1.62E-01	8.35E-02	9.32E-02	7.78E-02	7.55E-02	9.22E-02	7.18E-02	9.77E-02	8.12E-02	8.61E-02
36.25	1.08E-01	1.07E-02	1.10E-01	1.78E-01	1.05E-01	1.15E-01	9.76E-02	9.46E-02	1.11E-01	9.01E-02	1.23E-01	1.02E-01	1.08E-01
38.75	9.51E-02	1.02E-02	9.73E-02	1.62E-01	9.21E-02	1.01E-01	8.57E-02	8.31E-02	9.84E-02	7.91E-02	1.08E-01	8.93E-02	9.49E-02
41.25	7.93E-02	9.52E-03	8.15E-02	1.41E-01	7.65E-02	8.48E-02	7.13E-02	6.91E-02	8.31E-02	6.58E-02	8.95E-02	7.43E-02	7.89E-02
43.75	7.09E-02	9.06E-03	7.30E-02	1.30E-01	6.82E-02	7.59E-02	6.35E-02	6.16E-02	7.48E-02	5.86E-02	7.98E-02	6.63E-02	7.03E-02
46.25	6.46E-02	8.68E-03	6.67E-02	1.21E-01	6.20E-02	6.93E-02	5.78E-02	5.61E-02	6.86E-02	5.34E-02	7.26E-02	6.03E-02	6.40E-02
48.75	6.35E-02	8.70E-03	6.57E-02	1.20E-01	6.09E-02	6.81E-02	5.68E-02	5.51E-02	6.77E-02	5.24E-02	7.13E-02	5.93E-02	6.29E-02
51.25	5.99E-02	8.32E-03	6.20E-02	1.14E-01	5.74E-02	6.43E-02	5.35E-02	5.19E-02	6.39E-02	4.94E-02	6.72E-02	5.59E-02	5.92E-02
53.75	5.44E-02	8.03E-03	5.64E-02	1.06E-01	5.20E-02	5.85E-02	4.84E-02	4.70E-02	5.85E-02	4.47E-02	6.08E-02	5.06E-02	5.36E-02
56.25	5.07E-02	8.10E-03	5.28E-02	1.03E-01	4.83E-02	5.46E-02	4.50E-02	4.37E-02	5.52E-02	4.16E-02	5.65E-02	4.71E-02	4.98E-02
58.75	4.89E-02	8.35E-03	5.11E-02	1.03E-01	4.63E-02	5.27E-02	4.32E-02	4.20E-02	5.37E-02	3.99E-02	5.43E-02	4.53E-02	4.78E-02

Table D-05: Mean short term individual dose (Sievert) for 5 day inventory using NRC release fractions

Distance (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.50	3.81E+01	1.71E+02	3.12E+01	2.92E+01	1.52E+03	3.23E+01	3.05E+01	2.89E+01
1.75	7.49E+00	3.21E+01	6.24E+00	5.82E+00	2.87E+02	6.45E+00	6.08E+00	5.75E+00
3.75	3.07E+00	1.18E+01	2.63E+00	2.45E+00	1.10E+02	2.72E+00	2.56E+00	2.42E+00
6.25	1.29E+00	4.71E+00	1.12E+00	1.04E+00	4.44E+01	1.15E+00	1.09E+00	1.03E+00
8.75	5.71E-01	1.99E+00	5.03E-01	4.65E-01	1.86E+01	5.16E-01	4.87E-01	4.59E-01
11.25	3.71E-01	1.27E+00	3.29E-01	3.03E-01	1.17E+01	3.36E-01	3.17E-01	2.99E-01
13.75	2.76E-01	9.72E-01	2.42E-01	2.25E-01	9.18E+00	2.49E-01	2.35E-01	2.22E-01
16.25	2.19E-01	7.65E-01	1.92E-01	1.79E-01	7.37E+00	1.98E-01	1.87E-01	1.77E-01
18.75	2.25E-01	7.38E-01	2.01E-01	1.86E-01	7.07E+00	2.06E-01	1.94E-01	1.83E-01
21.25	1.84E-01	6.05E-01	1.63E-01	1.52E-01	5.91E+00	1.68E-01	1.59E-01	1.50E-01
23.75	1.61E-01	5.14E-01	1.43E-01	1.33E-01	5.16E+00	1.48E-01	1.39E-01	1.32E-01
26.25	2.00E-01	6.10E-01	1.78E-01	1.68E-01	6.53E+00	1.85E-01	1.75E-01	1.66E-01
28.75	1.66E-01	4.74E-01	1.54E-01	1.41E-01	4.55E+00	1.57E-01	1.48E-01	1.39E-01
31.25	1.46E-01	3.91E-01	1.37E-01	1.25E-01	3.67E+00	1.38E-01	1.31E-01	1.22E-01
33.75	1.36E-01	3.46E-01	1.29E-01	1.17E-01	3.34E+00	1.30E-01	1.23E-01	1.15E-01
36.25	1.39E-01	3.34E-01	1.33E-01	1.21E-01	3.30E+00	1.34E-01	1.27E-01	1.19E-01
38.75	1.23E-01	3.05E-01	1.15E-01	1.06E-01	3.25E+00	1.18E-01	1.11E-01	1.05E-01
41.25	1.00E-01	2.70E-01	9.17E-02	8.59E-02	2.96E+00	9.49E-02	8.96E-02	8.49E-02
43.75	8.45E-02	2.31E-01	7.76E-02	7.22E-02	2.43E+00	7.98E-02	7.54E-02	7.12E-02
46.25	6.98E-02	1.91E-01	6.43E-02	5.96E-02	1.97E+00	6.60E-02	6.23E-02	5.88E-02
48.75	6.37E-02	1.74E-01	5.86E-02	5.44E-02	1.81E+00	6.02E-02	5.68E-02	5.37E-02
51.25	5.82E-02	1.58E-01	5.33E-02	4.97E-02	1.70E+00	5.50E-02	5.19E-02	4.91E-02
53.75	5.49E-02	1.46E-01	5.04E-02	4.71E-02	1.60E+00	5.21E-02	4.92E-02	4.66E-02
56.25	5.49E-02	1.40E-01	5.08E-02	4.74E-02	1.55E+00	5.24E-02	4.95E-02	4.68E-02
58.75	5.61E-02	1.36E-01	5.22E-02	4.88E-02	1.56E+00	5.39E-02	5.09E-02	4.82E-02

Table D-06: Mean long term individual dose (Sievert) for 5 day inventory using NRC release fractions

Distance (km)	EFFECTIVE	SKIN	B.MARROW	B.SURFACE	BREAST	LUNG	STOMACH	COLON	LIVER	PANCREAS	THYROID	GONADS	REMAINDER
0.50	7.04E+02	2.17E+02	6.88E+02	7.27E+02	6.94E+02	7.26E+02	6.47E+02	6.28E+02	6.48E+02	5.99E+02	9.50E+02	6.68E+02	7.17E+02
1.75	1.45E+02	4.13E+01	1.42E+02	1.50E+02	1.43E+02	1.50E+02	1.34E+02	1.30E+02	1.34E+02	1.24E+02	1.93E+02	1.38E+02	1.48E+02
3.75	6.50E+01	1.63E+01	6.37E+01	6.74E+01	6.43E+01	6.73E+01	6.00E+01	5.82E+01	6.00E+01	5.54E+01	8.41E+01	6.19E+01	6.64E+01
6.25	2.84E+01	6.66E+00	2.78E+01	2.94E+01	2.81E+01	2.94E+01	2.62E+01	2.54E+01	2.62E+01	2.42E+01	3.63E+01	2.70E+01	2.90E+01
8.75	1.30E+01	2.80E+00	1.28E+01	1.35E+01	1.29E+01	1.35E+01	1.20E+01	1.16E+01	1.20E+01	1.11E+01	1.65E+01	1.24E+01	1.33E+01
11.25	8.58E+00	1.75E+00	8.42E+00	8.90E+00	8.50E+00	8.89E+00	7.93E+00	7.68E+00	7.93E+00	7.32E+00	1.08E+01	8.17E+00	8.78E+00
13.75	6.25E+00	1.39E+00	6.13E+00	6.48E+00	6.19E+00	6.47E+00	5.77E+00	5.59E+00	5.78E+00	5.33E+00	7.93E+00	5.95E+00	6.39E+00
16.25	4.98E+00	1.12E+00	4.89E+00	5.18E+00	4.94E+00	5.17E+00	4.61E+00	4.47E+00	4.61E+00	4.26E+00	6.32E+00	4.75E+00	5.10E+00
18.75	5.36E+00	1.08E+00	5.27E+00	5.57E+00	5.32E+00	5.56E+00	4.96E+00	4.81E+00	4.97E+00	4.58E+00	6.72E+00	5.12E+00	5.49E+00
21.25	4.40E+00	9.11E-01	4.33E+00	4.57E+00	4.37E+00	4.57E+00	4.07E+00	3.95E+00	4.07E+00	3.76E+00	5.52E+00	4.20E+00	4.51E+00
23.75	3.89E+00	8.05E-01	3.83E+00	4.05E+00	3.86E+00	4.04E+00	3.60E+00	3.49E+00	3.61E+00	3.33E+00	4.86E+00	3.71E+00	3.99E+00
26.25	4.96E+00	1.04E+00	4.88E+00	5.16E+00	4.92E+00	5.15E+00	4.59E+00	4.45E+00	4.59E+00	4.24E+00	6.15E+00	4.73E+00	5.08E+00
28.75	4.38E+00	7.14E-01	4.31E+00	4.55E+00	4.35E+00	4.55E+00	4.05E+00	3.93E+00	4.06E+00	3.74E+00	5.37E+00	4.18E+00	4.49E+00
31.25	3.96E+00	5.78E-01	3.90E+00	4.12E+00	3.94E+00	4.12E+00	3.67E+00	3.55E+00	3.67E+00	3.39E+00	4.83E+00	3.78E+00	4.06E+00
33.75	3.78E+00	5.36E-01	3.72E+00	3.93E+00	3.76E+00	3.93E+00	3.50E+00	3.39E+00	3.51E+00	3.23E+00	4.58E+00	3.61E+00	3.88E+00
36.25	3.96E+00	5.40E-01	3.90E+00	4.12E+00	3.94E+00	4.12E+00	3.67E+00	3.55E+00	3.67E+00	3.39E+00	4.77E+00	3.79E+00	4.07E+00
38.75	3.40E+00	5.35E-01	3.35E+00	3.54E+00	3.38E+00	3.53E+00	3.15E+00	3.05E+00	3.15E+00	2.91E+00	4.11E+00	3.25E+00	3.49E+00
41.25	2.66E+00	4.84E-01	2.62E+00	2.77E+00	2.65E+00	2.77E+00	2.47E+00	2.39E+00	2.47E+00	2.28E+00	3.25E+00	2.55E+00	2.73E+00
43.75	2.24E+00	3.93E-01	2.20E+00	2.33E+00	2.22E+00	2.33E+00	2.07E+00	2.01E+00	2.07E+00	1.92E+00	2.73E+00	2.14E+00	2.30E+00
46.25	1.85E+00	3.17E-01	1.82E+00	1.93E+00	1.84E+00	1.93E+00	1.72E+00	1.66E+00	1.72E+00	1.59E+00	2.26E+00	1.77E+00	1.90E+00
48.75	1.69E+00	2.92E-01	1.66E+00	1.76E+00	1.68E+00	1.76E+00	1.57E+00	1.52E+00	1.57E+00	1.45E+00	2.07E+00	1.62E+00	1.73E+00
51.25	1.54E+00	2.76E-01	1.52E+00	1.61E+00	1.53E+00	1.60E+00	1.43E+00	1.38E+00	1.43E+00	1.32E+00	1.88E+00	1.47E+00	1.58E+00
53.75	1.47E+00	2.62E-01	1.45E+00	1.53E+00	1.46E+00	1.53E+00	1.36E+00	1.32E+00	1.36E+00	1.26E+00	1.79E+00	1.40E+00	1.51E+00
56.25	1.50E+00	2.56E-01	1.48E+00	1.56E+00	1.49E+00	1.56E+00	1.39E+00	1.35E+00	1.39E+00	1.28E+00	1.82E+00	1.43E+00	1.54E+00
58.75	1.56E+00	2.61E-01	1.54E+00	1.63E+00	1.56E+00	1.63E+00	1.45E+00	1.40E+00	1.45E+00	1.34E+00	1.89E+00	1.49E+00	1.60E+00

Table D-07: Mean short term individual dose (Sievert) for 15 day inventory using NRC release fractions

Distance (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.50	2.77E+01	5.45E+01	2.55E+01	2.48E+01	8.92E+02	2.70E+01	2.57E+01	2.46E+01
1.75	5.24E+00	9.72E+00	4.91E+00	4.72E+00	1.55E+02	5.16E+00	4.91E+00	4.67E+00
3.75	1.88E+00	3.23E+00	1.80E+00	1.70E+00	4.96E+01	1.87E+00	1.78E+00	1.68E+00
6.25	9.61E-01	1.58E+00	9.18E-01	8.74E-01	2.61E+01	9.59E-01	9.11E-01	8.66E-01
8.75	5.38E-01	8.67E-01	5.13E-01	4.90E-01	1.49E+01	5.37E-01	5.10E-01	4.86E-01
11.25	2.84E-01	4.46E-01	2.77E-01	2.59E-01	6.79E+00	2.85E-01	2.71E-01	2.56E-01
13.75	1.86E-01	2.97E-01	1.79E-01	1.69E-01	4.79E+00	1.86E-01	1.76E-01	1.67E-01
16.25	1.55E-01	2.43E-01	1.51E-01	1.41E-01	3.77E+00	1.55E-01	1.48E-01	1.40E-01
18.75	1.63E-01	2.48E-01	1.60E-01	1.49E-01	3.57E+00	1.64E-01	1.56E-01	1.47E-01
21.25	1.44E-01	2.20E-01	1.41E-01	1.32E-01	3.37E+00	1.45E-01	1.37E-01	1.30E-01
23.75	1.20E-01	1.82E-01	1.17E-01	1.10E-01	2.86E+00	1.21E-01	1.15E-01	1.08E-01
26.25	9.56E-02	1.44E-01	9.33E-02	8.76E-02	2.27E+00	9.63E-02	9.14E-02	8.64E-02
28.75	7.44E-02	1.14E-01	7.17E-02	6.81E-02	1.93E+00	7.47E-02	7.10E-02	6.74E-02
31.25	6.22E-02	9.54E-02	5.98E-02	5.70E-02	1.65E+00	6.24E-02	5.93E-02	5.64E-02
33.75	6.60E-02	9.77E-02	6.47E-02	6.06E-02	1.51E+00	6.66E-02	6.32E-02	5.97E-02
36.25	7.98E-02	1.12E-01	8.08E-02	7.36E-02	1.39E+00	8.12E-02	7.70E-02	7.20E-02
38.75	7.07E-02	1.00E-01	7.10E-02	6.51E-02	1.32E+00	7.18E-02	6.81E-02	6.38E-02
41.25	5.95E-02	8.60E-02	5.91E-02	5.47E-02	1.23E+00	6.03E-02	5.72E-02	5.38E-02
43.75	5.34E-02	7.75E-02	5.27E-02	4.91E-02	1.17E+00	5.40E-02	5.13E-02	4.84E-02
46.25	4.89E-02	7.10E-02	4.80E-02	4.49E-02	1.12E+00	4.94E-02	4.69E-02	4.43E-02
48.75	4.81E-02	6.97E-02	4.71E-02	4.42E-02	1.12E+00	4.86E-02	4.61E-02	4.36E-02
51.25	4.53E-02	6.53E-02	4.44E-02	4.17E-02	1.07E+00	4.58E-02	4.35E-02	4.12E-02
53.75	4.14E-02	5.97E-02	4.02E-02	3.80E-02	1.03E+00	4.17E-02	3.96E-02	3.76E-02
56.25	3.89E-02	5.66E-02	3.73E-02	3.57E-02	1.04E+00	3.91E-02	3.72E-02	3.54E-02
58.75	3.77E-02	5.52E-02	3.59E-02	3.46E-02	1.07E+00	3.79E-02	3.60E-02	3.44E-02

Table D-08: Mean long term individual dose (Sievert) for 15 day inventory using NRC release fractions

Distance (km)	EFFECTIVE	SKIN	B.MARROW	B.SURFACE	BREAST	LUNG	STOMACH	COLON	LIVER	PANCREAS	THYROID	GONADS	REMAINDER
0.50	8.53E+02	1.62E+02	8.42E+02	8.90E+02	8.49E+02	8.88E+02	7.92E+02	7.68E+02	7.93E+02	7.32E+02	1.01E+03	8.17E+02	8.77E+02
1.75	1.66E+02	2.83E+01	1.63E+02	1.73E+02	1.65E+02	1.72E+02	1.54E+02	1.49E+02	1.54E+02	1.42E+02	1.96E+02	1.59E+02	1.70E+02
3.75	6.11E+01	9.13E+00	6.02E+01	6.37E+01	6.08E+01	6.36E+01	5.67E+01	5.49E+01	5.67E+01	5.24E+01	7.18E+01	5.85E+01	6.28E+01
6.25	3.13E+01	4.86E+00	3.09E+01	3.27E+01	3.12E+01	3.26E+01	2.91E+01	2.82E+01	2.91E+01	2.69E+01	3.68E+01	3.00E+01	3.22E+01
8.75	1.75E+01	2.78E+00	1.73E+01	1.83E+01	1.75E+01	1.82E+01	1.63E+01	1.58E+01	1.63E+01	1.50E+01	2.05E+01	1.68E+01	1.80E+01
11.25	9.48E+00	1.27E+00	9.36E+00	9.89E+00	9.45E+00	9.88E+00	8.81E+00	8.53E+00	8.81E+00	8.13E+00	1.11E+01	9.08E+00	9.75E+00
13.75	6.11E+00	8.95E-01	6.03E+00	6.37E+00	6.09E+00	6.36E+00	5.67E+00	5.49E+00	5.68E+00	5.24E+00	7.16E+00	5.85E+00	6.28E+00
16.25	5.16E+00	7.05E-01	5.09E+00	5.38E+00	5.14E+00	5.37E+00	4.79E+00	4.64E+00	4.79E+00	4.42E+00	6.04E+00	4.94E+00	5.30E+00
18.75	5.52E+00	6.68E-01	5.45E+00	5.76E+00	5.50E+00	5.75E+00	5.13E+00	4.96E+00	5.13E+00	4.73E+00	6.46E+00	5.29E+00	5.68E+00
21.25	4.86E+00	6.32E-01	4.79E+00	5.07E+00	4.84E+00	5.06E+00	4.51E+00	4.37E+00	4.52E+00	4.17E+00	5.68E+00	4.65E+00	5.00E+00
23.75	4.04E+00	5.38E-01	3.99E+00	4.22E+00	4.03E+00	4.21E+00	3.75E+00	3.64E+00	3.76E+00	3.47E+00	4.73E+00	3.87E+00	4.16E+00
26.25	3.23E+00	4.28E-01	3.19E+00	3.37E+00	3.22E+00	3.37E+00	3.00E+00	2.91E+00	3.01E+00	2.77E+00	3.78E+00	3.10E+00	3.33E+00
28.75	2.48E+00	3.64E-01	2.45E+00	2.59E+00	2.47E+00	2.58E+00	2.30E+00	2.23E+00	2.31E+00	2.13E+00	2.90E+00	2.38E+00	2.55E+00
31.25	2.07E+00	3.11E-01	2.04E+00	2.16E+00	2.06E+00	2.15E+00	1.92E+00	1.86E+00	1.92E+00	1.77E+00	2.42E+00	1.98E+00	2.13E+00
33.75	2.25E+00	2.84E-01	2.22E+00	2.35E+00	2.24E+00	2.34E+00	2.09E+00	2.02E+00	2.09E+00	1.93E+00	2.63E+00	2.15E+00	2.31E+00
36.25	2.82E+00	2.62E-01	2.79E+00	2.95E+00	2.82E+00	2.94E+00	2.62E+00	2.54E+00	2.62E+00	2.42E+00	3.29E+00	2.71E+00	2.90E+00
38.75	2.48E+00	2.48E-01	2.45E+00	2.59E+00	2.47E+00	2.58E+00	2.30E+00	2.23E+00	2.30E+00	2.13E+00	2.89E+00	2.38E+00	2.55E+00
41.25	2.06E+00	2.33E-01	2.03E+00	2.15E+00	2.06E+00	2.15E+00	1.91E+00	1.85E+00	1.92E+00	1.77E+00	2.41E+00	1.97E+00	2.12E+00
43.75	1.84E+00	2.22E-01	1.81E+00	1.92E+00	1.83E+00	1.91E+00	1.71E+00	1.65E+00	1.71E+00	1.58E+00	2.14E+00	1.76E+00	1.89E+00
46.25	1.67E+00	2.12E-01	1.65E+00	1.74E+00	1.67E+00	1.74E+00	1.55E+00	1.50E+00	1.55E+00	1.43E+00	1.95E+00	1.60E+00	1.72E+00
48.75	1.64E+00	2.13E-01	1.62E+00	1.71E+00	1.64E+00	1.71E+00	1.52E+00	1.48E+00	1.53E+00	1.41E+00	1.92E+00	1.57E+00	1.69E+00
51.25	1.55E+00	2.03E-01	1.53E+00	1.61E+00	1.54E+00	1.61E+00	1.44E+00	1.39E+00	1.44E+00	1.33E+00	1.81E+00	1.48E+00	1.59E+00
53.75	1.40E+00	1.96E-01	1.38E+00	1.46E+00	1.40E+00	1.46E+00	1.30E+00	1.26E+00	1.30E+00	1.20E+00	1.63E+00	1.34E+00	1.44E+00
56.25	1.30E+00	1.98E-01	1.28E+00	1.36E+00	1.30E+00	1.36E+00	1.21E+00	1.17E+00	1.21E+00	1.12E+00	1.52E+00	1.25E+00	1.34E+00
58.75	1.25E+00	2.04E-01	1.23E+00	1.30E+00	1.24E+00	1.30E+00	1.16E+00	1.13E+00	1.16E+00	1.07E+00	1.46E+00	1.20E+00	1.29E+00

Table D-09: Mean individual short term risk of mortality for 5 day inventory using MAAP release fractions

Distance (km)	Sum over organs	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	4.11E-02	4.57E-03	3.95E-02	5.91E-03	7.08E-02	3.54E-03
1.75	7.97E-03	2.96E-05	6.41E-03	1.62E-04	3.65E-02	1.88E-03
3.75	2.88E-03	0.00E+00	1.99E-03	9.71E-06	2.01E-02	9.77E-04
6.25	6.10E-04	1.66E-07	2.13E-04	1.11E-05	9.03E-03	4.00E-04
8.75	9.47E-05	0.00E+00	2.86E-05	3.73E-07	2.90E-03	6.61E-05
11.25	4.52E-05	0.00E+00	6.81E-06	0.00E+00	1.83E-03	3.84E-05
13.75	9.52E-06	0.00E+00	0.00E+00	0.00E+00	1.17E-03	9.52E-06
16.25	8.82E-06	0.00E+00	5.14E-06	0.00E+00	6.91E-04	3.90E-06
18.75	1.01E-04	0.00E+00	7.33E-05	0.00E+00	9.15E-04	2.74E-05
21.25	5.93E-05	0.00E+00	3.30E-05	0.00E+00	7.04E-04	2.63E-05
23.75	9.45E-06	0.00E+00	1.94E-06	0.00E+00	4.55E-04	7.51E-06
26.25	2.88E-05	0.00E+00	0.00E+00	0.00E+00	1.03E-03	2.88E-05
28.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.47E-04	0.00E+00
31.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.07E-04	0.00E+00
33.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-04	0.00E+00
36.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.07E-04	0.00E+00
38.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.15E-04	0.00E+00
41.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-04	0.00E+00
43.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-04	0.00E+00
46.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-04	0.00E+00
48.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	0.00E+00
51.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.12E-05	0.00E+00
53.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.12E-05	0.00E+00
56.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.04E-05	0.00E+00
58.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.03E-05	0.00E+00

Table D-10: Mean individual long term risk of mortality for 5 day inventory using MAAP release fractions

Distance km	TOTAL	b.marrow	b.surface	breast	lung	stomach	colon	liver	pancreas	thyroid	Hered.Eff	remainder	skin
0.50	4.03E-02	1.69E-02	3.73E-03	1.22E-02	2.55E-02	2.50E-02	2.15E-02	5.51E-03	6.86E-03	3.38E-03	2.55E-01	2.42E-02	2.07E-04
1.75	4.12E-02	1.51E-02	3.27E-03	1.09E-02	2.47E-02	2.43E-02	2.01E-02	4.88E-03	6.11E-03	2.97E-03	5.25E-02	2.33E-02	1.87E-04
3.75	3.77E-02	9.29E-03	1.94E-03	6.73E-03	1.62E-02	1.59E-02	1.26E-02	2.97E-03	3.78E-03	1.78E-03	2.36E-02	1.50E-02	1.05E-04
6.25	2.49E-02	5.11E-03	1.04E-03	3.77E-03	8.98E-03	8.81E-03	6.94E-03	1.64E-03	2.11E-03	9.80E-04	1.03E-02	8.31E-03	5.32E-05
8.75	1.46E-02	2.53E-03	4.80E-04	1.87E-03	4.52E-03	4.50E-03	3.52E-03	7.91E-04	1.05E-03	4.79E-04	4.71E-03	4.24E-03	2.30E-05
11.25	1.00E-02	1.70E-03	3.11E-04	1.26E-03	3.08E-03	3.09E-03	2.44E-03	5.25E-04	7.05E-04	3.21E-04	3.11E-03	2.92E-03	1.44E-05
13.75	8.54E-03	1.26E-03	2.40E-04	9.29E-04	2.35E-03	2.38E-03	1.81E-03	3.94E-04	5.20E-04	2.38E-04	2.27E-03	2.23E-03	1.15E-05
16.25	7.09E-03	1.00E-03	1.93E-04	7.33E-04	1.86E-03	1.86E-03	1.42E-03	3.13E-04	4.11E-04	1.88E-04	1.81E-03	1.75E-03	9.33E-06
18.75	6.38E-03	9.29E-04	1.83E-04	6.77E-04	1.73E-03	1.73E-03	1.32E-03	2.92E-04	3.79E-04	1.73E-04	1.95E-03	1.62E-03	8.95E-06
21.25	5.68E-03	8.25E-04	1.60E-04	6.06E-04	1.52E-03	1.51E-03	1.16E-03	2.60E-04	3.41E-04	1.55E-04	1.60E-03	1.42E-03	7.57E-06
23.75	5.56E-03	7.81E-04	1.49E-04	5.78E-04	1.42E-03	1.43E-03	1.10E-03	2.45E-04	3.24E-04	1.46E-04	1.42E-03	1.34E-03	6.80E-06
26.25	6.35E-03	1.00E-03	1.94E-04	7.33E-04	1.85E-03	1.85E-03	1.42E-03	3.14E-04	4.11E-04	1.84E-04	1.80E-03	1.74E-03	8.81E-06
28.75	5.67E-03	8.73E-04	1.52E-04	6.55E-04	1.61E-03	1.66E-03	1.27E-03	2.67E-04	3.66E-04	1.62E-04	1.59E-03	1.56E-03	6.06E-06
31.25	4.90E-03	7.85E-04	1.32E-04	5.92E-04	1.45E-03	1.52E-03	1.15E-03	2.38E-04	3.31E-04	1.45E-04	1.44E-03	1.42E-03	4.92E-06
33.75	4.83E-03	7.49E-04	1.26E-04	5.66E-04	1.38E-03	1.45E-03	1.09E-03	2.28E-04	3.16E-04	1.38E-04	1.37E-03	1.36E-03	4.59E-06
36.25	4.90E-03	7.85E-04	1.31E-04	5.93E-04	1.40E-03	1.43E-03	1.14E-03	2.38E-04	3.31E-04	1.44E-04	1.44E-03	1.35E-03	4.66E-06
38.75	4.76E-03	6.81E-04	1.21E-04	5.08E-04	1.26E-03	1.30E-03	9.85E-04	2.09E-04	2.84E-04	1.24E-04	1.23E-03	1.22E-03	4.64E-06
41.25	4.18E-03	5.39E-04	1.01E-04	3.98E-04	1.00E-03	1.02E-03	7.74E-04	1.67E-04	2.23E-04	9.82E-05	9.69E-04	9.56E-04	4.19E-06
43.75	3.46E-03	4.51E-04	8.22E-05	3.35E-04	8.36E-04	8.56E-04	6.49E-04	1.39E-04	1.87E-04	8.26E-05	8.13E-04	8.02E-04	3.38E-06
46.25	2.92E-03	3.72E-04	6.70E-05	2.77E-04	6.90E-04	7.10E-04	5.38E-04	1.15E-04	1.55E-04	6.83E-05	6.73E-04	6.65E-04	2.72E-06
48.75	2.71E-03	3.40E-04	6.16E-05	2.53E-04	6.31E-04	6.48E-04	4.91E-04	1.05E-04	1.41E-04	6.23E-05	6.14E-04	6.06E-04	2.51E-06
51.25	2.55E-03	3.12E-04	5.74E-05	2.31E-04	5.78E-04	5.91E-04	4.48E-04	9.64E-05	1.29E-04	5.69E-05	5.61E-04	5.53E-04	2.38E-06
53.75	2.45E-03	2.97E-04	5.50E-05	2.20E-04	5.52E-04	5.63E-04	4.27E-04	9.21E-05	1.23E-04	5.41E-05	5.35E-04	5.27E-04	2.27E-06
56.25	2.50E-03	3.03E-04	5.55E-05	2.24E-04	5.62E-04	5.75E-04	4.36E-04	9.36E-05	1.26E-04	5.50E-05	5.46E-04	5.38E-04	2.23E-06
58.75	2.59E-03	3.16E-04	5.78E-05	2.34E-04	5.85E-04	5.99E-04	4.54E-04	9.76E-05	1.31E-04	5.71E-05	5.69E-04	5.61E-04	2.28E-06

Table D-11: Mean individual short term risk of mortality for 15 day inventory using MAAP release fractions

Distance (km)	Sum over organs	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	2.99E-02	2.15E-03	2.81E-02	1.22E-03	6.55E-02	3.16E-03
1.75	3.62E-03	7.08E-05	2.48E-03	5.64E-05	2.79E-02	1.25E-03
3.75	1.12E-03	4.74E-06	7.04E-04	1.32E-06	1.30E-02	4.22E-04
6.25	2.14E-04	0.00E+00	8.77E-05	0.00E+00	5.58E-03	1.28E-04
8.75	1.06E-05	0.00E+00	3.37E-06	0.00E+00	2.16E-03	7.30E-06
11.25	9.01E-07	0.00E+00	0.00E+00	0.00E+00	1.13E-03	9.01E-07
13.75	1.48E-07	0.00E+00	0.00E+00	0.00E+00	5.30E-04	1.48E-07
16.25	3.98E-07	0.00E+00	0.00E+00	0.00E+00	5.31E-04	3.98E-07
18.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.30E-04	0.00E+00
21.25	3.12E-08	0.00E+00	0.00E+00	0.00E+00	5.32E-04	3.12E-08
23.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.56E-04	0.00E+00
26.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.46E-04	0.00E+00
28.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.61E-05	0.00E+00
31.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.99E-05	0.00E+00
33.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-04	0.00E+00
36.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.67E-04	0.00E+00
38.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-04	0.00E+00
41.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-04	0.00E+00
43.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E-04	0.00E+00
46.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.26E-05	0.00E+00
48.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.95E-05	0.00E+00
51.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.25E-05	0.00E+00
53.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-05	0.00E+00
56.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-05	0.00E+00
58.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.97E-06	0.00E+00

Table D-12: Mean individual long term risk of mortality for 15 day inventory using MAAP release fractions

Distance km	TOTAL	b.marrow	b.surface	breast	lung	stomach	colon	liver	pancreas	thyroid	Hered.Eff	remainder	skin
0.50	5.37E-02	3.00E-02	8.10E-03	2.39E-02	3.80E-02	3.84E-02	3.45E-02	1.16E-02	1.42E-02	6.02E-03	3.09E-01	3.75E-02	2.76E-04
1.75	4.47E-02	1.96E-02	5.06E-03	1.56E-02	2.72E-02	2.77E-02	2.37E-02	7.42E-03	9.18E-03	3.89E-03	6.00E-02	2.68E-02	1.70E-04
3.75	3.64E-02	9.68E-03	2.07E-03	7.07E-03	1.61E-02	1.66E-02	1.30E-02	3.18E-03	4.05E-03	1.71E-03	2.21E-02	1.57E-02	7.16E-05
6.25	2.63E-02	5.78E-03	1.20E-03	4.31E-03	9.45E-03	9.81E-03	7.62E-03	1.91E-03	2.48E-03	1.04E-03	1.13E-02	9.25E-03	3.90E-05
8.75	1.85E-02	3.49E-03	7.00E-04	2.58E-03	5.76E-03	5.99E-03	4.66E-03	1.12E-03	1.45E-03	6.10E-04	6.34E-03	5.65E-03	2.27E-05
11.25	1.05E-02	1.90E-03	3.48E-04	1.41E-03	3.16E-03	3.32E-03	2.60E-03	5.87E-04	7.87E-04	3.30E-04	3.42E-03	3.14E-03	1.03E-05
13.75	7.97E-03	1.23E-03	2.34E-04	9.06E-04	2.12E-03	2.24E-03	1.71E-03	3.84E-04	5.07E-04	2.13E-04	2.21E-03	2.11E-03	7.29E-06
16.25	6.69E-03	1.03E-03	1.91E-04	7.65E-04	1.81E-03	1.92E-03	1.46E-03	3.21E-04	4.28E-04	1.80E-04	1.86E-03	1.81E-03	5.74E-06
18.75	6.25E-03	1.09E-03	1.94E-04	8.20E-04	1.80E-03	1.90E-03	1.49E-03	3.37E-04	4.58E-04	1.92E-04	1.99E-03	1.80E-03	5.44E-06
21.25	5.85E-03	9.67E-04	1.77E-04	7.21E-04	1.65E-03	1.74E-03	1.36E-03	3.00E-04	4.03E-04	1.69E-04	1.75E-03	1.64E-03	5.15E-06
23.75	5.15E-03	8.06E-04	1.49E-04	6.00E-04	1.37E-03	1.45E-03	1.12E-03	2.51E-04	3.36E-04	1.41E-04	1.46E-03	1.37E-03	4.39E-06
26.25	4.32E-03	6.47E-04	1.19E-04	4.80E-04	1.09E-03	1.16E-03	8.92E-04	2.00E-04	2.68E-04	1.13E-04	1.17E-03	1.09E-03	3.50E-06
28.75	3.66E-03	5.01E-04	9.59E-05	3.68E-04	8.46E-04	8.94E-04	6.85E-04	1.56E-04	2.06E-04	8.63E-05	8.97E-04	8.40E-04	2.97E-06
31.25	3.19E-03	4.18E-04	8.09E-05	3.07E-04	7.22E-04	7.61E-04	5.86E-04	1.31E-04	1.72E-04	7.19E-05	7.48E-04	7.16E-04	2.54E-06
33.75	3.22E-03	4.49E-04	8.10E-05	3.34E-04	7.92E-04	8.55E-04	6.41E-04	1.38E-04	1.87E-04	7.82E-05	8.12E-04	8.01E-04	2.32E-06
36.25	3.18E-03	5.52E-04	8.92E-05	4.20E-04	9.47E-04	1.01E-03	8.04E-04	1.67E-04	2.34E-04	9.80E-05	1.02E-03	9.57E-04	2.14E-06
38.75	3.05E-03	4.87E-04	8.08E-05	3.68E-04	8.58E-04	9.26E-04	7.05E-04	1.48E-04	2.06E-04	8.61E-05	8.93E-04	8.78E-04	2.03E-06
41.25	2.86E-03	4.08E-04	7.06E-05	3.06E-04	7.21E-04	7.84E-04	5.87E-04	1.25E-04	1.71E-04	7.16E-05	7.43E-04	7.34E-04	1.90E-06
43.75	2.57E-03	3.65E-04	6.48E-05	2.73E-04	6.45E-04	6.99E-04	5.24E-04	1.12E-04	1.52E-04	6.38E-05	6.63E-04	6.54E-04	1.81E-06
46.25	2.45E-03	3.34E-04	6.04E-05	2.48E-04	5.89E-04	6.36E-04	4.77E-04	1.03E-04	1.39E-04	5.81E-05	6.03E-04	5.95E-04	1.74E-06
48.75	2.38E-03	3.28E-04	5.99E-05	2.44E-04	5.72E-04	6.10E-04	4.68E-04	1.02E-04	1.36E-04	5.70E-05	5.93E-04	5.74E-04	1.74E-06
51.25	2.27E-03	3.10E-04	5.70E-05	2.30E-04	5.36E-04	5.70E-04	4.39E-04	9.59E-05	1.29E-04	5.37E-05	5.59E-04	5.37E-04	1.66E-06
53.75	2.17E-03	2.82E-04	5.32E-05	2.08E-04	4.97E-04	5.32E-04	4.00E-04	8.78E-05	1.16E-04	4.87E-05	5.06E-04	4.99E-04	1.61E-06
56.25	2.16E-03	2.64E-04	5.15E-05	1.93E-04	4.64E-04	4.95E-04	3.72E-04	8.28E-05	1.08E-04	4.52E-05	4.71E-04	4.63E-04	1.62E-06
58.75	2.15E-03	2.55E-04	5.13E-05	1.85E-04	4.48E-04	4.75E-04	3.57E-04	8.06E-05	1.04E-04	4.34E-05	4.53E-04	4.45E-04	1.67E-06

Table D-13: Mean individual short term risk of mortality for 5 day inventory using NRC release fractions

Distance (km)	Sum over organs	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	8.58E-02	5.79E-02	8.50E-02	6.62E-02	1.09E-01	5.06E-03
1.75	5.12E-02	2.36E-02	4.98E-02	3.05E-02	7.58E-02	3.81E-03
3.75	4.34E-02	8.99E-03	4.15E-02	1.18E-02	7.92E-02	3.94E-03
6.25	2.80E-02	2.11E-03	2.63E-02	3.39E-03	5.81E-02	2.93E-03
8.75	1.34E-02	7.03E-04	1.19E-02	7.50E-04	4.21E-02	2.11E-03
11.25	7.53E-03	6.03E-04	6.22E-03	6.04E-04	3.26E-02	1.61E-03
13.75	6.95E-03	7.00E-05	5.79E-03	8.83E-05	2.90E-02	1.44E-03
16.25	4.92E-03	7.54E-05	3.81E-03	7.89E-05	2.62E-02	1.29E-03
18.75	3.84E-03	1.60E-04	2.78E-03	2.86E-04	2.37E-02	1.18E-03
21.25	3.06E-03	1.23E-04	2.07E-03	1.56E-04	2.16E-02	1.07E-03
23.75	3.38E-03	5.26E-05	2.46E-03	5.29E-05	2.08E-02	9.99E-04
26.25	4.06E-03	1.18E-04	3.07E-03	2.40E-04	2.26E-02	1.11E-03
28.75	2.78E-03	2.23E-04	1.88E-03	1.10E-04	2.03E-02	9.58E-04
31.25	1.91E-03	5.08E-04	1.08E-03	2.70E-04	1.88E-02	8.49E-04
33.75	1.94E-03	2.58E-04	1.22E-03	1.07E-04	1.71E-02	7.46E-04
36.25	2.03E-03	2.99E-04	1.39E-03	2.37E-04	1.72E-02	6.75E-04
38.75	1.83E-03	1.86E-04	1.21E-03	8.83E-05	1.76E-02	6.39E-04
41.25	1.46E-03	0.00E+00	9.88E-04	0.00E+00	1.42E-02	4.88E-04
43.75	1.19E-03	1.71E-05	6.85E-04	1.16E-05	1.22E-02	5.14E-04
46.25	1.26E-03	0.00E+00	8.47E-04	0.00E+00	1.02E-02	4.15E-04
48.75	1.12E-03	0.00E+00	7.27E-04	0.00E+00	9.70E-03	4.02E-04
51.25	8.40E-04	0.00E+00	5.00E-04	0.00E+00	8.97E-03	3.53E-04
53.75	6.45E-04	0.00E+00	3.52E-04	0.00E+00	8.39E-03	2.98E-04
56.25	6.90E-04	0.00E+00	4.07E-04	0.00E+00	8.26E-03	2.88E-04
58.75	8.84E-04	2.71E-06	6.08E-04	8.63E-07	8.46E-03	2.81E-04

Table D-14: Mean individual long term risk of mortality for 5 day inventory using NRC release fractions

Distance km	TOTAL	b.marrow	b.surface	breast	lung	stomach	colon	liver	pancreas	thyroid	Hered.Eff	remainder	skin
0.50	2.69E-02	8.35E-03	8.99E-04	6.83E-03	1.29E-02	1.42E-02	1.17E-02	2.40E-03	3.84E-03	1.88E-03	6.68E+00	1.36E-02	1.03E-04
1.75	4.11E-02	1.36E-02	1.46E-03	1.11E-02	2.09E-02	2.28E-02	1.91E-02	3.91E-03	6.26E-03	3.00E-03	1.38E+00	2.19E-02	1.62E-04
3.75	4.72E-02	2.25E-02	2.43E-03	1.85E-02	3.35E-02	3.51E-02	3.14E-02	6.50E-03	1.04E-02	4.86E-03	6.19E-01	3.44E-02	2.62E-04
6.25	4.39E-02	1.87E-02	2.06E-03	1.56E-02	2.75E-02	2.94E-02	2.55E-02	5.51E-03	8.83E-03	4.18E-03	2.70E-01	2.85E-02	2.19E-04
8.75	4.13E-02	1.86E-02	2.05E-03	1.55E-02	2.67E-02	2.84E-02	2.49E-02	5.47E-03	8.76E-03	4.12E-03	1.24E-01	2.77E-02	2.13E-04
11.25	3.59E-02	1.51E-02	1.64E-03	1.24E-02	2.23E-02	2.40E-02	2.07E-02	4.38E-03	7.02E-03	3.32E-03	8.17E-02	2.32E-02	1.72E-04
13.75	3.28E-02	1.27E-02	1.37E-03	1.04E-02	1.97E-02	2.12E-02	1.81E-02	3.66E-03	5.86E-03	2.76E-03	5.95E-02	2.05E-02	1.47E-04
16.25	3.26E-02	1.22E-02	1.33E-03	1.01E-02	1.88E-02	2.03E-02	1.73E-02	3.57E-03	5.71E-03	2.67E-03	4.75E-02	1.96E-02	1.38E-04
18.75	3.18E-02	1.18E-02	1.29E-03	9.75E-03	1.80E-02	1.95E-02	1.65E-02	3.44E-03	5.51E-03	2.56E-03	5.12E-02	1.88E-02	1.34E-04
21.25	3.03E-02	1.11E-02	1.19E-03	9.03E-03	1.72E-02	1.86E-02	1.58E-02	3.19E-03	5.11E-03	2.37E-03	4.20E-02	1.80E-02	1.25E-04
23.75	3.08E-02	1.01E-02	1.09E-03	8.21E-03	1.60E-02	1.76E-02	1.45E-02	2.92E-03	4.67E-03	2.16E-03	3.71E-02	1.69E-02	1.13E-04
26.25	3.31E-02	1.05E-02	1.17E-03	8.69E-03	1.66E-02	1.84E-02	1.49E-02	3.13E-03	5.00E-03	2.30E-03	4.73E-02	1.75E-02	1.14E-04
28.75	3.35E-02	1.12E-02	1.23E-03	9.26E-03	1.70E-02	1.87E-02	1.55E-02	3.30E-03	5.28E-03	2.41E-03	4.18E-02	1.79E-02	1.18E-04
31.25	3.36E-02	1.03E-02	1.13E-03	8.50E-03	1.64E-02	1.81E-02	1.47E-02	3.01E-03	4.82E-03	2.19E-03	3.78E-02	1.73E-02	1.03E-04
33.75	3.58E-02	9.79E-03	1.05E-03	7.99E-03	1.61E-02	1.79E-02	1.44E-02	2.82E-03	4.51E-03	2.03E-03	3.61E-02	1.71E-02	9.83E-05
36.25	4.06E-02	9.75E-03	1.05E-03	7.94E-03	1.68E-02	1.90E-02	1.47E-02	2.80E-03	4.48E-03	2.00E-03	3.79E-02	1.80E-02	9.76E-05
38.75	4.27E-02	9.80E-03	1.05E-03	7.99E-03	1.68E-02	1.91E-02	1.47E-02	2.81E-03	4.50E-03	2.00E-03	3.25E-02	1.80E-02	9.68E-05
41.25	3.98E-02	8.82E-03	9.77E-04	7.26E-03	1.49E-02	1.69E-02	1.31E-02	2.61E-03	4.18E-03	1.86E-03	2.55E-02	1.60E-02	8.83E-05
43.75	3.31E-02	7.47E-03	8.06E-04	6.09E-03	1.25E-02	1.41E-02	1.10E-02	2.15E-03	3.45E-03	1.54E-03	2.14E-02	1.34E-02	7.38E-05
46.25	2.77E-02	5.97E-03	6.37E-04	4.85E-03	1.02E-02	1.15E-02	8.93E-03	1.70E-03	2.73E-03	1.22E-03	1.77E-02	1.09E-02	6.04E-05
48.75	2.51E-02	5.71E-03	6.15E-04	4.65E-03	9.47E-03	1.07E-02	8.37E-03	1.64E-03	2.63E-03	1.17E-03	1.62E-02	1.01E-02	5.35E-05
51.25	2.49E-02	5.70E-03	6.16E-04	4.69E-03	9.28E-03	1.05E-02	8.24E-03	1.65E-03	2.64E-03	1.17E-03	1.47E-02	9.91E-03	5.11E-05
53.75	2.54E-02	5.68E-03	6.14E-04	4.66E-03	9.32E-03	1.05E-02	8.26E-03	1.64E-03	2.63E-03	1.16E-03	1.40E-02	9.95E-03	5.04E-05
56.25	2.60E-02	5.71E-03	6.17E-04	4.67E-03	9.56E-03	1.08E-02	8.48E-03	1.65E-03	2.64E-03	1.16E-03	1.43E-02	1.02E-02	4.95E-05
58.75	2.59E-02	5.62E-03	6.14E-04	4.58E-03	9.55E-03	1.08E-02	8.42E-03	1.64E-03	2.63E-03	1.15E-03	1.49E-02	1.02E-02	5.00E-05

Table D-15: Mean individual short term risk of mortality for 15 day inventory using NRC release fractions

Distance (km)	Sum over organs	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	8.48E-02	5.97E-02	8.41E-02	5.80E-02	1.04E-01	4.90E-03
1.75	4.77E-02	2.00E-02	4.68E-02	1.92E-02	6.80E-02	3.20E-03
3.75	3.65E-02	6.19E-03	3.53E-02	4.74E-03	6.24E-02	2.88E-03
6.25	2.19E-02	1.24E-03	2.03E-02	1.13E-03	5.45E-02	2.52E-03
8.75	1.44E-02	7.81E-04	1.31E-02	7.11E-04	4.43E-02	1.99E-03
11.25	5.53E-03	6.95E-04	4.45E-03	5.49E-04	2.98E-02	1.26E-03
13.75	3.07E-03	3.61E-04	2.11E-03	2.31E-04	2.53E-02	1.04E-03
16.25	2.18E-03	3.58E-04	1.42E-03	1.59E-04	2.11E-02	8.10E-04
18.75	2.71E-03	4.20E-04	2.11E-03	3.03E-04	1.90E-02	6.95E-04
21.25	2.25E-03	3.02E-04	1.78E-03	2.38E-04	1.63E-02	5.43E-04
23.75	2.00E-03	1.75E-04	1.58E-03	1.38E-04	1.48E-02	4.79E-04
26.25	1.24E-03	1.54E-04	8.41E-04	1.18E-04	1.32E-02	4.11E-04
28.75	1.05E-03	5.50E-05	6.95E-04	5.50E-05	1.19E-02	3.65E-04
31.25	8.63E-04	5.50E-05	5.99E-04	5.50E-05	9.87E-03	2.68E-04
33.75	9.51E-04	3.33E-06	7.50E-04	7.74E-07	8.64E-03	2.16E-04
36.25	1.04E-03	2.07E-04	8.58E-04	2.06E-04	7.89E-03	1.93E-04
38.75	1.18E-03	2.21E-04	9.72E-04	1.34E-04	7.96E-03	2.27E-04
41.25	1.11E-03	0.00E+00	8.71E-04	0.00E+00	7.79E-03	2.52E-04
43.75	8.47E-04	1.14E-05	6.20E-04	1.90E-06	7.14E-03	2.30E-04
46.25	8.44E-04	9.67E-06	6.48E-04	1.63E-06	6.62E-03	2.01E-04
48.75	8.53E-04	4.31E-05	6.68E-04	4.30E-05	6.25E-03	1.89E-04
51.25	7.25E-04	4.55E-05	5.77E-04	4.35E-05	5.73E-03	1.50E-04
53.75	4.92E-04	4.31E-05	3.84E-04	1.77E-05	4.94E-03	1.10E-04
56.25	5.13E-04	0.00E+00	3.95E-04	0.00E+00	5.61E-03	1.19E-04
58.75	2.77E-04	0.00E+00	1.85E-04	0.00E+00	5.46E-03	9.34E-05

Table D-16: Mean individual long term risk of mortality for 15 day inventory using NRC release fractions

Distance km	TOTAL	b.marrow	b.surface	breast	lung	stomach	colon	liver	pancreas	thyroid	Hered.Eff	remainder	skin
0.50	3.42E-02	1.25E-02	1.47E-03	1.06E-02	1.82E-02	1.96E-02	1.68E-02	3.92E-03	6.27E-03	2.67E-03	8.17E+00	1.89E-02	1.12E-04
1.75	3.70E-02	1.54E-02	1.79E-03	1.31E-02	2.15E-02	2.30E-02	2.00E-02	4.79E-03	7.68E-03	3.27E-03	1.59E+00	2.23E-02	1.37E-04
3.75	4.67E-02	2.02E-02	2.43E-03	1.74E-02	2.81E-02	2.98E-02	2.64E-02	6.48E-03	1.04E-02	4.41E-03	5.85E-01	2.90E-02	1.81E-04
6.25	5.60E-02	2.58E-02	3.16E-03	2.25E-02	3.48E-02	3.69E-02	3.25E-02	8.45E-03	1.35E-02	5.72E-03	3.00E-01	3.59E-02	2.36E-04
8.75	5.59E-02	2.23E-02	2.59E-03	1.89E-02	3.21E-02	3.47E-02	2.96E-02	6.92E-03	1.11E-02	4.68E-03	1.68E-01	3.36E-02	2.02E-04
11.25	4.91E-02	1.83E-02	2.08E-03	1.55E-02	2.69E-02	2.91E-02	2.47E-02	5.55E-03	8.90E-03	3.76E-03	9.08E-02	2.81E-02	1.64E-04
13.75	4.62E-02	1.66E-02	1.92E-03	1.41E-02	2.46E-02	2.68E-02	2.25E-02	5.12E-03	8.20E-03	3.46E-03	5.85E-02	2.58E-02	1.42E-04
16.25	4.30E-02	1.46E-02	1.64E-03	1.22E-02	2.16E-02	2.36E-02	1.98E-02	4.38E-03	7.02E-03	2.96E-03	4.94E-02	2.27E-02	1.21E-04
18.75	4.02E-02	1.23E-02	1.38E-03	1.02E-02	1.94E-02	2.14E-02	1.74E-02	3.68E-03	5.89E-03	2.48E-03	5.29E-02	2.05E-02	1.03E-04
21.25	3.93E-02	1.18E-02	1.31E-03	9.78E-03	1.81E-02	1.98E-02	1.64E-02	3.49E-03	5.59E-03	2.35E-03	4.65E-02	1.91E-02	9.95E-05
23.75	3.69E-02	1.04E-02	1.16E-03	8.62E-03	1.64E-02	1.82E-02	1.47E-02	3.10E-03	4.96E-03	2.09E-03	3.87E-02	1.74E-02	8.80E-05
26.25	3.48E-02	9.65E-03	1.06E-03	7.95E-03	1.55E-02	1.72E-02	1.39E-02	2.84E-03	4.54E-03	1.91E-03	3.10E-02	1.64E-02	7.94E-05
28.75	3.25E-02	8.32E-03	9.12E-04	6.84E-03	1.37E-02	1.54E-02	1.22E-02	2.44E-03	3.90E-03	1.64E-03	2.38E-02	1.46E-02	6.77E-05
31.25	3.01E-02	7.40E-03	8.02E-04	6.04E-03	1.21E-02	1.36E-02	1.08E-02	2.14E-03	3.43E-03	1.44E-03	1.98E-02	1.29E-02	5.93E-05
33.75	2.86E-02	6.90E-03	7.58E-04	5.65E-03	1.12E-02	1.25E-02	9.97E-03	2.03E-03	3.24E-03	1.36E-03	2.15E-02	1.19E-02	5.34E-05
36.25	2.69E-02	6.40E-03	7.04E-04	5.23E-03	1.04E-02	1.16E-02	9.27E-03	1.88E-03	3.01E-03	1.27E-03	2.71E-02	1.10E-02	4.91E-05
38.75	2.55E-02	5.93E-03	6.61E-04	4.87E-03	9.80E-03	1.10E-02	8.69E-03	1.77E-03	2.83E-03	1.19E-03	2.38E-02	1.04E-02	4.60E-05
41.25	2.48E-02	5.61E-03	6.05E-04	4.58E-03	9.40E-03	1.07E-02	8.31E-03	1.62E-03	2.59E-03	1.09E-03	1.97E-02	1.01E-02	4.37E-05
43.75	2.41E-02	5.33E-03	5.74E-04	4.34E-03	9.09E-03	1.03E-02	8.02E-03	1.53E-03	2.46E-03	1.03E-03	1.76E-02	9.72E-03	4.30E-05
46.25	2.33E-02	4.99E-03	5.44E-04	4.08E-03	8.47E-03	9.61E-03	7.47E-03	1.45E-03	2.33E-03	9.77E-04	1.60E-02	9.07E-03	4.11E-05
48.75	2.26E-02	4.80E-03	5.37E-04	4.00E-03	8.03E-03	9.14E-03	7.06E-03	1.44E-03	2.30E-03	9.64E-04	1.57E-02	8.61E-03	4.00E-05
51.25	2.22E-02	4.83E-03	5.39E-04	4.00E-03	8.02E-03	9.02E-03	7.08E-03	1.44E-03	2.30E-03	9.66E-04	1.48E-02	8.58E-03	3.96E-05
53.75	2.32E-02	4.94E-03	5.49E-04	4.13E-03	8.02E-03	9.03E-03	7.10E-03	1.47E-03	2.35E-03	9.84E-04	1.34E-02	8.55E-03	3.79E-05
56.25	2.44E-02	5.01E-03	5.37E-04	4.07E-03	8.68E-03	9.77E-03	7.64E-03	1.43E-03	2.30E-03	9.61E-04	1.25E-02	9.25E-03	3.87E-05
58.75	2.51E-02	5.32E-03	5.91E-04	4.37E-03	8.85E-03	1.00E-02	7.84E-03	1.58E-03	2.53E-03	1.06E-03	1.20E-02	9.46E-03	4.00E-05

Table D-17: Mean numbers of early deaths per distance band for 5 day inventory using MAAP release fractions

Distance (km)	Total	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	2.12E+01	0.00E+00	1.70E+01	1.28E-01	1.03E+00	5.11E+00
3.75	8.80E+00	0.00E+00	7.81E+00	6.32E-03	4.92E-01	1.36E+00
6.25	6.48E+00	7.50E-03	5.95E+00	4.39E-01	2.91E-01	6.79E-01
8.75	4.41E-01	0.00E+00	3.09E-01	0.00E+00	4.88E-02	1.32E-01
11.25	8.74E-01	0.00E+00	5.74E-03	0.00E+00	2.09E-01	8.69E-01
13.75	6.54E+00	0.00E+00	0.00E+00	0.00E+00	3.82E+00	6.54E+00
16.25	3.23E-01	0.00E+00	7.11E-02	0.00E+00	2.83E+00	2.52E-01
18.75	1.92E+01	0.00E+00	1.75E+01	0.00E+00	1.46E+00	1.73E+00
21.25	1.30E+01	0.00E+00	1.29E+01	0.00E+00	5.66E-01	7.83E-03
23.75	2.55E+00	0.00E+00	2.50E+00	0.00E+00	1.46E+00	4.15E-02
26.25	9.54E-03	0.00E+00	0.00E+00	0.00E+00	1.78E+00	9.54E-03
28.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.75E+00	0.00E+00
31.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E+01	0.00E+00
33.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E+01	0.00E+00
36.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E+01	0.00E+00
38.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.41E+01	0.00E+00
41.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E+00	0.00E+00
43.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.79E+00	0.00E+00
46.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.38E-01	0.00E+00
48.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-01	0.00E+00
51.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01	0.00E+00
53.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.73E-02	0.00E+00
56.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E-02	0.00E+00
58.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.65E-03	0.00E+00

Table D-18: Mean numbers of late deaths per distance band for 5 day inventory using MAAP release fractions

Distance (km)	Total	bone mar .	bone surf.	breast	lung	stomach	colon	liver	pancreas	thyroid	remainder	skin	hered.eff.
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	1.10E+02	4.28E+01	9.24E+00	1.55E+01	6.84E+01	6.72E+01	5.67E+01	1.39E+01	1.74E+01	8.45E+00	6.45E+01	5.26E-01	1.47E+02
3.75	6.13E+01	1.79E+01	2.94E+00	7.03E+00	3.09E+01	3.23E+01	2.51E+01	5.55E+00	7.85E+00	3.50E+00	3.05E+01	1.13E-01	6.61E+01
6.25	4.87E+01	1.74E+01	2.69E+00	7.04E+00	2.38E+01	2.39E+01	2.10E+01	5.43E+00	7.90E+00	3.46E+00	2.31E+01	8.33E-02	6.34E+01
8.75	1.47E+01	3.73E+00	6.45E-01	1.49E+00	5.95E+00	5.92E+00	4.92E+00	1.20E+00	1.68E+00	7.44E-01	5.71E+00	2.43E-02	8.34E+00
11.25	1.06E+02	1.65E+01	3.42E+00	5.94E+00	3.07E+01	3.01E+01	2.32E+01	5.24E+00	6.66E+00	3.13E+00	2.82E+01	1.85E-01	2.93E+01
13.75	1.23E+03	2.20E+02	4.28E+01	8.03E+01	4.10E+02	4.12E+02	3.13E+02	6.89E+01	9.00E+01	4.14E+01	3.86E+02	2.13E+00	3.93E+02
16.25	8.23E+02	1.70E+02	2.39E+01	6.62E+01	3.09E+02	3.29E+02	2.53E+02	5.00E+01	7.37E+01	3.19E+01	3.12E+02	6.34E-01	3.19E+02
18.75	7.61E+02	1.20E+02	1.75E+01	4.65E+01	2.20E+02	2.38E+02	1.79E+02	3.55E+01	5.19E+01	2.26E+01	2.23E+02	5.17E-01	2.96E+02
21.25	3.19E+02	5.17E+01	7.16E+00	2.07E+01	9.09E+01	9.97E+01	7.57E+01	1.58E+01	2.37E+01	1.02E+01	9.36E+01	1.56E-01	1.43E+02
23.75	8.95E+02	1.77E+02	2.35E+01	7.24E+01	2.79E+02	3.00E+02	2.39E+02	5.31E+01	8.05E+01	3.44E+01	2.85E+02	4.49E-01	3.53E+02
26.25	1.33E+03	2.02E+02	2.88E+01	7.86E+01	3.69E+02	4.02E+02	3.02E+02	5.96E+01	8.76E+01	3.80E+01	3.76E+02	8.00E-01	3.79E+02
28.75	1.83E+03	4.41E+02	5.48E+01	1.75E+02	7.99E+02	8.95E+02	6.70E+02	1.27E+02	1.95E+02	8.29E+01	8.38E+02	8.72E-01	8.42E+02
31.25	3.71E+03	9.86E+02	1.19E+02	3.93E+02	1.78E+03	2.01E+03	1.50E+03	2.84E+02	4.37E+02	1.85E+02	1.88E+03	1.62E+00	1.89E+03
33.75	3.84E+03	8.88E+02	1.10E+02	3.53E+02	1.61E+03	1.80E+03	1.35E+03	2.56E+02	3.93E+02	1.67E+02	1.69E+03	1.65E+00	1.70E+03
36.25	4.00E+03	1.33E+03	1.58E+02	5.30E+02	2.15E+03	2.28E+03	1.97E+03	3.81E+02	5.90E+02	2.49E+02	2.20E+03	1.84E+00	2.55E+03
38.75	4.04E+03	1.14E+03	1.38E+02	4.52E+02	2.05E+03	2.31E+03	1.73E+03	3.27E+02	5.02E+02	2.13E+02	2.16E+03	1.90E+00	2.17E+03
41.25	2.77E+03	4.05E+02	5.78E+01	1.57E+02	7.39E+02	8.04E+02	6.04E+02	1.20E+02	1.75E+02	7.57E+01	7.53E+02	1.57E+00	7.58E+02
43.75	3.13E+03	4.46E+02	6.66E+01	1.72E+02	8.16E+02	8.79E+02	6.61E+02	1.33E+02	1.92E+02	8.32E+01	8.23E+02	2.02E+00	8.30E+02
46.25	2.10E+03	2.66E+02	4.28E+01	1.01E+02	4.90E+02	5.19E+02	3.91E+02	8.03E+01	1.13E+02	4.96E+01	4.86E+02	1.50E+00	4.91E+02
48.75	8.92E+02	1.06E+02	1.74E+01	4.01E+01	1.95E+02	2.05E+02	1.55E+02	3.20E+01	4.48E+01	1.97E+01	1.92E+02	6.39E-01	1.94E+02
51.25	3.70E+02	4.61E+01	6.67E+00	1.79E+01	8.42E+01	9.15E+01	6.87E+01	1.36E+01	1.99E+01	8.56E+00	8.57E+01	1.76E-01	8.63E+01
53.75	3.00E+02	3.51E+01	5.03E+00	1.37E+01	6.41E+01	6.98E+01	5.24E+01	1.04E+01	1.52E+01	6.52E+00	6.54E+01	1.28E-01	6.58E+01
56.25	9.81E+01	1.28E+01	1.87E+00	4.94E+00	2.33E+01	2.53E+01	1.90E+01	3.79E+00	5.51E+00	2.37E+00	2.37E+01	5.11E-02	2.39E+01
58.75	5.69E+01	6.29E+00	1.07E+00	2.37E+00	1.16E+01	1.21E+01	9.16E+00	1.92E+00	2.65E+00	1.17E+00	1.14E+01	4.16E-02	1.15E+01

Table D-19: Mean numbers of early deaths per distance band for 15 day inventory using MAAP release fractions

Distance (km)	Total	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	1.23E+01	7.52E-01	9.97E+00	5.09E-01	6.29E-01	2.75E+00
3.75	9.71E+00	1.02E-02	8.98E+00	2.85E-03	4.63E-01	8.02E-01
6.25	7.87E+00	0.00E+00	3.03E-01	0.00E+00	1.58E+00	7.56E+00
8.75	1.27E-02	0.00E+00	6.36E-03	0.00E+00	1.48E-02	6.65E-03
11.25	6.91E-04	0.00E+00	0.00E+00	0.00E+00	1.46E-02	6.91E-04
13.75	1.42E-04	0.00E+00	0.00E+00	0.00E+00	1.03E+00	1.42E-04
16.25	1.15E-04	0.00E+00	0.00E+00	0.00E+00	3.44E+00	1.15E-04
18.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E+00	0.00E+00
21.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+00	0.00E+00
23.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.51E+00	0.00E+00
26.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E+00	0.00E+00
28.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E+00	0.00E+00
31.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+00	0.00E+00
33.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.66E+00	0.00E+00
36.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E+01	0.00E+00
38.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E+01	0.00E+00
41.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E+00	0.00E+00
43.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.79E+00	0.00E+00
46.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.31E+00	0.00E+00
48.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.17E-01	0.00E+00
51.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.46E-02	0.00E+00
53.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-02	0.00E+00
56.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E-04	0.00E+00
58.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.52E-04	0.00E+00

Table D-20: Mean numbers of late deaths per distance band for 15 day inventory using MAAP release fractions

Distance (km)	Total	bone mar .	bone surf.	breast	lung	stomach	colon	liver	pancreas	thyroid	remainder	skin	hered.eff.
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	9.07E+01	3.90E+01	8.74E+00	1.50E+01	5.48E+01	5.62E+01	4.77E+01	1.39E+01	1.81E+01	7.65E+00	5.42E+01	2.88E-01	1.90E+02
3.75	6.76E+01	2.65E+01	4.28E+00	1.02E+01	4.05E+01	4.14E+01	3.63E+01	8.13E+00	1.15E+01	4.83E+00	4.01E+01	1.01E-01	1.03E+02
6.25	2.93E+02	8.70E+01	1.97E+01	3.09E+01	1.50E+02	1.55E+02	1.17E+02	2.85E+01	3.51E+01	1.47E+01	1.45E+02	7.20E-01	1.59E+02
8.75	1.96E+01	3.23E+00	6.67E-01	1.19E+00	5.41E+00	5.63E+00	4.35E+00	1.04E+00	1.34E+00	5.62E-01	5.30E+00	2.21E-02	5.87E+00
11.25	4.85E+01	6.65E+00	1.45E+00	2.37E+00	1.16E+01	1.21E+01	9.14E+00	2.14E+00	2.66E+00	1.12E+00	1.13E+01	5.24E-02	1.16E+01
13.75	4.47E+02	9.66E+01	1.47E+01	3.73E+01	1.71E+02	1.85E+02	1.42E+02	2.89E+01	4.15E+01	1.74E+01	1.78E+02	3.12E-01	1.80E+02
16.25	9.53E+02	2.42E+02	3.25E+01	9.50E+01	4.31E+02	4.80E+02	3.63E+02	7.07E+01	1.06E+02	4.42E+01	4.52E+02	4.81E-01	4.57E+02
18.75	5.99E+02	1.40E+02	1.83E+01	5.53E+01	2.26E+02	2.48E+02	1.97E+02	4.08E+01	6.16E+01	2.57E+01	2.35E+02	2.43E-01	2.66E+02
21.25	3.32E+02	8.52E+01	1.07E+01	3.38E+01	1.46E+02	1.60E+02	1.27E+02	2.46E+01	3.76E+01	1.57E+01	1.52E+02	1.20E-01	1.62E+02
23.75	8.05E+02	1.87E+02	2.47E+01	7.55E+01	2.95E+02	3.23E+02	2.55E+02	5.55E+01	8.40E+01	3.51E+01	3.06E+02	3.11E-01	3.63E+02
26.25	9.70E+02	1.96E+02	2.69E+01	7.66E+01	3.22E+02	3.50E+02	2.75E+02	5.74E+01	8.53E+01	3.57E+01	3.32E+02	4.29E-01	3.69E+02
28.75	1.37E+03	2.50E+02	3.45E+01	9.77E+01	3.99E+02	4.36E+02	3.44E+02	7.33E+01	1.09E+02	4.55E+01	4.13E+02	5.60E-01	4.71E+02
31.25	2.22E+03	3.37E+02	4.70E+01	1.32E+02	5.83E+02	6.41E+02	4.97E+02	9.91E+01	1.47E+02	6.13E+01	6.05E+02	7.90E-01	6.34E+02
33.75	3.09E+03	5.35E+02	7.16E+01	2.10E+02	9.56E+02	1.08E+03	8.03E+02	1.56E+02	2.34E+02	9.79E+01	1.01E+03	1.04E+00	1.01E+03
36.25	4.13E+03	1.35E+03	1.58E+02	5.41E+02	2.25E+03	2.40E+03	2.06E+03	3.87E+02	6.02E+02	2.52E+02	2.32E+03	1.06E+00	2.60E+03
38.75	4.02E+03	1.13E+03	1.37E+02	4.49E+02	2.02E+03	2.21E+03	1.71E+03	3.25E+02	5.00E+02	2.09E+02	2.15E+03	1.26E+00	2.16E+03
41.25	4.36E+03	8.84E+02	1.09E+02	3.52E+02	1.58E+03	1.80E+03	1.34E+03	2.55E+02	3.91E+02	1.63E+02	1.68E+03	1.04E+00	1.69E+03
43.75	4.24E+03	8.73E+02	1.10E+02	3.46E+02	1.56E+03	1.77E+03	1.32E+03	2.53E+02	3.85E+02	1.61E+02	1.66E+03	1.20E+00	1.66E+03
46.25	3.00E+03	5.54E+02	7.40E+01	2.18E+02	9.88E+02	1.11E+03	8.30E+02	1.62E+02	2.42E+02	1.01E+02	1.04E+03	1.06E+00	1.05E+03
48.75	1.76E+03	2.75E+02	3.65E+01	1.08E+02	4.91E+02	5.53E+02	4.13E+02	8.02E+01	1.20E+02	5.03E+01	5.18E+02	5.05E-01	5.20E+02
51.25	1.88E+02	2.66E+01	4.00E+00	1.02E+01	4.72E+01	5.24E+01	3.92E+01	7.91E+00	1.14E+01	4.77E+00	4.90E+01	8.15E-02	4.95E+01
53.75	1.17E+02	1.43E+01	2.40E+00	5.38E+00	2.52E+01	2.75E+01	2.06E+01	4.34E+00	6.01E+00	2.51E+00	2.58E+01	6.15E-02	2.61E+01
56.25	3.89E+01	4.43E+00	7.87E-01	1.65E+00	7.82E+00	8.47E+00	6.35E+00	1.36E+00	1.85E+00	7.74E-01	7.93E+00	2.20E-02	8.04E+00
58.75	7.49E+01	8.62E+00	1.27E+00	3.33E+00	1.53E+01	1.71E+01	1.28E+01	2.56E+00	3.72E+00	1.55E+00	1.60E+01	2.47E-02	1.61E+01

Table D-21: Mean numbers of early deaths per distance band for 5 day inventory using NRC release fractions

Distance (km)	Total	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	1.42E+02	6.40E+01	1.40E+02	8.61E+01	1.80E+00	8.89E+00
3.75	7.48E+01	1.68E+01	7.32E+01	2.49E+01	1.06E+00	5.28E+00
6.25	5.63E+01	1.86E+01	5.42E+01	1.96E+01	1.02E+00	4.81E+00
8.75	1.49E+01	3.04E+00	1.38E+01	3.06E+00	3.62E-01	1.75E+00
11.25	1.15E+02	1.33E+00	1.04E+02	1.33E+00	3.23E+00	1.60E+01
13.75	1.44E+03	1.55E+01	1.40E+03	1.58E+01	2.35E+01	1.04E+02
16.25	6.83E+02	6.16E+01	6.26E+02	6.11E+01	2.11E+01	8.69E+01
18.75	7.15E+02	2.23E+01	6.31E+02	3.08E+01	2.38E+01	9.55E+01
21.25	3.40E+02	1.70E+01	3.19E+02	1.70E+01	8.10E+00	3.00E+01
23.75	8.58E+02	5.55E+01	8.11E+02	5.56E+01	2.14E+01	6.68E+01
26.25	1.17E+03	6.40E+00	1.03E+03	3.41E+00	4.16E+01	1.70E+02
28.75	1.29E+03	2.71E+02	1.12E+03	8.99E+01	5.21E+01	1.79E+02
31.25	2.27E+03	1.55E+03	1.91E+03	6.93E+02	1.03E+02	3.67E+02
33.75	3.09E+03	2.95E+02	2.84E+03	1.36E+02	8.77E+01	3.31E+02
36.25	3.48E+03	1.35E+03	3.21E+03	1.13E+03	9.00E+01	3.37E+02
38.75	3.21E+03	1.27E+03	2.95E+03	5.99E+02	9.34E+01	3.32E+02
41.25	1.51E+03	0.00E+00	1.25E+03	0.00E+00	8.44E+01	2.79E+02
43.75	1.21E+03	0.00E+00	8.41E+02	0.00E+00	1.20E+02	3.67E+02
46.25	1.46E+03	0.00E+00	1.14E+03	0.00E+00	8.06E+01	3.25E+02
48.75	2.20E+02	0.00E+00	6.70E+01	0.00E+00	4.19E+01	1.54E+02
51.25	1.00E+02	0.00E+00	8.65E+01	0.00E+00	1.03E+01	1.52E+01
53.75	2.54E+01	0.00E+00	1.80E+01	0.00E+00	1.09E+01	7.51E+00
56.25	4.17E+01	0.00E+00	3.67E+01	0.00E+00	3.32E+00	5.12E+00
58.75	8.61E+00	0.00E+00	2.41E+00	0.00E+00	2.33E+00	6.23E+00

Table D-22: Mean numbers of late deaths per distance band for 5 day inventory using NRC release fractions

Distance (km)	Total	bone mar .	bone surf.	breast	lung	stomach	colon	liver	pancreas	thyroid	remainder	skin	hered.eff.
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	5.67E+01	1.96E+01	2.09E+00	7.95E+00	3.18E+01	3.52E+01	2.87E+01	5.57E+00	8.92E+00	4.33E+00	3.36E+01	2.37E-01	3.86E+03
3.75	5.85E+01	1.87E+01	2.02E+00	7.69E+00	3.01E+01	3.30E+01	2.73E+01	5.41E+00	8.66E+00	4.12E+00	3.16E+01	2.14E-01	1.75E+03
6.25	8.69E+01	2.95E+01	3.16E+00	1.20E+01	4.48E+01	4.87E+01	4.12E+01	8.45E+00	1.35E+01	6.24E+00	4.69E+01	2.81E-01	1.68E+03
8.75	3.86E+01	1.47E+01	1.63E+00	6.17E+00	2.10E+01	2.26E+01	1.94E+01	4.36E+00	6.99E+00	3.26E+00	2.19E+01	1.60E-01	2.20E+02
11.25	2.83E+02	1.00E+02	1.08E+01	4.08E+01	1.72E+02	1.94E+02	1.52E+02	2.90E+01	4.64E+01	2.22E+01	1.84E+02	1.29E+00	7.67E+02
13.75	1.84E+03	5.62E+02	6.07E+01	2.29E+02	9.12E+02	9.86E+02	8.30E+02	1.62E+02	2.60E+02	1.20E+02	9.52E+02	5.90E+00	1.03E+04
16.25	2.12E+03	8.17E+02	8.89E+01	3.37E+02	1.30E+03	1.42E+03	1.18E+03	2.38E+02	3.80E+02	1.73E+02	1.36E+03	7.05E+00	8.45E+03
18.75	2.26E+03	7.91E+02	8.56E+01	3.26E+02	1.23E+03	1.38E+03	1.11E+03	2.29E+02	3.66E+02	1.70E+02	1.31E+03	7.83E+00	7.83E+03
21.25	7.20E+02	2.75E+02	2.98E+01	1.13E+02	4.30E+02	4.64E+02	3.88E+02	7.95E+01	1.27E+02	5.82E+01	4.48E+02	2.46E+00	3.79E+03
23.75	2.58E+03	8.12E+02	8.84E+01	3.34E+02	1.29E+03	1.42E+03	1.16E+03	2.36E+02	3.78E+02	1.72E+02	1.36E+03	6.72E+00	9.38E+03
26.25	5.23E+03	1.54E+03	1.66E+02	6.29E+02	2.60E+03	2.88E+03	2.32E+03	4.43E+02	7.09E+02	3.25E+02	2.75E+03	1.48E+01	1.00E+04
28.75	6.63E+03	2.08E+03	2.24E+02	8.46E+02	3.46E+03	3.85E+03	3.07E+03	5.98E+02	9.56E+02	4.35E+02	3.66E+03	1.82E+01	2.23E+04
31.25	1.23E+04	4.73E+03	5.55E+02	2.06E+03	7.07E+03	7.77E+03	6.40E+03	1.49E+03	2.37E+03	1.06E+03	7.44E+03	3.48E+01	5.01E+04
33.75	1.28E+04	3.27E+03	3.47E+02	1.33E+03	5.59E+03	6.26E+03	4.93E+03	9.28E+02	1.49E+03	6.72E+02	5.94E+03	2.91E+01	4.50E+04
36.25	9.80E+03	3.04E+03	3.29E+02	1.23E+03	5.33E+03	5.89E+03	4.65E+03	8.80E+02	1.41E+03	6.37E+02	5.68E+03	2.84E+01	6.76E+04
38.75	1.01E+04	3.31E+03	3.50E+02	1.34E+03	5.63E+03	6.14E+03	4.99E+03	9.35E+02	1.50E+03	6.77E+02	5.90E+03	2.91E+01	5.76E+04
41.25	1.23E+04	4.52E+03	6.24E+02	2.00E+03	6.57E+03	7.17E+03	5.95E+03	1.67E+03	2.67E+03	1.17E+03	6.88E+03	3.26E+01	2.01E+04
43.75	1.68E+04	6.52E+03	6.91E+02	2.64E+03	1.00E+04	1.11E+04	9.08E+03	1.85E+03	2.95E+03	1.31E+03	1.06E+04	4.52E+01	2.19E+04
46.25	1.32E+04	3.53E+03	3.82E+02	1.45E+03	6.17E+03	7.00E+03	5.37E+03	1.02E+03	1.63E+03	7.38E+02	6.63E+03	3.35E+01	1.30E+04
48.75	5.84E+03	2.27E+03	2.52E+02	9.40E+02	3.46E+03	3.80E+03	3.16E+03	6.74E+02	1.08E+03	4.74E+02	3.64E+03	1.44E+01	5.12E+03
51.25	2.88E+03	8.42E+02	9.41E+01	3.59E+02	1.19E+03	1.31E+03	1.09E+03	2.52E+02	4.02E+02	1.73E+02	1.26E+03	3.81E+00	2.28E+03
53.75	2.50E+03	7.68E+02	8.82E+01	3.26E+02	1.21E+03	1.32E+03	1.09E+03	2.36E+02	3.77E+02	1.61E+02	1.27E+03	2.91E+00	1.74E+03
56.25	7.81E+02	1.82E+02	2.09E+01	7.58E+01	3.08E+02	3.50E+02	2.70E+02	5.57E+01	8.91E+01	3.88E+01	3.30E+02	1.15E+00	6.31E+02
58.75	7.41E+02	1.47E+02	1.55E+01	5.93E+01	2.61E+02	3.00E+02	2.26E+02	4.15E+01	6.64E+01	2.93E+01	2.81E+02	9.56E-01	3.02E+02

Table D-23: Mean numbers of early deaths per distance band for 15 day inventory using NRC release fractions

Distance (km)	Total	pulmonary syn.	hematop. syn.	GI syndrome	pre-/neo natal	skin burns
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	1.04E+02	4.11E+01	1.03E+02	3.91E+01	1.37E+00	6.45E+00
3.75	7.67E+01	3.10E+01	7.60E+01	3.03E+01	1.07E+00	4.46E+00
6.25	2.89E+02	5.04E+00	2.83E+02	4.28E+00	4.15E+00	2.01E+01
8.75	1.23E+01	5.21E-01	1.06E+01	4.86E-01	5.00E-01	2.14E+00
11.25	1.58E+01	3.64E-01	1.06E+01	2.48E-01	1.42E+00	5.65E+00
13.75	1.95E+02	1.01E+02	1.57E+02	5.75E+01	1.21E+01	4.63E+01
16.25	5.60E+02	2.65E+02	5.18E+02	6.98E+01	2.01E+01	6.45E+01
18.75	2.40E+02	6.82E+01	2.20E+02	5.29E+01	1.48E+01	3.04E+01
21.25	2.11E+02	3.18E+01	2.02E+02	2.92E+01	6.78E+00	1.72E+01
23.75	5.62E+02	6.11E+01	5.35E+02	6.08E+01	1.63E+01	5.07E+01
26.25	5.84E+02	1.06E+02	5.44E+02	7.85E+01	2.24E+01	4.45E+01
28.75	9.04E+02	7.03E+01	8.32E+02	7.03E+01	3.39E+01	7.49E+01
31.25	1.80E+03	6.99E+01	1.70E+03	6.99E+01	5.37E+01	1.11E+02
33.75	2.03E+03	1.18E+00	1.91E+03	2.74E-01	7.24E+01	1.55E+02
36.25	3.24E+03	1.13E+03	3.16E+03	1.13E+03	7.00E+01	1.55E+02
38.75	3.02E+03	1.45E+03	2.91E+03	8.58E+02	7.57E+01	1.98E+02
41.25	3.43E+03	0.00E+00	3.33E+03	0.00E+00	7.80E+01	1.71E+02
43.75	2.97E+03	8.01E+01	2.85E+03	1.33E+01	8.44E+01	1.40E+02
46.25	2.09E+03	6.88E+01	2.00E+03	1.16E+01	6.10E+01	9.65E+01
48.75	1.64E+03	1.86E-02	1.58E+03	1.86E-02	4.20E+01	6.99E+01
51.25	1.09E+02	7.92E-01	1.06E+02	1.28E-01	3.17E+00	3.48E+00
53.75	3.07E+01	0.00E+00	2.93E+01	0.00E+00	1.61E+00	1.37E+00
56.25	3.13E+00	0.00E+00	1.74E+00	0.00E+00	1.31E+00	1.41E+00
58.75	2.43E+00	0.00E+00	6.67E-01	0.00E+00	2.70E+00	1.76E+00

Table D-24: Mean numbers of late deaths per distance band for 15 day inventory using NRC release fractions

Distance (km)	Total	bone mar .	bone surf.	breast	lung	stomach	colon	liver	pancreas	thyroid	remainder	skin	hered.eff.
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	6.74E+01	2.53E+01	2.91E+00	1.06E+01	3.69E+01	3.94E+01	3.40E+01	7.78E+00	1.25E+01	5.28E+00	3.82E+01	1.96E-01	5.06E+03
3.75	7.02E+01	2.31E+01	2.81E+00	9.87E+00	3.56E+01	3.93E+01	3.19E+01	7.50E+00	1.20E+01	5.05E+00	3.76E+01	1.34E-01	2.76E+03
6.25	2.31E+02	8.09E+01	8.94E+00	3.34E+01	1.32E+02	1.47E+02	1.18E+02	2.39E+01	3.83E+01	1.61E+01	1.40E+02	7.08E-01	4.18E+03
8.75	1.06E+02	3.14E+01	3.50E+00	1.30E+01	4.84E+01	5.30E+01	4.41E+01	9.34E+00	1.50E+01	6.29E+00	5.08E+01	2.78E-01	1.55E+02
11.25	3.06E+02	1.07E+02	1.22E+01	4.59E+01	1.53E+02	1.65E+02	1.43E+02	3.26E+01	5.22E+01	2.21E+01	1.60E+02	1.01E+00	3.06E+02
13.75	2.21E+03	7.92E+02	9.30E+01	3.38E+02	1.17E+03	1.28E+03	1.06E+03	2.49E+02	3.98E+02	1.67E+02	1.23E+03	5.90E+00	4.80E+03
16.25	3.61E+03	1.31E+03	1.42E+02	5.33E+02	1.85E+03	1.99E+03	1.73E+03	3.80E+02	6.07E+02	2.55E+02	1.93E+03	8.26E+00	1.22E+04
18.75	2.75E+03	1.06E+03	1.21E+02	4.62E+02	1.51E+03	1.61E+03	1.40E+03	3.24E+02	5.18E+02	2.17E+02	1.57E+03	4.74E+00	7.12E+03
21.25	1.19E+03	3.81E+02	4.20E+01	1.57E+02	5.74E+02	6.34E+02	5.20E+02	1.12E+02	1.80E+02	7.53E+01	6.05E+02	2.07E+00	4.34E+03
23.75	3.25E+03	8.97E+02	9.74E+01	3.69E+02	1.47E+03	1.63E+03	1.31E+03	2.60E+02	4.16E+02	1.75E+02	1.56E+03	5.49E+00	9.72E+03
26.25	5.44E+03	1.44E+03	1.60E+02	5.95E+02	2.33E+03	2.56E+03	2.12E+03	4.27E+02	6.83E+02	2.87E+02	2.46E+03	8.97E+00	9.86E+03
28.75	7.31E+03	1.99E+03	2.20E+02	8.17E+02	3.25E+03	3.59E+03	2.91E+03	5.89E+02	9.41E+02	3.95E+02	3.43E+03	1.23E+01	1.26E+04
31.25	1.11E+04	2.94E+03	3.24E+02	1.20E+03	4.90E+03	5.41E+03	4.39E+03	8.67E+02	1.38E+03	5.81E+02	5.17E+03	1.68E+01	1.69E+04
33.75	1.35E+04	3.86E+03	4.53E+02	1.60E+03	6.45E+03	7.18E+03	5.69E+03	1.21E+03	1.94E+03	8.12E+02	6.87E+03	1.97E+01	2.71E+04
36.25	1.12E+04	3.01E+03	3.19E+02	1.22E+03	4.99E+03	5.60E+03	4.44E+03	8.53E+02	1.37E+03	5.72E+02	5.32E+03	1.62E+01	6.97E+04
38.75	1.16E+04	3.61E+03	4.58E+02	1.57E+03	5.54E+03	6.22E+03	4.95E+03	1.23E+03	1.96E+03	8.20E+02	5.89E+03	1.72E+01	5.78E+04
41.25	1.20E+04	3.77E+03	4.04E+02	1.55E+03	5.61E+03	6.23E+03	5.04E+03	1.08E+03	1.73E+03	7.22E+02	5.93E+03	1.68E+01	4.52E+04
43.75	1.82E+04	4.21E+03	4.60E+02	1.72E+03	7.30E+03	8.33E+03	6.39E+03	1.23E+03	1.97E+03	8.24E+02	7.83E+03	2.65E+01	4.45E+04
46.25	1.50E+04	3.27E+03	3.53E+02	1.34E+03	5.64E+03	6.46E+03	4.92E+03	9.43E+02	1.51E+03	6.32E+02	6.07E+03	2.40E+01	2.80E+04
48.75	5.59E+03	1.44E+03	1.56E+02	5.85E+02	2.53E+03	2.91E+03	2.20E+03	4.17E+02	6.67E+02	2.79E+02	2.73E+03	1.18E+01	1.39E+04
51.25	1.59E+03	2.82E+02	3.17E+01	1.17E+02	4.73E+02	5.40E+02	4.15E+02	8.47E+01	1.36E+02	5.67E+01	5.08E+02	1.94E+00	1.32E+03
53.75	1.52E+03	2.54E+02	2.82E+01	1.06E+02	4.24E+02	4.83E+02	3.72E+02	7.53E+01	1.20E+02	5.04E+01	4.55E+02	1.49E+00	6.94E+02
56.25	4.50E+02	1.03E+02	1.11E+01	4.21E+01	1.77E+02	2.01E+02	1.54E+02	2.97E+01	4.74E+01	1.99E+01	1.89E+02	5.32E-01	2.13E+02
58.75	5.69E+02	2.18E+02	2.31E+01	8.84E+01	3.11E+02	3.31E+02	2.94E+02	6.17E+01	9.86E+01	4.13E+01	3.21E+02	6.00E-01	4.30E+02

Table D-25: Deaths Per Distance Band

Distance/km	Deaths per Distance Band			
	MAAP Release Fractions		NRC release fractions	
	Outage Mode	Normal Mode	Outage Mode	Normal Mode
0.50	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.75	1.31E+02	1.03E+02	1.98E+02	1.71E+02
3.75	7.01E+01	7.73E+01	1.33E+02	1.47E+02
6.25	5.51E+01	3.01E+02	1.43E+02	5.20E+02
8.75	1.51E+01	1.96E+01	5.35E+01	1.18E+02
11.25	1.07E+02	4.85E+01	3.97E+02	3.21E+02
13.75	1.24E+03	4.47E+02	3.27E+03	2.41E+03
16.25	8.23E+02	9.53E+02	2.81E+03	4.17E+03
18.75	7.80E+02	5.99E+02	2.98E+03	2.99E+03
21.25	3.32E+02	3.32E+02	1.06E+03	1.40E+03
23.75	8.97E+02	8.05E+02	3.43E+03	3.81E+03
26.25	1.33E+03	9.70E+02	6.41E+03	6.02E+03
28.75	1.83E+03	1.37E+03	7.92E+03	8.22E+03
31.25	3.71E+03	2.22E+03	1.46E+04	1.29E+04
33.75	3.84E+03	3.09E+03	1.58E+04	1.55E+04
36.25	4.00E+03	4.13E+03	1.33E+04	1.44E+04
38.75	4.04E+03	4.02E+03	1.33E+04	1.46E+04
41.25	2.77E+03	4.36E+03	1.38E+04	1.55E+04
43.75	3.13E+03	4.24E+03	1.80E+04	2.11E+04
46.25	2.10E+03	3.00E+03	1.47E+04	1.71E+04
48.75	8.92E+02	1.76E+03	6.06E+03	7.23E+03
51.25	3.70E+02	1.88E+02	2.98E+03	1.70E+03
53.75	3.00E+02	1.17E+02	2.52E+03	1.55E+03
56.25	9.81E+01	3.89E+01	8.23E+02	4.54E+02
58.75	5.69E+01	7.49E+01	7.50E+02	5.71E+02
Total	***3.29E+04***	***3.33E+04***	***1.45E+05***	***1.53E+05***
RC Freq/y	***1.99E-09***	***4.83E-08***	***1.99E-09***	***4.83E-08***

Population (1.75 km)	2.08E+03
Population (national)	5.18E+07

Peak Public Risk	1.26E-10	2.40E-09	1.90E-10	3.99E-09
	2.52E-09		***4.18E-09***	
Avg Public Risk	1.26E-12	3.10E-11	5.59E-12	1.43E-10
	3.23E-11		***1.48E-10***	

Table D-26: Conditional Individual Mortality Risks

Distance (km)	Individual Risks of Mortality			
	MAAP Release Fractions		NRC Release Fractions	
	Outage Mode	Normal Mode	Outage Mode	Normal Mode
0.50	8.14E-02	8.36E-02	1.13E-01	1.19E-01
1.75	4.92E-02	4.83E-02	9.23E-02	8.47E-02
3.75	4.05E-02	3.76E-02	9.06E-02	8.32E-02
6.25	2.55E-02	2.66E-02	7.19E-02	7.79E-02
8.75	1.47E-02	1.85E-02	5.47E-02	7.04E-02
11.25	1.01E-02	1.05E-02	4.34E-02	5.46E-02
13.75	8.55E-03	7.97E-03	3.98E-02	4.92E-02
16.25	7.10E-03	6.69E-03	3.75E-02	4.52E-02
18.75	6.48E-03	6.25E-03	3.56E-02	4.29E-02
21.25	5.74E-03	5.85E-03	3.33E-02	4.16E-02
23.75	5.57E-03	5.15E-03	3.42E-02	3.89E-02
26.25	6.38E-03	4.32E-03	3.72E-02	3.60E-02
28.75	5.67E-03	3.66E-03	3.63E-02	3.36E-02
31.25	4.90E-03	3.19E-03	3.56E-02	3.09E-02
33.75	4.83E-03	3.22E-03	3.78E-02	2.95E-02
36.25	4.90E-03	3.18E-03	4.27E-02	2.79E-02
38.75	4.76E-03	3.05E-03	4.45E-02	2.66E-02
41.25	4.18E-03	2.86E-03	4.13E-02	2.59E-02
43.75	3.46E-03	2.57E-03	3.42E-02	2.49E-02
46.25	2.92E-03	2.45E-03	2.89E-02	2.41E-02
48.75	2.71E-03	2.38E-03	2.62E-02	2.35E-02
51.25	2.55E-03	2.27E-03	2.57E-02	2.30E-02
53.75	2.45E-03	2.17E-03	2.60E-02	2.37E-02
56.25	2.50E-03	2.16E-03	2.66E-02	2.49E-02
58.75	2.59E-03	2.15E-03	2.67E-02	2.54E-02
Total	***3.10E-01***	***2.97E-01***	***1.12E+00***	***1.09E+00***
RC Freq (/y)	***1.99E-09***	***4.83E-08***	***1.99E-09***	***4.83E-08***

Peak Site Personnel Risk	1.62E-10	4.04E-09	2.24E-10	5.75E-09
	4.20E-09		***5.97E-09***	
Average Site Personnel Risk	1.62E-10	4.04E-09	2.24E-10	5.75E-09
	4.20E-09		***5.97E-09***	

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