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Commercial Spent Nuclear Fuel Waste Package Misload Analysis

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II - BWR Misload Event Trees	6
III - Mathcad Spreadsheets	19
IV - CD-ROM of compressed SAPHIRE files	0

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ACRONYMS AND ABBREVIATIONS

ACC	accession number
BSC	Bechtel SAIC Company
BWR	boiling water reactor
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
EOC	error of commission
M&O	Management and Operating Contractor
NRC	U.S. Nuclear Regulatory Commission
PWR	pressurized water reactor
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
SAPHIRE	System Analysis Programs for Hands-on Integrated Reliability Evaluations
TIC	Technical Information Center catalog number

1. PURPOSE

The purpose of this calculation is to estimate the probability of misloading a commercial spent nuclear fuel waste package with a fuel assembly(s) that has a reactivity (i.e., enrichment and/or burnup) outside the waste package design. The waste package designs are based on the expected commercial spent nuclear fuel assemblies and previous analyses (Macheret, P. 2001, Section 4.1 and Table 1). For this calculation, a misloaded waste package is defined as a waste package that has a fuel assembly(s) loaded into it with an enrichment and/or burnup outside the waste package design. An example of this type of misload is a fuel assembly designated for the 21-PWR Control Rod waste package being incorrectly loaded into a 21-PWR Absorber Plate waste package. This constitutes a misloaded 21-PWR Absorber Plate waste package, because the reactivity (i.e., enrichment and/or burnup) of a 21-PWR Control Rod waste package fuel assembly is outside the design of a 21-PWR Absorber Plate waste package. These types of misloads (i.e., fuel assembly with enrichment and/or burnup outside waste package design) are the only types that are evaluated in this calculation. This calculation utilizes information from *Frequency of SNF Misload for Uncanistered Fuel Waste Package* (CRWMS M&O 1998) as the starting point.

The scope of this calculation is limited to the information available. The information is based on the whole population of fuel assemblies and the whole population of waste packages, because there is no information about the arrival of the waste stream at this time. The scope of this calculation deviates from that specified in *Technical Work Plan for: Risk and Criticality Department* (BSC 2002a, Section 2.1.30) in that only waste package misload is evaluated. The remaining issues identified (i.e., flooding and geometry reconfiguration) will be addressed elsewhere.

The intended use of the calculation is to provide information and inputs to the Preclosure Safety Analysis Department. Before using the results of this calculation, the reader is cautioned to verify that the assumptions made in this calculation regarding the waste stream, the loading process, and the staging of the spent nuclear fuel assemblies are applicable.

2. QUALITY ASSURANCE

The calculation is developed in accordance with the *Technical Work Plan for: Risk and Criticality Department* (BSC 2002a). Additionally, the calculation is subject to the requirement of the *Quality Assurance Requirements and Description* (QARD), as shown in Section 8 of the *Technical Work Plan for: Risk and Criticality Department* (BSC 2002a).

The calculation is governed by AP-3.12Q, *Design Calculations and Analyses*.

The control of the electronic management of information was evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of the Information*, as specified in the *Technical Work Plan for: Risk and Criticality Department* (BSC 2002a), Section 8).

3. USE OF SOFTWARE

The computer code System Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) V7.18 (BSC 2002b) is used to develop and quantify event trees in the calculation. SAPHIRE V7.18 is qualified software that was obtained from Software Configuration Management. It is appropriate for use in the present calculation, and is used only within its range of validation, in accordance with AP-SI.1Q, *Software Management*. SAPHIRE V7.18 (software tracking number 10325-7.18-00) was installed on a Dell Optiplex GX260 running Microsoft Windows 2000 Professional (central processing unit 152369). The inputs and output files are given in Attachment IV.

Matchcad 2001i Professional, a commercial off-the-shelf software program is used in the preparation of this calculation. This software program was installed on a Dell Optiplex GX260 running Microsoft Windows 2000 Professional (central processing unit 152369). A paper version of the Mathcad calculations performed in the calculation is given in Attachment III. This attachment lists all the inputs and formulas used, as well as the corresponding outputs, so that the work can be reproduced and checked independently without recourse to the originator of the calculation. Thus, the use of this software can be considered exempt from the requirements of AP-SI.1Q, *Software Management*.

4. INPUTS

4.1 DATA AND PARAMETERS

4.1.1 Number of Waste Packages

Table 1 lists the number of waste packages used in this calculation, which is from *Repository/PA IED Typical Waste Package Components Assembly (2)* (BSC 2003a, Table 11). The number of commercial waste packages is based on the repository legal limit of 70,000 MTHM (metric tons heavy metal). The number of expected waste packages are rounded up using the number of expected spent nuclear fuel assemblies for each waste package design (CRWMS M&O 2000, Table 10). The number of fuel assemblies for each waste package type is also listed in Table 1.

Table 1. Total Number of Waste Packages and Fuel Assemblies for 70,000 MTHM

Number	Waste Package Design	Number of Waste Packages[a]	Number of Fuel Assemblies
1	21-PWR Absorber Plate	4,299	90,262
2	21-PWR Control Rod	95	1,992
3	12-PWR Long	163	1,955
4	44-BWR (boiling water reactor) Absorber Plate	2,831	124,532
5	24-BWR Absorber Plate	84	2,013
Note: [a]The total number of waste packages has been rounded up to the nearest integer.			

4.1.2 Human Error Probabilities

Estimates of human error probabilities found in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report* (Swain and Guttman 1983) are used in this calculation. These probability estimates are accepted data. This is based on the fact that these data are suggested for use by the U.S. Nuclear Regulatory Commission (NRC) (NRC 1983, Sections 4.1 and 4.5.7) in order to evaluate the probability of occurrence of human errors, in the conduct of probabilistic risk assessments for nuclear power plants.

The human error probabilities used are summarized in Table 2. Notice that based on the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report* (Swain and Guttman 1983, pp. 2-18 and 2-19), the estimated human error probabilities are considered to follow a lognormal distribution. The nominal probability is represented by the median. The 5th percentile and the 95th percentile are calculated by dividing and multiplying, respectively, the median by an error factor, also shown in Table 2.

Table 2. Estimates of Human Error Probabilities

Item #	Description	Nominal Probability	Error Factor	Source: Swain & Guttmann 1983
1	Nominal human error probability for error of commission when no other human error can be found in the Tables	3.00×10^{-3}	5	HEP - page G-1 Error Factor - Item 7 of Table 20-20
2	Errors in selecting unannunciated displays – from similar-appearing displays that are part of well-delineated functional groups on a panel	1.00×10^{-3}	3	Item 3 of Table 20-9
3	Checker fails to detect error by others – Checking that involves active participation	1.00×10^{-2}	5	Item 4 of Table 20-22
4	Error of commission in reading and recording quantitative information Recording Task: Number of digits or "letters[a]" to be recorded > 3	1.00×10^{-3} (per symbol)	3	Item 9 of Table 20-10
5	Checker will fail to detect errors made by other Checking routine tasks, checker using written Material (checking written lists)	1.00×10^{-1}	5	Item 1 from Table 20-22

Note: [a]In this case, "letters" refer to those that convey no meaning. Groups of letters such as MOV do convey meaning, and the recording human error probability is considered to be negligible.

The parameters given above are appropriate for use in the calculation because they pertain to tasks performed in the nuclear industry, which adequately accounts for the highly-controlled conditions under which the loading activities are expected to be performed.

4.1.3 Fuel Assembly Movements and Misloads

The number of fuel assembly misloads due to selection, procedures, and other errors was determined in *Waste Package Misload Probability* (BSC 2001, Section 6). The total number of misloads was 327 out of a total of 1,199,000 fuel assembly movements (BSC 2001, Section 6).

4.2 CRITERIA

NRC requirements that pertain to the conduct of performance assessments are applicable to this evaluation. 10 CFR Part 63, in Section 63.102 (j), indicates that:

> "The features, events and processes considered in the performance assessment should represent a wide range of both beneficial and potentially adverse effects on performance […]. Those features, events, and processes expected to materially affect compliance with Sec. 113(b) or be potentially adverse to performance are included, while events (event classes or scenario classes) that are very unlikely (less than one chance in 10,000 over 10,000 years) can be excluded from the analysis."

The current inventory for the different waste package designs is listed in Table 1. Using the information from Table 1 and the above requirement would indicate that any feature, event, or process that has a probability of occurrence of less than the 10^{-4} divided by the individual waste package design over 10,000 years (i.e., potential critical misload) can be excluded from the performance assessment. Therefore, if the probability of occurrence for each waste package design is less than the probability listed in Table 3 can be excluded. Thus, for the purposes of this calculation any misload that is estimated to occur with a probability less than the individual probability listed in Table 3 will be excluded from further consideration.

Table 3. Probability Criterion for Exclusion from Further Calculation

Waste Package Design	Probability Criterion
21-PWR Absorber Plate	10^{-4}/4,299 = 2.33×10^{-8} per WP
21-PWR Control Rod	10^{-4}/95 = 1.05×10^{-6} per WP
12-PWR Long Absorber Plate	10^{-4}/163 = 6.14×10^{-7} per WP
44-BWR Absorber Plate	10^{-4}/2,831 = 3.53×10^{-8} per WP
24-BWR Thick Absorber Plate	10^{-4}/84 = 1.19×10^{-6} per WP

4.3 WASTE PACKAGE EXTRA INFORMATION

The parameters discussed below are for information only about the current design of the waste packages. The waste packages are designed to hold spent nuclear fuel from both PWRs and BWRs.

Repository Design Project, RDP/PA IED Typical Waste Package Components Assembly 1 of 9 (BSC 2003b, Table 1) provides information about the design dimensions for the different waste package, which are summarized in Table 4.

Table 4. Physical Dimensions of Commercial Waste Package Designs

No.	Waste Package Design	Outer Diameter In. (mm)	Outer Length in. (mm)
1	21-PWR Absorber Plate	64.7 (1,644)	203.3 (5,165)
2	21-PWR Control Rod	64.7 (1,644)	203.3 (5,165)
3	12-PWR Long	52.4 (1,330)	222.5 (5,651)
4	44-BWR	65.9 (1,674)	203.3 (5,165)
5	24-BWR	51.9 (1,318)	201 (5,105)

The internal components are discussed in *Yucca Mountain Science and Engineering Report* (DOE 2001, Section 3.2.3). The internal components for the different waste package designs are for information only and are listed in Table 5.

Table 5. Waste Package Design Component Materials

Component	Material
Dual-layer design (all waste packages): Inner structural shell Outer corrosion-resistant barrier	 Stainless Steel Type 316NG Alloy 22 (SB 575 N06022)
Waste package fill gas	Helium
Fuel Tubes for commercial spent nuclear fuel waste package basket design	Carbon steel (SA 516 Grade 70)
Neutron absorber interlocking plates for commercial spent nuclear fuel waste package (44-BWR, 24-BWR, and 21-PWR)	Neutronit A 978 (borated 316 stainless steel)
Interlocking plates for 21-PWR Control Rod design	Carbon steel (SA 516 Grade 70)
Structural guides for commercial spent nuclear fuel waste package basket design	Carbon steel (SA 516 Grade 70)
Canister guide for 5-DHLW/DOE spent nuclear fuel designs	Carbon steel (SA 516 Grade 70)
Thermal shunts for commercial spent nuclear fuel waste package basket design	Aluminum plate (SB-209 6061 T4)

This section is to provide information about the different waste package designs and parameters. As can be seen from the Tables 4 and 5, the 21-PWR Control Rod and 21-PWR Absorber Plate waste packages are identical except for the basket material. The 21-Control Rod waste package has its basket constructed of carbon steel, while the 21-PWR Absorber Plate waste package has its basket constructed of Neutronit (DOE 2001, Section 3.2.3).

5. ASSUMPTIONS

The assumptions below are used to calculate the probability that a spent nuclear fuel assembly is incorrectly misloaded into a waste package (e.g., a spent nuclear fuel assembly required to be loaded into a 21-PWR Control Rod waste package is incorrectly loaded into a 21-PWR Absorber Plate waste package).

5.1 It is assumed that no BWR spent nuclear fuel assembly will be loaded into a PWR waste package and conversely, no PWR spent nuclear fuel assembly will loaded into a BWR waste package. The rationale for this assumption is based on the size difference between the fuel assemblies. The PWR fuel assemblies are larger than the BWR fuel assemblies therefore, if a PWR fuel assembly is loaded into a BWR waste package it would be recognized and removed. The same goes for attempting to load a BWR fuel assembly into a PWR waste package.

5.2 It is assumed that no standard PWR fuel assembly (e.g., Babcock & Wilcox) will be misloaded into a 12-PWR Long Absorber Plate waste package. It is also assumed that no PWR fuel assembly required to be loaded into a 12-PWR Long Absorber Plate waste package (e.g., South Texas or Combustion Engineering System 80) will be loaded into a 21-PWR Absorber Plate or 21-PWR Control Rod waste package. The rationale for this assumption is based on the size differences between the waste packages and fuel assemblies. The South Texas or Combustion Engineering System 80 fuel assemblies are longer than the standard PWR fuel assembly (e.g., Babcok & Wilcox) and therefore, will be noticed if loaded into a 21-PWR Absorber Plate or 21-PWR Control Rod waste package since they will stick out the top. The loading of a standard PWR fuel assembly into a 12-PWR Long Absorber Plate waste package would also be noticed since the fuel assembly would be some distance from the top of the waste package.

5.3 It is assumed that the total number of each type of fuel assembly (i.e., BWR, standard PWR, and PWR long) is available for the operator to select. This assumption is used to calculate the overall average probability of waste package misload because it allows for the selection from the whole population of fuel assemblies. By allowing the selection from the whole population of fuel assemblies, this provides an average of the potential spikes and valleys that could occur over the waste package loading cycle. This assumption is required since there is no information about the potential waste stream. The rationale for this assumption is it provides the best estimate at this time for the probability of waste package misload. Once more information about the waste stream, PWR and BWR loading curves, and fuel assembly staging, a time line probability can be calculated. However, this time line probability will have approximately the same average probability that is calculated in this report.

5.4 It is assumed that only uncanistered fuel is loaded into the waste packages for this calculation. All canistered fuel that is shipped to the repository will be loaded into a waste package upon receipt. The rationale for this assumption is canistered fuel will be the last fuel products sent to the repository and since these fuel products are canistered the chance of misloading one is negligible.

5.5 It is assumed that the shipping records for the fuel assemblies are correct. The utilities document each fuel assembly and keep records about its initial status and life cycle through the reactor. This information is assumed to be correct for this calculation. The rationale for this assumption is based on the requirements of the utilities for proper bookkeeping since they are regulated by the NRC.

5.6 It is assumed that fuel assemblies requiring control rods will be inserted once the fuel assembly has been loaded into the 21-PWR Control Rod waste package. The rationale for this assumption is based on a loading scheme that has not been defined. The other potential loading scheme would have the control rods inserted into the fuel assembly upon receipt. This loading scheme, which has the control rods inserted into the fuel assemblies upon receipt, will be evaluated as a sensitivity calculation (see Section 6.3.3).

5.7 It is assumed that fuel assemblies loaded into the 21-PWR Control Rod waste package without having a control rod will be detected and removed. The operator will notice this misload every time and the fuel assembly will be corrected every time. The rationale for this assumption is based on the difference in appearance between fuel assemblies with control rods and without control rods. The waste package will be loaded with fuel assemblies with control rods except one or at most two fuel assemblies without control rods and this difference will easily be spotted and corrected.

5.8 It is assumed that the documentation used in the waste package loading process is correct. This assumption is used in order to define a starting point for the calculation. That is the loading operators have documentation that states which waste package is to be loaded and what fuel assemblies are to be loaded into the waste package. The rationale for this assumption is based on the process to generate the loading documentation is outside the scope of this calculation.

6. ANALYSIS

In order to calculate the probability of misloading a waste package (i.e., placing an incorrect fuel assembly(s) into the wrong waste package), the process of how fuel assemblies are received and loaded into the waste package must be understood. The process of receipt and loading fuel assemblies into waste packages is described in *Yucca Mountain Science and Engineering Report* (DOE 2001, Section 2.2).

The fuel assemblies are shipped to the repository in shipping casks via truck or train. The shipping casks (either train or truck) are moved into the Carrier Bay to have their tie-downs removed and up-righted. The shipping casks are then placed on a cask transfer cart and moved to the Assembly Transfer System for preparation and unloading. Once in the Assembly Transfer System, the shipping cask is removed from the transfer cart and placed into a cask preparation/purge pit where its outer lid is removed. The shipping cask is then moved to the Unloading Pool where the inner lid is removed and the cask is unloaded. The fuel assemblies are removed from the shipping cask and placed into basket staging racks. The shipping casks are then removed and sent back to be decontaminated and shipped offsite to receive more fuel assemblies.

The fuel assemblies (up to nine per basket) contained in the baskets are removed from the staging racks and transferred to the assembly handling cell. The baskets are placed into drying vessels where water will be removed. After the fuel assemblies are completely dry, they are loaded into the waste package. The waste package is then temporarily sealed and inerted prior to being moved to the Disposal Container Handling System for permanent closure.

For hot fuel assemblies (i.e., younger fuel assemblies), the Assembly Transfer System is designed to store these assemblies along with colder fuel assemblies (i.e., older fuel assemblies) for fuel assembly blending. The fuel assemblies are stored in the Fuel Blending Inventory Pools in order to meet thermal loading limits. The Fuel Blending Pools provide enough space to store sufficient inventory to provide flexibility in waste package loading.

Prior to the fuel assembly loading, the waste package must be selected from the Empty DC Preparation Area. The Line operator (Assembly Transfer System Line operator) requests an empty waste package from the DC operator (Empty Disposal Container Area operator), who places the appropriate waste package on a transfer cart and sends it to the Assembly Transfer System for loading.

This process as noted above is documented in *Yucca Mountain Science and Engineering Report* (DOE 2001, Section 2.2) for Site Recommendation. The process of unloading the shipping casks, staging of fuel assemblies, and loading the waste packages may change during License Application. However, for this calculation this is the waste package loading process that will be used.

To calculate the misload probability, an event tree will be used to express the process of selecting a waste package and fuel assembly. The event tree will identify the potential processes and pathways that can lead to a misload (i.e., placing a fuel assembly with an enrichment and/or burnup outside the waste package design).

6.1 MISLOAD EVENT TREE

The misload event tree identifies the processes that can lead to a waste package being misloaded with the incorrect fuel assembly. The event tree identifies the processes required to request a waste package, verify the waste package design, request a fuel assembly, and verify the correct fuel assembly is loaded. The control rods for the fuel assemblies that are loaded into the 21-PWR Control Rod waste package are inserted after the fuel assemblies have been loaded into the waste package (see Assumption 5.6). These processes are top events on the misload event tree along with the fraction of waste package designs and fraction of fuel assemblies for each waste package design. The misload event tree is created in SAPHIRE V7.18 in order to evaluate the probability of a misloaded waste package (i.e., a waste package loaded with a fuel assembly that has an enrichment and/or burnup outside its design). SAPHIRE V7.18 will also be used to propagate the parameter uncertainty of the human error probabilities for each sequence that is designated as being misloaded. For this calculation, a misloaded waste package is defined as a waste package that has a fuel assembly(s) loaded into it that is outside the waste package design. As an example, a fuel assembly designated for the 21-PWR Control Rod waste package that is incorrectly loaded into a 21-PWR Absorber Plate waste package represents a misloaded 21-PWR Absorber Plate waste package.

There are two misload event trees, one for the PWR waste packages and one for the BWR waste packages. The PWR event tree is shown in Figures I-1 through I-3 and the BWR event tree is shown in Figures II-1 through II-2. Figure I-1 illustrates the processes required to load a 21-PWR Absorber Plate waste package and identifies the processes where human errors can lead to a misloaded waste package.

The top events are common to both the PWR and BWR misload event trees. The PWR event tree, shown in Figure I-1, represents the nominal process where fuel assemblies that have characteristics requiring control rods are inserted into them after being loaded into the waste package.

6.1.1 Decision Event Tree Top Events

WP-USAGE - This top event represents the waste package that is expected to store the PWR or BWR commercial spent nuclear fuel. This top event is broken down into three branches for the PWR waste packages (i.e., 21-PWR Absorber Plate, 21-PWR Control Rod, and 12-PWR Long Absorber Plate) and two branches for the BWR waste packages (i.e., 44-BWR Absorber Plate and 24-BWR Absorber Plate). The probability used for this top event is based on the fraction of waste packages listed in Table 7.

WP-REQUEST - This top event represents the Assembly Transfer System Line operator (Line operator) requesting a waste package from the Disposal Container Area operator (DC operator). This top event is the first human action in the process of loading a waste package. The Line operator requests a waste package based on the procedures (no information at this time) and the fuel assemblies that are ready to be loaded. However, the Line operator requests the wrong waste package by making a slip/mistake (i.e., mentally requests the wrong waste package) after following the procedures. This type of human error is called an error of commission - request. The median human error probability for this top event is Item 1 from Table 2.

W-REQU-WP - This top event represents the waste package that was incorrectly requested by the Line operator. The probability used for this top event is based on the fraction of the remaining waste package types that can be incorrectly requested. The probability for this top event is based on the fraction of waste packages listed in Table 7.

WP-SELECTED - This top event represents the waste package that was selected by the DC operator. The failure of this top event is called an error of commission - selection. This human error represents the operator following all of the procedures (no information at this time) and for some reason makes a mistake in selecting the correct waste package because of a distraction or some other mechanism. The median human error probability used for this top event is Item 2 from Table 2.

WP-TYPE - This top event represents the waste package that was incorrectly selected by the DC operator. The probability used for this top event is based on the fraction of the remaining waste package types that can be incorrectly selected. The probability for this top event is based on the fraction of waste packages listed in Table 7. This top event is also used as a mechanism for keeping track of which waste package design is currently being loaded by identifying the waste package type on the event tree.

WP-VERIF - This top event represents the Line operator verifying if the waste package that was documented from following the procedures is the one that was selected and sent by the DC operator. The median human error probability used for the Line operator failing to verify that the waste package sent by the DC operator is the correct waste package is Item 3 from Table 2.

FA-SELECT - This top event represents the different potential failures of the Line operator during the loading process of a waste package. Both human errors (i.e., error of commission - request and selection) are developed under this top event.

The first operator action is the Line operator can make a slip/mistake during the process of requesting a fuel assembly to be loaded into the waste package. This slip/mistake causes the Line operator to request an incorrect fuel assembly (i.e., error of commission - request). The median human error probability for this top event is Item 1 from Table 2.

The second operator action modeled under this top event is the human error that can happen by the Line operator. This human error performed by the Line operator is an error of commission - selection of an incorrect fuel assembly. This human error has the Line operator selecting the wrong fuel assembly. The median human error probability used for this top event is Item 2 from Table 2.

FA-TYPE - This top event has been developed in order to handle two separate and different aspects of the fuel assembly loading and specification. This top event ultimately represents the fuel assembly type that is being loaded into the waste package except there are different probabilities that is being represented by this top event. Each of these representations will be discussed below.

> The first representation of this top event is based on the arrival of the fuel assemblies. The operator upon receipt of the fuel assemblies reviews the shipping records and records the fuel assembly information. The operator at this time can make a mistake on writing down the information about the fuel assembly. This is an error of commission in reading and recording information. This mistake is important for criticality issues if a highly reactive fuel assembly is mislabeled as having a lower reactivity. By making this error, the fuel assembly can be loaded into the wrong waste package. As an example, the PWR misload of concern here is the loading of a highly reactive fuel assembly into a 21-PWR Absorber Plate waste package. Under correct identification, this highly reactive fuel assembly would be designated as required for loading into a 21-PWR Control Rod waste package. The median human error probability used for this error on incorrectly recording the fuel assembly information is Item 4 from Table 2.
>
> The second representation of this top event deals with the fraction of wrong fuel assemblies that can be loaded into the waste package either due to an error of commission - request or error of commission - select. The probability for this representation takes on different values based on the type of human error from top event FA-SELECT. The different values are based on the fraction of the fuel assemblies listed in Table 8.

FA-VERIF - This top event represents two different checking processes based on the branching under top event, FA-TYPE. Each operator verification process will be discussed.

> The first operator verification is a check of the fuel assembly documentation prior to staging. The operator will check the written documentation to the shipping records as a back check prior to staging the fuel assembly. The median human error probability used

for this verification is Item 5 from Table 2. This is important because once the fuel assembly is staged with incorrect records there is no way of fixing this error and the fuel assembly will be loaded into the wrong waste package leading to a misloaded waste package.

The second operator verification is based on verifying the correct fuel assembly has been loaded into the correct waste package. This is the final check of the loaded waste package prior to sending it for final closure. The median human error probability for the independent checker failing to verify the correct fuel assembly is loaded into the correct waste package based on the matching of records to the loaded waste package is Item 3 from Table 2.

6.1.2 Input Data into SAPHIRE

The data listed in Section 4 requires some modifications prior to it being used as inputs into SAPHIRE for the quantification of the misload probability. The first modification is converting the median human error probability to its mean probability. The reason for this conversion is because SAPHIRE requires the mean probability for quantification and mean values are required to allow for the propagation of the human error uncertainty within SAPHIRE. Equation 1 is used to calculate the mean probability from the median probability and error factor (Evans et. al., p. 102).

$$\mu = 50^{th} \cdot \exp\left(\frac{1}{2} \cdot \sigma^{2}\right) \qquad \text{Eq. 1}$$

where:
μ = mean human error probability
50^{th} = median human error probability
$\sigma = \left(\frac{\ln(EF)}{1.645}\right)$ (Modarres 1993, p. 266)
EF = error factor

Equation 1 is used to determine the mean probabilities for the human errors that will be input into SAPHIRE for quantification of misloading a PWR and BWR waste package. The error factors are also input into SAPHIRE since the human error probabilities are lognormal distributions. The resultant mean values along with their error factors are listed in Table 6.

Table 6. Mean Human Error Probabilities Input into SAPHIRE

Item # (from Table 2)	Description	Nominal Probability	Error Factor
1	Error of commission - request	4.84×10^{-3}	5
2	Error of commission - selection	1.25×10^{-3}	3
3	Independent checker fails to detect wrong fuel assembly loaded into waste package	1.61×10^{-2}	5
4	Error of commission - reading and recording information[a]	1.25×10^{-3}	3
5	Independent checker fails to detect the incorrect information documented between what was written down versus fuel assembly shipping records	1.61×10^{-1}	5
[a]The information used for this human error probability is based on reading and recording information on a per symbol basis conveying no meaning (see Table 2 Item 4). The representing operator action is performing the same operation (i.e., transcribing fuel assembly shipping records) where most if not all of the information conveys meaning. Therefore, this human error probability as a whole (not trying to define or develop the number of symbols) is a good approximation for this operator action until a detailed human factor analysis can be performed.			

The different fractions of waste packages that can be selected based on the pathway through the misload event tree are listed in Table 7. This information is based on the fraction of the wrongly requested and/or selected waste package. These fractions are used as inputs into SAPHIRE for quantifying the misload probability. These fractions are based on the total population listed in Table 1. The fractions are calculated in the Mathcad spreadsheet listed in Attachment III. The fractions are based on the number of specific waste packages divided by the total number of waste packages for that particular scenario.

Table 7. Fraction of Waste Packages Input into SAPHIRE

Waste Package Combination	Fraction of Waste Packages (see Attachment III)
12-PWR Long Absorber Plate and 21-PWR Control Rod	
12-PWR Long Absorber Plate waste packages	6.32×10^{-1}
21-PWR Control Rod waste packages	3.68×10^{-1}
12-PWR Long Absorber Plate and 21-PWR Absorber Plate	
12-PWR Long Absorber Plate waste packages	3.70×10^{-2}
21-PWR Absorber Plate waste packages	9.63×10^{-1}
21-PWR Absorber Plate and 21-PWR Control Rod	
21-PWR Absorber Plate waste packages	9.78×10^{-1}
21-PWR Control Rod waste packages	2.20×10^{-2}
21-PWR Absorber Plate, 21-PWR Control Rod, 12-PWR Long Absorber Plate	
12-PWR Long Absorber Plate waste packages	3.60×10^{-2}
21-PWR Control Rod waste packages	2.10×10^{-2}
21-PWR Absorber Plate waste packages	9.43×10^{-1}
44-BWR Absorber Plate and 24-BWR Absorber Plate	
44-BWR Absorber Plate waste packages	9.71×10^{-1}
24-BWR Absorber Plate waste packages	2.90×10^{-1}

Table 8 lists the different fractions of fuel assemblies that can be selected based on the pathway through the misload event tree. These fractions are based on the fraction of the wrongly requested and/or selected fuel assembly. These fractions are used as inputs into SAPHIRE for the quantification of the misload probability. These fractions are based on the total population listed in Table 1. The fractions are calculated in the Mathcad spreadsheet listed in Attachment III. The fractions are based on the number of specific fuel assemblies divided by the total number of fuel assemblies for that particular scenario.

Table 8. Fraction of Fuel Assemblies Input into SAPHIRE

Fuel Assembly Combination	Fraction of Fuel Assemblies (see Attachment III)
12-PWR Long Absorber Plate and 21-PWR Control Rod	
12-PWR Long Absorber Plate fuel assemblies	4.95×10^{-1}
21-PWR Control Rod fuel assemblies	5.05×10^{-1}
12-PWR Long Absorber Plate and 21-PWR Absorber Plate	
12-PWR Long Absorber Plate fuel assemblies	2.10×10^{-2}
21-PWR Absorber Plate fuel assemblies	9.79×10^{-1}
21-PWR Absorber Plate and 21-PWR Control Rod	
21-PWR Absorber Plate fuel assemblies	9.78×10^{-1}
21-PWR Control Rod fuel assemblies	2.20×10^{-2}
21-PWR Absorber Plate, 21-PWR Control Rod, 12-PWR Long Absorber Plate	
12-PWR Long Absorber Plate fuel assemblies	2.10×10^{-2}
21-PWR Control Rod fuel assemblies	2.10×10^{-2}
21-PWR Absorber Plate fuel assemblies	9.58×10^{-1}
44-BWR and 24-BWR	
44-BWR Absorber Plate fuel assemblies	9.84×10^{-1}
24-BWR Absorber Plate fuel assemblies	1.60×10^{-2}

6.1.3 Misload Event Tree End States

The misload event tree for both PWR and BWR waste packages end in two different end states either "OK" or "POT-CRIT." The end states that end with "OK" represent those loaded waste packages that are within their design (i.e., loading a fuel assembly with the enrichment and/or burnup required for the waste package). This end state is classified as: 1) loading of the correct fuel assembly into the correct waste package, 2) loading a fuel assembly into an incorrect waste package but is within its design (i.e., fuel assembly for a 44-BWR waste package loaded into a 24-BWR waste package), or 3) the incorrect loading of a fuel assembly into a waste package that gets discovered and corrected. The other end state classified as "POT-CRIT" denotes those fuel assemblies that have been loaded into a waste package that exceeds its design (i.e., loading a fuel assembly with an enrichment and/or burnup outside the waste package design). Only the end states that end in "POT-CRIT" are quantified, since these end states are classified as a misloaded waste package.

All of the sequences identified as misloaded waste packages in the PWR misload event tree are discussed in Table 9. This table provides the information on the process of selecting a waste package, the process of selecting a fuel assembly, and the verification processes that leads to a misloaded waste package.

Table 9. PWR Waste Package Misload Event Tree Sequences

Sequences	Description
3C	This sequence starts with loading the 21-PWR Absorber Plate (ABS) waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a misloaded waste package; therefore, the end state is denoted as “POT-CRIT.”
10C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An error of commission (EOC) - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.
13C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC - select) the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR Control Rod (CR) waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
18C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC - select) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
20C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC - select) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
24C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
29C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
31C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”

All of the sequences identified as misloaded waste packages in the BWR misload event tree are discussed in Table 10. This table provides the information on the process of selecting a waste package, the process of selecting a fuel assembly, and the verification processes that leads to a misloaded waste package.

Table 10. BWR Waste Package Misload Sequences

Sequences	Description
3C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a critical misload; therefore, the end state is denoted as "POT-CRIT."
6C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly that requested was a fuel assembly outside of the design of the waste package and the independent checker fails to discover this mistake. Since the operator failed to discover the mistake, the misload was not recovered. This end state is denoted as "POT-CRIT."
10C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT.

6.2 CALCULATION OF MISLOAD PROBABILITY

The human error probabilities listed in Table 6 and the fraction of waste packages and fraction of fuel assemblies listed in Tables 7 and 8, respectively are input into SAPHIRE for quantification. All of the sequences that lead to end states defined as "POT-CRIT" for both the PWR and BWR event trees are generated in SAPHIRE. Only those sequences with the "POT-CRIT" end state are quantified in SAPHIRE by multiplying the top event probabilities together. Once the sequence quantification process is performed, all of the sequences are summed together to get the overall misload probability. The following subsections provide the information about the calculation of the PWR and BWR misload probability.

6.2.1 PWR Misload Probability Calculation

The sequences for the PWR event tree are generated to obtain all of the "POT-CRIT" end states. The probabilities for the "POT-CRIT" sequences are now ready to be evaluated. The top event probabilities that lead to the "POT-CRIT" end states are multiplied together to obtain the overall sequence probability. These sequence probabilities are then summed together to get the overall misload probability. However, prior to the summation of all of the sequences that end in "POT-CRIT" some of these sequences are modified. This modification is based on the pathway that leads to the "POT-CRIT" end state.

Those sequences that have the operator selecting the wrong fuel assembly due to an error of commission - selection (FA-SELECT), are modified prior to being summed up with the remaining sequences. These sequences are modified because the operator can make a selection error for any one of the fuel assemblies that are being loaded into the waste package. For these sequences, the probability is calculated by using the Binomial distribution. The Binomial distribution is used because each selection is independent from the previous selection (Modarres 1993, p. 24). The Binomial distribution is shown in Equation 2.

$$\Pr(x) = \binom{n}{x} p^{x} (1-p)^{n-x} \qquad \text{Eq. 2}$$

where:

$\binom{n}{x} = \dfrac{n!}{x!(n-x)!}$

p is the sequence probability based on operator selecting the wrong fuel assembly
n is the total number of fuel assemblies that specific waste package can hold
x is the number of misloaded fuel assemblies

To illustrate the use of Equation 2, for the 21-PWR Absorber Plate waste package, n is 21 (number of fuel assemblies), and p is 3.96×10^{-7} (sequence 10 probability), and x is one fuel assembly. The equation for one misloaded fuel assembly can be approximated by multiplying the probability, p, to the number of fuel assemblies, n. Therefore, the sequence probability is approximated as $(3.96\times10^{-7})*(21) = 8.32\times10^{-6}$ (see sequence 10C in Attachment I, Figure I-1). This process is applied to sequences 10C, 18C, 20C, 29C, and 31C on the event tree shown in Attachment I, Figure I-1 because each of these sequences are based the operator making an error of commission - selection. The remaining sequences are calculated by just multiplying their top event probabilities together (i.e., 3C, 13C, and 24C), because these are waste package misload sequences that are based on other types of operator failures.

To calculate the probability of two fuel assemblies being misloaded, Equation 2 is modified by setting x equal to two. This represents the probability of exactly two fuel assemblies being misloaded into a waste package. Using Equation 2 and the information from sequence 10C, the probability of misloading two fuel assemblies into a 21-PWR Absorber Plate waste package is 3.29×10^{-11}. From the results of using Equation 2 to calculate the probability of two incorrect fuel assemblies being loaded into a 21-PWR Absorber Plate waste package, this probability is orders of magnitude lower than a single fuel assembly being misloaded. As can be seen, this probability is approximately five orders of magnitude lower than the probability of misloading a single fuel assembly. The probability is also below the criteria discussed in Section 4.2 and therefore, the probability of misloading two fuel assemblies will no longer be evaluated for PWR waste packages.

After all of the sequence probabilities are calculated, an uncertainty analysis is performed within SAPHIRE. The uncertainty analysis is performed to propagate the variability of the operator failure probabilities to obtain an overall uncertainty result. The uncertainty analysis uses the

Monte Carlo sampling technique built into SAPHIRE. The uncertainty analysis used 10,000 samples and a seed value of 4321.

The mean probability for each of the individual sequences along with their uncertainty values (i.e., 5th, 50th, and 95th percentiles) from the PWR waste package misload calculation is shown in Table 11.

Table 11. Individual Sequence Probability Results of Misloaded PWR Waste Packages

Sequence	Mean (per waste package)	5th Percentile (per waste package)	50th Percentile (per waste package)	95th Percentile (per waste package)
3C	3.52×10^{-6}	2.72×10^{-7}	1.90×10^{-6}	1.19×10^{-5}
10C	8.35×10^{-6}	5.82×10^{-7}	4.20×10^{-6}	2.98×10^{-5}
13C	2.94×10^{-7}	1.07×10^{-9}	3.47×10^{-8}	1.04×10^{-6}
18C	1.24×10^{-8}	1.45×10^{-11}	7.62×10^{-10}	3.84×10^{-8}
20C	2.72×10^{-10}	3.19×10^{-13}	1.67×10^{-11}	8.42×10^{-10}
24C	1.10×10^{-6}	2.69×10^{-9}	1.01×10^{-7}	3.93×10^{-6}
29C	3.04×10^{-8}	4.82×10^{-11}	2.17×10^{-9}	9.85×10^{-8}
31C	6.66×10^{-10}	1.06×10^{-12}	4.75×10^{-11}	2.16×10^{-9}

The overall results from the PWR waste package misload calculation are shown in Table 12. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 11 that lead to a misloaded waste package. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 10C and so forth until all the sampled sequence probabilities are summed together. This process is performed 10,000 times. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are those listed in Table 12. The probability results listed in Table 12 are on a per PWR waste package basis.

Table 12. Overall Probability Results of Misloaded PWR Waste Package

Results	Probability (per waste package)
Mean	1.33×10^{-5}
5th	1.41×10^{-6}
50th	7.45×10^{-6}
95th	4.14×10^{-5}

The results for the PWR misload calculation are broken down into the probability of misloading a 21-PWR Absorber Plate waste package and a 21-PWR Control Rod waste package. The process of calculating the individual waste package type misload probability is based on the sequence pathway. Sequences 3C and 10C are classified as sequences that lead to a misloaded 21-PWR Absorber Plate waste package. Therefore, these sequences are summed together to represent the probability of misloading a 21-PWR Absorber Plate waste package. The remaining sequences represent the probability of misloading a 21-PWR Control Rod waste package.

The sequences, which represent the misload of a 21-PWR Control Rod waste package, are based on two different processes. The two processes are based on the sequence paths that lead to the misload end state of a 21-PWR Control Rod waste package. Sequences 18C, 20C, 29C, and 31C represent the probability of misloading the waste package based on a per fuel assembly basis. This is based on the fuel assembly that is being loaded into the waste package is the wrong fuel assembly due to an operator error (i.e., error of commission - selection) and at the end of loading each fuel assembly there is a final verification check. Because of this operator error (i.e., error of commission - selection), these sequences have the calculated probability multiplied by the number of spaces (i.e., twenty-one) available due to the fact that any one of the loaded fuel assemblies can be an incorrect fuel assembly.

Sequences 13C and 24C also represent the probability of misloading the 21-PWR Control Rod waste package; however, all of the loaded fuel assemblies are wrong. The reason all of the loaded fuel assemblies are wrong is based on the fact that the operator believes the waste package being loaded is a 21-PWR Absorber Plate. This belief stems from the fact that both the 21-PWR Absorber Plate and 21-PWR Control Rod waste packages are similar in design and size with the only difference being the basket material (see Section 4.3). Therefore, all of the fuel assemblies that are loaded into the 21-PWR Control Rod waste package based on these sequences are those required to be in a 21-PWR Absorber Plate waste package. However, for this analysis all of these sequences (i.e., 18C, 20C, 29C, 31C, 13C, and 24C) are summed together to represent the probability of misloading a 21-PWR Control Rod waste package.

An uncertainty analysis is performed on the sequences that represent a misloaded 21-PWR Absorber Plate and 21-PWR Control Rod waste package. The sequences are sampled 10,000 times in order to determine the mean probability per waste package type along with their uncertainty parameters. The results of the 10,000 Monte Carlo samples are shown in Table 13 for both waste package types. The 12-PWR Long waste package can not be misloaded because any fuel assembly that is not within its design will be identified and recovered (see Assumption 5.2).

Table 13. Individual PWR Waste Package Results

21-PWR Absorber Plate		**21-PWR Control Rod**	
Results	**Probability/WP**	**Results**	**Probability/WP**
Mean	1.18×10^{-5}	Mean	1.43×10^{-6}
5^{th}	1.36×10^{-6}	5^{th}	4.39×10^{-9}
50^{th}	7.05×10^{-6}	50^{th}	1.59×10^{-7}
95^{th}	3.68×10^{-5}	95^{th}	5.36×10^{-6}

Using the results in Table 13 and the total number of each waste package type, the probability of having at least one (i.e., one or more) waste package misloaded is calculated. The total number of 21-PWR Absorber Plate waste packages is 4,299 and the total number of 21-PWR Control Rod wastes package is 95 (see Table 1). The probability of at least one (i.e., one or more) misloaded waste package can be calculated using the Binomial distribution (Modarres 1993, p. 24). The Binomial distribution is:

$$\Pr(x) = \binom{n}{x} p^{x} (1-p)^{n-x} \qquad \text{Eq. 3}$$

where:

$\binom{n}{x} = \dfrac{n!}{x!(n-x)!}$

p is the probability of misloaded waste package

n is the number of waste packages (4,299 for 21-PWR Absorber Plate and 95 for 21-PWR Control Rod)

x is the number of misloaded waste packages

The mean probability per waste package listed in Table 13 is used to calculate the probability of at least one (i.e., one or more) waste package being misloaded (i.e., an incorrect fuel assembly(s) loaded into a waste package). Not only is the mean probability used in the calculation, a Latin Hypercube Sampling process is developed to propagate the uncertainty of each waste package misload probability. The principle of Latin Hypercube Sampling is provided in Modarres (1993, p. 244). The Latin Hypercube Sampling process is developed in Mathcad and shown in Attachment III. The uncertainty about the mean probability per waste package is fit to a lognormal distribution. A lognormal distribution is chosen to fit the mean probability because the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report* (Swain and Guttman 1983, pp. A-2 and A-4) states that the product of lognormal probabilities are also lognormal.

To obtain the lognormal parameter (i.e., error factor), the 95^{th} and 5^{th} probability are used. The error factor and subsequent lognormal standard deviation are calculated using the following equations. The error factor is calculated by using the fact that the 5^{th} percentile (respectively the 95^{th} percentile) is obtained by dividing (respectively multiplying) the median, 50^{th}, by the error factor (Swain and Guttman 1983, pp. 2-18 and 2-19).

$$5^{th} = \frac{50^{th}}{EF} \quad \text{and} \quad 95^{th} = EF \cdot 50^{th} \qquad \text{Eq. 4}$$

Equation 5 is developed by solving equation 4 for the error factor (EF).

$$EF = \sqrt{\frac{95^{th}\ percentile}{5^{th}\ percentile}} \qquad \text{Eq. 5}$$

The error factor is converted to the lognormal standard deviation that is used in Equation 3 to propagate the uncertainty of the misload probability. The lognormal standard deviation is calculated using Equation 6 (Modarres 1993, p. 266).

$$\sigma_{\ln} = \frac{\ln(EF)}{1.645} \qquad \text{Eq. 6}$$

The misload mean probability and lognormal uncertainty parameter per 21-PWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The results of allowing the uncertainty for the probability of misloading a 21-PWR Absorber Plate waste package to propagate through Equation 3 are listed in Table 14. Table 14 lists the mean probability, the 5th probability, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 14. Probability of At Least One 21-PWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	7.57×10^{-2}
5th	9.72×10^{-3}
50th	4.95×10^{-2}
95th	2.32×10^{-1}

The misload mean probability and lognormal uncertainty parameter per 21-PWR Control Rod waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The results of allowing the uncertainty for the probability of misloading a 21-PWR Control Rod waste package to propagate through Equation 3are listed in Table 15. Table 15 lists the mean probability, the 5th probability, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 15. Probability of At Least One 21-PWR Control Rod Waste Package Misloaded

Probabilities from LHS Process	
Mean	1.35×10^{-3}
5th	3.90×10^{-6}
50th	1.36×10^{-4}
95th	4.74×10^{-3}

6.2.2 BWR Misload Probability Calculation

The sequences for the BWR event tree are generated to obtain all of the "POT-CRIT" end states. The probabilities for the "POT-CRIT" sequences are now ready to be evaluated. The top event probabilities that lead to the "POT-CRIT" end states are multiplied together to obtain the overall sequence probability. These sequence probabilities are then summed together to get the overall misload probability. However, prior to the summation of all of the sequences that end in "POT-CRIT" some of these sequences are modified. This modification is based on the pathway that leads to the "POT-CRIT" end state.

Those sequences that have the operator selecting the wrong fuel assembly due to an error of commission - select (FA-SELECT), are modified prior to being summed up with the remaining sequences. These sequences are modified because the operator can make a selection error for any one of the fuel assemblies that are being loaded into the waste package. For these sequences, the probability is calculated by using the Binomial distribution.

To illustrate the use of Equation 2 (Binomial Distribution), for the 44-BWR Absorber Plate waste package, n is 44 (number of fuel assemblies), and p is 3.11×10^{-7} (sequence 10 probability), and x is one fuel assembly. The equation for one misloaded fuel assembly can be approximated by multiplying the probability, p, to the number of fuel assemblies, n. Therefore, the sequence probability is approximated as $(3.11\times10^{-7})*(44) = 1.37\times10^{-5}$ (see sequence 10C in Attachment II, Figure II-1). This process is applied to only sequence 10C on the event tree shown in Attachment II, Figure II-1 because this sequence deals with the operator making an error of commission - selection. The remaining sequences are calculated by just multiplying their top event probabilities together (i.e., 3C and 6C), because these are waste package misload sequences that are based on other types of operator failures.

To calculate the probability of two fuel assemblies being misloaded, Equation 2 is modified by setting x equal to two. This represents the probability of exactly two fuel assemblies being misloaded into a waste package. Using Equation 2 and the information from sequence 10C, the probability of misloading two fuel assemblies into a 44-BWR Absorber Plate waste package is 9.15×10^{-11}. As can be seen, this probability is approximately five orders of magnitude lower than the probability of misloading a single fuel assembly. The probability is also below the criteria discussed in Section 4.2 and therefore, the probability of misloading two fuel assemblies will no longer be evaluated for BWR waste packages.

The sequence probabilities that end in "POT-CRIT" for the BWR misload event tree are quantified in the same manner as the PWR misload event tree. Once the quantification process is complete, an uncertainty analysis is performed on the potential misload sequences using the Monte Carlo sampling technique built into SAPHIRE. The results of the individual sequences from the BWR waste package misload calculation are shown in Table 16 along with the uncertainty results. The uncertainty analysis is performed using 10,000 samples and a seed value of 4321.

Table 16. Individual Sequence Probability Results of Misloaded BWR Waste Packages

Sequence	Mean (per waste package)	5^{th} Percentile (per waste package)	50^{th} Percentile (per waste package)	95^{th} Percentile (per waste package)
3C	2.86×10^{-6}	2.13×10^{-7}	1.51×10^{-6}	1.02×10^{-5}
6C	1.17×10^{-6}	4.50×10^{-8}	4.48×10^{-7}	4.54×10^{-6}
10C	1.37×10^{-5}	9.56×10^{-7}	6.91×10^{-6}	4.90×10^{-5}

The overall results from the BWR waste package misload calculation are shown in Table 17. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 16 that lead to a misloaded waste package. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 6C, which is added to the sampled probability from sequence 10C. This process is performed 10,000 times. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are those listed in Table 17. The probability results listed in Table 17 are per 44-BWR Absorber Plate waste package basis, because only the 44-BWR

Absorber Plate waste package can be misloaded, since any BWR fuel assembly can be loaded into the 24-BWR Absorber Plate waste package and still be within its design.

Table 17. 44-BWR Absorber Plate Waste Package Overall Results

Results	Probability/WP
Mean	1.73×10^{-5}
5th	1.96×10^{-6}
50th	1.02×10^{-5}
95th	5.56×10^{-5}

Using the results in Table 17 and the total number of 44-BWR Absorber Plate waste packages, the probability of having at least one (i.e., one or more) 44-BWR Absorber Plate waste package misloaded can be calculated. The total number of 44-BWR Absorber Plate waste packages is 2,831. The probability of one or more misloaded waste package is calculated using Equation 3. The results are shown in Table 18.

The mean probability and lognormal uncertainty parameter (calculated using Equations 5 and 6) per 44-BWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times using Latin Hypercube Sampling. The results of allowing the uncertainty for the probability of misloading a 44-BWR waste package to propagate through Equation 3 are listed in Table 18. Table 18 lists the mean, 5^{th}, 50^{th}, and 95^{th} probability from the Latin Hypercube Sampling process (see Attachment III).

Table 18. Probability of At Least One 44-BWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	7.42×10^{-2}
5th	9.16×10^{-3}
50th	4.78×10^{-2}
95th	2.30×10^{-1}

6.3 SENSITIVITY CALCULATIONS

Multiple sensitivity calculations are performed to calculate the probability of misloading a PWR or a BWR waste package. The sensitivity calculations range from modification of the fuel assembly selection probability to process modifications. Each sensitivity calculation is discussed individually.

6.3.1 Modification to Operator Selection Error

This sensitivity calculation modifies the human error probability for selecting the wrong fuel assembly. The failure probability for selecting the wrong fuel assembly is determined from *Waste Package Misload Probability* (BSC 2001, Section 6). The number of fuel assembly misloads due to selection, procedures, and other errors was 327 out of a total of 1,199,000 fuel assembly movements (see Section 4.1.3). This misload information needs to be developed into a probability distribution in order for it to be input into SAPHIRE. This sensitivity calculation will use the same event tree shown in Figure I-1 through I-3 except the probability of selecting the wrong fuel assembly (top event FA-SELECT [error of commission - selection]) will use the probability calculated below.

The probability distribution for selecting the wrong fuel assembly is obtained by using the Bayesian approach. The Bayesian approach on determining parameters is discussed in detail in *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (NRC 1983, Section 5.5.2) and *Bayesian Reliability Analysis* (Martz and Waller 1991, Section 7.2). Bayesian estimation consists of updating the analyst's belief about the parameter (embodied in the prior distribution) with information from the observations (quantified in a likelihood function), to obtain a posterior distribution. This posterior distribution is what will be input into SAPHIRE in order to re-calculate the waste package misload probability for both PWR and BWR waste packages.

The reason for using the Bayesian approach versus the classical approach is that a probability distribution on the parameter is estimated. This probability distribution expresses the uncertainty about the parameter that can be reflected in the overall results.

In order to utilize the Bayesian approach, a prior distribution needs to be obtained. For this evaluation, a noninformative distribution is used as the prior distribution. The reason for using the noninformative prior distribution is due to how it minimizes its impact on the data. However, because of the large amount of data, limited impact from the prior distribution is expected on the posterior distribution.

The beta distribution is chosen to fit the data. The reason for selecting the beta distribution is based on its use when fitting demand failure data. The beta distribution is a natural fit to demand-related data that follows a binomial sampling process. The following equations are used to obtain the probability distribution using the Bayesian approach. Equation 7 shows the prior distribution used in the Bayesian analysis, which is the noninformative prior distribution based on the binomial distribution (Martz and Waller 1991, Section 7.2.2).

$$g(p) = [p(1-p)]^{-0.5} \qquad (0 \le \text{p} \le 1) \qquad \text{Eq. 7}$$

where:
g(p) is the noninformative prior distribution
p is probability parameter

Applying Bayesian analysis to the prior distribution, the posterior distribution along with the posterior mean probability is determined using Equations 8 and 9. Equation 8 is the posterior distribution that is input into SAPHIRE along with the mean misload probability calculated using Equation 9 (Martz and Waller 1991, Section 7.2.2).

$$g(p \mid x) = \frac{\Gamma(n+1)}{\Gamma(x+0.5)\Gamma(n-x+0.5)} p^{(x+0.5)-1}(1-p)^{(n-x+0.5)-1} \qquad (0 \le \text{p} \le 1) \qquad \text{Eq. 8}$$

where:
g(p|x) is the posterior distribution of p given x
p is the probability parameter
n is the total number of fuel assembly movements (1,199,000)
x is the total number of fuel assembly misloads (327)

The mean is

$$\mu = \frac{x + 0.5}{n + 1} \qquad \text{Eq. 9}$$

where:
μ is the mean probability
n is the total number of fuel assembly movements
x is the total number of fuel assembly misloads

Based on the equations above, the mean fuel assembly misload probability that is input into SAPHIRE is 2.73×10^{-4}. The beta probability distribution input into SAPHIRE for uncertainty analysis is Beta(x+0.5,n+1). This probability is input into the operator error that represents top event FA-SELECT (error of commission - selection).

The results of the individual sequences using the new operator error probability from the PWR waste package misload calculation are shown in Table 19. Table 19 shows the uncertainty results from the 10,000 Monte Carlo samples performed within SAPHIRE (seed value of 4321).

Table 19. Individual Sequence Probability Results of Misloaded PWR Waste Packages

Sequence	Mean (per waste package)	5th Percentile (per waste package)	50th Percentile (per waste package)	95th Percentile (per waste package)
3C	3.52×10^{-6}	2.72×10^{-7}	1.90×10^{-6}	1.20×10^{-5}
10C	1.83×10^{-6}	2.19×10^{-7}	1.14×10^{-6}	5.50×10^{-5}
13C	2.94×10^{-7}	1.07×10^{-9}	3.47×10^{-8}	1.04×10^{-6}
18C	1.64×10^{-9}	6.13×10^{-12}	2.01×10^{-10}	5.70×10^{-9}
20C	3.59×10^{-11}	1.34×10^{-13}	4.41×10^{-12}	1.25×10^{-10}
24C	1.10×10^{-6}	2.69×10^{-9}	1.01×10^{-7}	3.93×10^{-6}
29C	6.14×10^{-9}	1.62×10^{-11}	6.04×10^{-10}	2.23×10^{-8}
31C	1.35×10^{-10}	3.55×10^{-13}	1.33×10^{-11}	4.90×10^{-10}

The overall results for the PWR waste package misload calculation using the fuel assembly misload probability calculated above for error of commission - selection are shown in Table 20. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 19. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 10C and so forth until all of the sampled sequence probabilities are summed together. This process is performed 10,000 times. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are listed Table 20 and are on a per PWR waste package basis.

Table 20. Overall Probability Results of Misloaded PWR Waste Package Using New Probability for Fuel Assembly Selection

Results	Probability/WP
Mean	6.70×10^{-6}
5^{th}	1.02×10^{-6}
50^{th}	4.11×10^{-6}
95^{th}	1.90×10^{-5}

The results for the PWR misload calculation are broken down into the probability of misloading a 21-PWR Absorber Plate waste package and a 21-PWR Control Rod waste package. The process of calculating the individual waste package type misload probability is based on the sequence pathway. Sequences 3C and 10C are classified as sequences that lead to a misloaded 21-PWR Absorber Plate waste package. The remaining sequences represent the probability of misloading a 21-PWR Control Rod waste package. An uncertainty analysis is performed on the sequences that represent a misloaded 21-PWR Absorber Plate waste package and 21-PWR Control Rod waste package. The sequences are sampled 10,000 times in order to determine the mean probability per waste package type along with their uncertainty parameters. The results from the 10,000 Monte Carlo samples are listed in Table 21 for both waste package types. The 12-PWR Long waste package can not be misloaded because any fuel assembly that is not within its design will be recovered (see Assumption 5.2).

Table 21. Individual PWR Waste Package Results Using New Probability for Fuel Assembly Selection

21-PWR Absorber Plate		21-PWR Control Rod	
Results	Probability/WP	Results	Probability/WP
Mean	5.37×10^{-6}	Mean	1.35×10^{-6}
5^{th}	9.86×0^{-7}	5^{th}	4.78×10^{-9}
50^{th}	3.71×10^{-6}	50^{th}	1.57×10^{-7}
95^{th}	1.50×10^{-5}	95^{th}	4.95×10^{-6}

The mean probability and lognormal uncertainty parameter per 21-PWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Absorber Plate waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Absorber Plate waste package are listed in Table 22. Table 22 lists the mean, 5^{th}, 50^{th}, and 95^{th} probability from the Latin Hypercube Sampling process (see Attachment III).

Table 22. Probability of At Least One 21-PWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	3.15×10^{-2}
5th	5.91×10^{-3}
50th	2.28×10^{-2}
95th	8.62×10^{-2}

The mean probability and lognormal uncertainty parameter per 21-PWR Control Rod waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Control Rod waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Control Rod waste package are listed in Table 23. Table 23 lists the mean, 5th, 50th, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 23. Probability of At Least One 21-PWR Control Rod Waste Package Misloaded

Probabilities from LHS Process	
Mean	1.20×10^{-3}
5th	3.87×10^{-6}
50th	1.28×10^{-4}
95th	4.26×10^{-3}

The new operator failure probability for top event FA-SELECT (error of commission - selection) is input into the BWR event tree (see Figure II-1). The results of the individual sequences from the BWR waste package misload calculation are shown in Table 24. Table 24 shows the uncertainty results from the 10,000 Monte Carlo samples performed within SAPHIRE (seed value of 4321).

Table 24. Individual Sequence Probability Results of Misloaded BWR Waste Packages

Sequence	**Mean (per waste package)**	**5th Percentile (per waste package)**	**50th Percentile (per waste package)**	**95th Percentile (per waste package)**
3C	2.86×10^{-6}	2.13×10^{-7}	1.51×10^{-6}	1.02×10^{-5}
6C	1.17×10^{-6}	4.50×10^{-8}	4.48×10^{-7}	4.54×10^{-6}
10C	3.01×10^{-6}	3.59×10^{-7}	1.87×10^{-6}	9.04×10^{-6}

The overall results for the BWR waste package misload calculation using the fuel assembly misload probability calculated above for error of commission - selection are shown in Table 25. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 24. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 6C, which is added to the sampled probability from sequence 10C. This process is performed 10,000 times. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are listed Table 25 and are per 44-BWR Absorber Plate waste package basis, because only the 44-BWR Absorber Plate waste package can be misloaded, since any BWR fuel assembly can be loaded into the 24-BWR Absorber Plate waste package and still be within its design.

Table 25. Overall Probability Results of Misloaded 44-BWR Absorber Plate Waste Package Using New Probability for Fuel Assembly Selection

Results	Probability/WP
Mean	7.03×10^{-6}
5th	1.38×10^{-6}
50th	5.00×10^{-6}
95th	1.88×10^{-5}

The mean probability and lognormal uncertainty parameter per 44-BWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 44-BWR Absorber Plate waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 44-BWR Absorber Plate waste package are listed in Table 26. Table 26 lists the mean, 5th, 50th, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 26. Probability of At Least One 44-BWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	2.66×10^{-2}
5th	5.38×10^{-3}
50th	1.97×10^{-2}
95th	7.09×10^{-2}

6.3.2 All PWR Waste Packages Contain Absorber Plate

This sensitivity calculation looks at the possibility of a misload if all PWR waste packages contain absorber plates. This would require design modifications to the 21-PWR Control Rod waste package. These waste packages currently do not contain any criticality control built into their design. The pretense for using these waste packages is that the fuel assemblies themselves would have control rods inserted for criticality control and thereby require no criticality control designed into the waste package. This sensitivity calculation is performed to determine if there could be a misload of a PWR waste package if all the PWR waste packages contained absorber plates.

The same event trees shown in Figure I-1 through I-3 are used for this calculation. The difference is fewer sequences will lead to a misload. The sequences that lead to a misload (i.e., those waste packages that have fuel assemblies with an enrichment and/or burnup outside its design) are listed and discussed in Table 27. The sequence definitions are based on the same loading process of adding control rods to the fuel assemblies requiring extra control once they are loaded into the waste package.

Table 27. PWR Waste Package Misload Event Tree Sequences

Sequences	Description
3C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a critical misload; therefore, the end state is denoted as "POT-CRIT."
10C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT.
20C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT."
31C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT."

Each of these sequences, which lead to a misload, is evaluated on the premise that all of the waste packages have absorber plates. The same operator actions and probabilities for the nominal calculation are used for this sensitivity calculation.

After all of the sequence probabilities are calculated, an uncertainty analysis is performed within SAPHIRE. The uncertainty analysis is performed to propagate the variability of the operator failure probabilities to obtain an overall uncertainty result. The uncertainty analysis uses the Monte Carlo sampling technique built into SAPHIRE. The uncertainty analysis used 10,000 samples and a seed value of 4321.

The mean probability for each of the individual sequences along with their uncertainty values (i.e., 5^{th}, 50^{th}, and 95^{th} percentiles) from the PWR waste package misload calculation is shown in Table 28.

Table 28. Individual Sequence Probability Results of Misloaded PWR Waste Packages

Sequence	Mean (per waste package)	5^{th} Percentile (per waste package)	50^{th} Percentile (per waste package)	95^{th} Percentile (per waste package)
3C	3.52×10^{-6}	2.72×10^{-7}	1.90×10^{-6}	1.20×10^{-5}
10C	8.35×10^{-6}	5.82×10^{-7}	4.20×10^{-6}	2.98×10^{-5}
20C	2.72×10^{-10}	3.19×10^{-13}	1.67×10^{-11}	8.42×10^{-10}
31C	6.66×10^{-10}	1.06×10^{-12}	4.75×10^{-11}	2.16×10^{-9}

The overall results for the PWR waste package misload calculation are shown in Table 29. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 28. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 10C and so forth until all of the sampled sequence probabilities are summed together. This process is performed for the 10,000 samples. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are listed Table 29 and are on a per PWR waste package basis.

Table 29. Overall Probability Results of Misloaded PWR Waste Package

Results	Probability/WP
Mean	1.18×10^{-5}
5^{th}	1.36×10^{-6}
50^{th}	7.05×10^{-6}
95^{th}	3.68×10^{-5}

The results for the PWR misload calculation are broken down into the probability of misloading a 21-PWR Absorber Plate waste package and a 21-PWR Control Rod waste package. The process of calculating the individual waste package type misload probability is based on the sequence pathway. Sequences 3C and 10C are classified as sequences that lead to a misloaded 21-PWR Absorber Plate waste package. The remaining sequences represent the probability of misloading a 21-PWR Control Rod waste package. An uncertainty analysis is performed on the sequences that represent a misloaded 21-PWR Absorber Plate waste package and 21-PWR Control Rod waste package. The sequences are sampled 10,000 times in order to determine the mean probability per waste package type along with their uncertainty parameters. The results from the 10,000 Monte Carlo samples are listed in Table 30 for both waste package types. The 12-PWR Long waste package can not be misloaded because any fuel assembly that is not within its design will be recovered (see Assumption 5.2).

Table 30. Individual PWR Waste Package Results

21-PWR Absorber Plate		21-PWR Control Rod	
Results	Probability/WP	Results	Probability/WP
Mean	1.18×10^{-5}	Mean	9.39×10^{-10}
5th	1.36×10^{-6}	5th	1.70×10^{-12}
50th	7.05×10^{-6}	50th	7.22×10^{-11}
95th	3.68×10^{-5}	95th	3.12×10^{-9}

The mean probability and lognormal uncertainty parameter per 21-PWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Absorber Plate waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Absorber Plate waste package are listed in Table 31. Table 31 lists the mean, 5th, 50th, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 31. Probability of At Least One 21-PWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	7.57×10^{-2}
5th	9.72×10^{-3}
50th	4.95×10^{-2}
95th	2.32×10^{-1}

The mean probability and lognormal uncertainty parameter per 21-PWR Control Rod waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Control Rod waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Control Rod waste package are listed in Table 32. Table 32 lists the mean, 5th, 50th, and 95th probability from the Latin Hypercube Sampling process (see Attachment III).

Table 32. Probability of At Least One 21-PWR Control Rod Waste Package Misloaded

Probabilities from LHS Process	
Mean	1.21×10^{-6}
5th	2.09×10^{-9}
50th	8.93×10^{-8}
95th	3.83×10^{-6}

6.3.3 Different PWR Waste Package Loading Scheme

This sensitivity calculation looks at the process of loading control rods into all fuel assemblies requiring control rods for criticality control upon their receipt. The only difference between this sensitivity calculation and the nominal calculation is the fact that the control rods are inserted into fuel assemblies requiring extra criticality control upon their receipt.

The same event tree structure shown in Figures I-1 through I-3 is used for this sensitivity calculation. The only difference is the sequences that lead to a misload (i.e., those waste packages that have fuel assemblies with an enrichment and/or burnup outside its design). The sequences that lead to a misload for this sensitivity calculation are listed in Table 33. These sequences are derived based on the same philosophy used for the nominal case except the fuel assemblies already contain control rods. Therefore, there are fewer misload opportunities.

This loading scheme is looked at to see if there would be any difference between placing the control rods into fuel assemblies upon receipt or after loading them into the waste package. The control rods are loaded into the fuel assemblies that are identified as requiring control rods for criticality control based on the documented records.

Table 33. PWR Waste Package Misload Event Tree Sequences

Sequences	Description
3C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a critical misload; therefore, the end state is denoted as “POT-CRIT.”
13C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
18C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
24C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
29C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”

Each of these sequences, which lead to a misload, is evaluated on the premise that control rods were inserted into the fuel assemblies upon arrival. The same operator actions and probabilities for the nominal calculation are used for this sensitivity calculation.

After all of the sequence probabilities are calculated, an uncertainty analysis is performed within SAPHIRE. The uncertainty analysis is performed to propagate the variability of the operator failure probabilities to obtain the overall uncertainty results. The uncertainty analysis uses the Monte Carlo sampling technique built into SAPHIRE. The uncertainty analysis used 10,000 samples and a seed value of 4321.

The event tree sequences discussed above are evaluated using the same inputs that are used for the nominal calculation. The mean probability for each of the individual sequences along with their uncertainty values (i.e., 5th, 50th, and 95th percentiles) from the PWR waste package misload calculation is shown in Table 34.

Table 34. Individual Sequence Probability Results of Misloaded PWR Waste Packages

Sequence	Mean (per waste package)	5th Percentile (per waste package)	50th Percentile (per waste package)	95th Percentile (per waste package)
3C	3.52×10^{-6}	2.72×10^{-7}	1.90×10^{-6}	1.20×10^{-5}
13C	2.94×10^{-7}	1.07×10^{-9}	3.47×10^{-8}	1.04×10^{-6}
18C	1.24×10^{-8}	1.45×10^{-11}	7.62×10^{-10}	3.84×10^{-8}
24C	1.10×10^{-6}	2.69×10^{-9}	1.01×10^{-7}	3.93×10^{-6}
29C	3.04×10^{-8}	4.82×10^{-11}	2.17×10^{-9}	9.85×10^{-8}

The overall results for the PWR waste package misload calculation based on this sensitivity are shown in Table 35. The overall results are based on performing an uncertainty analysis on the individual sequences listed in Table 34. The uncertainty analysis is basically the summation of the individual sequences using a Monte Carlo sampling process. The process samples a probability from sequence 3C and adds it to the sampled probability from sequence 13C and so forth until all of the sampled sequence probabilities are summed together. This process is performed 10,000 times. The 10,000 samples are then used to determine the mean probability and the uncertainty parameters. These results are listed Table 35 and are on a per PWR waste package basis.

Table 35. PWR Waste Package Misload Overall Results Using Different Loading Scheme

Results	Probability/WP
Mean	5.08×10^{-6}
5th	4.18×10^{-7}
50th	2.56×10^{-6}
95th	1.61×10^{-5}

The results for the PWR misload calculation are broken down into the probability of misloading a 21-PWR Absorber Plate waste package and a 21-PWR Control Rod waste package. The process of calculating the individual waste package type misload probability is based on the sequence pathway. Sequence 3C is classified as the sequence that leads to a misloaded 21-PWR Absorber Plate waste package. The remaining sequences represent the probability of misloading a 21-PWR Control Rod waste package. An uncertainty analysis is performed on the sequences that represent a misloaded 21-PWR Absorber Plate waste package and 21-PWR Control Rod waste package. The sequences are sampled 10,000 times in order to determine the mean probability per waste package type along with their uncertainty parameters. The results from the 10,000 Monte Carlo samples are listed in Table 36 for both waste package types. The 12-PWR Long waste package can not be misloaded because any fuel assembly that is not within its design will be recovered (see Assumption 5.2).

Table 36. Individual PWR Waste Package Results Using Different Loading Scheme

21-PWR Absorber Plate		21-PWR Control Rod	
Results	**Probability/WP**	**Results**	**Probability/WP**
Mean	3.52×10^{-6}	Mean	1.43×10^{-6}
5^{th}	2.72×10^{-7}	5^{th}	4.93×10^{-9}
50^{th}	1.90×10^{-6}	50^{th}	1.59×10^{-7}
95^{th}	1.20×10^{-5}	95^{th}	5.35×10^{-6}

The mean probability and lognormal uncertainty parameter per 21-PWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Absorber Plate waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Absorber Plate waste package are listed in Table 37. Table 37 lists the mean, 5^{th}, 50^{th}, and 95^{th} probability from the Latin Hypercube Sampling process (see Attachment III).

Table 37. Probability of At Least One 21-PWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	2.79×10^{-2}
5^{th}	2.28×10^{-3}
50^{th}	1.50×10^{-2}
95^{th}	9.57×10^{-2}

The mean probability and lognormal uncertainty parameter per 21-PWR Control Rod waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Control Rod waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Control Rod waste package are listed in Table 38. Table 38 lists the mean, 5^{th}, 50^{th}, and 95^{th} probability from the Latin Hypercube Sampling process (see Attachment III).

Table 38. Probability of At Least One 21-PWR Control Rod Waste Package Misloaded

Probabilities from LHS Process	
Mean	1.26×10^{-3}
5th	4.13×10^{-6}
50th	1.36×10^{-4}
95th	4.47×10^{-3}

6.3.4 All PWR Waste Packages Contain Absorber Plate and Control Rods Pre-Inserted

This final sensitivity calculation is similar to the calculation performed in Section 6.3.3. The only difference is all 21-PWR waste packages contain absorber plates. The same event tree structure as used for all of the calculations is used for this sensitivity calculation.

By stepping through the process of selecting and loading a waste package, only one sequence leads to a misload (i.e., those waste packages that have fuel assemblies with an enrichment and/or burnup outside its design). All of the previously analyzed sequences disappear because all 21-PWR waste packages contain some sort of criticality control built in and the fuel assemblies already contain control rods. Since any fuel assembly requiring a control rod will already have one inserted and based on the assumption that a fuel assembly without a control rod would be recovered (see Assumption 5.7), all sequences that lead to a misload except one are eliminated.

The only sequence remaining is sequence 3C. This sequence is based on the operator documenting incorrect information about the fuel assembly. The operator documents a fuel assembly requiring a control rod as having a lower reactivity and therefore does not have a control rod inserted. This sequence leads to a misload of only a 21-PWR Absorber Plate waste package with a probability of 3.87×10^{-6}. The sequence uncertainty was propagated in SAPHIRE using 10,000 samples with a seed number of 4321 to obtain the results listed in Table 39.

Table 39. PWR Waste Package Overall Results Using Different Loading Scheme and All Waste Packages Contain Absorber Plates

Results	Probability/WP
Mean	3.52×10^{-6}
5th	2.72×10^{-7}
50th	1.90×10^{-6}
95th	1.20×10^{-5}

The mean probability and lognormal uncertainty parameter per 21-PWR Absorber Plate waste package are input into Equation 3 (Binomial distribution), which is sampled 10,000 times. The uncertainty analysis calculated the probability of at least one 21-PWR Absorber Plate waste package being misloaded. The results from the propagation of the misload probability uncertainty for the 21-PWR Absorber Plate waste package are listed in Table 40. Table 40 lists the mean, 5^{th}, 50^{th}, and 95^{th} probability from the Latin Hypercube Sampling process (see Attachment III).

Table 40. Probability of At Least One 21-PWR Absorber Plate Waste Package Misloaded

Probabilities from LHS Process	
Mean	2.79×10^{-2}
5th	2.28×10^{-3}
50th	1.50×10^{-2}
95th	9.57×10^{-2}

7. CONCLUSIONS

The probability of misloading a waste package with fuel assembly(s) outside their design (e.g., a spent nuclear fuel assembly required to be loaded into a 21-PWR Control Rod waste package is incorrectly loaded into a 21-PWR Absorber Plate waste package) is calculated. This misload calculation is based on the assumption that during the loading process the whole population of waste packages and fuel assemblies is available for selection. The calculation also made assumptions on how the waste packages and fuel assemblies are received, selected, and loaded since no formal procedures are available at the time of this calculation. This misload calculation is performed for both the PWR waste packages and the BWR waste packages.

The misload calculation first showed that the probability of misloading two or more fuel assemblies into a waste package due to operator selection error can be eliminated based on the final probability being below the criterion discussed in Section 4.2. Therefore, only the misloading of a single fuel assembly outside the design of a waste package is evaluated in the event tree process.

The misload calculation secondly showed that the probability of misloading at least one 21-PWR Absorber Plate, 21-PWR Control Rod, and 44-BWR Absorber Plate waste packages is above the criteria discussed in Section 4.2. The misload calculation showed that both the 12-PWR Long and 24-BWR Absorber Plate waste packages can not be misloaded. The 24-BWR Absorber Plate waste package can not be misloaded because any BWR fuel assembly can be loaded into it and still be within its design. As for the 12-PWR Long waste package, all fuel assemblies outside its design will be discovered and recovered; therefore, no potential of being misloaded (see Assumption 5.2).

The results of misloading the different waste package types (e.g., a fuel assembly required to be loaded into a 21-PWR Control Rod waste package is incorrectly loaded into a 21-PWR Absorber Plate waste package) are listed in Table 41. The results listed in Table 41 are the mean probability on a per waste package type basis.

Table 41. Final Individual Waste Package Results

Waste Package Type	Mean Probability/WP
21-PWR Absorber Plate	1.18×10^{-5}
21-PWR Control Rod	1.43×10^{-6}
12-PWR Long	0.0
44-BWR Absorber Plate	1.73×10^{-5}
24-BWR Absorber Plate	0.0

Multiple sensitivity calculations were performed to calculate the probability of misloading a waste package with a fuel assembly outside its design. The different sensitivity calculations were 1) different operator failure probability for fuel assembly selection, 2) adjusting the 21-PWR Control Rod waste package design, and 3) varying the loading scheme (no procedures on how the waste packages are to be selected and loaded at this time). These sensitivity calculations provided a range of misload probabilities that are the same as the nominal probability all the way to zero probability.

From the different sensitivity calculations, the lowest misload probability is based on the assumption that all fuel assemblies requiring control rods have them inserted upon arrival and all the 21-PWR waste packages contain absorber plates. This sensitivity showed that no 21-PWR waste package could be misloaded based on operator error loading the wrong fuel assembly. The only sequence for this scenario that has a probability of misload is based on the operator error of mislabeling the fuel assembly upon receipt and loading this fuel assembly into a 21-PWR Absorber Plate waste package.

The results from the other sensitivity calculations had misload probabilities that are similar or lower than the results from the nominal calculation. Therefore, the nominal case can be viewed as the upper bound misload probability.

The results from the misload calculation are reasonable based on the inputs. The misload calculation is directly driven by the human error probabilities used for the top events. The human error probabilities are appropriate for this misload calculation, since there are no loading procedures available at this time. Once this information becomes available, a detailed human factors analysis can be performed in order to develop specific human error probabilities instead of using representative human error probabilities.

The results are suitable for their intended use. The results provide a representative misload probability based on the current available information.

This calculation contains four attachments:

- Attachment I contains the PWR misload event tree graphics along with information about the different PWR misload end states.

- Attachment II contains the BWR misload event tree graphics along with information about the different BWR misload end states.

- Attachment III contains a paper copy of the Mathcad calculations performed.

- Attachment IV is a CD-ROM containing two files developed for the SAPHIRE evaluations. One file contains the SAPHIRE binary data files for the PWR misload evaluation and the other file contains the SAPHIRE data files for the BWR misload evaluation. The two files are in a compressed format, which contain the SAPHIRE binary data files. Extracting the compressed file to a local directory using Winzip 8.1 will restore the SAPHIRE files to a useable form. The compressed files are called pwr-misload-saph.zip and bwr-misload-saph.zip. The pwr-misload-saph.zip file is 94,328 bytes large, and the date and time of last update are 09/15/2003, 03:52 pm. The bwr-misload-saph.zip file is 49,173 bytes large, and the date and time of last update are 09/15/2003, 03:53 pm.

  The CD-ROM also contains the Mathcad file used in the calculation called misload-all.mcd, which is 165,923 bytes large and the date and time of last update are 9/11/2003, 04:36 pm.

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

BSC (Bechtel SAIC Company) 2001. *Waste Package Misload Probability*. CAL-WHS-MD-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20011212.0186.

BSC 2002a. *Technical Work Plan for: Risk and Criticality Department.* TWP-EBS-MD-000014. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021209.0011.

BSC 2002b. *Software Code: SAPHIRE*. V7.18. PC. 10325-7.18-00.

BSC 2003a. *Repository Design Project, RDP/PA IED Typical Waste Package Components Assembly (2).* 800-IED-WIS0-00202-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20030702.0002.

BSC 2003b. *Repository Design Project, RDP/PA IED Typical Waste Package Components Assembly 1 of 9.* 800-IED-WIS0-00201-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20030702.0001.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. *Frequency of SNF Misload for Uncanistered Fuel Waste Package.* BBA000000-01717-0210-00011 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980806.0604.

CRWMS M&O 2000. *Waste Packages and Source Terms for the Commercial 1999 Design Basis Waste Streams.* CAL-MGR-MD-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000214.0479.

DOE 2001. *Yucca Mountain Science and Engineering Report*. DOE/RW-0539. [Washington, D.C.]: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010524.0272.

Evans, M.; Hastings, N.; and Peacock, B. 1993. *Statistical Distributions.* 2nd Edition. New York, New York: John Wiley & Sons. TIC: 246114.

Macheret, P. 2001. *Waste Package Design Sensitivity Report.* TDR-EBS-MD-000008 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010313.0506.

Martz, H.F. and Waller, R.A. 1991. *Bayesian Reliability Analysis.* Malabar, Florida: Krieger Publishing Company. TIC: 252996.

Modarres, M. 1993. *What Every Engineer Should Know About Reliability and Risk Analysis.* New York, New York: Marcel Dekker. TIC: 238168.

NRC 1983. *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*. NUREG/CR-2300. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 205084.

Swain, A.D. and Guttmann, H.E. 1983. *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report*. NUREG/CR-1278. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 246563.

8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Readily available.

AP-3.12Q, Rev. 2, ICN 1. *Design Calculations and Analyses.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030827.0013.

AP-SI.1Q, Rev. 5, ICN 2. *Software Management.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030902.0003

AP-SV.1Q, Rev. 1, ICN 0. *Control of the Electronic Management of Information.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030929.0004.

ATTACHMENT I

PWR MISLOAD EVENT TREES

Table I-1. PWR Waste Package Misload Event Tree Sequences

Sequences	Description
1C	This sequence starts with loading the 21-PWR Absorber Plate (21-PWR ABS) waste package. The correct waste package was requested and selected. The fuel assembly based on the design criteria of the waste package was selected and placed into the waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as "OK."
2C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier discovers the discrepancy and makes the correct change. Because, the independent verifier discovered and corrected the documentation of the fuel assembly, the correct fuel assembly is loaded into the correct waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as "OK."
3C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a critical misload; therefore, the end state is denoted as "POT-CRIT."
4C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An error of commission (EOC) - request was committed and the wrong fuel assembly was requested. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as "OK."
5C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a fuel assembly requiring a control rod to be inserted and therefore, the independent checker discovered the mistake. Based on assumption 5.12, all control rod fuel assemblies loaded into an absorber plate waste package will be recovered; therefore, this end state is denoted as "OK."
6C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as "OK."
7C & 8C	These sequences start with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - selection was committed; however, the correct fuel assembly was selected (for bookkeeping purposes these two sequences are in the event tree). The correct fuel assembly for the waste package was selected and the independent checker verified the fuel assembly. Since the correct fuel assembly was selected, the end state is denoted as "OK."
9C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package, but the independent checker discovered the mistake. Since the operator mistake was recovered, the end state is denoted as "OK."
10C	This sequence starts with loading the 21-PWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT.
11C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as "OK."

Table I-1. PWR Waste Package Misload Event Tree Sequences (continued)

Sequence	Description
12C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR Control Rod (21-PWR CR) waste package, which has no criticality control mechanism. A final verification detects the wrong waste package was loaded. Since the mistake was discovered, the end state is denoted as “OK.”
13C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
14C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
15C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a fuel assembly requiring a control rod to be inserted and therefore, the independent checker discovered the mistake. Since the operator mistake was recovered, the end state is denoted as “OK.”
16C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
17C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package, however, the independent checker verified this mistake and it was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
18C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
19C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker discovers the mistake. Since the operator mistake was recovered, the end state is denoted as “OK.”

Table I-1. PWR Waste Package Misload Event Tree Sequences (continued)

Sequence	Description
20C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
21C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (South Texas). During the verification process, the operator discovers this mistake and the loading process is stopped. Since the operator mistake was recovered, the end state is denoted as “OK.”
22C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as “OK.”
23C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification detects the wrong waste package was loaded. Since the mistake was discovered, the end state is denoted as “OK.”
24C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. The loading process continues with the loading of the intended fuel assembly. The intended fuel assembly is loaded into the 21-PWR CR waste package, which has no criticality control mechanism. A final verification fails to detect the fuel assemblies were loaded into the wrong waste package. Since the mistake was not discovered, the end state is denoted as “POT-CRIT.”
25C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
26C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a fuel assembly requiring a control rod to be inserted and therefore, the independent checker discovered the mistake. Since the operator mistake was recovered, the end state is denoted as “OK.”
27C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
28C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package, however, the independent checker verified this mistake and it was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”

Table I-1. PWR Waste Package Misload Event Tree Sequences (continued)

Sequence	Description
29C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR ABS waste package was selected. This is an incorrect fuel assembly to be loaded into the 21-PWR CR waste package and the independent checker failed to discover this mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
30C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker discovers the mistake. Since the operator mistake was recovered, the end state is denoted as “OK.”
31C	This sequence starts with loading the 21-PWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (21-PWR CR). During the verification process, the operator fails to discover this mistake. An EOC - selection was committed and the fuel assembly for a 21-PWR CR waste package was selected. This is the correct fuel assembly to be loaded into the 21-PWR CR waste package, however, this is not the intended fuel assembly and the control rod is not inserted. The independent checker fails to discover the mistake. Since the operator mistake was not recovered, the end state is denoted as “POT-CRIT.”
32C through 37C	These sequences are the same as those discussed above except their probabilities would be smaller; therefore, they are not expanded for evaluation.
38C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. The fuel assembly based on the design criteria of the waste package is selected and placed into the waste package. This sequence represents the correct loading of a waste package; therefore, the end state is denoted as “OK.”
39C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier discovers the discrepancy and makes the correct change. Because, the independent verifier discovered and corrected the documentation of the fuel assembly, the correct fuel assembly is loaded into the correct waste package. This sequence represents the correct loading of a waste package; therefore, the end state is denoted as “OK.”
40C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information written down. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are below the design of the waste package (i.e., the fuel assembly will have a control rod inserted). This sequence represents a misload, but it is not critical; therefore, the end state is denoted as “OK.”
41C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
42C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly requested does not require a control rod to be inserted and therefore, the independent checker discovered the mistake. Based on the assumption, all control rod fuel assemblies loaded into a waste package will be recovered; therefore, this end state is denoted as “OK.”

Table I-1. PWR Waste Package Misload Event Tree Sequences (continued)

Sequence	Description
43C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a South Texas fuel assembly and therefore, the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
44C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a lower reactive fuel assembly and the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
45C	This sequence starts with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - selection was committed and the wrong fuel assembly was selected. The fuel assembly was a lower reactive fuel assembly and a control rod was inserted. The independent checker failed to verify the correct fuel assembly; however, a control rod was inserted which makes the fuel assembly below the design of the waste package. Although the operator mistake was not recovered, the end state is not critical and denoted as “OK.”
46C & 47C	These sequences start with loading the 21-PWR CR waste package. The correct waste package was requested and selected. An EOC - selection was committed; however, the correct fuel assembly was selected (for bookkeeping purposes these two sequences are in the event tree). The correct fuel assembly for the waste package was selected and the independent checker verified the fuel assembly. Since the correct fuel assembly was selected, the end state is denoted as “OK.”
48C	This sequence starts with loading the 21-PWR CR waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as “OK.”
49C through 57C	This sequence starts with loading the 21-PWR CR waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues assuming the waste package is the 21-PWR CR. Using the assumption that fuel assemblies without a control rod will be detected and recovered, all fuel assemblies will contain a control rod and therefore, be below the design of the waste package. Since all misload fuel assemblies will be detected and recovered, the end states for these sequences are denoted as “OK.”
58C	This sequence starts with loading the 21-PWR CR waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (South Texas). During the verification process, the operator discovers this mistake and the loading process is stopped. Since the operator mistake was recovered, the end state is denoted as “OK.”
59C	This sequence starts with loading the 21-PWR CR waste package. The Line operator requests the wrong (EOC - request) waste package and the DC operator selects this wrong waste package. During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as “OK.”
60C through 68C	This sequence starts with loading the 21-PWR CR waste package. The Line operator requests the wrong (EOC - request) waste package and the DC operator selects the wrong waste package. During the verification process, the operator fails to discover this mistake. The loading process continues assuming the waste package is the 21-PWR CR. Using the assumption that fuel assemblies without a control rod will be detected and recovered, all fuel assemblies will contain a control rod and therefore, be below the design of the waste package. Since all misload fuel assemblies will be detected and recovered, the end states for these sequences are denoted as “OK.”
69C through 74C	These sequences are the same as those discussed above except their probabilities would be smaller; therefore, they are not expanded for evaluation.
75C through 88C	These sequences start with loading the 12-PWR Long (South Texas) waste package. All EOCs either request or selection will be recovered for both the waste package and the fuel assembly. Since all errors will be recovered, these sequence end states are denoted as “OK.”

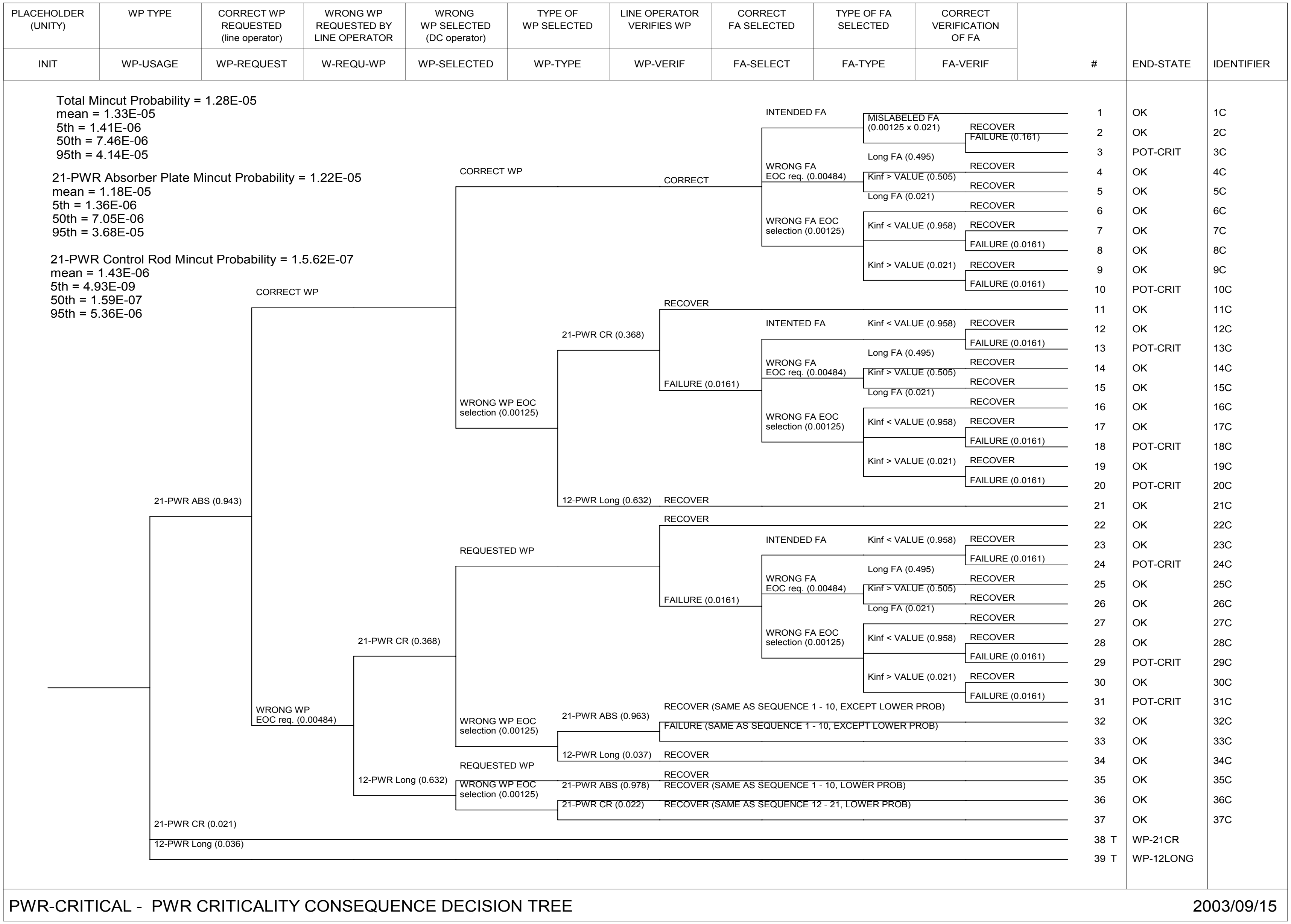

Figure I-1. PWR Waste Package Misload Event Tree (21-PWR Absorber Plate).

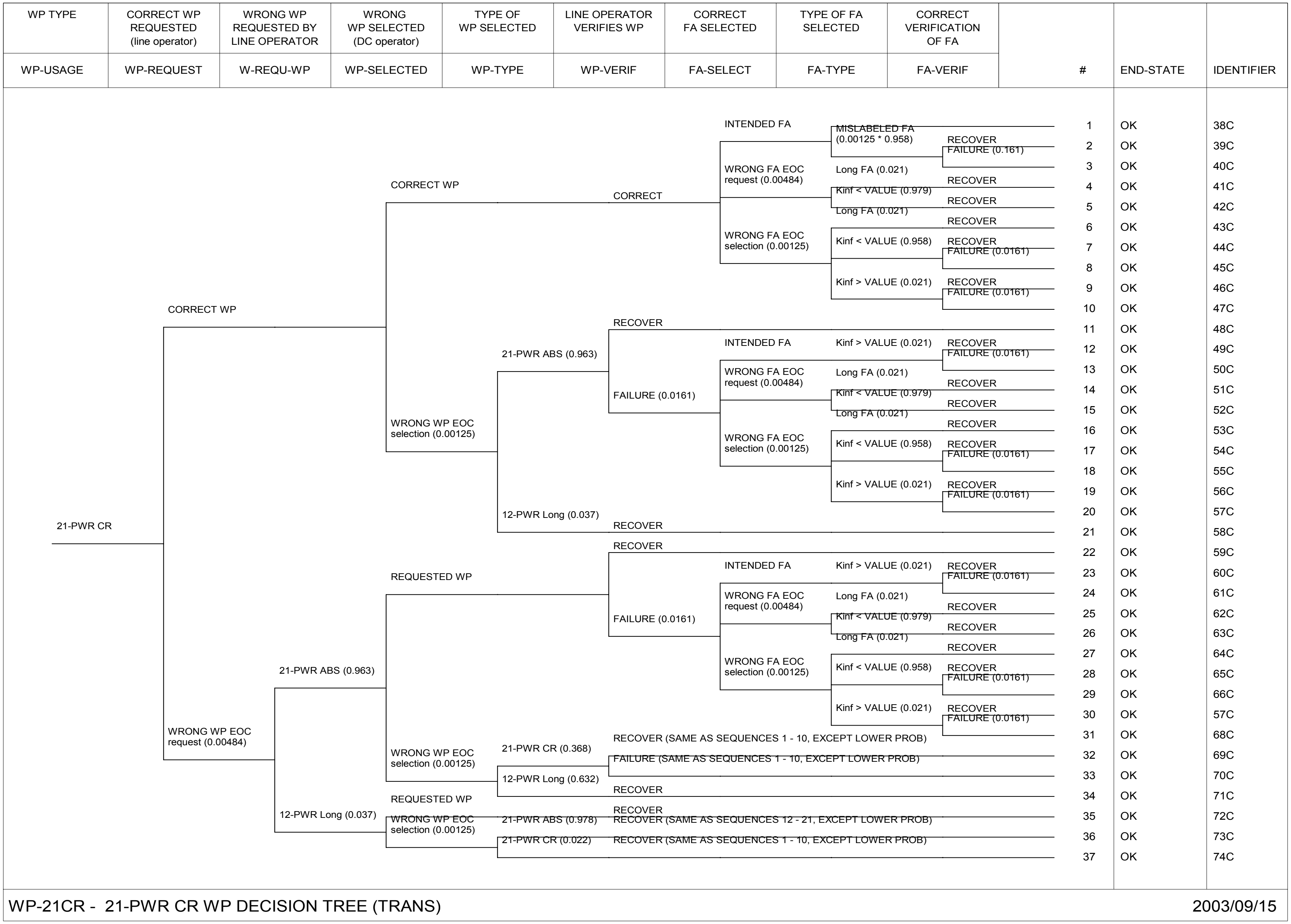

Figure I-2. PWR Waste Package Misload Event Tree (21-PWR Control Rod).

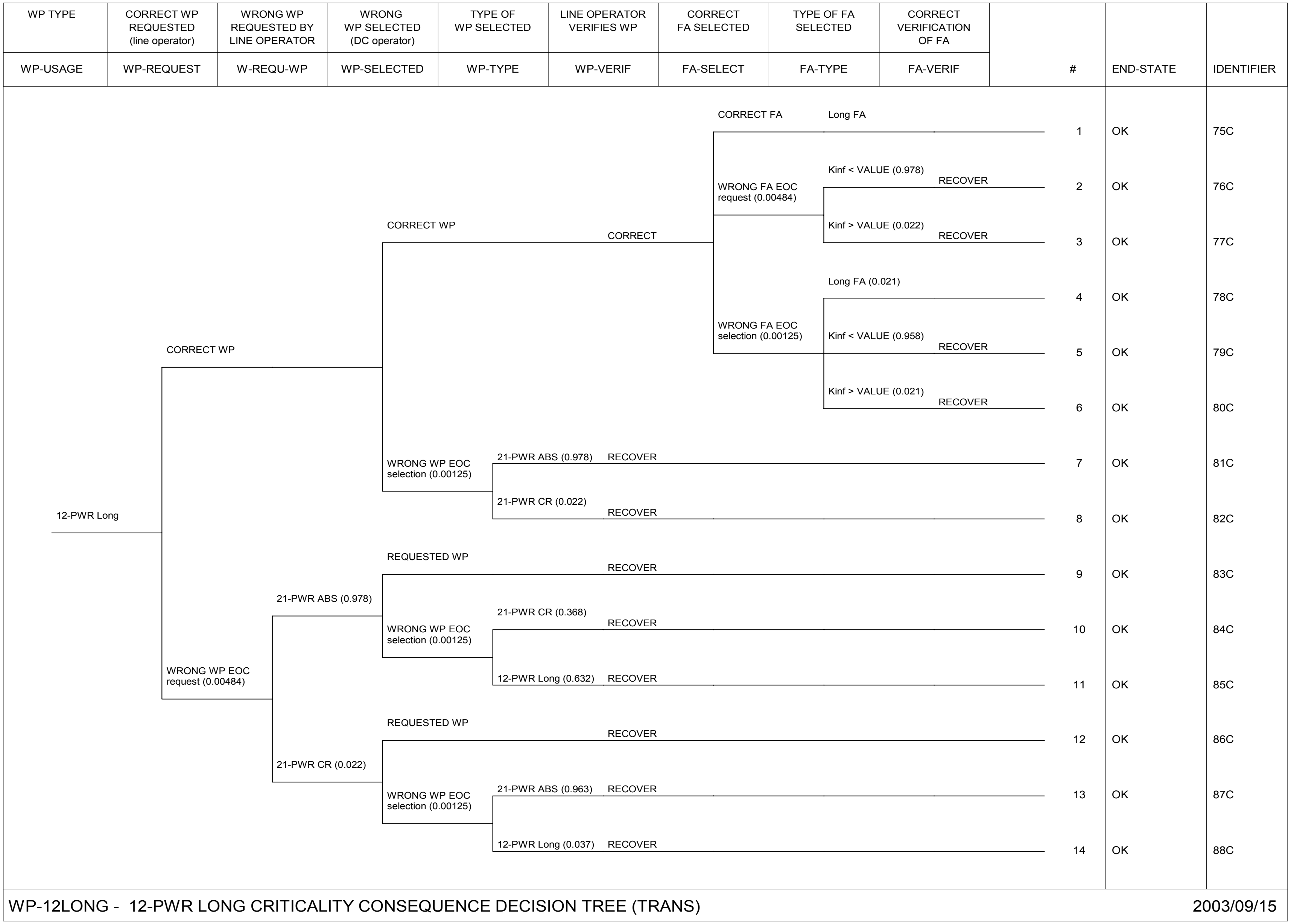

Figure I-3. PWR Waste Package Misload Event Tree (12-PWR Long).

ATTACHMENT II

BWR MISLOAD EVENT TREES

Table II-1. BWR Waste Package Misload Sequences

Sequences	Description
1C	This sequence starts with loading the 44-BWR Absorber Plate (44-BWR ABS) waste package. The correct waste package was requested and selected. The fuel assembly based on the design criteria of the waste package is selected and placed into the waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as "OK."
2C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier discovers the discrepancy and makes the correct change. Because, the independent verifier discovered and corrected the documentation of the fuel assembly, the correct fuel assembly is loaded into the correct waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as "OK."
3C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are outside of the design of the waste package. This sequence represents a critical misload; therefore, the end state is denoted as "POT-CRIT."
4C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An error of commission (EOC) - request was committed and the fuel assembly was requested. The fuel assembly is the correct fuel assembly and is only listed for bookkeeping and the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as "OK."
5C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly that requested was a fuel assembly outside of the design of the waste package and the independent checker discovered this mistake. Since the operator mistake was recovered, this end state is denoted as "OK."
6C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly that requested was a fuel assembly outside of the design of the waste package and the independent checker fails to discover this mistake. Since the operator failed to discover the mistake, the misload was not recovered. This end state is denoted as "POT-CRIT."
7C & 8C	These sequences start with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - selection was committed; however, the correct fuel assembly was selected (for bookkeeping purposes these two sequences are in the event tree). The correct fuel assembly for the waste package was selected and the independent checker verified the fuel assembly. Since the correct fuel assembly was selected, the end state is denoted as "OK."
9C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package, but the independent checker discovered the mistake. Since the operator mistake was recovered, the end state is denoted as "OK."
10C	This sequence starts with loading the 44-BWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is outside the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the operator mistake was not recovered, the end state is denoted as "POT-CRIT.
11C	This sequence starts with loading the 44-BWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (24-BWR). During the verification process, the operator discovers this mistake and the loading process is stopped. Since the operator mistake was recovered, the end state is denoted as "OK."

Table II-1. BWR Waste Package Misload Sequences (continued)

Sequence	Description
12C	This sequence starts with loading the 44-BWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (24-BWR). During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as “OK.”
13C	This sequence starts with loading the 44-BWR ABS waste package. The Line operator requests the wrong waste package (EOC - request, 24-BWR) and the DC operator selects (EOC) the waste package that was not requested (44-BWR). This sequence can be expanded to look like sequences 1 through 10. However, these sequences were not created because their probabilities are negligible compared to the probabilities from sequences 1 through 10. Therefore, the end state is denoted as “OK.”
14C	This sequence starts with loading the 24-BWR waste package. The correct waste package was requested and selected. The fuel assembly based on the design criteria of the waste package is selected and placed into the waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as “OK.”
15C	This sequence starts with loading the 24-BWR waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier discovers the discrepancy and makes the correct change. Because, the independent verifier discovered and corrected the documentation of the fuel assembly, the correct fuel assembly is loaded into the correct waste package. This sequence represents the correct loading of the waste package; therefore, the end state is denoted as “OK.”
16C	This sequence starts with loading the 24-PWR waste package. The correct waste package was requested and selected. The correct fuel assembly based on its associated records was selected. However, during the receipt of the fuel assembly, the fuel assembly characteristics from the shipping records were incorrectly documented. Therefore, the fuel assembly characteristics do not represent the information documented. The independent verifier fails to discover this discrepancy. Because the independent verifier failed to notice the discrepancy, an incorrectly documented fuel assembly was loaded into the waste package. The fuel assembly characteristics are below the design of the waste package (i.e., the fuel assembly enrichment and burn-up are below the loading curve). This sequence represents a misload, but it is not critical; therefore, the end state is denoted as “OK.”
17C	This sequence starts with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An error of commission (EOC) - request was committed and the fuel assembly was requested. The fuel assembly is the correct fuel assembly and is only listed for bookkeeping purposes and the mistake was recovered. Since the operator mistake was recovered, the end state is denoted as “OK.”
18C	This sequence starts with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly that was requested was a fuel assembly below the design of the waste package and the independent checker discovered this mistake. Since the operator mistake was recovered, this end state is denoted as “OK.”
19C	This sequence starts with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An EOC - request was committed and the wrong fuel assembly was requested. The fuel assembly that was requested was a fuel assembly below the design of the waste package and the independent checker failed to discover this mistake. Since the operator failed to discover the mistake, the misload was not recovered. Since the fuel assembly is below the design and the misload does not have a criticality potential, the end state is denoted as “OK.”
20C & 21C	These sequences start with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An EOC - selection was committed; however, the selection is assumed the correct fuel assembly (for bookkeeping purposes these two sequences are in the event tree). The correct fuel assembly for the waste package was selected and the independent checker verified the fuel assembly. Since the correct fuel assembly was selected, the end state is denoted as “OK.”

Table II-1. BWR Waste Package Misload Sequences (continued)

Sequence	Description
22C	This sequence starts with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is below the design of the waste package. The independent checker discovered the mistake and corrected the mistake. Since the operator mistake was recovered, the end state is denoted as “OK.”
23C	This sequence starts with loading the 24-BWR ABS waste package. The correct waste package was requested and selected. An EOC - select was committed and the wrong fuel assembly was selected. The fuel assembly is below the design of the waste package. The independent checker fails to discover this mistake and the fuel assembly gets loaded into the waste package. Since the fuel assembly is below the design of the waste package even though the operator mistake was not recovered, there is no misload criticality potential. The end state is therefore denoted as “OK.
24C	This sequence starts with loading the 24-BWR ABS waste package. The Line operator requests the correct waste package; however, the DC operator selects (EOC) the wrong waste package (44-BWR). During the verification process, the operator discovers this mistake and the loading process is stopped. Since the operator mistake was recovered, the end state is denoted as “OK.”
25C	This sequence starts with loading the 24-BWR ABS waste package. The Line operator requests the wrong waste package (EOC - request) and the DC operator selects this waste package (44-BWR). During the verification process, this mistake was detected and the loading process stopped. Since the operator mistake was discovered, the end state is denoted as “OK.”
26C	This sequence starts with loading the 24-BWR ABS waste package. The Line operator requests the wrong waste package (EOC - request, 44-BWR) and the DC operator selects (EOC) the waste package that was not requested (44-BWR). This sequence can be expanded to look like sequences 14 through 23. However, these sequences were not created because their probabilities are negligible compared to the probabilities from sequences 14 through 23. Therefore, the end state is denoted as “OK.”

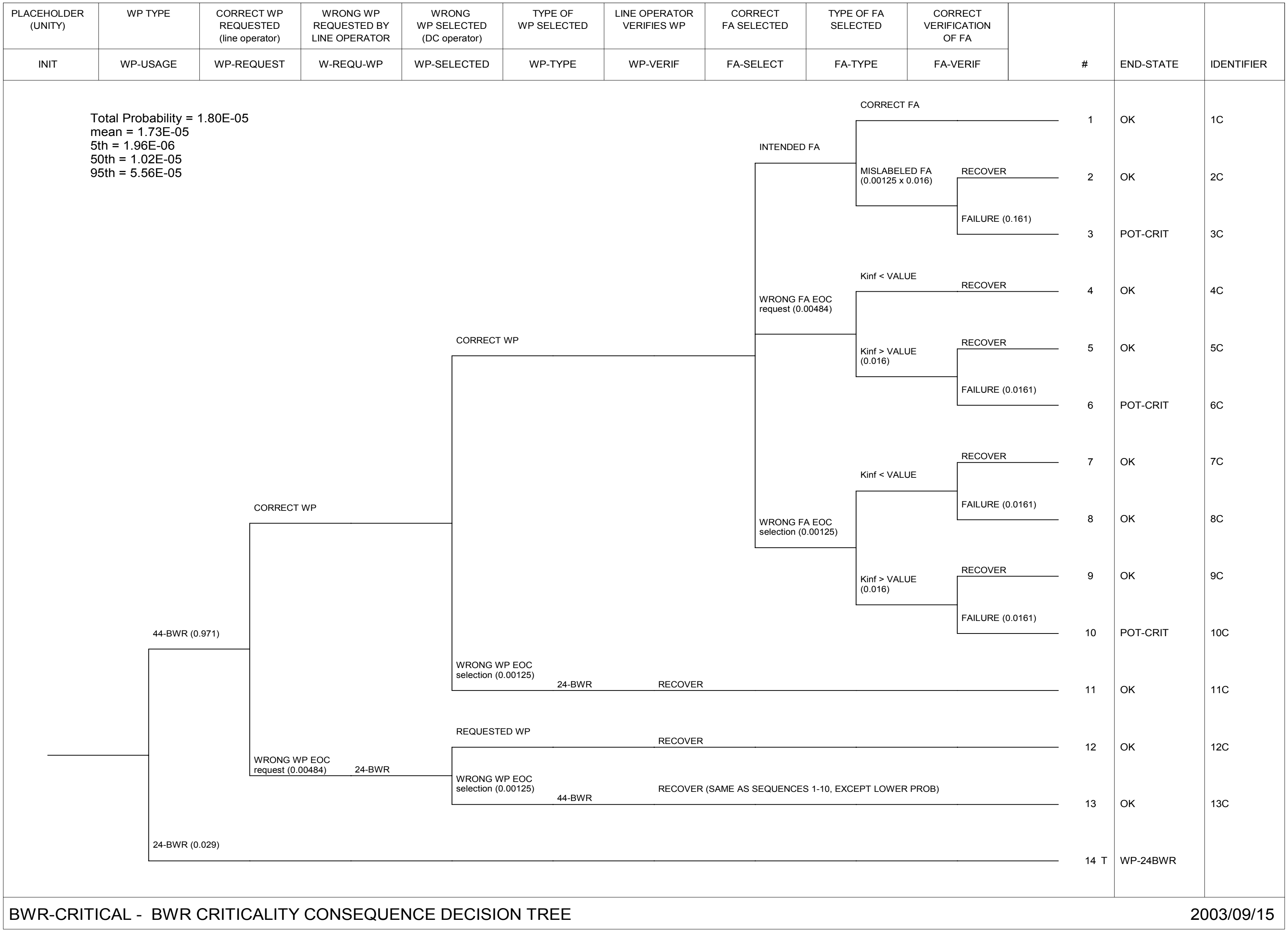

Figure II-1. BWR Waste Package Misload Event Tree (44-BWR).

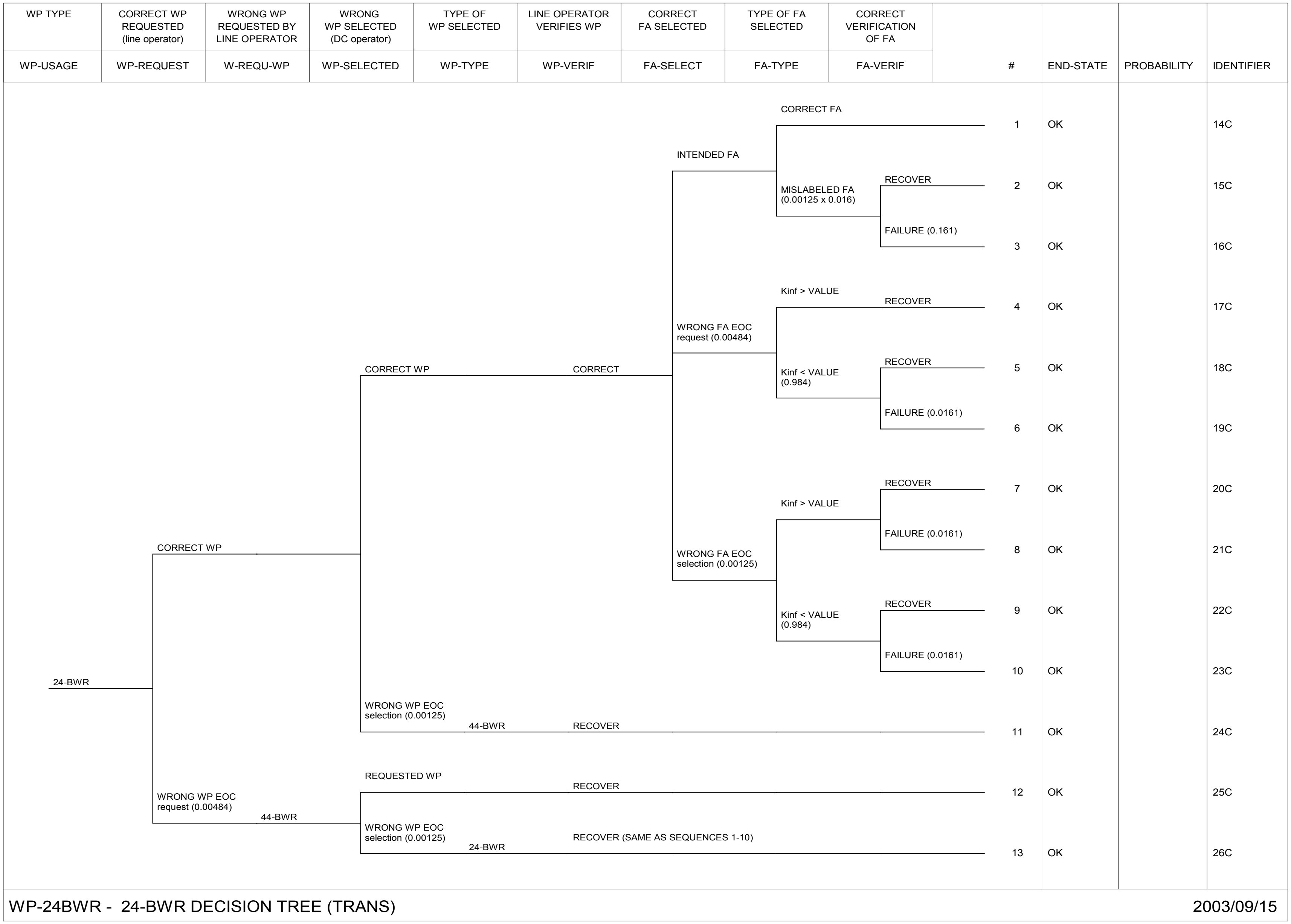

Figure II-2. BWR Waste Package Misload Event Tree (24-BWR).

ATTACHMENT III

MATHCAD SPREADSHEETS

Waste Package and Fuel Assembly Fractional Calculations

$WP21AB := 4299$ number of 21-PWR Absorber Plate waste packages

$WP21CR := 95$ number of 21-PWR Control Rod waste packages

$WP12L := 163$ number of 12-PWR Long waste packages

$WP44AB := 2831$ number of 44-BWR Absorber Plate waste packages

$WP24AB := 84$ number of 24-BWR Absorber Plate waste packages

Fraction of PWR waste packages (all)

$$FWP21AB := \frac{WP21AB}{WP21AB + WP21CR + WP12L} \qquad FWP21AB = 0.943$$ fraction of 21-PWR ABS Plate

$$FWP21CR := \frac{WP21CR}{WP21AB + WP21CR + WP12L} \qquad FWP21CR = 0.021$$ fraction of 21-PWR Control Rod

$$FWP12L := \frac{WP12L}{WP21AB + WP21CR + WP12L} \qquad FWP12L = 0.036$$ fraction of 12-PWR Long

Fraction of 21-PWR Control Rod and 12-PWR Long waste packages

$$FWP21CR1 := \frac{WP21CR}{WP21CR + WP12L} \qquad FWP21CR1 = 0.368$$ fraction of 21-PWR Control Rod

$$FWP12L1 := \frac{WP12L}{WP21CR + WP12L} \qquad FWP12L1 = 0.632$$ fraction of 12-PWR Long

Fraction of 21-PWR Absorber Plate and 12-PWR Long waste packages

$$FWP21AB1 := \frac{WP21AB}{WP21AB + WP12L} \qquad FWP21AB1 = 0.963$$ fraction of 21-PWR Abs Plate

$$FWP12L2 := \frac{WP12L}{WP21AB + WP12L} \qquad FWP12L2 = 0.037$$ fraction of 12-PWR Long

Fraction of 21-PWR Absorber Plate and 21-PWR Control Rod waste packages

$$FWP21AB2 := \frac{WP21AB}{WP21AB + WP21CR} \qquad FWP21AB2 = 0.978$$ fraction of 21-PWR Abs Plate

$$FWP21CR2 := \frac{WP21CR}{WP21AB + WP21CR} \qquad FWP21CR2 = 0.022$$ fraction of 21-PWR Control Rod

Fraction of 44-BWR Absorber Plate and 24-BWR Absorber Plate waste packages

$$FWP44AB1 := \frac{WP44AB}{WP44AB + WP24AB} \qquad FWP44AB1 = 0.971$$ fraction of 44-BWR Abs Plate

$$FWP24AB1 := \frac{WP24AB}{WP44AB + WP24AB} \qquad FWP24AB1 = 0.029$$ fraction of 24-BWR Absorber Plate

Fuel Assembly Fractional Calculations

$FA21AB := 90262$ number of 21-PWR Absorber Plate fuel assemblies

$FA21CR := 1992$ number of 21-PWR Control Rod fuel assemblies

$FA12L := 1955$ number of 12-PWR Long fuel assemblies

$FA44AB := 124532$ number of 44-BWR Absorber Plate fuel assemblies

$FA24AB := 2013$ number of 24-BWR Absorber Plate fuel assemblies

Fraction of PWR fuel assemblies (all)

$$FFA21AB := \frac{FA21AB}{FA21AB + FA21CR + FA12L}$$ $FFA21AB = 0.958$ fraction of 21-PWR Abs Plate

$$FFA21CR := \frac{FA21CR}{FA21AB + FA21CR + FA12L}$$ $FFA21CR = 0.021$ fraction of 21-PWR Control Rod

$$FFA12L := \frac{FA12L}{FA21AB + FA21CR + FA12L}$$ $FFA12L = 0.021$ fraction of 12-PWR Long

Fraction of 21-PWR Control Rod and 12-PWR Long fuel assemblies

$$FFA21CR1 := \frac{FA21CR}{FA21CR + FA12L}$$ $FFA21CR1 = 0.505$ fraction of 21-PWR Control Rod

$$FFA12L1 := \frac{FA12L}{FA21CR + FA12L}$$ $FFA12L1 = 0.495$ fraction of 12-PWR Long

Fraction of 21-PWR Absorber Plate and 12-PWR Long fuel assemblies

$$FFA21AB1 := \frac{FA21AB}{FA21AB + FA12L}$$ $FFA21AB1 = 0.979$ fraction of 21-PWR Abs Plate

$$FFA12L2 := \frac{FA12L}{FA21AB + FA12L}$$ $FFA12L2 = 0.021$ fraction of 12-PWR Long

Fraction of 21-PWR Absorber Plate and 21-PWR Control Rod fuel assemblies

$$FFA21AB2 := \frac{FA21AB}{FA21AB + FA21CR}$$ $FFA21AB2 = 0.978$ fraction of 21-PWR Abs Plate

$$FFA21CR2 := \frac{FA21CR}{FA21AB + FA21CR}$$ $FFA21CR2 = 0.022$ fraction of 21-PWR Control Rod

Fraction of 44-BWR Absorber Plate and 24-BWR Absorber Plate fuel assemblies

$$FFA44AB1 := \frac{FA44AB}{FA44AB + FA24AB}$$ $FFA44AB1 = 0.984$ fraction of 44-BWR Abs Plate

$$FFA24AB1 := \frac{FA24AB}{FA44AB + FA24AB}$$ $FFA24AB1 = 0.016$ fraction of 24-BWR Absorber Plate

Section 6.2.1 Calculations

21-PWR Absorber Plate waste package Nominal Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Absorber Plate waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree [21-PWR Absorber Plate (Table 11)].

mean	**5th**	**50th**	**95th**
$AB\lambda 1 := 1.18\times 10^{-5}$	$ABf_{th} := 1.36\times 10^{-6}$	$ABft_{th} := 7.05\times 10^{-6}$	$ABnf_{th} := 3.68\times 10^{-5}$

The results were fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{AB} := \sqrt{\frac{ABnf_{th}}{ABf_{th}}} \qquad EF_{AB} = 5.202$$

Required parameters for the lognormal distribution.

$$\lambda_{AB} := \ln(AB\lambda 1) \qquad \zeta_{AB} := \frac{\ln(EF_{AB})}{1.645}$$

Since, the misload probability per waste package has uncertainty this needs to be included in the calculation. Therefore, a Latin Hypercube sampling (LHS) routine is developed to calculate the probability of at least one waste package is misloaded taking into account the misload probability uncertainty. [LHS is a stratified type of Monte Carlo Sampling (i.e., LHS stratifies the distribution into n pieces and then samples from each of the n pieces to obtain the value of interest).]

Set up the LHS routine.

$n_s := 10000$ n_s is the number of random samples

$i := 1..n_s$

$RD_{i-1,0} := i$

$RD_{i-1,1} := \mathrm{rnd}(1.0)$ Generate the LHS random numbers used for sampling.

$RK1 := \mathrm{csort}(RD, 1)$

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n_s, 0, 1)}{n_s}$$

Define sets of random values. Each random value is selected within one of the equipropabable n_s intervals that partition [0,1].

Calculate a set of sample values for each of the random variables:

$j := 0..n_s - 1$

$YAB_{j,0} := \mathrm{qlnorm}(X_{j,0}, \lambda_{AB}, \zeta_{AB})$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

$n21ABS := 4299$ number of 21-PWR Absorber Plate waste packages

k represents the number of misloaded waste packages (i.e., zero, one, etc.)

$k0 := 0$

The probability calculation follows the binomial process.

$B_{AB_{j,0}} := \text{dbinom}\left(k0, n21ABS, Y_{AB_{j,0}}\right)$ Probability of exactly 0 waste packages misloaded

$G_{AB_{j,0}} := 1 - B_{AB_{j,0}}$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$P_{1ABWP} := \text{sort}\left(G_{AB}^{\langle 0 \rangle}\right)$

Set up cdf to determine the percentiles

$P_{WP_{j,1}} := \frac{j}{n_s}$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Absorber Plate waste package is misloaded

$\mu_{1ABWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{AB_{i,0}}$ $\mu_{1ABWP} = 7.573 \times 10^{-2}$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABWP}^{\langle 0 \rangle}, 0.05\right) = 9.715 \times 10^{-3}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABWP}^{\langle 0 \rangle}, 0.5\right) = 4.948 \times 10^{-2}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABWP}^{\langle 0 \rangle}, 0.95\right) = 2.321 \times 10^{-1}$

21-PWR Control Rod waste package Nominal Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Control Rod waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Control Rod).

mean	5th	50th	95th
$CR\lambda 1 := 1.43\times 10^{-6}$	$CRf_{th} := 4.39\times 10^{-9}$	$CRft_{th} := 1.59\times 10^{-7}$	$CRnf_{th} := 5.36\times 10^{-6}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{CR} := \sqrt{\frac{CRnf_{th}}{CRf_{th}}} \qquad EF_{CR} = 34.942$$

Required parameters for the lognormal distribution.

$$\lambda_{CR} := \ln(CR\lambda 1)$$

$$\zeta_{CR} := \frac{\ln(EF_{CR})}{1.645}$$

$$Y_{CR_{j,0}} := \text{qlnorm}\left(X_{j,0}, \lambda_{CR}, \zeta_{CR}\right)$$

sample from the lognormal distribution to obtain a misload probability

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

$n21CR := 95$ number of 21-PWR Control Rod waste packages

The probability calculation follows the binomial process.

$$B_{CR_{j,0}} := \text{dbinom}\left(k0, n21CR, Y_{CR_{j,0}}\right)$$

Probability of exactly 0 waste packages misloaded

$$G_{CR_{j,0}} := 1 - B_{CR_{j,0}}$$

The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1CRWP} := \text{sort}\left(G_{CR}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Control Rod waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Control Rod waste package is misloaded

$$\mu_{1CRWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s-1} G_{CR_{i,0}} \qquad \mu_{1CRWP} = 1.347 \times 10^{-3}$$ **mean probability**

5th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRWP}^{\langle 0 \rangle}, 0.05\right) = 3.897 \times 10^{-6}$

50th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRWP}^{\langle 0 \rangle}, 0.5\right) = 1.359 \times 10^{-4}$

95th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRWP}^{\langle 0 \rangle}, 0.95\right) = 4.744 \times 10^{-3}$

Section 6.2.2 Calculations

44-BWR Absorber Plate waste package Nominal Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 44-BWR Absorber Plate waste package.

The mean, 5th, 50th, and 95th probability from analyzing the BWR misload event tree (44-BWR).

mean	**5th**	**50th**	**95th**
$BW\lambda 1 := 1.73 \times 10^{-5}$	$BWf_{th} := 1.96 \times 10^{-6}$	$BWft_{th} := 1.02 \times 10^{-5}$	$BWnf_{th} := 5.56 \times 10^{-5}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{BW} := \sqrt{\frac{BWnf_{th}}{BWf_{th}}} \qquad EF_{BW} = 5.326$$

Required parameters for the lognormal distribution.

$$\lambda_{BW} := \ln(BW\lambda 1)$$

$$\zeta_{BW} := \frac{\ln(EF_{BW})}{1.645}$$

$$Y_{BW_{j,0}} := \mathrm{qlnorm}\left(X_{j,0}, \lambda_{BW}, \zeta_{BW}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

$n44BW := 2831$ number of 44-BWR Absorber Plate waste packages

The probability calculation follows the binomial process.

$B_{BW_{j,0}} := \text{dbinom}\left(k0, n44BW, Y_{BW_{j,0}}\right)$ Probability of exactly 0 waste packages misloaded

$G_{BW_{j,0}} := 1 - B_{BW_{j,0}}$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$P_{1BWWP} := \text{sort}\left(G_{BW}^{\langle 0\rangle}\right)$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 44-BWR Absorber Plate waste package is misloaded

$\mu_{1BWWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s-1} G_{BW_{i,0}}$ $\mu_{1BWWP} = 7.415 \times 10^{-2}$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1\rangle}, P_{1BWWP}^{\langle 0\rangle}, 0.05\right) = 9.164 \times 10^{-3}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1\rangle}, P_{1BWWP}^{\langle 0\rangle}, 0.5\right) = 4.781 \times 10^{-2}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1\rangle}, P_{1BWWP}^{\langle 0\rangle}, 0.95\right) = 2.298 \times 10^{-1}$

Section 6.3.1 Sensitivity Calculations

21-PWR Absorber Plate waste package Selection Error Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Absorber Plate waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Absorber Plate).

mean	5th	50th	95th
$ABS\lambda 1 := 5.37 \times 10^{-6}$	$ABSf_{th} := 9.86 \times 10^{-7}$	$ABSft_{th} := 3.71 \times 10^{-6}$	$ABSnf_{th} := 1.50 \times 10^{-5}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{ABS} := \sqrt{\frac{ABSnf_{th}}{ABSf_{th}}} \qquad EF_{ABS} = 3.9$$

Required parameters for the lognormal distribution.

$$\lambda_{ABS} := \ln(ABS\lambda 1) \qquad \zeta_{ABS} := \frac{\ln(EF_{ABS})}{1.645}$$

$$Y_{ABS_{j,0}} := \text{qlnorm}\left(X_{j,0}, \lambda_{ABS}, \zeta_{ABS}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{ABS_{j,0}} := \text{dbinom}\left(k0, n21ABS, Y_{ABS_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$$G_{ABS_{j,0}} := 1 - B_{ABS_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1ABSWP} := \text{sort}\left(G_{ABS}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Absorber Plate waste package is misloaded

$$\mu_{1ABSWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{ABS_{i,0}} \qquad \mu_{1ABSWP} = 3.15 \times 10^{-2}$$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABSWP}^{\langle 0 \rangle}, 0.05\right) = 5.907 \times 10^{-3}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABSWP}^{\langle 0 \rangle}, 0.5\right) = 2.283 \times 10^{-2}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABSWP}^{\langle 0 \rangle}, 0.95\right) = 8.616 \times 10^{-2}$

21-PWR Control Rod waste package Selection Error Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Control Rod waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Control Rod).

mean	**5th**	**50th**	**95th**
$CRS\lambda 1 := 1.35 \times 10^{-6}$	$CRSf_{th} := 4.48 \times 10^{-9}$	$CRSft_{th} := 1.57 \times 10^{-7}$	$CRSnf_{th} := 4.95 \times 10^{-6}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{CRS} := \sqrt{\frac{CRSnf_{th}}{CRSf_{th}}} \qquad EF_{CRS} = 33.24$$

Required parameters for the lognormal distribution.

$$\lambda_{CRS} := \ln(CRS\lambda 1) \qquad \zeta_{CRS} := \frac{\ln(EF_{CRS})}{1.645}$$

$$Y_{CRS_{j,0}} := \mathrm{qlnorm}\left(X_{j,0}, \lambda_{CRS}, \zeta_{CRS}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{CRS_{j,0}} := \mathrm{dbinom}\left(k0, n21CR, Y_{CRS_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$$G_{CRS_{j,0}} := 1 - B_{CRS_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1CRSWP} := \mathrm{sort}\left(G_{CRS}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Control Rod waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Control Rod waste package is misloaded

$$\mu_{1CRSWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s-1} G_{CRS_{i,0}} \qquad \mu_{1CRSWP} = 1.2 \times 10^{-3}$$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRSWP}^{\langle 0 \rangle}, 0.05\right) = 3.867 \times 10^{-6}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRSWP}^{\langle 0 \rangle}, 0.5\right) = 1.283 \times 10^{-4}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRSWP}^{\langle 0 \rangle}, 0.95\right) = 4.261 \times 10^{-3}$

44-BWR Absorber Plate waste package Selection Error Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 44-BWR Absorber Plate waste package.

The mean, 5^{th}, 50th, and 95^{th} probability from analyzing the BWR misload event tree (44-BWR).

mean	**5th**	**50th**	**95th**
$BWS\lambda1 := 7.03 \times 10^{-6}$	$BWSf_{th} := 1.38 \times 10^{-6}$	$BWSft_{th} := 5.00 \times 10^{-6}$	$BWSnf_{th} := 1.88 \times 10^{-5}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5^{th} and 95^{th} are used to calculate the error factor for the lognormal distribution.

$$EF_{BWS} := \sqrt{\frac{BWSnf_{th}}{BWSf_{th}}} \qquad EF_{BWS} = 3.691$$

Required parameters for the lognormal distribution.

$$\lambda_{BWS} := \ln(BWS\lambda1) \qquad \zeta_{BWS} := \frac{\ln\left(EF_{BWS}\right)}{1.645}$$

$$Y_{BWS_{j,0}} := \text{qlnorm}\left(X_{j,0}, \lambda_{BWS}, \zeta_{BWS}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{BWS_{j,0}} := \text{dbinom}\left(k0, n44BW, Y_{BWS_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$G_{BWS_{j,0}} := 1 - B_{BWS_{j,0}}$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$P_{1BWSWP} := \mathrm{sort}\left(G_{BWS}^{\langle 0 \rangle}\right)$

Estimate the mean probability and percentiles of a 44-BWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 44-BWR Absorber Plate waste package is misloaded

$\mu_{1BWSWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s-1} G_{BWS_{i,0}}$ $\mu_{1BWSWP} = 2.66 \times 10^{-2}$ **mean probability**

5th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1BWSWP}^{\langle 0 \rangle}, 0.05\right) = 5.382 \times 10^{-3}$

50th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1BWSWP}^{\langle 0 \rangle}, 0.5\right) = 1.971 \times 10^{-2}$

95th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1BWSWP}^{\langle 0 \rangle}, 0.95\right) = 7.087 \times 10^{-2}$

Section 6.3.2 Sensitivity Calculations

21-PWR Absorber Plate waste package (all PWR waste packages contain absorber plate) Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Absorber Plate).

mean	5th	50th	95th
$ABs\lambda 1 := 1.18 \times 10^{-5}$	$ABsf_{th} := 1.36 \times 10^{-6}$	$ABsft_{th} := 7.05 \times 10^{-6}$	$ABsnf_{th} := 3.68 \times 10^{-5}$

The results were fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$EF_{ABs} := \sqrt{\frac{ABsnf_{th}}{ABsf_{th}}}$ $EF_{ABs} = 5.202$

Required parameters for the lognormal distribution.

$$\lambda_{ABs} := \ln(ABs\lambda1) \qquad \zeta_{ABs} := \frac{\ln(EF_{ABs})}{1.645}$$

$$Y_{ABs_{j,0}} := qlnorm(X_{j,0}, \lambda_{ABs}, \zeta_{ABs})$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{ABs_{j,0}} := dbinom(k0, n21ABS, Y_{ABs_{j,0}})$$ Probability of exactly 0 waste packages misloaded

$$G_{ABs_{j,0}} := 1 - B_{ABs_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1ABsWP} := sort\left(G_{ABs}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Absorber Plate waste package is misloaded

$$\mu_{1ABsWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{ABs_{i,0}} \qquad \mu_{1ABsWP} = 7.573 \times 10^{-2}$$ **mean probability**

5th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1ABsWP}^{\langle 0 \rangle}, 0.05\right) = 9.715 \times 10^{-3}$

50th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1ABsWP}^{\langle 0 \rangle}, 0.5\right) = 4.948 \times 10^{-2}$

95th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1ABsWP}^{\langle 0 \rangle}, 0.95\right) = 2.321 \times 10^{-1}$

21-PWR Control Rod waste package (all PWR waste packages contain absorber plate) Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Control Rod waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Control Rod).

mean	**5th**	**50th**	**95th**
$CRs\lambda1 := 9.39\times 10^{-10}$	$CRsf_{th} := 1.70\times 10^{-12}$	$CRsft_{th} := 7.22\times 10^{-11}$	$CRsnf_{th} := 3.12\times 10^{-9}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{CRs} := \sqrt{\frac{CRsnf_{th}}{CRsf_{th}}} \qquad EF_{CRs} = 42.84$$

Required parameters for the lognormal distribution.

$$\lambda_{CRs} := \ln(CRs\lambda1) \qquad \zeta_{CRs} := \frac{\ln\left(EF_{CRs}\right)}{1.645}$$

$$Y_{CRs_{j,0}} := \mathrm{qlnorm}\left(X_{j,0}, \lambda_{CRs}, \zeta_{CRs}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{CRs_{j,0}} := \mathrm{dbinom}\left(k0, n21CR, Y_{CRs_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$$G_{CRs_{j,0}} := 1 - B_{CRs_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1CRsWP} := \mathrm{sort}\left(G_{CRs}^{\langle 0\rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Control Rod waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Control Rod waste package is misloaded

$$\mu_{1CRsWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s-1} G_{CRs_{i,0}} \qquad \mu_{1CRsWP} = 1.211 \times 10^{-6}$$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRsWP}^{\langle 0 \rangle}, 0.05\right) = 2.087 \times 10^{-9}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRsWP}^{\langle 0 \rangle}, 0.5\right) = 8.926 \times 10^{-8}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1CRsWP}^{\langle 0 \rangle}, 0.95\right) = 3.829 \times 10^{-6}$

Section 6.3.3 Sensitivity Calculations

21-PWR Absorber Plate waste package (Loading Schema) Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Absorber Plate).

mean	5th	50th	95th
$ABL\lambda1 := 3.52 \times 10^{-6}$	$ABLf_{th} := 2.72 \times 10^{-7}$	$ABLft_{th} := 1.90 \times 10^{-6}$	$ABLnf_{th} := 1.20 \times 10^{-5}$

The results were fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{ABL} := \sqrt{\frac{ABLnf_{th}}{ABLf_{th}}} \qquad EF_{ABL} = 6.642$$

Required parameters for the lognormal distribution.

$$\lambda_{ABL} := \ln(ABL\lambda1) \qquad \zeta_{ABL} := \frac{\ln(EF_{ABL})}{1.645}$$

$$Y_{ABL_{j,0}} := \text{qlnorm}\left(X_{j,0}, \lambda_{ABL}, \zeta_{ABL}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$B_{ABL_{j,0}} := \text{dbinom}\left(k0, n21ABS, Y_{ABL_{j,0}}\right)$ Probability of exactly 0 waste packages misloaded

$G_{ABL_{j,0}} := 1 - B_{ABL_{j,0}}$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$P_{1ABLWP} := \text{sort}\left(G_{ABL}^{\langle 0 \rangle}\right)$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Absorber Plate waste package is misloaded

$\mu_{1ABLWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{ABL_{i,0}}$ $\mu_{1ABLWP} = 2.791 \times 10^{-2}$ **mean probability**

5th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABLWP}^{\langle 0 \rangle}, 0.05\right) = 2.279 \times 10^{-3}$

50th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABLWP}^{\langle 0 \rangle}, 0.5\right) = 1.502 \times 10^{-2}$

95th percentile: $\text{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABLWP}^{\langle 0 \rangle}, 0.95\right) = 9.571 \times 10^{-2}$

21-PWR Control Rod waste package (Loading Schema) Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the 21-PWR Control Rod waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Control Rod).

mean	**5th**	**50th**	**95th**
$CRL\lambda 1 := 1.43 \times 10^{-6}$	$CRLf_{th} := 4.93 \times 10^{-9}$	$CRLft_{th} := 1.59 \times 10^{-7}$	$CRLnf_{th} := 5.35 \times 10^{-6}$

The results are fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{CRL} := \sqrt{\frac{CRLnf_{th}}{CRLf_{th}}} \qquad EF_{CRL} = 32.942$$

Required parameters for the lognormal distribution.

$$\lambda_{CRL} := \ln(CRL\lambda 1) \qquad \zeta_{CRL} := \frac{\ln(EF_{CRL})}{1.645}$$

$$Y_{CRL_{j,0}} := qlnorm\left(X_{j,0}, \lambda_{CRL}, \zeta_{CRL}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{CRL_{j,0}} := dbinom\left(k0, n21CR, Y_{CRL_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$$G_{CRL_{j,0}} := 1 - B_{CRL_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1CRLWP} := sort\left(G_{CRL}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Control Rod waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Control Rod waste package is misloaded

$$\mu_{1CRLWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{CRL_{i,0}} \qquad \mu_{1CRLWP} = 1.255 \times 10^{-3}$$ **mean probability**

5th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1CRLWP}^{\langle 0 \rangle}, 0.05\right) = 4.133 \times 10^{-6}$

50th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1CRLWP}^{\langle 0 \rangle}, 0.5\right) = 1.359 \times 10^{-4}$

95th percentile: $linterp\left(P_{WP}^{\langle 1 \rangle}, P_{1CRLWP}^{\langle 0 \rangle}, 0.95\right) = 4.473 \times 10^{-3}$

Section 6.3.4 Sensitivity Calculations

21-PWR Absorber Plate waste package (Sequence 3) Calculation

Calculate the uncertainty of misloading at least one Waste Package (i.e., one or more) with a fuel assembly that is outside the design limits of the waste package.

The mean, 5th, 50th, and 95th probability from analyzing the PWR misload event tree (21-PWR Absorber Plate).

mean	**5th**	**50th**	**95th**
$ABO\lambda 1 := 3.52 \times 10^{-6}$	$ABOf_{th} := 2.72 \times 10^{-7}$	$ABOft_{th} := 1.90 \times 10^{-6}$	$ABOnf_{th} := 1.20 \times 10^{-5}$

The results were fit to a lognormal distribution (Swain and Guttmann 1983, pp. A-2 and A-4).

To obtain the required parameters for a lognormal distribution, the 5th and 95th are used to calculate the error factor for the lognormal distribution.

$$EF_{ABO} := \sqrt{\frac{ABOnf_{th}}{ABOf_{th}}} \qquad EF_{ABO} = 6.642$$

Required parameters for the lognormal distribution.

$$\lambda_{ABO} := \ln(ABO\lambda 1) \qquad \zeta_{ABO} := \frac{\ln(EF_{ABO})}{1.645}$$

$$Y_{ABO_{j,0}} := \text{qlnorm}\left(X_{j,0}, \lambda_{ABO}, \zeta_{ABO}\right)$$ **sample from the lognormal distribution to obtain a misload probability**

Calculate the probability of at least one waste package (i.e., one or more) allowing the epistemic uncertainty of the misload probability.

The probability calculation follows the binomial process.

$$B_{ABO_{j,0}} := \text{dbinom}\left(k0, n21ABS, Y_{ABO_{j,0}}\right)$$ Probability of exactly 0 waste packages misloaded

$$G_{ABO_{j,0}} := 1 - B_{ABO_{j,0}}$$ The probability of at least one WP being misloaded is equal to 1 minus the probability of zero waste packages misloaded.

Set up individual results to determine the mean and uncertainty parameters

$$P_{1ABOWP} := \text{sort}\left(G_{ABO}^{\langle 0 \rangle}\right)$$

Estimate the mean probability and percentiles of a 21-PWR Absorber Plate waste package being misloaded (i.e., a fuel assembly outside its design limit loaded into the waste package).

At least One, 21-PWR Absorber Plate waste package is misloaded

$$\mu_{1ABOWP} := \frac{1}{n_s} \cdot \sum_{i=0}^{n_s - 1} G_{ABO_{i,0}} \qquad \mu_{1ABOWP} = 2.791 \times 10^{-2}$$ **mean probability**

5th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABOWP}^{\langle 0 \rangle}, 0.05\right) = 2.279 \times 10^{-3}$

50th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABOWP}^{\langle 0 \rangle}, 0.5\right) = 1.502 \times 10^{-2}$

95th percentile: $\mathrm{linterp}\left(P_{WP}^{\langle 1 \rangle}, P_{1ABOWP}^{\langle 0 \rangle}, 0.95\right) = 9.571 \times 10^{-2}$