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Design Analysis Cover Sheet

Complete only applicable items.

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2. DESIGN ANALYSIS TITLE

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Table of Contents:

1. Purpose

Due to the large variability in spent nuclear fuel (SNF) characteristics (physical, neutronic, and thermal), several separate waste package (WP) designs will be required to accommodate all of the SNF planned for disposal in the first repository. It could be argued that there is a potential engineering solution to any SNF decay heat or criticality problem such that one design could accommodate all of the SNF assembly types. However, common sense and economics dictate that multiple WP designs be tailored to portions of the waste stream; that is, it is not cost effective to allow the most stressing 10% of the waste stream to drive the design for the other 90%. Therefore, a family of WP designs is required and each individual WP design must have a specifically designated design basis fuel. The purpose of this document is to develop rational WP design and DBF combinations supported by waste stream coverages, past WP analyses, and engineering judgement.

This analysis is prepared by the Mined Geologic Disposal System (MGDS) Waste Package Development Department (WPDD) to set the capacity (number of assemblies) for the WP designs and the number of different types of WP design types which will be required to handle 100% of the anticipated commercial SNF waste stream. The objective of this evaluation is to determine: 1) the number of different types of WPs needed, 2) the capacity of each WP type, 3) the SNF parameters which provide the limits for each WP type, and 4) provide a reasonable rationale that the selected system of WP types may be capable of disposing 100% of the anticipated commercial SNF waste stream to be shipped to the MGDS repository. This information will then determine the scope of the WP design efforts and provide goals for determining the design basis SNF fuel type for thermal, structural, and neutronics/criticality analysis.

2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the preliminary WP design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the Mined Geologic Disposal System waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (pp. 4, 15, Ref. 5.1). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 evaluation. As determined by an evaluation performed in accordance with QAP-2-0, *Conduct of Activities*, the work performed for this analysis is subject to *Quality Assurance Requirements and Description* (QARD; Ref. 5.3) requirements. As specified in NLP-3-18, this activity is subject to QA controls. Although a documented evaluation is not required by the current revision of QAP-2-0, the WPDD Responsible Manager has selected the applicable procedural controls for this activity commensurate with the work control activity evaluation entitled "Perform Waste Stream Analysis to Determine Design Basis Fuel" (Ref. 5.2).

All design inputs which are identified in this document are for the preliminary stage of the WP design process; all of these design inputs, excluding the codes and standards, will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and, therefore, is not required to be procedurally controlled as TBV (to be verified). In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

3. Method

The goal for the method used is to determine a combination of WP types that will handle all of the commercial SNF assemblies, that will be delivered to the MGDS according to the waste receipt scenarios developed in reference 5.5, with the best repository performance and for the most favorable WP estimated cost. Various systems of WPs, selected based upon engineering judgement, are evaluated with regard to the percentage of the commercial SNF waste stream handled by the WP system. Also, the estimated total fabrication and licensing cost of each WP type in the WP system will be factored into the evaluation. The individual WP types and the WP system selected to be evaluated are based upon the design information provided in reference 5.6 which identifies the important design parameters for WPs (i.e., WP total heat load, assembly reactivity, and performance assessment data for WP degradation) and the estimated cost of the WP system based on the cost information from reference 5.11.

4. Design Inputs

All design inputs which are identified in this document are for the preliminary stage of the design process; all of these design inputs, excluding the codes and standards, will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and therefore is not required to be procedurally controlled as TBV. In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

4.1 Design Parameters

The WP fabrication cost information used in this analysis is documented in reference 5.11 and is provided in Table 4.1-1 for quick reference (see assumption 4.3.1). Additional costs for preparing a Safety Analysis Report (SAR) and a Nuclear Regulatory Commission (NRC) licensing submittal for each individual WP design is estimated to be $10,000,000 and is included in the cost analysis (see assumption 4.3.2).

Table 4.1-1 Waste Package Fabrication Cost Information

SNF Type (Reactor Type)	WP Capacity (# of Assemblies)	Criticality Control	Cost (1996 Dollars)
PWR	21	No Absorbers	$312,000
PWR	21	Borated Stainless Steel Plates	$391,000
PWR	21	B_4C Control Rods	$342,000[2] - $488,000[3]
PWR	12	No Absorbers	$216,000
PWR	12	Borated Stainless Steel Plates	$252,000
PWR	12	B_4C Control Rods	$233,000[2] - $317,000[3]
PWR	12/Long Cavity[1]	No Absorbers	$237,000[4]
PWR	12/Long Cavity[1]	Borated Stainless Steel Plates	$277,000[4]
PWR	12/Long Cavity[1]	B_4C Control Rods	$256,000[2&4] - $348,000[3&4]
PWR	24	No Absorbers	$335,000
PWR	24	Borated Stainless Steel Plates	$433,000
PWR	24	B_4C Control Rods	$378,000[2] - $546,000[3]
BWR	44	No Absorbers	$317,000
BWR	44	Borated Stainless Steel Plates	$422,000
BWR	24	No Absorbers	$247,000
BWR	24	Borated Stainless Steel Plates	$324,000

Notes:
[1] Long Cavity WP design is for the South Texas SNF assembly lengths.
[2] Assumes 4 control rods per SNF assembly.
[3] Assumes 24 control rods per SNF assembly.
[4] Assumes long cavity 12 PWR is 1.0992 times more expensive than the normal length WP for the borated plate option.

The additional cost penalty for any commercial SNF assemblies which are identified as not being able to be placed into any of the WP types for a given scenario will be $50,000 per assembly (see assumption 4.3.8). This will cover any costs of storage for additional aging, additional criticality materials, etc. which may be required to handle these assemblies and serve to penalize any WP system which can not handle 100% of the anticipated waste stream.

The specific MGDS commercial SNF assembly receipt scenarios to be considered were identified in reference 5.5 and the required SNF assembly data was provided as input for this analysis (see assumption 4.3.3). This information specifies the time at which SNF assemblies are received by the MGDS repository facility, the assembly age (i.e., cooling time), assembly burnup (i.e., MWd/MTU), assembly initial average enrichment (i.e., wt% U235), assembly loading (i.e., MTU), assembly type (i.e., Pressurized Water Reactor (PWR) or Boiling Water Reactor (BWR)), and assembly thermal power (i.e., W/MTU) for each MGDS acceptance scenario identified. This information is voluminous and is not repeated here (Ref. 5.5).

4.2 Criteria

The design of individual WPs required for handling commercial SNF assemblies will depend on development of a reasonable rationale to select a system of WP types capable of disposing 100% of the anticipated commercial SNF waste stream. Criteria that relate to the development and design of repository components are derived from the applicable requirements and planning documents. Upper-level systems requirements are provided in the Mined Geologic Repository System Requirements Document (MGDSRD, Ref. 5.10). The requirements flow down to the Engineered Barrier Design Requirements Document (EBDRD, Ref. 5.8) as specific requirements for engineered barrier segment design and the Repository Design Requirements Document (RDRD, Ref. 5.7). The Controlled Design Assumptions Document (CDA, Ref. 5.9) provides guidance for requirements listed in the EBDRD and RDRD which have unqualified or unconfirmed data associated with the requirement. The criteria applicable to the development of WP designs for the MGDS are equivalent to the applicable requirements, interface requirements, and criteria cited in the EBDRD. Specifically, the criticality requirement is provided as EBDRD 3.2.2.6, repository thermal limits are provided in EBDRD 3.7.G, WP compatibility with the repository environment and the contiained waste form requirements are provided in EBDRD 3.7.1.A, EBDRD 3.7.1.B, and EBDRD 3.7.1.2.G, and WP internal structure requirements are provided in EBDRD 3.7.1.3. The EBDRD requirements must be addressed for all WP designs and were specifically addressed in the analysis provided in reference 5.6.

The "TBD", "TBV", and "TBR" items identified in the applicable criteria documents will not be carried to the conclusions of this analysis based on the rationale that the conclusions derived by this analysis are for preliminary design and will not be used as input into documents supporting construction, fabrication, or procurement of specific waste package designs.

Finally, this design analysis is not intended to satisfy the referenced requirements, as identified in this section, in their entirety because this analysis is for the preliminary stage of WP design. The determination of full compliance with the EBDRD requirements will be performed in another design analysis when the WP designs are beyond the preliminary design phase.

4.3 Assumptions

Based on the rationale that the conclusions derived by this analysis are for preliminary design and will not be used as input into documents supporting construction, fabrication, or procurement, a TBD (to be determined) or TBV will not be carried to the conclusions of this analysis.

4.3.1 The WP fabrication cost information provided in Table 4.1-1 is assumed to be representative of the true WP fabrication cost. Reference 5.11 provides cost data which is currently being used by the MGDS program and is considered to be the best available data at this time. The time value of money is not considered in this analysis and is judged to affect the costs for each WP scenario approximately equally. The WP cost values in this analysis are for comparison purposes only and should not be used outside of this analysis. This assumption is based upon engineering judgement. This assumption is used in Section 4.1 and throughout Section 7.

4.3.2 The WP SAR/Licensing cost of $10,000,000 per WP design is assumed to be representative of the true cost for the SAR/Licensing effort. This assumption is based upon engineering judgement and experience of the Lead Design Engineer (LDE) and the originating engineer for this design analysis. This SAR/Licensing cost information for WP designs is the best available data at this time. This assumption is used in Section 4.1 and throughout Section 7.

4.3.3 The specific MGDS commercial SNF assembly receipt scenarios to consider were identified in reference 5.5 and have been developed based upon the best information available to the MGDS program (see also Ref. 5.9; CDA Key 002). The specific SNF assembly receipt scenarios and the associated assembly data from reference 5.5 is assumed to be representative of the range of waste receipt variability that the MGDS can reasonably expect. This assumption is based upon engineering judgement. This assumption is used in Section 4.1 and throughout Section 7.

4.3.4 The use of the fully moderated SNF assembly $k_{infinity}$ as a indicator of the level of criticality control required to maintain a commercial SNF assembly in a subcritical condition is assumed to bound the fully moderated $k_{effective}$ of a WP which is fully loaded with the same commercial SNF assembly. The use of $k_{infinity}$, rather than the $k_{effective}$, for a commercial SNF assembly is conservative due to the neutron leakage term which is not used for $k_{infinity}$. This assumption implies that the enrichment/burnup parameters for a commercial SNF assembly which determines the constant $k_{infinity}$ isopleths are assumed to be the same enrichment/burnup values which determine the $k_{effective}$ isopleth if a detailed WP calculation were performed. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.5 The use of the following equation obtained from page 5-4 of reference 5.6 is assumed to provide representative, but slightly conservative values for PWR SNF assembly $k_{infinity}$ values.

$$k_{infinity} = 1.06-(0.01\cdot b)-(0.002\cdot c)+(0.114\cdot a)+(0.00007081\cdot b^2)+(0.00007565\cdot c^2)-(0.007\cdot a^2)-(0.0002671\cdot b\cdot a)-(0.0001145\cdot b\cdot c)+(0.0002318\cdot c\cdot a)+(0.000009366\cdot b\cdot c\cdot a)$$

Where:
a = initial U235 enrichment in weight percent
b = assembly burnup in GWd/MTU
c = assembly cooling time (i.e., age) in years

The usage and development of this equation for PWR SNF is presented in detail in reference 5.6. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.6 The use of the following equation developed in Attachment II is assumed to provide representative, but slightly conservative values for BWR SNF assembly $k_{infinity}$ values.

$$k_{infinity}=0.92601-(0.012598\cdot b)+(0.19901\cdot a)+(0.0000949922\cdot b^2)-(0.006702\cdot a^2)-(0.001243\cdot b\cdot a)$$

Where:
a = initial U235 enrichment in weight percent
b = assembly burnup in GWd/MTU

The data which forms the basis for this equation was obtained from NRC approved BWR rack analysis documentation and is provided in references 5.4, 5.14, 5.15, and 5.16. The data in these references are documented as bounding $k_{infinity}$ values for BWR assembly designs of various initial enrichments, assembly exposures, and assembly configurations. The equation development is provided in Attachment II. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.7 The WP/repository design and performance parameters documented in reference 5.6 and 5.9 (i.e., Principle Isotope Burnup Credit (CDA, Key 009), the drift emplacement concept (CDA, Key 011), thermal loading of 80 to 100 MTU/acre (CDA, Key 019), criticality methods, WP degradation modes, etc.) are assumed to be representative of the current MGDS repository conditions and provide reasonable indication of the performance requirements for the WP designs in the repository environment. Reference 5.6 provides all references to the CDA (Ref. 5.9) and the specific CDA references are not repeated here. This assumption is based upon engineering judgement. This assumption is used throughout Section 7.

4.3.8 The cost penalty of $50,000 per commercial SNF assembly which is not directly handled by a WP system scenario is assumed to be a representative bounding estimate of the true cost

for requiring an additional option to handle these "non-standard" SNF assemblies (e.g., temporarily storing the assemblies to increase assembly age, designing additional criticality control materials, design modifications to a WP type, etc.). This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used in Section 4.1 and throughout Section 7.

4.3.9 All commercial SNF is assumed to fit into the basic WP SNF basket envelope developed in reference 5.6. There are two notable exceptions which must be accommodated in this analysis: 1) South Texas PWR SNF assemblies are designed for a 14 foot reactor core rather than the standard 12 foot reactor core. The South Texas PWR assemblies fit the standard PWR cross section but will require a longer WP length. 2) Big Rock Point BWR SNF assemblies are designed with an assembly square cross section of 6.52 inches rather than the standard 5.44 inch square cross section. The Big Rock Point Assemblies are also approximately half the length of the standard BWR assembly design.

Clearly, the South Texas PWR SNF will require a new WP design since these assemblies require a longer WP basket envelope and there are not enough of these long assemblies to justify the cost of fabricating all WPs with the additional length. Thus, specific accommodation of a South Texas SNF WP will be included in this analysis in order to capture the additional cost of this WP type. However, additional options to handle the Big Rock Point BWR SNF are available; such as (but not limited to) putting these assemblies into a standard PWR WP. Finally, there is a very small number of Big Rock Point BWR assemblies, and assuming for this analysis that they are handled as part of the standard BWR SNF waste stream will not significantly affect the results of this analysis. This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used throughout Section 7.

4.4 Codes and Standards

Not applicable.

5. References

5.1 *Yucca Mountain Site Characterization Project Q-List*, YMP/90-55Q, REV 4, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).

5.2 "Perform Waste Stream Analysis to Determine Design Basis Fuel," Document Identifier (DI) Number: BB0000000-01717-2200-00029 REV 02, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O).

5.3 *Quality Assurance Requirements and Description*, DOE/RW-0333P REV 6, U.S. DOE OCRWM.

5.4 "Pilgrim Nuclear Power Plant Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-92925, U.S. Nuclear Regulatory Commission Docket Number: 50-293, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.5 CRWMS M&O Interoffice Correspondence LV.WP.TLL.02/97-026, "Transmittal of Preliminary Design Basis Fuel Data," From T.L. Lotz to File, February 10, 1997.

5.6 *Mined Geologic Disposal System Advanced Conceptual Design Report, Volume III of IV, Engineered Barrier Segment/Waste Package*, DI Number: B00000000-01717-5705-00027 REV 00, CRWMS M&O.

5.7 *Repository Design Requirements Document*, YMP/CM-0023, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.8 *Engineered Barrier Design Requirements Document*, YMP/CM-0024, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.9 *Controlled Design Assumptions Document*, DI Number: B00000000-01717-4600-00032 REV 04, CRWMS M&O.

5.10 *Mined Geological Disposal System Requirements Document*, DOE/RW-0404P (DI Number: B00000000-00811-1708-00002 REV 02), U.S. DOE OCRWM.

5.11 CRWMS M&O Interoffice Correspondence LV.WP.JAC.02/97-032, "Waste Package Cost Estimates," From J.A. Cogar to T.L. Lotz, February 13, 1997.

5.12 Software Qualification Report for the Spent Nuclear Fuel Decay Heat Function (SNFDHF) (CSCI: 20026 V1.0), DI Number: 20026-2003 REV 00, CRWMS M&O.

5.13 Software Life Cycle Plan for the Spent Nuclear Fuel Decay Heat Function (SNFDHF) (CSCI: 20026 V1.0), DI Number: 20026-2001 REV 00, CRWMS M&O.

5.14 "Proposed Modification to the Technical Specifications for the Pilgrim Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-93126, U.S. Nuclear Regulatory Commission Docket Number: 93-016, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.15 Lotz, T. L., "ATEA BWR Rack Scoping Analysis", Framatome Technologies Incorporated Document Number: 32-1257226-00, August, 1996.

5.16 "Duane Arnold Nuclear Power Plant Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-92987, U.S. Nuclear Regulatory Commission Docket Number: 50-331, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.17 CRWMS M&O Interoffice Correspondence LV.WP.TLL.04/97-069, "Transmittal of Waste Package Design Configuration Data," From T.L. Lotz to File, April 1, 1997.

6. Use of Computer Software

6.1 Scientific and Engineering Software

The GETHEAT program and its HEAT.DAT data file provided in the Spent Nuclear Fuel Decay Heat Function (SNFDHF) code system (Ref. 5.12) version (V) 1.0 (CSCI: 20026 V1.0) is used in this analysis. GETHEAT program with its HEAT.DAT data file is designed to calculate PWR and BWR SNF decay heat rates given the assembly burnup, decay time (i.e., age), and assembly average initial U235 enrichment. Thus, GETHEAT program is appropriate for use with the WPBIN00a program provided in Attachment I to determine SNF decay heat loads in order to evaluate waste package loading scenarios. The GETHEAT software is executed on a IBM compatible PC with the DOS 6.2 operating system. The software qualification of the GETHEAT software, including problems of the type analyzed in this report, is summarized in the Software Qualification Report for the SNFDHF code system (Ref. 5.12). The GETHEAT evaluations performed for this design analysis are fully within the range of the validation for the GETHEAT software used. Access to and use of the GETHEAT software for this analysis was granted by Software Configuration Management and performed in accordance with the Life Cycle Plan for the SNFDHF code system (Ref. 5.13) and the QAP-SI series procedures. Inputs and outputs to the GETHEAT software are included as attachments as described in the following design analysis.

6.2 Computational Support Software

The percent values of the commercial SNF waste stream handled, the number of WP of each type required, and the number of SNF assemblies not handled by a proposed WP system scenario were generated with the computer code WPBIN00a version (V) 00A and is classified as computational support software. WPBIN00a V00A is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures. WPBIN00a requires the data provided in assumptions 4.3.3, 4.3.5, 4.3.6, and 4.3.7 as inputs. Based upon the data provided in assumption 4.3.3, WPBIN00a determines commercial SNF assembly characteristics from GETHEAT (see Section 6.1), the equation from either assumption 4.3.5 (i.e, PWR SNF) or 4.3.6 (i.e, BWR SNF), and then determines which WP type in a WP scenario (WP scenario is based upon assumption 4.3.7) the SNF assembly can be loaded into and then tallies that assembly to the selected WP type. If the SNF assembly does not meet any of the WP type criteria, then the assembly is tallied into a non-standard SNF bin. Once each assembly in the waste stream has been tallied,WPBIN00a then summarizes the number of each WP type required and prints the final summary table.

The WPBIN00a code listing is provided in Attachment I, the output files with an input listing are listed in Attachment V, and provided in reference 5.17. The WPBIN00a code is simply an automation of a simple data manipulation process which can easily be checked by hand. The data is provided in this analysis and the references for the purpose of performing hand calculation checks. The data manipulation has been checked by hand and will be used in this analysis on that basis. The WPBIN00a code was utilized for the purpose of computational support software as it was intended. The WPBIN00a software was executed on an IBM PC compatible with a DOS 6.2 operating system.

The BWR $k_{infinity}$ data curve fit was performed in Microsoft's EXCEL Version 5.0 and is classified as computational support software. Microsoft's EXCEL Version 5.0 is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures and will not be qualified under the M&O procedures. EXCEL simply provides a framework to automate simple mathematical calculations which can easily be checked by hand or through alternate calculational methods. Based upon the data provided in assumption 4.3.6, EXCEL generates a simple curve via direct equation calculation. Once the proper equation coefficients for the equations are determined, EXCEL summarizes the numeric values at selected data points. The EXCEL spread sheet file is provided as Attachment II. The data points used are provided in this analysis for the purpose of performing hand calculation checks. The data manipulation has been checked by hand and will be used in this analysis on that basis. EXCEL was utilized for the purpose of computational support software as it was intended and it is appropriate for the use of generating a curve given an equation form. The EXCEL software was executed on an IBM PC compatible with a Windows 3.1 operating system.

The presentation graphics provided in Attachment III was generated with the computer code Harvard Graphics Version 2.0 and is classified as computational support software. Harvard Graphics Version 2.0 was executed on a IBM PC compatible with a Windows 3.1 operating system. Harvard Graphics Version 2.0 is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures and will not be qualified under the M&O procedures. Harvard Graphics Version 2.0 simply provides a framework to create a graphical representation of data. No calculation or modification beyond cut and paste operations with tabular data from reference 5.5 and WPBIN00a software was performed in Harvard Graphics.

7. Design Analysis

Previous WPDD efforts have focused upon determining the performance characteristics of a WP with regard to Engineered Barrier System (EBS) and MGDS performance (Ref. 5.6). This involved determining performance requirements for criticality control, heat transfer, shielding, structural strength, and degraded mode performance with a nearly bounding commercial SNF assembly type. Thus, much of the assumed performance requirements and the cost data used in this analysis is based upon these documented results. However, these analyses did not provide the rationale for, nor identify, the required mix of WP types which will need to be licensed in order to cover 100% of the commercial SNF waste stream in an reasonable manner. This analysis is intended to perform this function using the WP performance data summarized in reference 5.6.

7.1 Design Basis Fuel (DBF)

It is likely that the license application for the waste package will be reviewed by the Nuclear Regulatory Commission using criteria similar to those already in place for dry cask storage systems. That is not to say the requirements placed upon the disposal device are the same as for storage casks, but that the topical safety analysis report (SAR) for the waste package should follow the standard format and content established for dry cask storage SARs. The *Standard Review Plan for Dry Cask Storage Systems* (NUREG-1536) states that:

> "Specifications must be provided for the spent fuel to be stored in the cask, such as, but not limited to, type of spent fuel (i.e., Boiling Water Reactor (BWR), Pressurized Water Reactor (PWR), both), maximum allowable enrichment of the fuel prior to any irradiation, burn-up (i.e., megawatt-days/Metric Ton Uranium), minimum acceptable cooling time of the spent fuel prior to storage in the cask (aged at least one year), maximum heat designed to be dissipated, maximum spent fuel loading limit, condition of the spent fuel (i.e., intact assembly or consolidated fuel rods), and the inert atmosphere requirements."

Due to the large variability in SNF characteristics, several separate WP designs will be required to accommodate all of the SNF planned for disposal in the first repository. It could be argued that there is a potential engineering solution to any SNF decay heat or criticality problem such that one design could accommodate all of the SNF assembly types. However, common sense and economics dictate that multiple WP designs be tailored to portions of the waste stream (that is, it is not cost effective to allow the most stressing 10% of the waste stream to drive the design for the other 90%). Therefore, a family of WP designs is required and each individual WP design must have a specifically designated design basis fuel. The purpose of this document is to develop rational WP design and DBF combinations supported by waste stream coverages, past WP analyses, and engineering judgement.

7.2 Waste Acceptance Issues

Due to the uncertainty in waste acceptance parameters, eight waste stream scenarios will be considered (see assumption 4.3.3):

Scenario W1: YFF10_DPC_NoISF_63

Take from reactor spent fuel pool the youngest fuel that is at least 10 years old (YFF10). Take from pool 5 - 10 year old fuel when older pool fuel is gone. Then take from dry storage oldest fuel first; which is stored and shipped using dual purpose canisters (DPC). No interim storage facility is used. Continue for first 63,000 MTUs of SNF.

Scenario W2: YFF10_DPC_ISF_63

Same as scenario W1, except that an Interim Storage Facility (ISF) begins DPC receipt starting in 2003. No SNF is shipped from the ISF to the repository until all of the reactor allocations have been met.

Scenario W3: YFF10_SPC_NoISF_63

Same as scenario W1, except that any dry storage SNF is stored using single purpose canisters (SPC).

Scenario W4: YFF10_SPC_ISF_63

Same as scenario W2, except that DPCs are used for reactor storage and to ship SNF to the ISF for the first two years, then SPCs are used for storage at the ISF.

Scenario W5: OFF_SPC_NoISF_63

Same as scenario W3, except that reactors ship spent fuel based on an oldest fuel first (OFF) strategy. Take from reactor spent fuel pool the oldest fuel first until only 5 year old or younger SNF remains, then take from dry storage oldest fuel first. Continue for first 63,000 MTUs of SNF.

Scenario W6: OFF_SPC_ISF_63

Same as scenario W5, except that DPCs are used for reactor storage prior to 2003 and to ship SNF to the ISF for two years starting in 2003, then SPCs are used for storage at the ISF. No spent fuel is shipped from the ISF to the repository until all of the reactor allocations have been met.

Scenario W7: YFF10_DPC_NoISF_87

Same as scenario W1, except that waste receipt is continued for the full 86,800 MTUs projected to be discharged from the existing reactor facilities (86,800 MTUs is beyond the current statutory limit for a single repository).

Scenario W8: YFF10_DPC_ISF_87

Same as scenario W2, except that waste receipt is continued for the full 86,800 MTUs projected to be discharged from the existing reactor facilities (86,800 MTUs is beyond the current statutory limit for a single repository).

Attachment III provides a graphical summary of each of the commercial waste stream scenarios. The data from reference 5.5 (assumption 4.3.3) was processed by the WPBIN00a software to generate the commercial SNF $k_{infinity}$ values, using the equations from either assumption 4.3.5 (i.e., PWR SNF) or 4.3.6 (i.e., BWR SNF), and SNF assembly heat rates based upon the GETHEAT software (Ref. 5.12). These WPBIN00a output files are listed in Attachment V, and provided in reference 5.17, as files case1.all, case2.all, case3.all, case4.all, case5.all, case6.all, case7.all, and case8.all for waste stream scenarios W1, W2, W3, W4, W5, W6, W7, and W8, respectively. The data was then put into Harvard Graphics to create each cumulative distribution plot and each histogram plot.

Notice that both the PWR (pp. 3, 4; Attachment III) and BWR (pp. 7, 8; Attachment III) $k_{infinity}$ plots show very little variation with respect to the different waste stream scenarios. This indicates that the criticality problem is relatively independent of the details of the waste stream delivery system. Waste stream scenarios W2, W5, and W8 appear to be representative of a lower, middle, and high range of waste stream characteristics with regard to criticality concerns. Waste streams W1, W3, W4, W6, and W7 fall within these three scenarios and will provide similar results.

The SNF assembly initial heat plots for PWR (pp. 1, 2; Attachment III) and BWR (pp. 5, 6; Attachment III) assemblies display a much greater sensitivity to the waste stream delivery system. This characteristic of the waste stream was not unexpected, since SNF assembly heat rates decay fairly quickly with cooling time. However, this makes selecting a WP system more difficult, since at this time each waste stream scenario must be considered as equally likely to be correct. Thus, tailoring a WP system to a specific waste stream scenario to reduce costs is not a realistically viable option. Thus, any WP system which is designed should be set up to handle any of these waste stream scenarios for a reasonable cost.

The data provided in Attachment III show that evaluating waste stream scenarios W2, W3, W5, and W8 will both bound and provide a reasonable estimate of the median for the given variations in waste stream characteristics. These waste stream scenarios will be evaluated further in this analysis.

7.3 Waste Package Performance Issues

The performance characteristics of WPs with regard to containment of waste, efficient use of material (i.e., packing density), criticality safety, thermal performance, predictability of degraded modes, and performance in degraded modes has been documented in analyses performed during the WP conceptual design (Ref. 5.6). These analyses provide a basis with which to determine the best WP design with regard to individual WP performance and the results of the conceptual design will be used to provide the first cut in determining WP SNF assembly capacities and how they should be combined into a WP system capable of emplacing the commercial SNF waste stream (see assumptions 4.3.7 and 4.3.9). The conceptual design efforts showed that the larger capacity WP designs were desirable from a cost and handling perspective, but the largest practical sizes which still meet the repository performance criteria limited the WP designs to capacities of 24 PWR assemblies or 44 BWR assemblies. Larger capacity WP designs will have significant difficulty meeting repository thermal and criticality performance requirements and present structural design difficulties during the degradation phase of the WP performance life (Ref. 5.6).

The conceptual design provides the following ranking for WP performance versus SNF assembly capacity:

Best performance characteristics:	21 PWR assembly capacity 12 PWR assembly capacity 44 BWR assembly capacity 24 BWR assembly capacity
Moderate performance characteristics:	24 PWR assembly capacity

All other WP designs showed significant problems concerning degraded mode performance and efficient use of materials (i.e., packing density). As the internal structures degraded and slumped, only the designs listed above provided predictable geometries, sufficient criticality control, and sufficient structural performance to keep the commercial SNF in an intact form. Thus, only WP systems comprised of the listed WP capacities will be considered in this analysis since these have the highest probability for meeting all of the repository performance criteria (Ref. 5.6).

The 24 PWR assembly capacity WP will be considered in this analysis to determine if it has a large cost advantage over the 21 PWR assembly capacity WP. However, if the cost advantage is not significant, then a WP system comprised of WPs from the best performance characteristics list will be selected instead based on the higher probability for meeting all of the repository performance criteria.

Additional performance constraints are discussed in the following sections.

7.3.1 Thermal Issues

The thermal load on the waste package (and consequently its temperature) is most directly determined by the rate of heat generation. Of course, both heat rate and waste package temperature change with time depending on the total repository thermal loading. However, heat at time of emplacement is the single strongest determining parameter for peak waste package temperature, which is a very important design parameter, constrained by the need to avoid cladding creep and mineral phase transformations at the emplacement drift wall. The performance parameter, heat at emplacement, is primarily a function of age at emplacement and burnup and provides a criteria for distinguishing between assembly thermal categories.

While the WP design basis fuel is specified on a per-assembly basis, the total WP heat load will impact the emplacement drift structures and the surrounding rock. Previous preliminary analyses (Ref. 5.6) have indicated that initial individual WP heat loads of around 18 kW can be tolerated assuming a reference repository thermal loading range of 80 to 100 MTU/acre. It may be possible to accept a higher initial heat, such as 19 kW; however, for other system interface issues, total initial WP heat loads could be limited to lower values (such as the 14.2 kW heat at emplacement limit indicated for the conceptual multi-purpose canister design). Note that the data provided in reference 5.6 show that the 19 kW WP total heat load has a significant risk of not meeting the repository thermal performance criteria for rock media temperatures if thermal loads in the 90 to 100 MTU/acre range are selected. A significant cost advantage must exist for this higher WP heat load to be selected and the additional design risk accepted. To determine the trending and costs with respect to the waste stream, three total WP initial heat loads will be considered: 14.2, 18, and 19 kW. Individual assembly heats have been rounded off to the nearest multiple of 10 watts.

Given the three maximum WP heat load conditions and the data provided in Attachment III, the following WP rated heat load options will be considered. The PWR SNF assembly portion of the waste stream is the most complicated to handle due to the higher heat load per assembly and larger assembly size as compared to the BWR SNF assemblies. The derated WP options are discussed further in Section 7.4. The derated configurations are selected based on maintaining a balanced (i.e., symmetrical) WP loading configuration. WP systems will be based on combinations of these WP types and use the given capacity and thermal rating. Each of the following scenarios is a combination of large and small PWR and BWR WPs, with the largest PWR WP heat total heat load limited to the stated value:

Scenario T1: Three PWR categories with maximum WP heat of 19 kW

Base options (watts)

0 < heat < 900	For 21 PWR (total 18.9 kW)
0 < heat < 900	For 12 PWR (total 10.8 kW)
0 < heat < 790	For 24 PWR (total 19.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

900 < heat < 1030	For 12 PWR (total 12.4 kW)
900 < heat < 1030	For 16 PWR (derated 21, 16.5 kW)
790 < heat < 950	For 20 PWR (derated 24, 19.0 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
1030 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
950 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)

Scenario T2: Two PWR categories with maximum WP heat of 19 kW

Base options (watts)

0 < heat < 900	For 21 PWR (total 18.9 kW)
0 < heat < 900	For 12 PWR (total 10.8 kW)
0 < heat < 790	For 24 PWR (total 19.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

900 < heat < 1370	For 12 PWR (total 16.4 kW)
900 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
790 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Scenario T3: Three PWR categories with maximum WP heat of 18 kW

Base options (watts)

0 < heat < 850	For 21 PWR (total 17.9 kW)
0 < heat < 850	For 12 PWR (total 10.2 kW)
0 < heat < 750	For 24 PWR (total 18.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

850 < heat < 1030	For 12 PWR (total 12.4 kW)
850 < heat < 1030	For 16 PWR (derated 21, 16.5 kW)
750 < heat < 900	For 20 PWR (derated 24, 18.0 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
1030 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
900 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)

Scenario T4: Two PWR categories with maximum WP heat of 18 kW

Base options (watts)

0 < heat < 850	For 21 PWR (total 17.9 kW)
0 < heat < 850	For 12 PWR (total 10.2 kW)
0 < heat < 750	For 24 PWR (total 18.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

850 < heat < 1370	For 12 PWR (total 16.4 kW)
850 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
750 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Scenario T5: Three PWR categories with maximum WP heat of 14.2 kW

Base options (watts)

0 < heat < 670	For 21 PWR (total 14.1 kW)
0 < heat < 670	For 12 PWR (total 8.0 kW)
0 < heat < 590	For 24 PWR (total 14.2 kW)
0 < heat < 320	For 44 BWR (total 14.1 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

670 < heat < 1030	For 12 PWR (total 12.4 kW)
670 < heat < 880	For 16 PWR (derated 21, 14.1 kW)
590 < heat < 710	For 20 PWR (derated 24, 14.2 kW)
320 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
880 < heat < 1370	For 10 PWR (derated 21, 13.7 kW)
710 < heat < 1370	For 10 PWR (derated 24, 13.7 kW)

Scenario T6: Two PWR categories with maximum WP heat of 14.2 kW

Base options (watts)

0 < heat < 670	For 21 PWR (total 14.1 kW)
0 < heat < 670	For 12 PWR (total 8.0 kW)
0 < heat < 590	For 24 PWR (total 14.2 kW)
0 < heat < 320	For 44 BWR (total 14.1 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

670 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
670 < heat < 1370	For 10 PWR (derated 21, 13.7 kW)
590 < heat < 1370	For 10 PWR (derated 24, 13.7 kW)
320 < heat < 520	For 24 BWR (total 12.5 kW)

7.3.2 Criticality Issues

The criticality performance parameter, $k_{infinity}$ (see assumption 4.3.4), and the WP loading scenarios developed for this analysis are based on advanced conceptual design (Ref. 5.6) analysis results. All of the WP designs considered assume that Principal Isotope Burnup Credit will be accepted by the NRC (see assumption 4.3.7). This means that each WP is designed with 5 mm thick carbon steel tubes around the fuel assemblies. When included, the neutron absorber plates are 7 mm thick borated SS-B6A and the absorber control rods are zirconium clad B_4C rods. It is also noted that there is no reason based on criticality potential to derate a WP or use a smaller WP for PWR SNF (i.e., derating for PWRs is only performed for thermal reasons, BWRs are derated as specified above). This is due to the fact that derating for criticality relies on increased neutron leakage to reduce the multiplication factor. However, this effect is reduced significantly when the WP internals degrade and is not sufficient for criticality control in large WPs. Thus, other options, such as control rods, are utilized (see Ref. 5.6).

All SNF assembly $k_{infinity}$ values are determined based upon assumption 4.3.5 or 4.3.6. The basis for each WP rated $k_{infinity}$ limit is provided in reference 5.6. The following WP rated heat load options will be considered. WP systems will be based on combinations of these WP types and use the given capacity and criticality rating.

Scenario C1: Three criticality control categories

Base options

$0 < k_{\infty} < 1.00$	PWR fuel requiring no neutron absorbers in the WP basket
$0 < k_{\infty} < 1.00$	BWR fuel requiring no neutron absorbers in the WP basket

Intermediate options

$1.00 < k_{\infty} < 1.13$	PWR fuel requiring neutron absorber plates in the WP basket
$1.00 < k_{\infty} < 1.37$	BWR fuel requiring neutron absorber plates in the WP basket

Non-Standard Assembly options

$1.13 < k_{\infty} < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.37 < k_{\infty} < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

Scenario C2: Two criticality control categories

Base options

$0 < k_{\infty} < 1.13$	PWR fuel requiring neutron absorber plates in the WP basket
$0 < k_{\infty} < 1.37$	BWR fuel requiring neutron absorber plates in the WP basket

Non-Standard Assembly options

$1.13 < k_{\infty} < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.37 < k_{\infty} < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

Scenario C3: Two criticality control categories (no absorber plate option)

Base options

$0 < k_{\infty} < 1.00$	PWR fuel requiring no neutron absorbers in the WP basket
$0 < k_{\infty} < 1.00$	BWR fuel requiring no neutron absorbers in the WP basket

Non-Standard Assembly options

$1.00 < k_{\infty} < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.00 < k_{\infty} < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

7.4 Waste Package Loading Issues

A secondary purpose of this analysis is to determine the cost effectiveness of derating the base WP option (for thermal reasons) versus utilizing a second smaller capacity waste package for the assemblies that could not be placed in the larger capacity base option disposal device. It is also desirable to investigate the impact of base option WP total capacity on system cost. To bound these possible options, the following loading scenarios are considered (see assumption 4.3.9):

Scenario L1:
- 21 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 44 BWR Base option
- 24 BWR Non-Standard option if needed

Scenario L2:
- 21 PWR Base option
- 16 PWR (derated 21) Intermediate option
- 12 PWR (derated 21) Non-Standard option if needed
- 21 PWR South Texas
- 44 BWR Base option
- 20 BWR (derated 44) Non-Standard option if needed

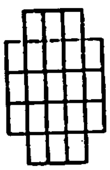
Scenario L3:
- 12 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 24 BWR Base option

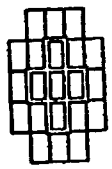
Scenario L4:
- 24 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 44 BWR Base option
- 24 BWR Non-Standard option if needed

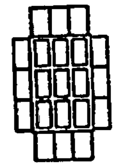
Scenario L5:
- 24 PWR Base option
- 20 PWR (derated 24) Intermediate option
- 12 PWR (derated 24) Non-Standard option if needed
- 24 PWR South Texas
- 44 BWR Base option
- 20 BWR (derated 44) Non-Standard option if needed

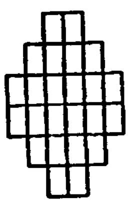
Scenario L6: Same as L5, but using small WP designs for Non-Standard option rather than a derated WP type.

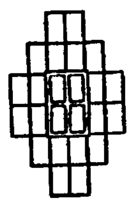
The following graphics depicts each WP Derating Options considered. The center assemblies in each WP are marked as blocked out in the derated WP.

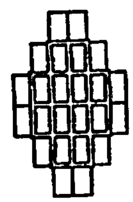

21 PWR

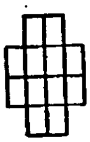

16 PWR
(derated 21)

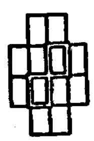

12 PWR
(derated 21)

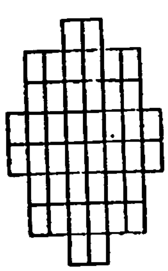

24 PWR

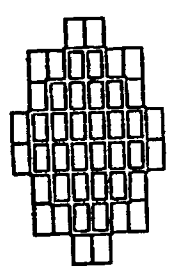

20 PWR
(derated 24)

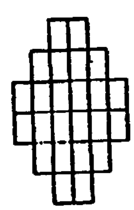

12 PWR
(derated 24)


12 PWR


10 PWR
(derated 12)


44 BWR


20 BWR
(derated 44)


24 BWR

7.5 WP Unit Costs

The WP cost estimates used to determine the economies of differing WP designs are provided in Section 4.1 (see assumptions 4.3.1, 4.3.2, 4.3.8, and 4.3.9). To determine the cost differences between each of the scenario combinations, it is assumed that $10,000,000 is required to perform the design and licensing activities for each WP design option. This cost is a rough estimate used only to demonstrate the cost savings of minimizing the total number of different WP designs to be licensed. Additionally, if a WP system did not directly handle all of the SNF assemblies in the waste stream scenario, a $50,000 per assembly penalty was assessed to the WP system costs.

All cost figures are based upon 1996 dollars and this analysis does not account for the time value of money. The cost figures are used only to evaluate the relative differences between WP system scenarios and will not be representative of the true cost of the WP system. Finally, since at this time each of the waste stream scenarios have an equal probability of occurring, the evaluation of each WP system will be performed on the average cost. The average cost is based upon the total cost of each waste stream scenario equally weighted to determine the average.

7.6 Waste Package System Cases

All of the required data has now been identified in order to perform the WP system evaluations. Section 7.2 specified that the waste stream scenarios W2, W3, W5, and W8 provide a representative range for waste stream variability. Section 7.3 specified the range of WP capacity, WP thermal rating, and WP criticality rating of favorable candidate WP types. Section 7.4 identified the range of candidate WP systems which should be evaluated. Finally, Section 7.5 provides the cost basis with which to help evaluate the relative differences between each WP system.

The evaluation process is begun by selecting a WP loading scenario (i.e., L1, L2, L3, L4, L5, or L6), then selecting a WP thermal strategy (i.e., T1, T2, T3, T4, T5, or T6), and finally selecting a criticality strategy (i.e., C1, C2, or C3). Each combination of these three items determines the WP types which comprise a WP system. Each WP system is then evaluated with each of the four selected waste stream scenarios (i.e., W2, W3, W5, and W8) to determine the number of each WP type, the number of assemblies which can not be put into a WP type, and the associated costs. Thus, a matrix of WP systems to be considered for evaluation is then created.

However, some observations can be made concerning the WP systems generated:

1) Criticality scenario C3 should be the most expensive due to the increased criticality control material costs.

2) Thermal scenarios T5 and T6 increase the number of WP required since the low WP total heat load limit of 14.2 kW will force the use of smaller WP capacities. This will either

increase cost or increase the number of assemblies not handled by the WP system. Given the data in reference 5.6, there is no justification limiting the WP total heat load to a value below 18 kW.

3) Thermal scenarios T1 and T2 will not reduce the number of the non-standard WP type required enough to provide sufficient incentive to accept the additional risks of not meeting repository thermal performance criteria. Given the data in Attachment III, an increase in base WP thermal rating from 850 W/assembly to 900 W/assembly will alter the cumulative coverage results by less than 5%. Thus, there is little incentive to select a high risk WP design.

4) Derating large WPs for non-standard SNF assemblies is generally not cost effective unless there are very few SNF assemblies which the base WP design can not handle. Generally, given the constraints provided in Section 7.3 and the data in Attachment III, this situation will not occur.

Based on these observations, the WP system matrix for evaluation can be reduced to those WP systems which may provide some benefit. A few additional cases to confirm the observations used to reduce the evaluation matrix will also be included. Table 7.5-1 lists all of the WP system cases evaluated in this analysis.

Table 7.5-1 WP System Cases Evaluated

L1-T1-C1	L1-T1-C2	L1-T1-C3	L1-T2-C1	L1-T2-C2	L1-T2-C3	L1-T3-C1
L1-T3-C2	L1-T3-C3	L1-T4-C1	L1-T4-C2	L1-T4-C3	L1-T5-C1	L1-T6-C1
L2-T3-C1	L2-T4-C1	L3-T4-C1	L4-T4-C1	L5-T3-C1	L5-T4-C1	L6-T4-C1

7.7 Resulting Coverages

The tables provided in Attachment IV indicate the bins resulting from the loading, thermal, criticality, and waste stream scenarios described above. These results were generated with the WPBIN00a code in Attachment I and all input/output files are listed in Attachment V (see Ref. 5.17). For example, the first table (page 1, Attachment IV) indicates the WP designs and corresponding thermal and criticality ratings for the WP system for case L1-T1-C1 (loading scenario L1, thermal scenario T1, and criticality scenario C1). Each table reports the resulting coverages for each WP system for waste stream scenarios W2, W3, W5, and W8 and the calculated costs. Number (#) indicates the number of filled (last one partially filled) waste packages, or the number of leftover assemblies that could not be placed into any of the WP types for that WP system. Percentages indicate the percentage amount of assemblies held by each waste package type calculated for PWRs and BWRs separately.

Examining the results, the lowest average cost (those less than $3.200 billion) WP systems are:

1) L1-T2-C1	Page 4, Attachment IV	$3.101 Billion
2) L6-T4-C1	Page 21, Attachment IV	$3.123 Billion
3) L4-T4-C1	Page 18, Attachment IV	$3.140 Billion
4) L1-T4-C1	Page 10, Attachment IV	$3.156 Billion
5) L1-T1-C1	Page 1, Attachment IV	$3.163 Billion
6) L1-T3-C1	Page 7, Attachment IV	$3.171 Billion
7) L2-T3-C1	Page 15, Attachment IV	$3.198 Billion

Notice that the highest cost WP systems were those using the criticality scenario C3; therefore, reducing the number of these cases was justified. Generally, criticality scenario C1 was less costly than C2; however, C2 provides one base WP design which covers 90% or more of the total waste stream. The criticality scenario C2 also provides some additional margin for misloaded WP types and a smaller number of WP types required. However, the cost benefit of criticality scenario C1 is attractive if a viable WP system can be created with it.

The observations made in Section 7.6 concerning the thermal scenarios T5 and T6 were shown to be accurate. These WP systems were among the higher cost options. Also, those WP systems which utilized derated WP types generally required very few if any of the derated WPs and were generally higher cost WP systems. This point is illustrated by comparing cases L5-T4-C1 (p. 20, Attachment IV) and L6-T4-C1 (p. 21, Attachment IV) which differed only in the use of derated large WP versus using small WP designs. The WP system which depended upon derated WP types was the higher cost system.

The lowest four average cost WP systems differ on cost by 2% or less. The lowest cost WP system has a maximum WP total heat load of 19 kW. As discussed in Section 7.3.1, this presents a significant risk to the repository thermal performance goals as long as a high thermal loading strategy is to be proposed for NRC license. An estimated 2% reduction in WP costs is not significant enough to warrant accepting the risk of repository and/or a WP redesign effort.

The next two lowest cost WP systems are dependent upon a 24 PWR assembly capacity WP design. As discussed in Section 7.3, this WP design has a performance deficiency with regard to WP degraded mode performance when compared to the other WP types. The fourth lowest cost WP system is comprised of WP types which have been determined to have the best performance characteristics. Each of these three WP systems (items 2, 3, and 4 in the cost list) are based upon a WP thermal rating of 18 kW or less (i.e., thermal scenario T4), the criticality scenario C1, and are low risk for not meeting WP performance requirements on these points. The two low cost 24 PWR WP systems (loading scenarios L4 and L6) differ in cost by 1% or less from the 21 PWR WP system (loading scenario L1). An estimated 1% reduction in WP costs is not significant enough to warrant accepting the risk of repository and/or a WP redesign effort.

Thus, the best WP system to handle the waste stream variability and provide a high probability for meeting all of the repository WP performance criteria is the L1-T4-C1 WP system. Table 7.7-1 summarizes the WP system components and the waste stream coverages for each WP type. All of the WP types provided in Table 7.7-1are requried in order to emplace 100% of the commercial SNF waste stream in the repository.

Table 7.7-1 WP System L1-T4-C1 Waste Stream Coverage

Case L1-T4-C1		Heat Range (W)		Criticality Range		Coverage Range	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1375 to 1835	26.9 to 40.6%
21 PWR - absorber plates criticality - p1	2	0	850	1.00	1.13	2399 to 3596	53.1% to 58.1%
21 PWR - absorber rods (no abs. plates) criticality - p2	3	0	850	1.13	1.45	119 to 257	2.6% to 4.1%
12 PWR - no absorber thermal - p1	4	850	1370	0.00	1.02	80 to 850	1.0% to 7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150 to 272	1.9% to 2.5%
44 BWR - no absorber base thermal & criticality	6	0	400	0.00	1.00	695 to 997	24.6% to 30.3%
44 BWR - absorber plates criticality - b1	7	0	400	1.00	1.37	1942 to 2704	68.2% to 74.6%
24 BWR - thick absorber plates thermal - option b1 criticality - b2	8	0	520	0.00	1.54	40 to 197	0.8% to 2.8%
Total WP Production Costs:		$3.156B Ave.				$2.873B to $4.020B	

8. Conclusions

As identified in Sections 2 and 4, this analysis is based on unqualified/unconfirmed input data and use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

This analysis is prepared by the Mined Geologic Disposal System Waste Package Development Department to set the capacity of the WP designs and the number of different types of WP design types which will be required to handle 100% of the anticipated commercial SNF waste stream. The objective of this evaluation is to determine: 1) the number of different types of WP needed, 2) the capacity of each WP type, 3) the SNF parameters which provide the limits for each WP type, and 4) provide a reasonable rationale that the selected system of WP types may be capable of disposing 100% of the anticipated commercial SNF waste stream to be shipped to the MGDS repository. This information will then determine the scope of the WP design efforts and provide goals for determining the design basis SNF fuel type for thermal, structural, and neutronics/criticality analysis.

The selected design basis WP system configuration is presented in Table 8-1 and the rationale supporting this selection is provided in Sections 7.2 through 7.7. Note, the 12 PWR assembly WP type can be designed to accept PWR assemblies with a 1500 W/assembly heat rate or less given a total WP heat load limit of 18 kW. This change will not significantly affect the WP coverage for the WP system reported in Table 8-1 and will provide additional capacity to handle non-standard PWR SNF assemblies. This is the WP system which is recommended for WP design efforts.

All of the WP types listed in Table 8-1 are requried in order to emplace 100% of the commercial SNF waste stream in the repository. Thus, all of the objectives of this design analysis have been met.

Table 8-1 Design Basis WP System Configuration Waste Stream Coverage

Case L1-T4-C1 (See Section 7.7) WP Types:	ID:	Heat Range (W)		Criticality Range		Coverage Range	
		Hmin	Hmax	k_min	k_max	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1375 to 1835	26.9 to 40.6%
21 PWR - absorber plates criticality - p1	2	0	850	1.00	1.13	2399 to 3596	53.1% to 58.1%
21 PWR - absorber rods (no abs. plates) criticality - p2	3	0	850	1.13	1.45	119 to 257	2.6% to 4.1%
12 PWR - no absorber thermal - p1	4	850	1370	0.00	1.02	80 to 850	1.0% to 7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150 to 272	1.9% to 2.5%
44 BWR - no absorber base thermal & criticality	6	0	400	0.00	1.00	695 to 997	24.6% to 30.3%
44 BWR - absorber plates criticality - b1	7	0	400	1.00	1.37	1942 to 2704	68.2% to 74.6%
24 BWR - thick absorber plates thermal - option b1 criticality - b2	8	0	520	0.00	1.54	40 to 197	0.8% to 2.8%

9. Attachments

Attachments to this design analysis are summarized in Table 9-1. Each attachment is identified by a specific number, file name, date of file, and number of pages.

Table 9-1 List of Attachments

Attachment Number	Description	Date	Number of Pages
I	WPBIN00a Program source code listing (File Name: WPBIN00A.CPP)	2/13/97	5
II	BWR assembly $k_{infinity}$ data curve fit (File Name: BWRKINF.FIT)	2/19/97	4
III	Waste stream data plots for thermal and criticality parameters (File Name: WADATA.GPH)	2/20/97	8
IV	WP system coverage and costs table summaries (File Name: WPCOVER.TBL)	2/27/97	21
V	WPBIN00a input/output files stored on magnetic media (File Name: WADATA.TPE; see reference 5.17)	2/21/97	2

```
/*wpbin00a.cpp Program to tabulate statistics according to a standard,
*regular, set of bins, or a special set of bins defined by limits on
*a set of records.
*This program uses the verified routines in for computing assembly
*heat, the object modules for which are incorporated in the link
*command, as described below.
*The command for compiling only is \msvc\bin\cl /c /FPi87 /AH wpbin00a.cpp
*The command for linking is
  \msvc\bin\link wpbin00a.obj heatmdh.obj gethtmdh.obj,,,,;
*The executable will be wpbin00a.exe      */

#include <string.h>
#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <malloc.h>
#include <string.h>
#include <ctype.h>
#define MAIN
#include "heat.h"
#define YEARS 40
#define CRITS 85
#define BHEATS 100
#define PHEATS 200
#define MAXBINS 20
#define FIRSTPYR 2010

int stdhbin(char,float),stdcbin(float),spcbin(int,char,float,float);
float getfloat(char*,int,int);
float mcritsp[CRITS]={0},mheatsp[PHEATS]={0},mcumhp[PHEATS]={0},
    mcumcp[CRITS]={0},mcritsb[CRITS]={0},mheatsb[BHEATS]={0},
    mcumhb[BHEATS]={0},mcumcb[CRITS]={0},
    mbins[MAXBINS][YEARS];
long int count=0,ntotalb=0,ntotalp=0,nobins[5]={0};
//Heat h;               // Use this only for Quickwin application
int getint(char*,int,int),ncount=0,bincap[MAXBINS];
FILE *ferr;
long int ncritsp[CRITS]={0},nheatsp[PHEATS]={0},ncumhp[PHEATS]={0},
    ncumcp[CRITS]={0},ncritsb[CRITS]={0},nheatsb[BHEATS]={0},
    ncumhb[BHEATS]={0},ncumcb[CRITS]={0},assybpyr[YEARS]={0},
    nbins[MAXBINS][YEARS],npkgs[MAXBINS][YEARS],assyppyr[YEARS]={0},
    totalassy[MAXBINS]={0};
float minheat[MAXBINS],maxheat[MAXBINS],mink[MAXBINS],
        maxk[MAXBINS],mtupyr[YEARS]={0},mobins[5]={0},
        totalmtu[MAXBINS]={0},totalpkg[MAXBINS]={0};
char brectype[MAXBINS];

void main()
{int i,j,k,ndyr,npyr,yr,m,na,nh,nk,lastpyr=0,timelimit,atype,
  nbinrecs,ndx;
long int gtotalassy=0;
float age,b,heat,w,a,c,cumheat=0,mtupassy,avage=0,
      gtotalmtu=0,
```

```
      kinf,cumcrit=0, wtotalb=0,wtotalp=0,youngtotal=0,gtotalpkg=0;
  FILE *fout,*find,*finp;
  char buffer[300],type,inname[13],outname[13],title[50],rname[15],
    subtitle[50],outchar[3]={'b','p','s'};
  if ((finp=fopen("wpbin00a.in","r"))==NULL)
   {printf("Can't open input parameter file\n");exit(0);}
  fgets(buffer,100,finp); /*readthrough labels*/
  fgets(buffer,100,finp);
  sscanf(buffer,"%d %s %s %s %d",&nbinrecs,inname,outname,title,&timelimit);
  fgets(buffer,100,finp); //readthrough more labels
  for(i=0;i<nbinrecs;i++)
   {fgets(buffer,100,finp);
   sscanf(buffer,"%c %d %f %f %f %f\n",&brectype[i],&bincap[i],
     &minheat[i],&maxheat[i],&mink[i],&maxk[i]);}
  if ((find=fopen(inname,"r"))==NULL)
   {printf("Can't open input data file %s\n",inname);exit(0);}
  fout=fopen(outname,"w");
  ferr=fopen("junk.out","w");
  while(fgets(buffer,300,find)!=NULL)
   {w=getfloat(buffer,21,10);
   b=getfloat(buffer,51,10);
   ndyr=getint(buffer,71,8);
   npyr=getint(buffer,287,4);
   type=tolower(buffer[123]);
   na=getint(buffer,31,10);
   a=getfloat(buffer,41,10);
   strncpy(rname,buffer+1,11);
   rname[11]='\0';
   if((na>0)&&(npyr<=timelimit)&&(npyr>0)&&((type=='p')||(type=='b')))
     {j=npyr-ndyr;
     yr=npyr-FIRSTPYR;
     mtupyr[yr]+=w;
     if(type=='b')assybpyr[yr]+=na;
     else assyppyr[yr]+=na;
     if(j<10)
      {fprintf(ferr,"age=%d , mass= %f\n",j,w);
      youngtotal+=na;}
     if(npyr>lastpyr)lastpyr=npyr;
     avage+=na*j;
     j=(j>=YEARS)?YEARS-1:j;
     j=(j<1)?1:j;
     mtupassy=w/na;
     heat=mtupassy*h.GetHeat((float)j,(type=='p'?1:0),b,a);
     c=(j>40)?40:(float)j;
     if(type=='b')
      {ntotalb+=na;
      wtotalb+=w;}
     else
      {ntotalp+=na;
      wtotalp+=w;}
     b/=1000;
     if(type=='b')
      {kinf=.92601-.012598*b+.19901*a+9.49922e-5*b*b-.006702*a*a-.001243*a*b;
```

```
    if((kinf>1.4)||(b<5))fprintf(ferr,"Nassy=%d burnup=%.2f kinf=%.3f Enrch=%.2f Dschg=%d %s\n",
         na,b,kinf,a,ndyr,rname);}
   else
    kinf=1.06-.01*b-.002*c+.114*a+.00007081*b*b+.00007565*c*c
      -.007*a*a-.0002671*b*a-.0001145*b*c+.0002318*c*a+
       .000009366*b*c*a;
   if(nbinrecs==0)
    {if(type=='b')
      {ncritsb[stdcbin(kinf)]+=na;
      nheatsb[stdhbin(type,heat)]+=na;
      mcritsb[stdcbin(kinf)]+=w;
      mheatsb[stdhbin(type,heat)]+=w;}
     else
      {ncritsp[stdcbin(kinf)]+=na;
      nheatsp[stdhbin(type,heat)]+=na;
      mcritsp[stdcbin(kinf)]+=w;
      mheatsp[stdhbin(type,heat)]+=w;}}
    else
     {if(strcmp(rname,"SOUTH TEXAS")==0) type='s';
     ndx=spcbin(nbinrecs,type,heat,kinf);
     nbins[ndx][yr]+=na;
     mbins[ndx][yr]+=w;}}}
  printf("Total assy %ld  Avg age %f  MTU B %f  MTU P %f  Final yr %d\n",
    ntotalp+ntotalb,avage/(ntotalp+ntotalb),wtotalb,wtotalp,lastpyr);
  fprintf(fout,"%s\n",title);
  if(nbinrecs==0) strcpy(subtitle,"Standard Table");
  else sprintf(subtitle,"%d %s",nbinrecs,"Bins");
  fprintf(fout,"%s\n",subtitle);
  if(nbinrecs==0)
   {ncumhb[0]=nheatsb[0];
   for(i=1;i<BHEATS;i++) ncumhb[i]=nheatsb[i]+ncumhb[i-1];
   fprintf(fout,"\n\nBWR Heat Percentiles\n");
   fprintf(fout,"%10s %10s %10s %10s\n",
        "Watts/Assy"," Assy","Cum Assy","Percent");
   for(i=0;i<BHEATS-1;i++) fprintf(fout,"%10d %10ld %10ld %10.2f\n",
     (i+1)*10,nheatsb[i],ncumhb[i],(float)ncumhb[i]*100/ntotalb);
   fprintf(fout,"%10s %10ld %10ld %10.2f\n",
     "Above",nheatsb[BHEATS-1],ncumhb[BHEATS-1],
     (float)ncumhb[BHEATS-1]*100/ntotalb);
   fprintf(fout,"\n\nBWR Kinf Percentiles\n");
   fprintf(fout,"%12s %12s %12s %12s\n","    Kinf","    Assy"," CumAssy", "Percent");
   ncumcb[0]=ncritsb[0];
   for(i=1;i<CRITS;i++) ncumcb[i]=ncritsb[i]+ncumcb[i-1];
   for(i=0;i<CRITS-1;i++)
     {kinf=((float)i+1+75)/100;
     fprintf(fout,"%12.3f %12ld %12ld %12.2f\n",kinf,ncritsb[i],
                ncumcb[i],(float)ncumcb[i]*100/ntotalb);}
   fprintf(fout,"%12s %12ld %12ld %12.2f\n","Above",ncritsb[CRITS-1],
                ncumcb[CRITS-1],(float)ncumcb[CRITS-1]*100/ntotalb);
   ncumhp[0]=nheatsp[0];
   for(i=1;i<PHEATS;i++) ncumhp[i]=nheatsp[i]+ncumhp[i-1];
   fprintf(fout,"\n\nPWR Heat Percentiles\n");
   fprintf(fout,"%10s %10s %10s %10s\n",
```

```
  "Watts/Assy"," Assy","Cum Assy","Percent");
 for(i=0;i<PHEATS-1;i++) fprintf(fout,"%10d %10ld %10ld %10.2f\n",
  (i+1)*10,nheatsp[i],ncumhp[i],(float)ncumhp[i]*100/ntotalp);
 fprintf(fout,"%10s %10ld %10ld %10.2f\n",
  "Above",nheatsp[PHEATS-1],ncumhp[PHEATS-1],
  (float)ncumhp[PHEATS-1]*100/ntotalp);
 fprintf(fout,"\n\nPWR Kinf Percentiles\n");
 fprintf(fout,"%12s %12s %12s %12s\n","    Kinf","    Assy"," CumAssy", "Percent");
 ncumcp[0]=ncritsp[0];
 for(i=1;i<CRITS;i++) ncumcp[i]=ncritsp[i]+ncumcp[i-1];
 for(i=0;i<CRITS-1;i++)
  {kinf=((float)i+1+75)/100;
  fprintf(fout,"%12.3f %12ld %12ld %12.2f\n",kinf,ncritsp[i],
          ncumcp[i],(float)ncumcp[i]*100/ntotalp);}
 fprintf(fout,"%12s %12ld %12ld %12.2f\n","Above",ncritsp[CRITS-1],
          ncumcp[CRITS-1],(float)ncumcp[CRITS-1]*100/ntotalp);
 fprintf(fout,"\n\n%10s%10s%10s%10s\n","Year","MTU","B Assy","P Assy");
 for(i=0;i<=timelimit-FIRSTPYR;i++) fprintf(fout,"%10d%10.2f%10ld%10ld\n",
  i+FIRSTPYR,mtupyr[i],assybpyr[i],assyppyr[i]);
 fprintf(fout,"\n\nAverage age = %7.3f\n",avage/(ntotalb+ntotalp));}
else
 {for(i=0;i<nbinrecs;i++)
  {fprintf(fout,"\n\n\nType=%c Cap=%d Hmin=%.1f Hmax=%.1f Kmin=%.2f Kmax=%.2f\n\n",
    brectype[i],bincap[i],minheat[i],maxheat[i],mink[i],maxk[i]);
  fprintf(fout,"%12s%12s%12s%12s\n","Year","Num_Assy","Num_Pkgs","MTU");
  for(j=0;j<=lastpyr-FIRSTPYR;j++)
   {totalassy[i]+=nbins[i][j];
   totalmtu[i]+=mbins[i][j];
   totalpkg[i]+=(float)nbins[i][j]/bincap[i];
   fprintf(fout,"%12d%12ld%12.2f%12.2f\n",j+FIRSTPYR,nbins[i][j],
     (float)nbins[i][j]/bincap[i],mbins[i][j]);}
  gtotalassy+=totalassy[i];
  gtotalpkg+=totalpkg[i];
  gtotalmtu+=totalmtu[i];
  fprintf(fout,"\n%12s%12ld%12.2f%12.2f\n",
    "Bin Total",totalassy[i],totalpkg[i],totalmtu[i]);}
 for(i=0;i<3;i++)
  {for(j=0;j<=timelimit-FIRSTPYR;j++) nobins[i]+=nbins[nbinrecs+i][j];
  for(j=0;j<=timelimit-FIRSTPYR;j++) mobins[i]+=mbins[nbinrecs+i][j];
  gtotalassy+=nobins[i];
  gtotalmtu+=mobins[i];}
 fprintf(fout,"\n\nSummary Table\n");
 fprintf(fout,"%10s%10s%10s%10s%10s%10s\n","Type","Cap","Num_Assy",
   "PctType","Num_Pkg","MTU");
 for(i=0;i<nbinrecs;i++)
  fprintf(fout,"%10c%10d%10ld%10.2f%10.2f%10.2f\n",brectype[i],
   bincap[i],totalassy[i],
   (float)totalassy[i]*100/(brectype[i]=='b'?ntotalb:ntotalp),
   totalpkg[i],totalmtu[i]);
 for(i=0;i<3;i++)
  fprintf(fout,"%10c%10d%10ld%10.2f%10.2f%10.2f\n",outchar[i],
   1,nobins[i],(float)nobins[i]*100/(i==0?ntotalb:ntotalp),
   (float)nobins[i],mobins[i]);
```

```
 fprintf(fout,"\n%10s%20ld%20.2f%10.2f\n","Totals",gtotalassy,
      gtotalpkg,gtotalmtu);}
printf("Done \n");}

int stdhbin(char t, float ht)
{int n;
n=ht/10;
if((10*n-ht)==0)n--;
if(n<0) n=0;
else
 {if (t=='b') if(n>BHEATS-1) n=BHEATS-1;
 else if(n>PHEATS-1) n=PHEATS-1;}
return n;}

int stdcbin(float k)
{int n;
n=(int)(100*k-75);
if((100*k-75-n)==0)n--;
if(n<0) n=0;
 else if(n>CRITS-1) n=CRITS-1;
return n;}

int spcbin(int num,char t,float ht, float k)
{int found=0,i=0;
while((found==0)&&(i<num))
 {if((brectype[i]==t)&&
   (ht>minheat[i])&&(ht<=maxheat[i])&&
   (k>mink[i])&&(k<=maxk[i])) found=1;
 i++;}
if(found==1)return(i-1);
else
 {fprintf(ferr,"No bin for %c %f %f\n",t,ht,k);
 if(t=='p') num++;   //default adds 0 for t=='b'
 else if(t=='s') num+=2;
 return num;}}

float getfloat(char* string, int start, int length)
{char temp[20];
int i,j;
for(i=start;i<start+length;i++) temp[i-start]=string[i];
temp[length]='\0';
return(atof(temp));}

int getint(char* string, int start, int length)
{char temp[20];
int i,j;
for(i=start;i<start+length;i++) temp[i-start]=string[i];
temp[length]='\0';
return(atoi(temp));}
```

Feb 19 1997 Filename: bwrKinf.fir BBAA00000-01717-0200-00017 REV00 Attachment II - p.1

BWR Kinf Curve Versus Initial U235 Enrichment

Assembly Average Burnup GWd/MTU	Lattice Average Initial E: 2.00%	Lattice Average Initial E: 2.50%	Lattice Average Initial E: 3.00%	Lattice Average Initial E: 3.50%	Lattice Average Initial E: 4.00%	Lattice Average Initial E: 4.50%
0	1.072	1.122	1.169	1.205	1.242	1.279
5	1.131	1.186	1.229	1.265	1.301	1.338
7.5	1.165	1.218	1.257	1.297	1.334	1.368
8.5	1.168					
10	1.148	1.235	1.283	1.333	1.366	1.398
12.5	1.122	1.202	1.270	1.347	1.389	1.426
15	1.094	1.173	1.241	1.310	1.381	1.433
17.5	1.061	1.140	1.208	1.277	1.348	1.401
20	1.034	1.108	1.173	1.240	1.311	1.365
25	0.982	1.105	1.114	1.177	1.242	1.290
30	0.927	0.995	1.054	1.115	1.178	1.225
35	0.882	0.945	1.000	1.056	1.114	1.157
40	0.845	0.904	0.955	1.007	1.061	1.100
45	0.809	0.866	0.915	0.965	1.017	1.055
50	0.782	0.835	0.880	0.927	0.975	1.010
55	0.754	0.806	0.850	0.895	0.942	0.976
60		0.781	0.828	0.868	0.911	0.942

Gd_2O_3 influenced range.

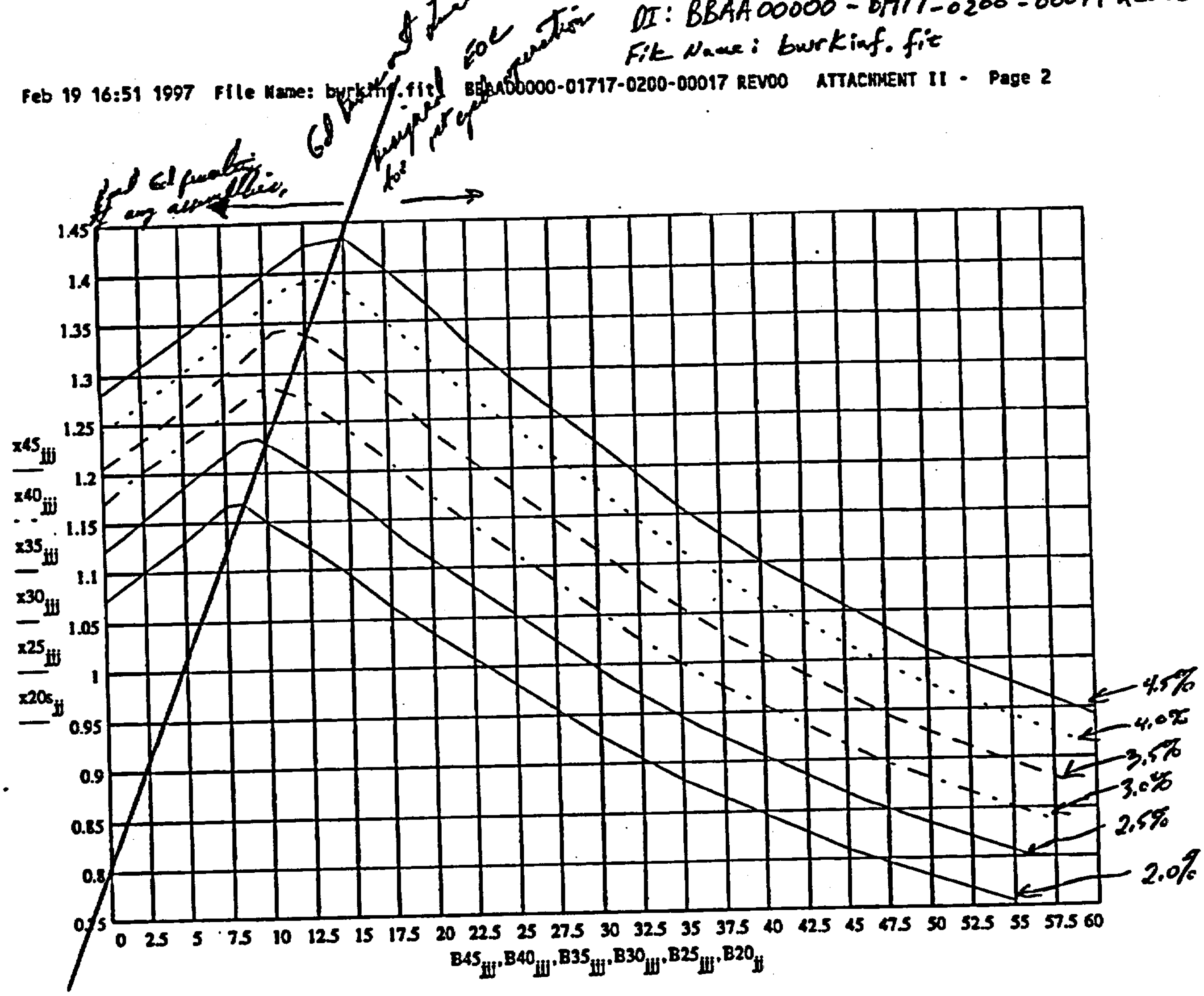
After Gd_2O_3 burnout range

Notes:
1) Curves are bounding with regard to assembly array and Gd2O3/U loading.
2) Curves are for time of discharge; use is conservative with if no cooling time is applied.
3) All values are based upon Holtec, Siemens, and ATEA rack designs for GE and Siemens BWR Fuel assmebly designs (i.e., from NRC license submittal data).
4) Gd burnout for all designs is in the 7.5 to 15 GWd/MTU burnup range, which is the designed end of first cycle. Any item to the left of the curve peak will need a GD penalty applied.

Data in table is from references 5.4, 5.14, 5.15, and 5.16. These values are all NRC reviewed values which are bounding for BWR assembly designs for each Burnup/U235 enrichment pair.

NOTE:
All hand written items are the work of the document originator.

DI: BBAA00000 - 01717-0200-00017 REV00
File Name: burkinf.fit



Graphical representation of the data in Table from page 1 of Attachment II. The design Gd burnout (i.e. end of cycle 1) is ~~shown~~ shown on the plot. The curve fit is to focus on the values to the right of ~~this~~ the Gd burnout line.

TW 2/19/97

BWR Kinf Curve Versus Initial U235 Enrichment

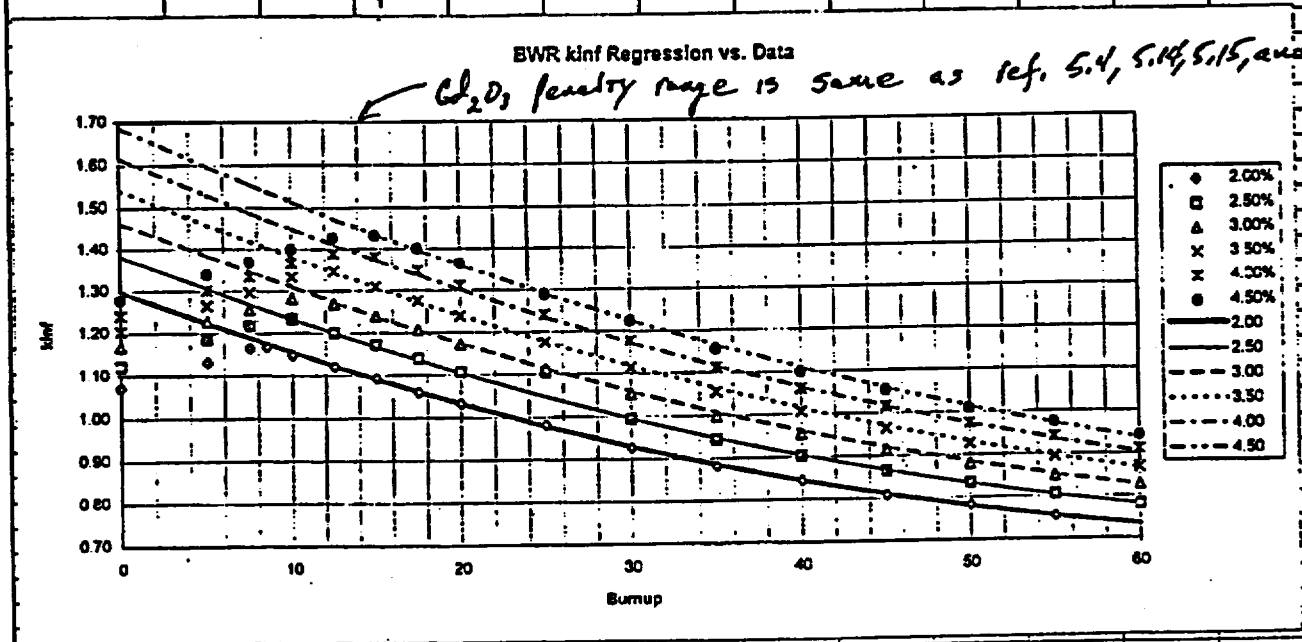
Data (ref. 5.4, 5.14, 5.15, 5.16) — Fit (Equation Values)

Assembly Average Burnup GWd/MTU	Data: Lattice Average Initial E: 2.00%	Data: Lattice Average Initial E: 2.50%	Data: Lattice Average Initial E: 3.00%	Data: Lattice Average Initial E: 3.50%	Data: Lattice Average Initial E: 4.00%	Data: Lattice Average Initial E: 4.50%	Fit: Lattice Average Initial E: 2.00	Fit: Lattice Average Initial E: 2.50	Fit: Lattice Average Initial E: 3.00	Fit: Lattice Average Initial E: 3.50	Fit: Lattice Average Initial E: 4.00	Fit: Lattice Average Initial E: 4.50
0	1.07	1.12	1.17	1.21	1.24	1.28	1.30	1.38	1.46	1.54	1.61	1.69
5	1.13	1.19	1.23	1.27	1.30	1.34	1.22	1.31	1.38	1.46	1.53	1.60
7.5	1.17	1.22	1.26	1.30	1.33	1.37	1.19	1.27	1.35	1.42	1.49	1.55
8.5	1.17						1.18	1.26	1.33	1.40	1.47	1.54
10	1.15	1.24	1.28	1.33	1.37	1.40	1.16	1.23	1.31	1.38	1.45	1.51
12.5	1.12	1.20	1.27	1.35	1.39	1.43	1.12	1.20	1.27	1.34	1.41	1.47
15	1.09	1.17	1.24	1.31	1.38	1.43	1.09	1.17	1.24	1.31	1.37	1.43
17.5	1.06	1.14	1.21	1.28	1.35	1.40	1.06	1.14	1.21	1.27	1.34	1.40
20	1.03	1.11	1.17	1.24	1.31	1.37	1.03	1.11	1.17	1.24	1.30	1.36
25	0.98	1.11	1.11	1.18	1.24	1.29	0.98	1.05	1.11	1.18	1.23	1.29
30	0.93	1.00	1.05	1.12	1.18	1.23	0.93	1.00	1.06	1.12	1.17	1.23
35	0.88	0.95	1.00	1.06	1.11	1.16	0.89	0.95	1.01	1.06	1.12	1.17
40	0.85	0.90	0.96	1.01	1.06	1.10	0.85	0.91	0.96	1.01	1.06	1.11
45	0.81	0.87	0.92	0.97	1.02	1.06	0.81	0.87	0.92	0.97	1.02	1.06
50	0.78	0.84	0.88	0.93	0.98	1.01	0.78	0.83	0.88	0.93	0.97	1.01
55	0.75	0.81	0.85	0.90	0.94	0.98	0.75	0.81	0.85	0.90	0.94	0.97
60		0.78	0.83	0.87	0.91	0.94	0.73	0.78	0.83	0.87	0.90	0.94

Gd_2O_3 penalty range

Fit range

Notes:
1) Curves are bounding with regard to assembly array and Gd2O3/U Loading.
2) Curves are for time of discharge; Use is conservative with if no cooling time is applied
3) All values are based upon Holtec, Siemens, and ATEA rack designs for GE and Siemens BWR Fuel assmebly designs. (i.e., from NRC license submittal data.)
4) Gd burnout for all designs is in the 7.5 to 15 GWd/MTU burnup range, which is the designed end of first cycle. Any item to the left of the curve peak will need a GD penalty applied.



SUMMARY OUTPUT			Valid Ranges			
			E (%)	B (GWd/MTU)	Line Fit	
Regression Statistics			2	8.5	8.38	Fit only the Gd_2O_3 burnup Range.
Multiple R	0.998732335		2.5	10	9.60	
R Square	0.997466278		3	10	10.81	
Adjusted R Square	0.997279975		3.5	12.5	12.02	
Standard Error	0.009203081		4	12.5	13.24	
Observations	74		4.5	15	14.45	
			6		18.10	
ANOVA			1		5.95	
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	5	2.267329287	0.453465857	5353.997068	8.38061E-87	
Residual	68	0.005759375	8.46967E-05			
Total	73	2.273088662				
(*)	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.926009985	0.018624601	49.7197212	3.39213E-55	0.888845193	0.963174776
B (b)	-0.012597677	0.000405282	-31.08372994	6.41499E-42	-0.013406404	-0.01178895
E (a)	0.199007692	0.011289601	17.62752225	4.65399E-27	0.176479658	0.221535727
B^2	9.49922E-05	5.36048E-06	17.72083358	3.46248E-27	8.42955E-05	0.000105689
E^2	-0.006702232	0.001751041	-3.827570527	0.000284176	-0.010196378	-0.003208087
BE	-0.001243395	8.5372E-05	-14.56443332	1.37392E-22	-0.001413752	-0.001073038

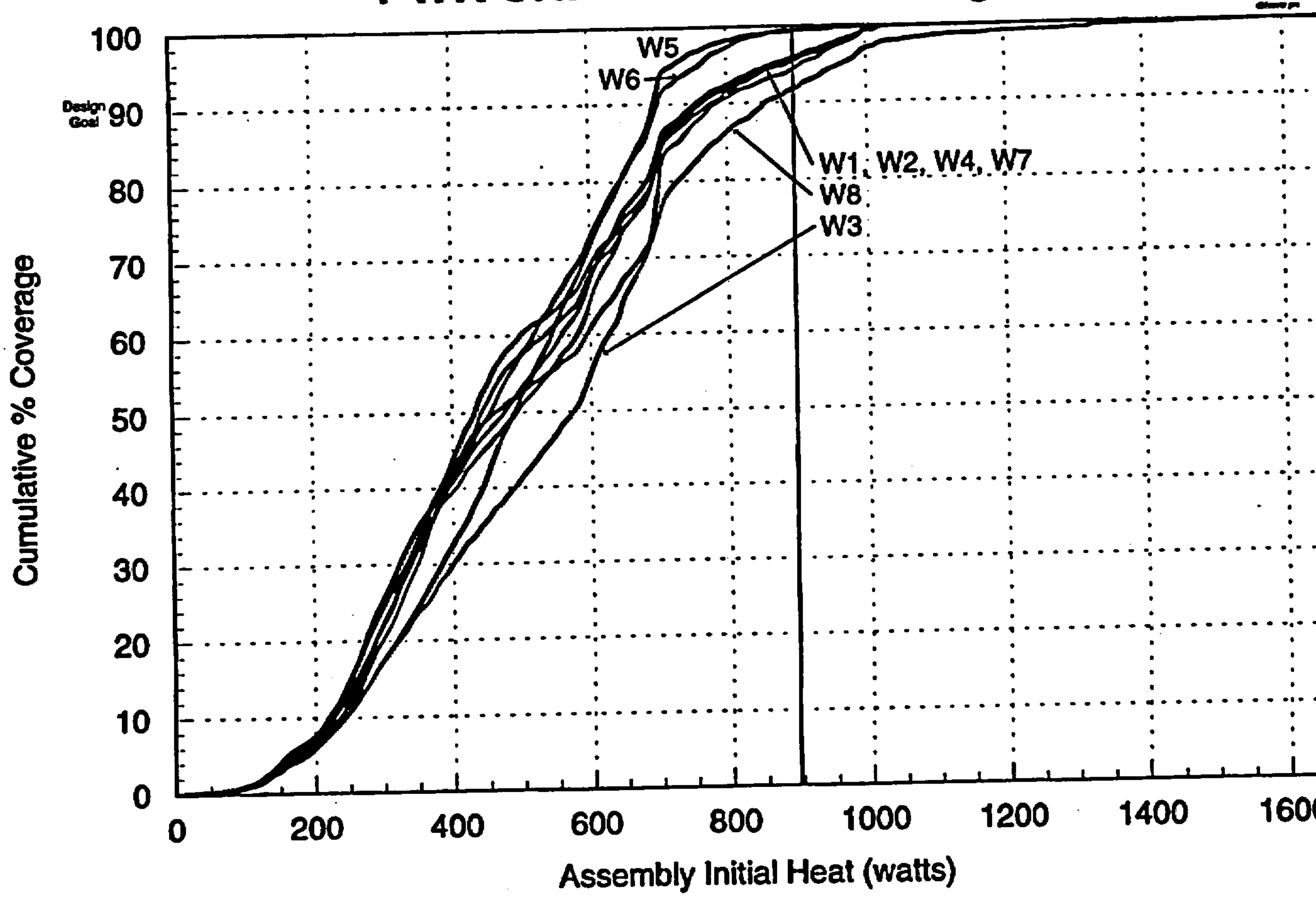
SUMMARY OUTPUT	Line Fit for Lower Burnup Limit as a Function of Enrichment					
Regression Statistics			Fit Statistics indicate a Good to Excellent Curve Fit to the Data points.			
Multiple R	0.965016432					
R Square	0.931256713					
Adjusted R Square	0.914070892					
Standard Error	0.690065559					
Observations	6					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	25.80357143	25.80357143	54.1875	0.001814368	
Residual	4	1.904761905	0.476190476			
Total	5	27.70833333				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.523809524	1.108613974	3.178572169	0.033581044	0.445797307	6.601821741
X Variable 1	2.428571429	0.32991444	7.361215932	0.001814368	1.512580201	3.344562657

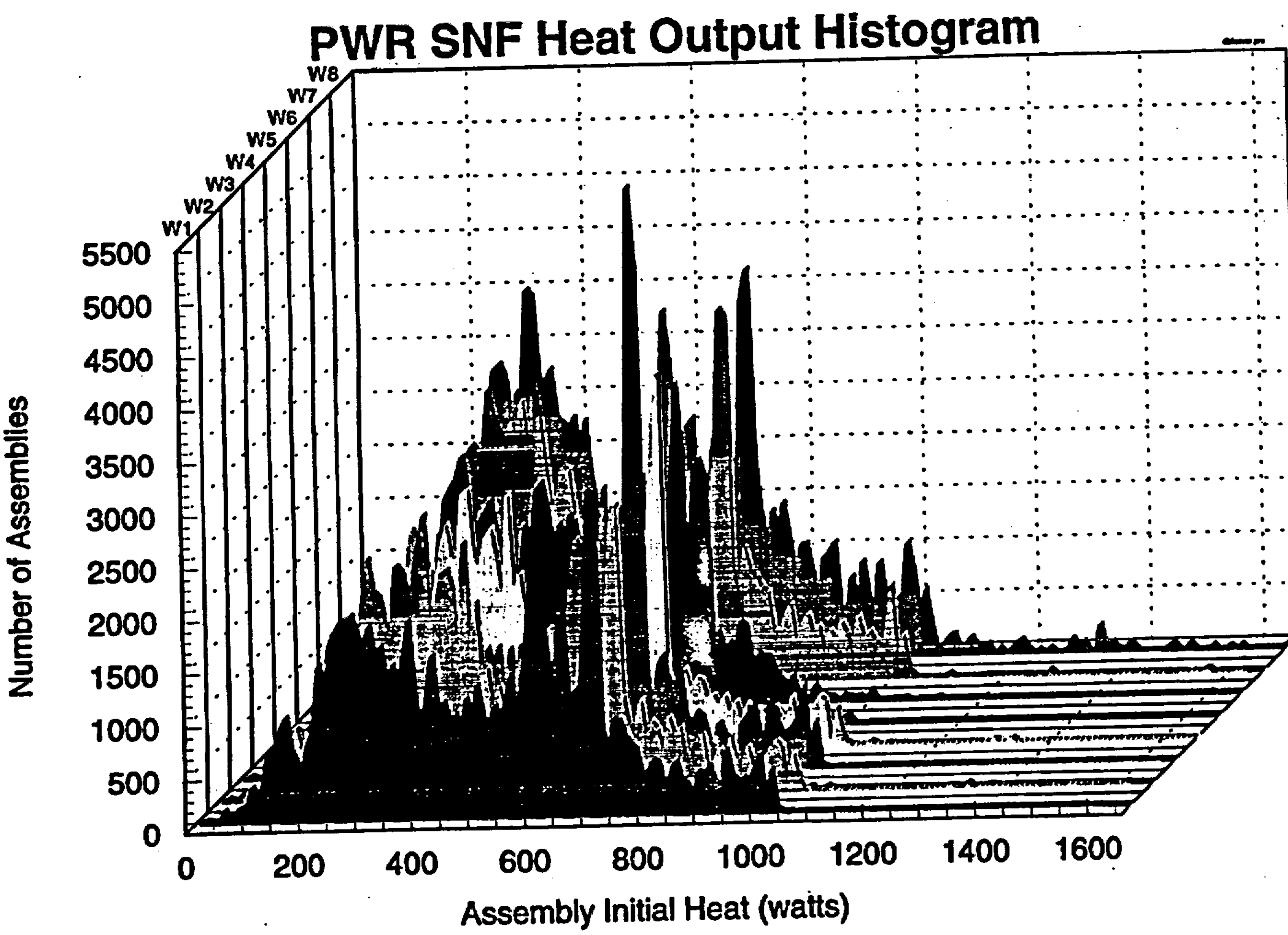
Result BWR K-inf equation:

$$K_{inf} = 0.92601 - (0.012598 \cdot b) + (0.19901 \cdot a) + (0.0000949922 \cdot b^2) - (0.006702 \cdot a^2) - (0.001243 \cdot b \cdot a)$$

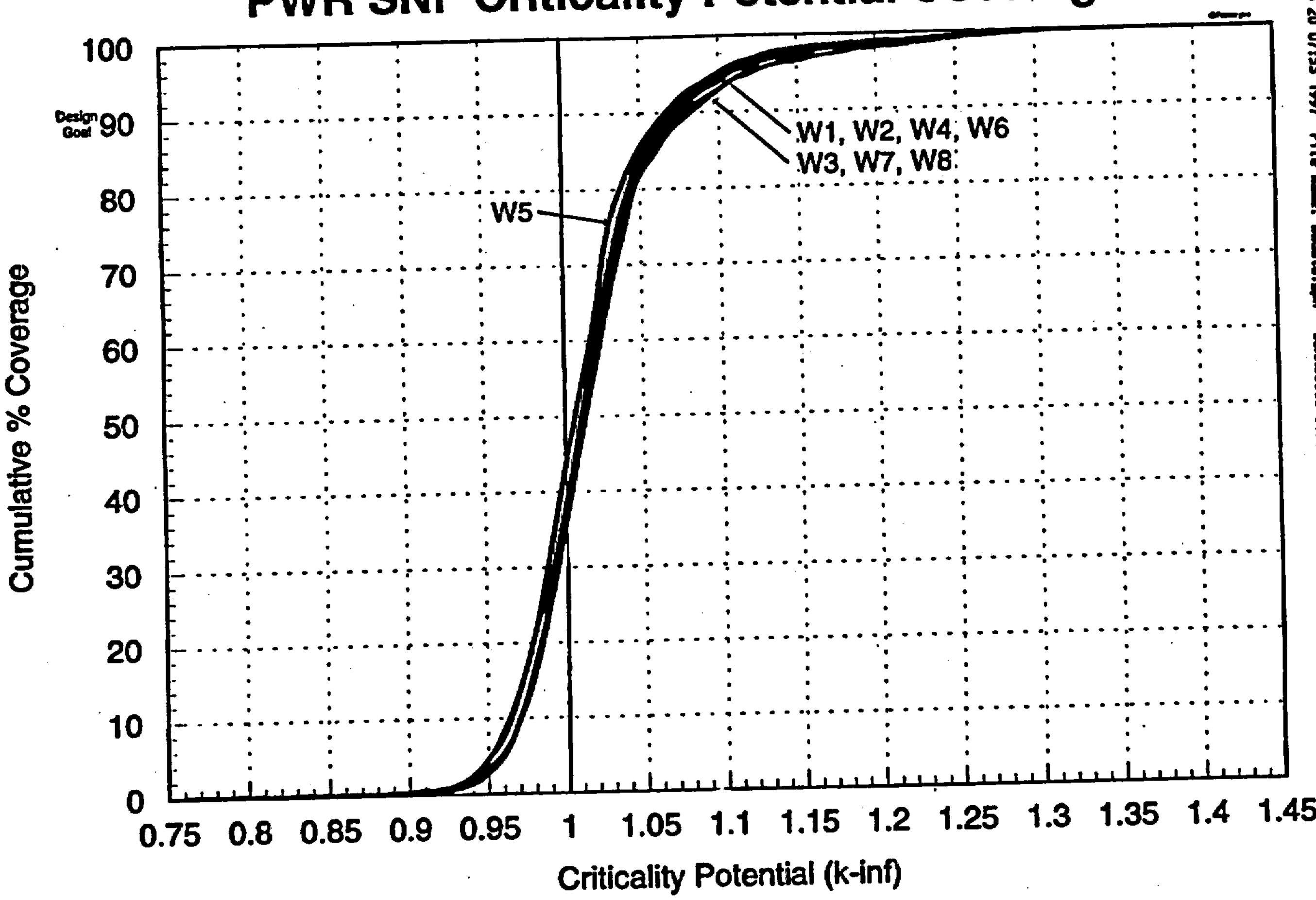
where: a ≡ initial U235 enrichment (Assembly Average)
b ≡ assembly average burnup in GWd/MTU

PWR SNF Thermal Coverage

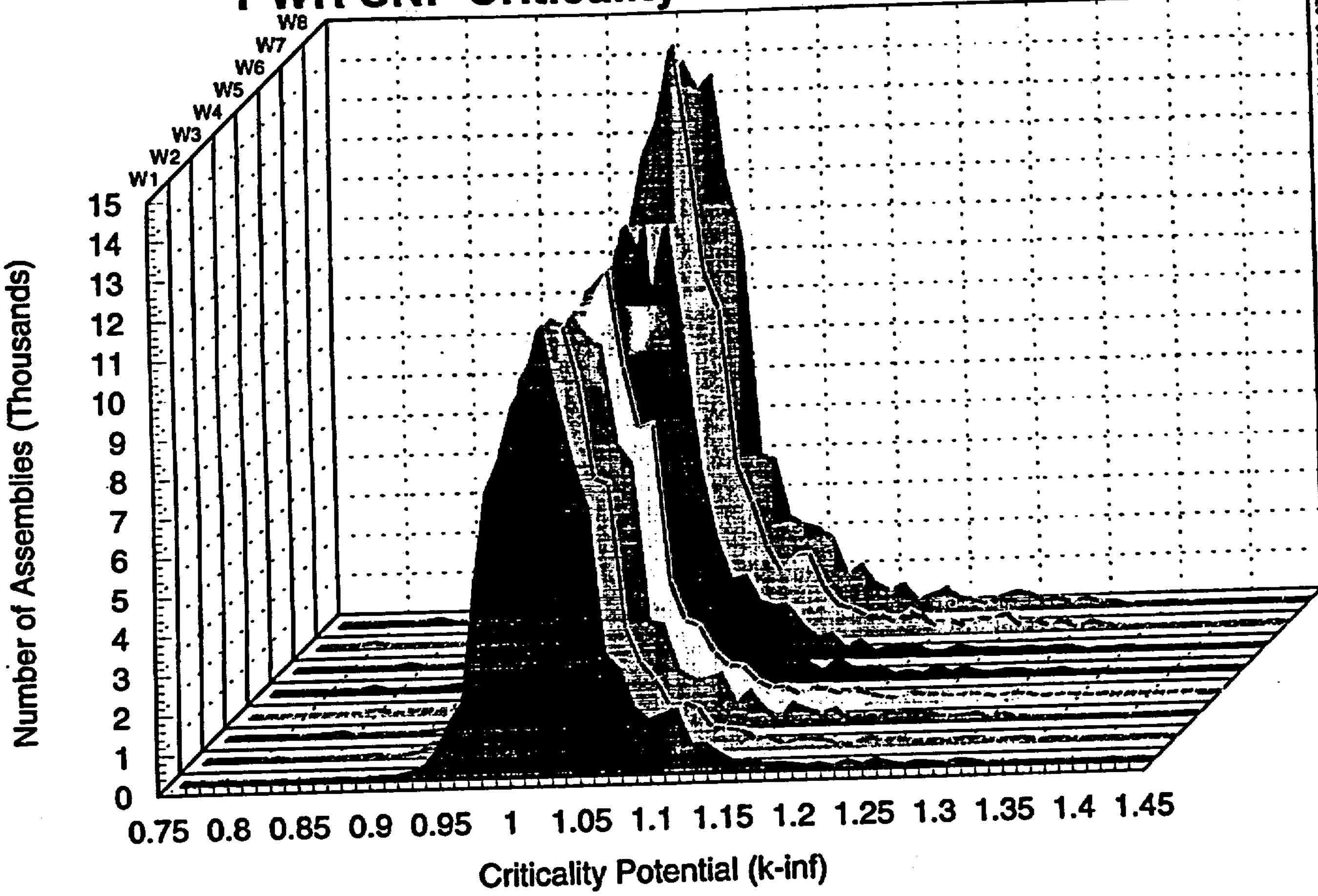



PWR SNF Heat Output Histogram
W1
W2
W3
W4
W5
W6
W7
W8
Number of Assemblies
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Assembly Initial Heat (watts)
0
200
400
600
800
1000
1200
1400
1600

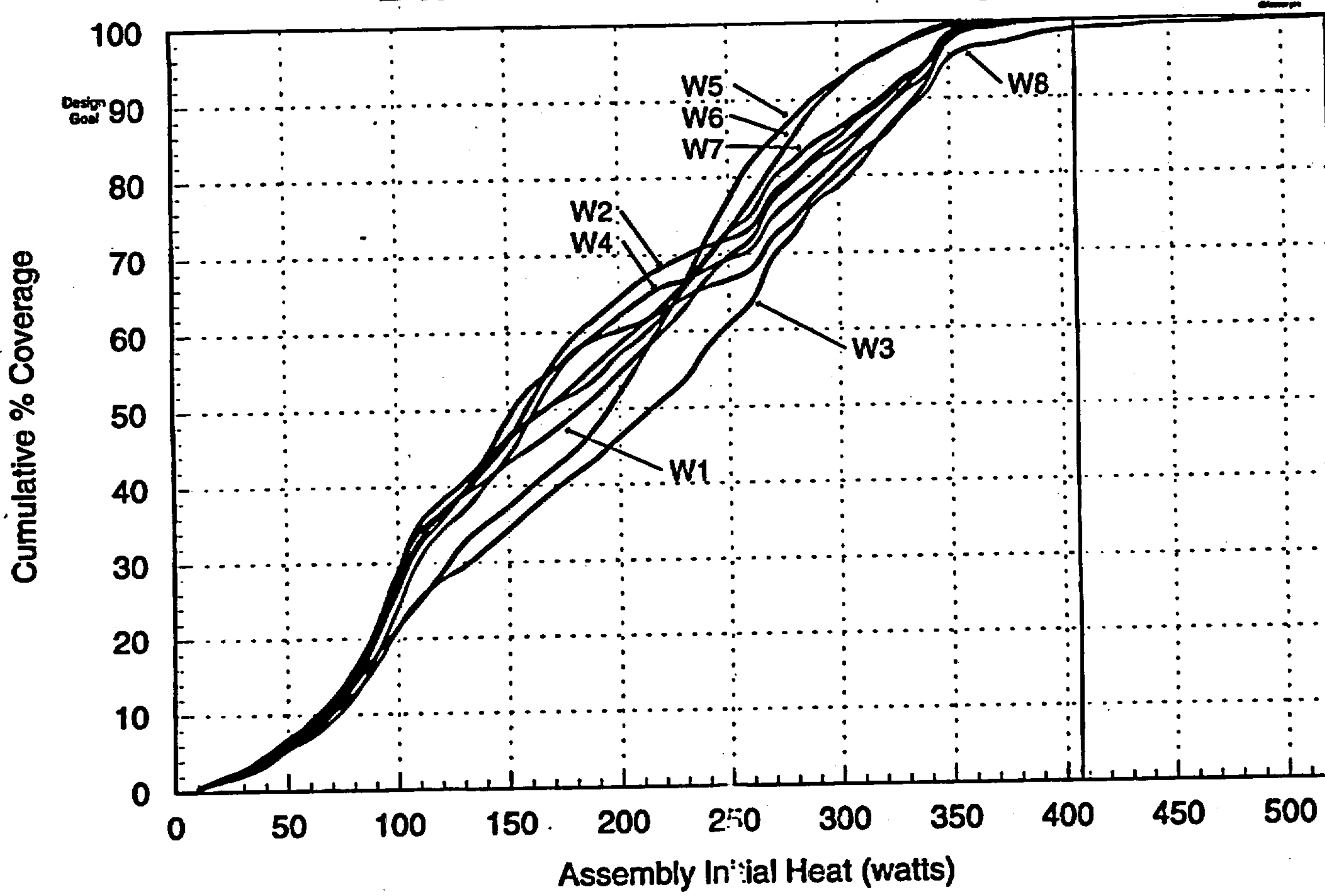
PWR SNF Criticality Potential Coverage



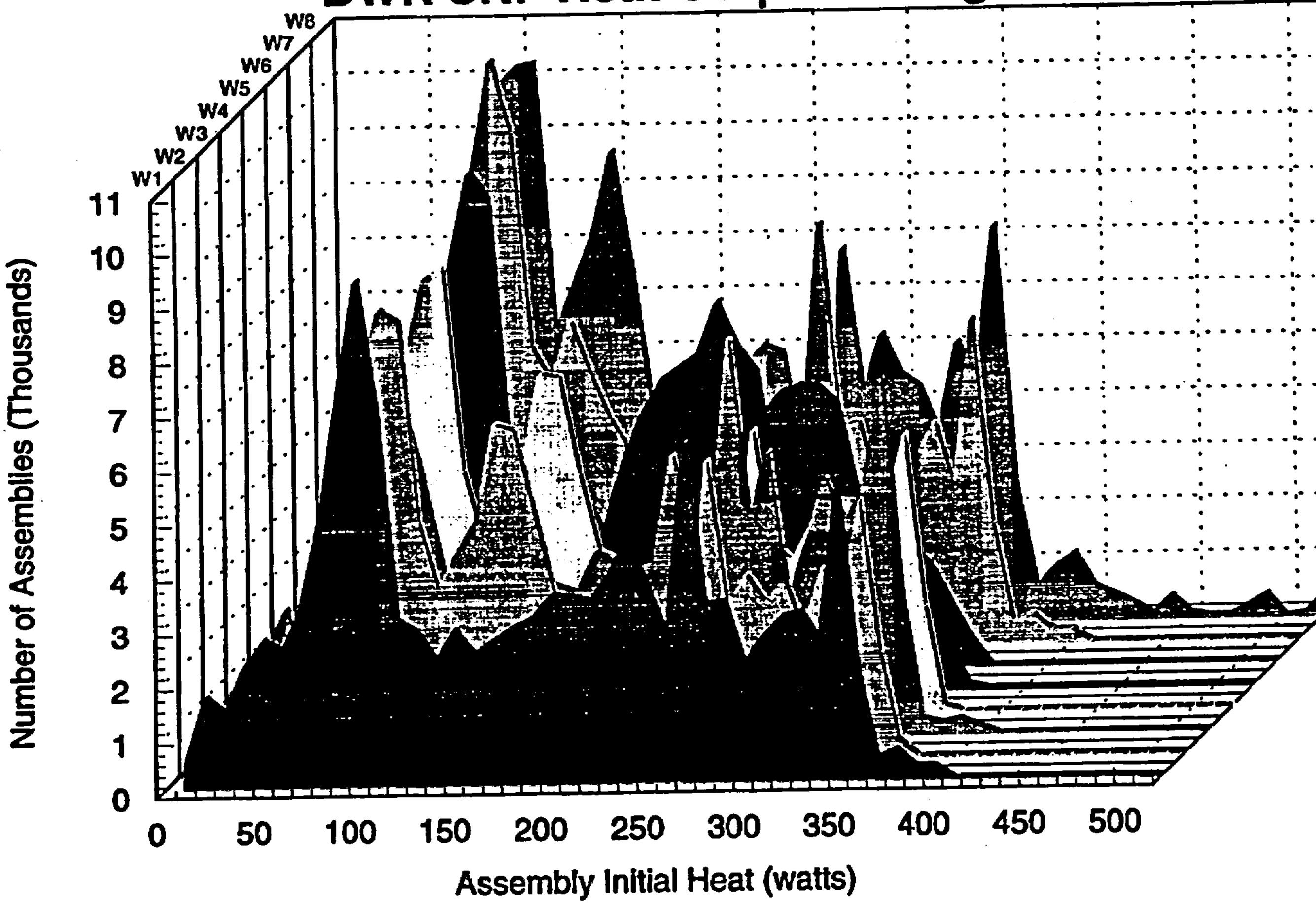
PWR SNF Criticality Potential Histogram



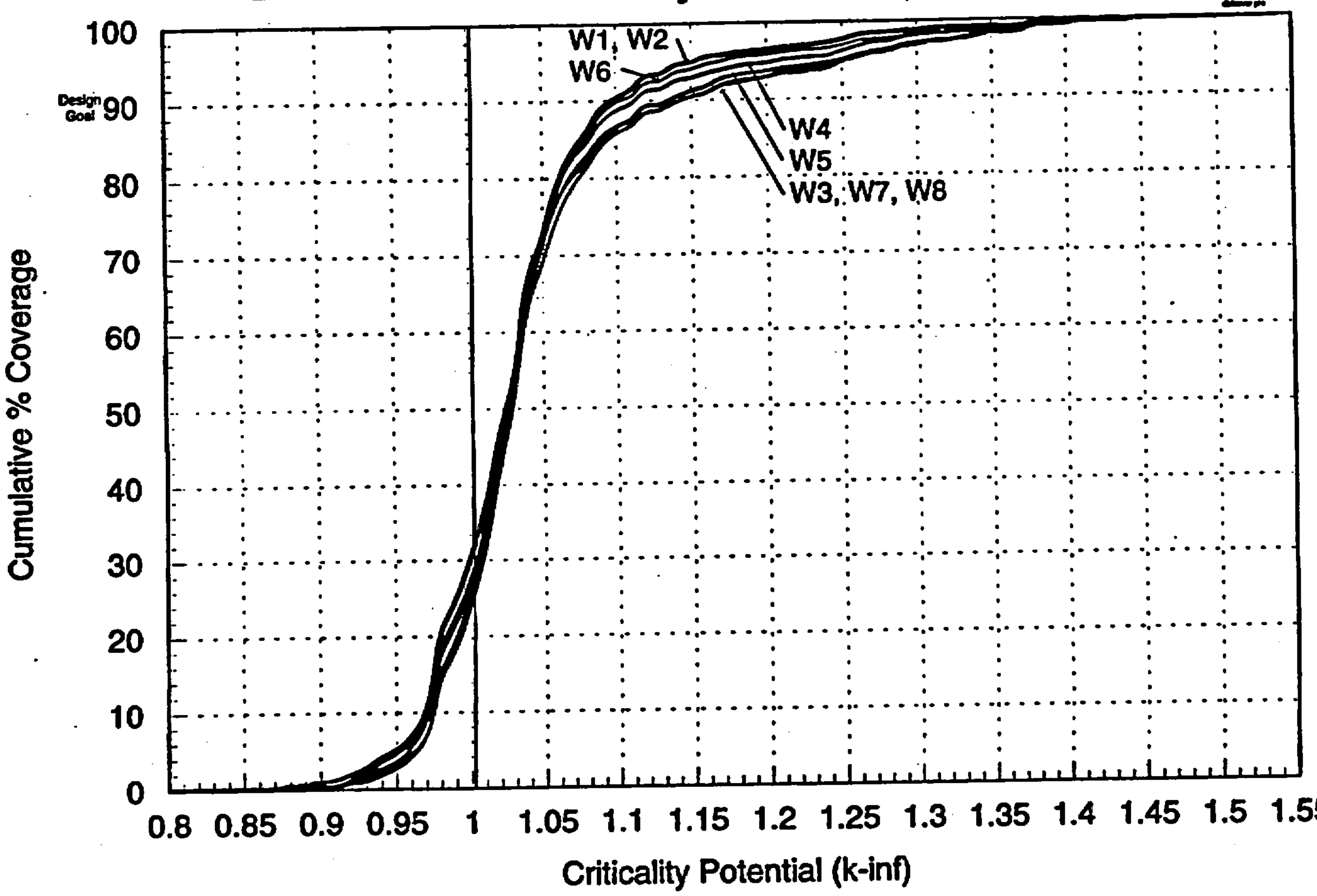
BWR SNF Thermal Coverage



BWR SNF Heat Output Histogram



BWR SNF Criticality Potential Coverage



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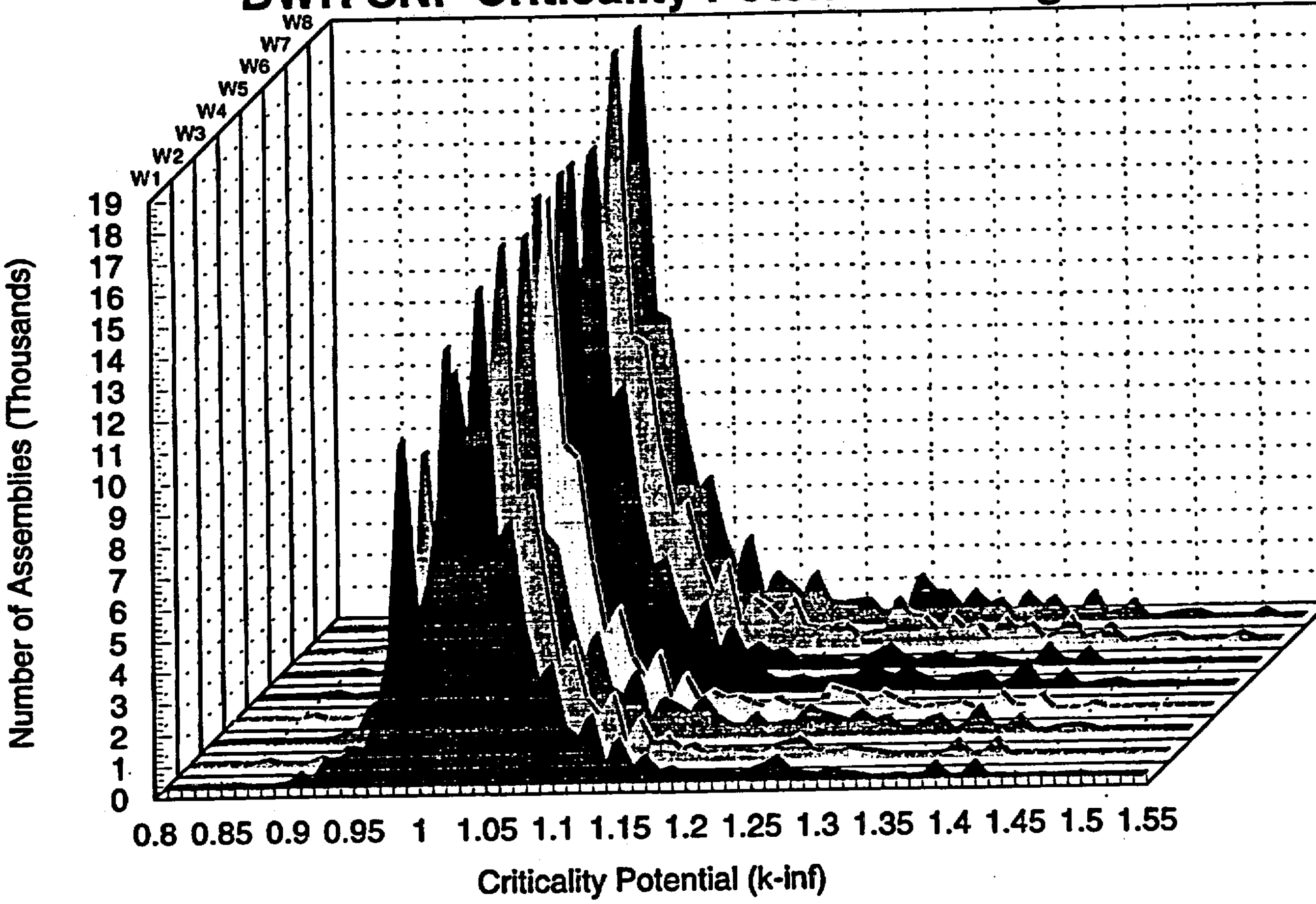
BWR SNF Criticality Potential Histogram



Case L1-T1-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber plates criticality option p1	2	0	900	1.00	1.13	2644	58.4%	2613	57.8%	2401	53.1%	3637	58.0%
21 PWR - absorber rods criticality - option p2	3	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	900	1030	0.00	1.02	265	3.3%	347	4.4%	44	0.6%	502	4.6%
10 PWR (derated 12) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	2107 (655)	1.6%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.163B Ave.				$2.878B		$2.887B		$2.859B		$4.029B	

Case L1-T1-C2 WP Types:	ID:	Heat Range (W) Hmin	 Hmax	Criticality Range k_min	 k_max	W2 (YFF10-63) #	 %	W3 (YFF10-63) #	 %	W5 (OFF-63) #	 %	W8 (YFF10-87) #	 %
21 PWR - absorber plates base thermal & criticality	1	0	900	0.00	1.13	4162	92.0%	4050	89.6%	4254	94.2%	5425	86.4%
21 PWR - absorber rods criticality - option p1	2	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	900	1030	0.00	1.15	265	3.3%	347	4.4%	44	0.6%	559	5.1%
10 PWR (derated 12) - abs. plates thermal - option p2	4	1030	1370	0.00	1.15	13	0.1%	0	0.0%	0	0.0%	189	1.4%
12 PWR - absorber plates base South Texas long WP	5	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	1060 (655)	0.8%
44 BWR - abosrber plates base thermal & criticality	6	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.365B Ave.				$3.060B		$3.083B		$3.068B		$4.249B	

Case L1-T1-C3 WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_min	k_max	W2 (YFF10-63) #	%	W3 (YFF10-63) #	%	W5 (OFF-63) #	%	W8 (YFF10-87) #	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber rods criticality - option p1	2	0	900	1.00	1.45	2763	61.1%	2799	61.9%	2554	56.5%	3894	62.0%
12 PWR - no absorber thermal - option p1	3	900	1030	0.00	1.02	265	3.3%	347	4.4%	44	0.6%	502	4.6%
10 PWR (derated 12) - no absorber thermal - option p2	4	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - no absorber base South Texas long WP	5	0	1030	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	111	1.0%
12 PWR - absorber rods South Texas long WP - option p1	6	0	1030	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	141	1.3%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	0 (0)	0.0%	1940 (488)	1.5%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	8	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.805B Ave.				$3.487B		$3.464B		$3.430B		$4.838B	

Case L1-T2-C1 WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_min	k_max	W2 (YFF10-63) #	%	W3 (YFF10-63) #	%	W5 (OFF-63) #	%	W8 (YFF10-87) #	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber plates criticality - option p1	2	0	900	1.00	1.13	2644	58.4%	2613	57.8%	2401	53.1%	3637	58.0%
21 PWR - absorber rods criticality - option p2	3	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	900	1370	0.00	1.02	276	3.5%	347	4.4%	44	0.6%	629	5.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	1694 (242)	1.3%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.101B Ave.				$2.867B		$2.877B		$2.657B		$4.002B	

Case L1-T2-C2		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - absorber plates base thermal & criticality	1	0	900	0.00	1.13	4162	92.0%	4050	89.6%	4254	94.2%	5425	86.4%
21 PWR - absorber rods criticality - option p1	2	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	900	1370	0.00	1.15	276	3.5%	347	4.4%	44	0.6%	716	6.5%
12 PWR - absorber plates base South Texas long WP	4	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	647 (242)	0.5%
44 BWR - abosrber plates base thermal & criticality	5	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	6	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.350B Ave.				$3.050B		$3.073B		$3.058B		$4.220B	

Case L1-T2-C3		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber rods criticality - option p1	2	0	900	1.00	1.45	2763	61.1%	2799	61.9%	2554	56.5%	3894	62.0%
12 PWR - no absorber thermal - option p1	3	900	1370	0.00	1.02	276	3.5%	347	4.4%	44	0.6%	629	5.7%
12 PWR - no absorber base South Texas long WP	4	0	1370	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	126	1.2%
12 PWR - absorber rods South Texas long WP - option p1	5	0	1370	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	160	1.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	0 (0)	0.0%	1527 (75)	1.2%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997*	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.791B Ave.				$3.477B		$3.454B		$3.420B		$4.812B	

Case L1-T3-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber plates criticality - option p1	2	0	850	1.00	1.13	2630	58.1%	2599	57.5%	2399	53.1%	3596	57.3%
21 PWR - absorber rods criticality - option p2	3	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	850	1030	0.00	1.02	388	4.9%	479	6.1%	80	1.0%	723	6.6%
10 PWR (derated 12) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	7 (7)	0.0%	2464 (655)	1.9%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.171B Ave.				$2.884B		$2.892B		$2.860B		$4.047B	

Case L1-T3-C2		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - absorber plates base thermal & criticality	1	0	850	0.00	1.13	4088	90.4%	3973	87.9%	4233	93.7%	5282	84.2%
21 PWR - absorber rods criticality - option p1	2	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	850	1030	0.00	1.15	394	5.0%	481	6.1%	80	1.0%	810	7.4%
10 PWR (derated 12) - abs. plates thermal - option p2	4	1030	1370	0.00	1.15	13	0.1%	0	0.0%	0	0.0%	189	1.4%
12 PWR - absorber plates base South Texas long WP	5	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	1060 (655)	0.8%
44 BWR - abosrber plates base thermal & criticality	6	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.369B Ave.				$3.064B		$3.087B		$3.068B		$4.256B	

Case L1-T3-C3 WP Types:	ID:	Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
		Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber rods criticality - option p1	2	0	850	1.00	1.45	2749	60.8%	2784	61.6%	2551	56.5%	3853	61.4%
12 PWR - no absorber thermal - option p1	3	850	1030	0.00	1.02	388	4.9%	479	6.1%	80	1.0%	723	6.6%
10 PWR (derated 12) - no absorber thermal - option p2	4	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - no absorber base South Texas long WP	5	0	1030	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	111	1.0%
12 PWR - absorber rods South Texas long WP - option 1	6	0	1030	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	141	1.3%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	0 (0)	0.0%	2297 (488)	1.7%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	8	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.810B Ave.				$3.492B		$3.467B		$3.431B		$4.851B	

Case L1-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber plates criticality - option p1	2	0	850	1.00	1.13	2630	58.1%	2599	57.5%	2399	53.1%	3596	57.3%
21 PWR - absorber rods criticality - option p2	3	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	850	1370	0.00	1.02	399	5.0%	479	6.1%	80	1.0%	850	7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	7 (7)	0.0%	2051 (242)	1.4%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.156B Ave.				$2.873B		$2.882B		$2.850B		$4.020B	

Case L1-T4-C2		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - absorber plates base thermal & criticality	1	0	850	0.00	1.13	4087	90.4%	3973	87.9%	4233	93.7%	5282	84.2%
21 PWR - absorber rods criticality - option p1	2	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	850	1370	0.00	1.15	405	5.1%	481	6.1%	80	1.0%	967	8.8%
12 PWR - absorber plates base South Texas long WP	4	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	647 (242)	0.5%
44 BWR - abosrber plates base thermal & criticality	5	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	6	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.354B Ave.				$3.053B		$3.076B		$3.058B		$4.227B	

Case L1-T4-C3		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber rods criticality - option p1	2	0	850	1.00	1.45	2749	60.8%	2784	61.6%	2551	56.5%	3853	61.4%
12 PWR - no absorber thermal - option p1	3	850	1370	0.00	1.02	399	5.0%	479	6.1%	80	1.0%	850	7.7%
12 PWR - no absorber base South Texas long WP	4	0	1370	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	126	1.2%
12 PWR - absorber rods South Texas long WP - option 1	5	0	1370	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	160	1.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	0 (0)	0.0%	1884 (75)	1.4%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.796B Ave.				$3.481B		$3.457B		$3.421B		$4.825B	

Case L1-T5-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	670	0.00	1.00	1182	26.1%	837	18.5%	1350	29.9%	1211	19.3%
21 PWR - absorber plates criticality - option p1	2	0	670	1.00	1.13	2157	47.7%	2038	45.1%	2240	49.6%	2839	45.2%
21 PWR - absorber rods criticality - option p2	3	0	670	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	670	1030	0.00	1.02	1398	17.7%	2066	26.1%	1122	14.2%	2292	20.9%
10 PWR (derated 12) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		3678 (0)	3.9%	4063 (0)	4.3%	1027 (7)	1.1%	9496 (655)	7.2%
44 BWR - no abosrber base thermal & criticality	7	0	320	0.00	1.00	423	15.0%	467	16.4%	664	23.3%	539	14.1%
44 BWR - absorber plates criticality - option b1	8	0	320	1.00	1.37	2081	73.8%	1919	67.4%	2023	71.2%	2647	69.5%
24 BWR - thick absorber plates thermal - option b1 tertiary criticality - option b2	9	0	520	0.00	1.54	580	11.2%	848	16.2%	286	5.5%	1140	16.3%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.409B Ave.				$3.091B		$3.162B		$2.954B		$4.429B	

Case L1-T6-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	670	0.00	1.00	1182	26.1%	837	18.5%	1350	29.9%	1211	19.3%
21 PWR - absorber plates criticality - option p1	2	0	670	1.00	1.13	2157	47.7%	2038	45.1%	2240	49.6%	2839	45.2%
21 PWR - absorber rods criticality - option p2	3	0	670	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	670	1370	0.00	1.02	1409	17.8%	2066	26.1%	1122	14.2%	2419	22.0%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		3678 (0)	3.9%	4063 (0)	4.3%	1027 (7)	1.1%	9083 (242)	6.9%
44 BWR - no abosrber base thermal & criticality	6	0	320	0.00	1.00	423	15.0%	467	16.4%	664	23.3%	539	14.1%
44 BWR - absorber plates criticality - option b1	7	0	320	1.00	1.37	2081	73.8%	1919	67.4%	2023	71.2%	2647	69.5%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	580	11.2%	848	16.2%	286	5.5%	1140	16.3%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.395B Ave.				$3.080B		$3.152B		$2.944B		$4.403B	

Case L2-T3-C1 WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_min	k_max	W2 (YFF10-63) #	%	W3 (YFF10-63) #	%	W5 (OFF-63) #	%	W8 (YFF10-87) #	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber plates criticality - option p1	2	0	850	1.00	1.13	2630	58.1%	2599	57.5%	2399	53.1%	3596	57.3%
21 PWR - absorber rods criticality - option p2	3	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
16 PWR (derated 21) - no absorber thermal - option p1	4	850	1030	0.00	1.02	291	4.9%	359	6.1%	60	1.0%	542	6.6%
12 PWR (derated 21) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	11	0.1%	0	0.0%	0	0.0%	128	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	7 (7)	0.0%	2464 (655)	1.9%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
20 BWR (derated 44) - abs. plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	48	0.8%	97	1.5%	91	1.4%	237	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.198B Ave.				$2.899B		$2.915B		$2.875B		$4.103B	

Case L2-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber plates criticality - option p1	2	0	850	1.00	1.13	2630	58.1%	2599	57.5%	2399	53.1%	3596	57.3%
21 PWR - absorber rods criticality - option p2	3	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR (derated 21) - no absorber thermal - option p1	4	850	1370	0.00	1.02	399	5.0%	479	6.1%	80	1.0%	850	7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	7 (7)	0.0%	2051 (242)	1.4%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
20 BWR (derated 44) - abs. plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	48	0.8%	97	1.5%	91	1.4%	237	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.218B Ave.				$2.919B		$2.942B		$2.871B		$4.138B	

Case L3-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
12 PWR - no absorber base thermal & criticality	1	0	1370	0.00	1.02	4678	59.1%	4510	57.0%	4881	61.8%	5877	53.5%
12 PWR - absorber plates criticality - option p1	2	0	1370	1.02	1.15	2936	37.1%	2969	37.5%	2654	33.6%	4431	40.3%
12 PWR - absorber rods criticality - option p2	3	0	1370	1.15	1.45	152	1.9%	280	3.5%	220	2.8%	351	3.2%
12 PWR - absorber plates base South Texas long WP	4	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	647 (242)	1.4%
24 BWR - no abosrber base thermal & criticality	5	0	520	0.00	1.00	1273	24.6%	1581	30.3%	1415	27.2%	1928	27.6%
24 BWR - absorber plates criticality - option b1	6	0	520	1.00	1.37	3856	74.6%	3560	68.2%	3719	71.4%	4956	71.0%
24 BWR - thick absorber plates criticality - option b2	7	0	520	1.37	1.54	40	0.8%	81	1.5%	76	1.4%	96	1.4%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.813B Ave.				$3.487B		$3.493B		$3.484B		$4.788B	

Case L4-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
24 PWR - no absorber base thermal & criticality	1	0	750	0.00	1.00	1198	30.3%	1109	28.0%	1531	38.7%	1318	24.0%
24 PWR - absorber plates criticality - option p1	2	0	750	1.00	1.13	2158	54.5%	2148	54.3%	2080	52.6%	2901	52.8%
24 PWR - absorber rods criticality - option p2	3	0	750	1.13	1.45	105	2.6%	163	4.1%	134	3.4%	225	4.1%
12 PWR - no absorber thermal - option p1	4	750	1370	0.00	1.02	741	9.4%	836	10.6%	255	3.2%	1437	13.1%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		1270 (0)	1.3%	1036 (0)	1.1%	150 (7)	0.2%	4683 (242)	3.6%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.140B Ave.				$2.859B		$2.864B		$2.796B		$4.041B	

Case L5-T3-C1 WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_min	k_max	W2 (YFF10-63) #	%	W3 (YFF10-63) #	%	W5 (OFF-63) #	%	W8 (YFF10-87) #	%
24 PWR - no absorber base thermal & criticality	1	0	750	0.00	1.00	1198	30.3%	1109	28.0%	1531	38.7%	1318	24.0%
24 PWR - absorber plates criticality - option p1	2	0	750	1.00	1.13	2158	54.5%	2148	54.3%	2080	52.6%	2901	52.8%
24 PWR - absorber rods criticality - option p2	3	0	750	1.13	1.45	105	2.6%	163	4.1%	134	3.4%	225	4.1%
20 PWR (derated 24) - no absorber thermal - option p1	4	750	900	0.00	1.02	280	5.9%	294	6.2%	127	2.7%	485	7.4%
12 PWR (derated 24) - no absorber thermal - option p2	5	900	1370	0.00	1.02	276	3.5%	347	4.4%	44	0.6%	629	5.7%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		1270 (0)	1.3%	1036 (0)	1.1%	150 (7)	0.2%	5096 (655)	3.9%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
20 BWR (derated 44) - abs. plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	48	0.8%	97	1.5%	91	1.4%	237	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.202B Ave.				$2.902B		$2.923B		$2.822B		$4.161B	

Case L5-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
24 PWR - no absorber base thermal & criticality	1	0	750	0.00	1.00	1198	30.3%	1109	28.0%	1531	38.7%	1318	24.0%
24 PWR - absorber plates criticality - option p1	2	0	750	1.00	1.13	2158	54.5%	2148	54.3%	2080	52.6%	2901	52.8%
24 PWR - absorber rods criticality - option p2	3	0	750	1.13	1.45	105	2.6%	163	4.1%	134	3.4%	225	4.1%
12 PWR (derated 24) - no absorber thermal - option p1	4	750	1370	0.00	1.02	741	9.4%	836	10.6%	255	3.2%	1437	13.1%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		1270 (0)	1.3%	1036 (0)	1.1%	150 (7)	0.2%	4683 (242)	3.6%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
20 BWR (derated 44) - abs. plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	48	0.8%	97	1.5%	91	1.4%	237	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.255B Ave.				$2.954B		$2.978B		$2.841B		$4.249B	

Case L6-T4-C1		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
24 PWR - no absorber base thermal & criticality	1	0	750	0.00	1.00	1198	30.3%	1109	28.0%	1531	38.7%	1318	24.0%
24 PWR - absorber plates criticality - option p1	2	0	750	1.00	1.13	2158	54.5%	2148	54.3%	2080	52.6%	2901	52.8%
24 PWR - absorber rods criticality - option p2	3	0	750	1.13	1.45	105	2.6%	163	4.1%	134	3.4%	225	4.1%
12 PWR - absorber plates thermal - option p1	4	750	1370	0.00	1.15	847	10.7%	922	11.7%	267	3.4%	1773	16.1%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	647 (242)	0.5%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.123B Ave.				$2.849B		$2.864B		$2.801B		$3.976B	

in Ref. 5.17 [initials] 4/1/97

The following computer generated output files, electronically stored data in DOS-ASCII format, are provided on the magnetic media (DC 2120 cassette tapes) included ~~in this attachment~~. The equipment used to create the magnetic media was a Colorado 350MB external tape drive supplied by the M&O Computer Hotline. The software used to copy the ASCII data files to the magnetic media was Colorado Backup Version 2.80 with the tape drive driver Version 5.0, which is also supplied by the M&O Computer Hotline. The software requires either DOS 6.0, Windows 3.1, or Windows95 operating system on a IBM compatible PC. The attached tapes have been labeled with this document identifier "BBAA00000-01717-0200-00017 REV00" and this attachment number "V" to aid in the retrieval of the magnetic media from records storage. The following table lists the file name as it was generated on the computer and the file name as it appears on the magnetic media. The computer file description is provided in Section 7 of the document.

Computer File Name	Tape Backup File Name	Number of Print Pages	File Date (Output)	File Size (Bytes)	File Type (Format)
case1.all	aVf1.mag	12	Feb 20 1997	4244	ASCII
case2.all	aVf2.mag	12	Feb 20 1997	4086	ASCII
case3.all	aVf3.mag	12	Feb 20 1997	4094	ASCII
case4.all	aVf4.mag	12	Feb 20 1997	4114	ASCII
case5.all	aVf5.mag	12	Feb 20 1997	4181	ASCII
case6.all	aVf6.mag	12	Feb 20 1997	4094	ASCII
case7.all	aVf7.mag	14	Feb 20 1997	4692	ASCII
case8.all	aVf8.mag	37	Feb 20 1997	8466	ASCII
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l1t1c1w3.all	aVf10.mag	9	Feb 20 1997	3030	ASCII
l1t1c1w5.all	aVf11.mag	9	Feb 20 1997	3134	ASCII
l1t1c1w8.all	aVf12.mag	39	Feb 20 1997	8574	ASCII
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l1t2c1w3.all	aVf22.mag	8	Feb 20 1997	2886	ASCII
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l5t4c1w3.all	aVf86.mag	10	Feb 20 1997	3299	ASCII
l5t4c1w5.all	aVf87.mag	9	Feb 20 1997	3050	ASCII
l5t4c1w8.all	aVf88.mag	42	Feb 20 1997	9196	ASCII
l6t4c1w2.all	aVf89.mag	8	Feb 20 1997	2878	ASCII
l6t4c1w3.all	aVf90.mag	8	Feb 20 1997	2886	ASCII
l6t4c1w5.all	aVf91.mag	9	Feb 20 1997	2990	ASCII
l6t4c1w8.all	aVf92.mag	36	Feb 20 1997	7814	ASCII

Interoffice Correspondence
Civilian Radioactive Waste Management System
Management & Operating Contractor

TRW
TRW Environmental Safety Systems Inc.

INFORMATION ONLY

QA: N/A

Subject
Input Files and Models Used in the Waste Quantity, Mix and Throughput Study

Date
March 21, 1997
VA.SAI.MF.03/97.007

From
M. Fleming

MOL.19970811.1264

To
R. Bahney
O. Lev

cc
D.R. Gibson w/o attachment
RPC

Location/Phone
TES1/6500P
(703) 204-8749

Attached is a 120MB tape cartridge created with a Colorado Trakker 250 tape drive, containing a copy of the input files and models used in generating the commercial SNF logistic data for the *Waste Quantity, Mix and Throughput Study*. In addition, there is a copy of the primary output of the fuel selection model (WSM) for use as input to your binning model. Table 1 identifies and describes the scenarios examined. A summary of the assumptions used in setting up the scenarios can be found in IOC VA.SAI.DRG.03/97.005.

Table 1. Commercial SNF Scenario Parameters

Case #	ISF		Pick Up		Total Acceptance		Unload Shutdown		Reactor Dry Storage		Shipment Mode from Reactor Pools	
	Yes	No	OFF	YFF10	63K	87K	Yes	No	DPC	SPC	To ISF	To MGDS
1	X			X	X		X		X		DPC	UCF
2	X			X	X			X		X	DPC-1st 2 yrs, UCF	UCF
3		X		X	X			X		X	N/A	DPC-1st 2 yrs, UCF
4		X		X	X			X		X	N/A	UCF
5	X		X		X		X		X		DPC	UCF
6	X		X		X			X		X	DPC-1st 2 yrs, UCF	UCF
7		X	X		X			X		X	N/A	DPC-1st 2 yrs, UCF
8		X	X		X			X		X	N/A	UCF
9	X			X		X	X		X		DPC	UCF
10		X		X		X		X		X	N/A	UCF
11	X		X			X	X		X		DPC	UCF
12		X	x			X		X		X	N/A	UCF

Directory of \MF\WASTEQAN\WSM

Filename	Size	Creation Date & Time	
WSM35.EXE	357,375	10-20-95	2:21p
INT32.EXE	318,712	02-25-97	7:56a
BINASSEM.EXE	69,405	02-28-97	1:52p
HEATASSM.EXE	70,297	02-26-97	9:50a
HEATDCY.EXE	63,589	02-25-97	4:10p
GEN_INP.ZIP	210,648	03-19-97	10:40a
C1_INP.ZIP	58,417	03-19-97	10:32a
C2_INP.ZIP	58,142	03-19-97	10:33a
C3_INP.ZIP	58,392	03-19-97	10:34a
C4_INP.ZIP	58,389	03-19-97	10:34a
C5_INP.ZIP	58,417	03-19-97	10:35a
C6_INP.ZIP	58,190	03-19-97	10:35a
C7_INP.ZIP	58,392	03-19-97	10:36a
C8_INP.ZIP	58,389	03-19-97	10:37a
C9_INP.ZIP	58,393	03-19-97	10:38a
C10_INP.ZIP	58,396	03-19-97	10:38a
C11_INP.ZIP	58,409	03-19-97	10:39a
C12_INP.ZIP	58,396	03-19-97	10:39a
C1_WSM.ZIP	847,188	02-28-97	9:50a
C2_WSM.ZIP	768,927	02-28-97	9:51a
C3_WSM.ZIP	652,440	02-28-97	8:20p
C4_WSM.ZIP	650,737	02-28-97	9:52a
C5_WSM.ZIP	836,279	02-28-97	9:53a
C6_WSM.ZIP	757,807	02-28-97	9:54a
C7_WSM.ZIP	652,912	02-28-97	6:05p
C8_WSM.ZIP	650,663	02-28-97	9:55a
C9_WSM.ZIP	934,083	02-28-97	9:56a
C10_WSM.ZIP	773,687	02-28-97	9:57a
C11_WSM.ZIP	923,741	02-28-97	9:58a
C12_WSM.ZIP	769,288	02-28-97	9:59a
32 file(s)	11,008,100 bytes		

MODELS:

WSM35.EXE	Waste Stream Model, Version 3.5-Fuel Selection and containerization
INT32.EXE-	Interface Version 3.2-Transportation cask fleet size, reformatting of WSM output
BINASSEM.EXE	Selects waste package type for incoming fuel and generates statistical reports of emplaced fuel (minimum, maximum, standard deviations, mean) for heat and MTU
HEATASSM.EXE	Produces 1000 year integrated heat table grouped by waste package type
HEATDCY.EXE	Produces decay heat table grouped by waste package type

INPUT FILES:

GEN_INP.ZIP	Input files used by all scenarios (SNF discharge file, CDB based heat rate tables used in calculating decay and cumulative heat)

C#_INP.ZIP — Scenario specific input files (see *User's Guide, Waste Stream Model (WSM)* Version 3.3 Rev 4, A00000000-01717-2003-20014 Rev 4 and *User's Guide, Interface Code* Version 3.1, A00000000-01717-2001-20009 Rev 4 for descriptions)

OUTPUT FILES:

C#_WSM.ZIP — Primary output file produced by WSM containing a history from discharge to emplacement for each assembly

MOL.19970805.0310

CRWMS/M&O

Design Analysis Cover Sheet

Complete only applicable items.

(1.) QA: L

2. DESIGN ANALYSIS TITLE Determination of Waste Package Design Configurations			
3. DOCUMENT IDENTIFIER (Including Rev. No.) BBAA00000-01717-0200-00017 REV 00			4. TOTAL PAGES 30
5. TOTAL ATTACHMENTS 5	6. ATTACHMENT NUMBERS - NO. OF PAGES IN EACH Total: 40 pages; See Table 9-1 (p. 30) for attachment numbers and page count.		
	Printed Name	Signature	Date
7. Originator	Thomas L. Lotz	Thomas L Lotz	4/1/97
8. Checker	Wayne E. Wallin	Wayne E. Wallin	4/1/97
9. Lead Design Engineer	Thomas W. Doering	Hugh A. Benton for T.W. Doering	4/1/97
10. QA Manager	Fred Arth for	Fred Arth	4-1-97
11. Department Manager	Hugh A. Benton	Hugh A. Benton	4/1/97

12. REMARKS

INFORMATION ONLY

INFORMATION ONLY

QAP-3-9 (Effective 01/03/96) 0492 (Rev. 12/14/95)

102.2

~~9902240333~~

2. DESIGN ANALYSIS TITLE

Determination of Waste Package Design Configurations

3. DOCUMENT IDENTIFIER (Including Rev. No.)

BBAA00000-01717-0200-00017 REV 00

4. Revision No.	5. Description of Revision
00	Issued Approved.

Table of Contents:

Item **Page**

1. Purpose

Due to the large variability in spent nuclear fuel (SNF) characteristics (physical, neutronic, and thermal), several separate waste package (WP) designs will be required to accommodate all of the SNF planned for disposal in the first repository. It could be argued that there is a potential engineering solution to any SNF decay heat or criticality problem such that one design could accommodate all of the SNF assembly types. However, common sense and economics dictate that multiple WP designs be tailored to portions of the waste stream; that is, it is not cost effective to allow the most stressing 10% of the waste stream to drive the design for the other 90%. Therefore, a family of WP designs is required and each individual WP design must have a specifically designated design basis fuel. The purpose of this document is to develop rational WP design and DBF combinations supported by waste stream coverages, past WP analyses, and engineering judgement.

This analysis is prepared by the Mined Geologic Disposal System (MGDS) Waste Package Development Department (WPDD) to set the capacity (number of assemblies) for the WP designs and the number of different types of WP design types which will be required to handle 100% of the anticipated commercial SNF waste stream. The objective of this evaluation is to determine: 1) the number of different types of WPs needed, 2) the capacity of each WP type, 3) the SNF parameters which provide the limits for each WP type, and 4) provide a reasonable rationale that the selected system of WP types may be capable of disposing 100% of the anticipated commercial SNF waste stream to be shipped to the MGDS repository. This information will then determine the scope of the WP design efforts and provide goals for determining the design basis SNF fuel type for thermal, structural, and neutronics/criticality analysis.

2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the preliminary WP design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the Mined Geologic Disposal System waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (pp. 4, 15, Ref. 5.1). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 evaluation. As determined by an evaluation performed in accordance with QAP-2-0, *Conduct of Activities*, the work performed for this analysis is subject to *Quality Assurance Requirements and Description* (QARD; Ref. 5.3) requirements. As specified in NLP-3-18, this activity is subject to QA controls. Although a documented evaluation is not required by the current revision of QAP-2-0, the WPDD Responsible Manager has selected the applicable procedural controls for this activity commensurate with the work control activity evaluation entitled "Perform Waste Stream Analysis to Determine Design Basis Fuel" (Ref. 5.2).

All design inputs which are identified in this document are for the preliminary stage of the WP design process; all of these design inputs, excluding the codes and standards, will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and, therefore, is not required to be procedurally controlled as TBV (to be verified). In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

3. Method

The goal for the method used is to determine a combination of WP types that will handle all of the commercial SNF assemblies, that will be delivered to the MGDS according to the waste receipt scenarios developed in reference 5.5, with the best repository performance and for the most favorable WP estimated cost. Various systems of WPs, selected based upon engineering judgement, are evaluated with regard to the percentage of the commercial SNF waste stream handled by the WP system. Also, the estimated total fabrication and licensing cost of each WP type in the WP system will be factored into the evaluation. The individual WP types and the WP system selected to be evaluated are based upon the design information provided in reference 5.6 which identifies the important design parameters for WPs (i.e., WP total heat load, assembly reactivity, and performance assessment data for WP degradation) and the estimated cost of the WP system based on the cost information from reference 5.11.

4. Design Inputs

All design inputs which are identified in this document are for the preliminary stage of the design process; all of these design inputs, excluding the codes and standards, will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and therefore is not required to be procedurally controlled as TBV. In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

4.1 Design Parameters

The WP fabrication cost information used in this analysis is documented in reference 5.11 and is provided in Table 4.1-1 for quick reference (see assumption 4.3.1). Additional costs for preparing a Safety Analysis Report (SAR) and a Nuclear Regulatory Commission (NRC) licensing submittal for each individual WP design is estimated to be $10,000,000 and is included in the cost analysis (see assumption 4.3.2).

Table 4.1-1 Waste Package Fabrication Cost Information

SNF Type (Reactor Type)	WP Capacity (# of Assemblies)	Criticality Control	Cost (1996 Dollars)
PWR	21	No Absorbers	$312,000
PWR	21	Borated Stainless Steel Plates	$391,000
PWR	21	B_4C Control Rods	$342,000[2] - $488,000[3]
PWR	12	No Absorbers	$216,000
PWR	12	Borated Stainless Steel Plates	$252,000
PWR	12	B_4C Control Rods	$233,000[2] - $317,000[3]
PWR	12/Long Cavity[1]	No Absorbers	$237,000[4]
PWR	12/Long Cavity[1]	Borated Stainless Steel Plates	$277,000[4]
PWR	12/Long Cavity[1]	B_4C Control Rods	$256,000[2&4] - $348,000[3&4]
PWR	24	No Absorbers	$335,000
PWR	24	Borated Stainless Steel Plates	$433,000
PWR	24	B_4C Control Rods	$378,000[2] - $546,000[3]
BWR	44	No Absorbers	$317,000
BWR	44	Borated Stainless Steel Plates	$422,000
BWR	24	No Absorbers	$247,000
BWR	24	Borated Stainless Steel Plates	$324,000

Notes:
[1] Long Cavity WP design is for the South Texas SNF assembly lengths.
[2] Assumes 4 control rods per SNF assembly.
[3] Assumes 24 control rods per SNF assembly.
[4] Assumes long cavity 12 PWR is 1.0992 times more expensive than the normal length WP for the borated plate option.

The additional cost penalty for any commercial SNF assemblies which are identified as not being able to be placed into any of the WP types for a given scenario will be $50,000 per assembly (see assumption 4.3.8). This will cover any costs of storage for additional aging, additional criticality materials, etc. which may be required to handle these assemblies and serve to penalize any WP system which can not handle 100% of the anticipated waste stream.

The specific MGDS commercial SNF assembly receipt scenarios to be considered were identified in reference 5.5 and the required SNF assembly data was provided as input for this analysis (see assumption 4.3.3). This information specifies the time at which SNF assemblies are received by the MGDS repository facility, the assembly age (i.e., cooling time), assembly burnup (i.e., MWd/MTU), assembly initial average enrichment (i.e., wt% U235), assembly loading (i.e., MTU), assembly type (i.e., Pressurized Water Reactor (PWR) or Boiling Water Reactor (BWR)), and assembly thermal power (i.e., W/MTU) for each MGDS acceptance scenario identified. This information is voluminous and is not repeated here (Ref. 5.5).

4.2 Criteria

The design of individual WPs required for handling commercial SNF assemblies will depend on development of a reasonable rationale to select a system of WP types capable of disposing 100% of the anticipated commercial SNF waste stream. Criteria that relate to the development and design of repository components are derived from the applicable requirements and planning documents. Upper-level systems requirements are provided in the Mined Geologic Repository System Requirements Document (MGDSRD, Ref. 5.10). The requirements flow down to the Engineered Barrier Design Requirements Document (EBDRD, Ref. 5.8) as specific requirements for engineered barrier segment design and the Repository Design Requirements Document (RDRD, Ref. 5.7). The Controlled Design Assumptions Document (CDA, Ref. 5.9) provides guidance for requirements listed in the EBDRD and RDRD which have unqualified or unconfirmed data associated with the requirement. The criteria applicable to the development of WP designs for the MGDS are equivalent to the applicable requirements, interface requirements, and criteria cited in the EBDRD. Specifically, the criticality requirement is provided as EBDRD 3.2.2.6, repository thermal limits are provided in EBDRD 3.7.G, WP compatibility with the repository environment and the contiained waste form requirements are provided in EBDRD 3.7.1.A, EBDRD 3.7.1.B, and EBDRD 3.7.1.2.G, and WP internal structure requirements are provided in EBDRD 3.7.1.3. The EBDRD requirements must be addressed for all WP designs and were specifically addressed in the analysis provided in reference 5.6.

The "TBD", "TBV", and "TBR" items identified in the applicable criteria documents will not be carried to the conclusions of this analysis based on the rationale that the conclusions derived by this analysis are for preliminary design and will not be used as input into documents supporting construction, fabrication, or procurement of specific waste package designs.

Finally, this design analysis is not intended to satisfy the referenced requirements, as identified in this section, in their entirety because this analysis is for the preliminary stage of WP design. The determination of full compliance with the EBDRD requirements will be performed in another design analysis when the WP designs are beyond the preliminary design phase.

4.3 Assumptions

Based on the rationale that the conclusions derived by this analysis are for preliminary design and will not be used as input into documents supporting construction, fabrication, or procurement, a TBD (to be determined) or TBV will not be carried to the conclusions of this analysis.

4.3.1 The WP fabrication cost information provided in Table 4.1-1 is assumed to be representative of the true WP fabrication cost. Reference 5.11 provides cost data which is currently being used by the MGDS program and is considered to be the best available data at this time. The time value of money is not considered in this analysis and is judged to affect the costs for each WP scenario approximately equally. The WP cost values in this analysis are for comparison purposes only and should not be used outside of this analysis. This assumption is based upon engineering judgement. This assumption is used in Section 4.1 and throughout Section 7.

4.3.2 The WP SAR/Licensing cost of $10,000,000 per WP design is assumed to be representative of the true cost for the SAR/Licensing effort. This assumption is based upon engineering judgement and experience of the Lead Design Engineer (LDE) and the originating engineer for this design analysis. This SAR/Licensing cost information for WP designs is the best available data at this time. This assumption is used in Section 4.1 and throughout Section 7.

4.3.3 The specific MGDS commercial SNF assembly receipt scenarios to consider were identified in reference 5.5 and have been developed based upon the best information available to the MGDS program (see also Ref. 5.9; CDA Key 002). The specific SNF assembly receipt scenarios and the associated assembly data from reference 5.5 is assumed to be representative of the range of waste receipt variability that the MGDS can reasonably expect. This assumption is based upon engineering judgement. This assumption is used in Section 4.1 and throughout Section 7.

4.3.4 The use of the fully moderated SNF assembly $k_{infinity}$ as a indicator of the level of criticality control required to maintain a commercial SNF assembly in a subcritical condition is assumed to bound the fully moderated $k_{effective}$ of a WP which is fully loaded with the same commercial SNF assembly. The use of $k_{infinity}$, rather than the $k_{effective}$, for a commercial SNF assembly is conservative due to the neutron leakage term which is not used for $k_{infinity}$. This assumption implies that the enrichment/burnup parameters for a commercial SNF assembly which determines the constant $k_{infinity}$ isopleths are assumed to be the same enrichment/burnup values which determine the $k_{effective}$ isopleth if a detailed WP calculation were performed. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.5 The use of the following equation obtained from page 5-4 of reference 5.6 is assumed to provide representative, but slightly conservative values for PWR SNF assembly $k_{infinity}$ values.

$$k_{infinity} = 1.06-(0.01\cdot b)-(0.002\cdot c)+(0.114\cdot a)+(0.00007081\cdot b^2)+(0.00007565\cdot c^2)-(0.007\cdot a^2)-(0.0002671\cdot b\cdot a)-(0.0001145\cdot b\cdot c)+(0.0002318\cdot c\cdot a)+(0.000009366\cdot b\cdot c\cdot a)$$

Where: a = initial U235 enrichment in weight percent
b = assembly burnup in GWd/MTU
c = assembly cooling time (i.e., age) in years

The usage and development of this equation for PWR SNF is presented in detail in reference 5.6. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.6 The use of the following equation developed in Attachment II is assumed to provide representative, but slightly conservative values for BWR SNF assembly $k_{infinity}$ values.

$$k_{infinity}=0.92601-(0.012598\cdot b)+(0.19901\cdot a)+(0.0000949922\cdot b^2)-(0.006702\cdot a^2)-(0.001243\cdot b\cdot a)$$

Where: a = initial U235 enrichment in weight percent
b = assembly burnup in GWd/MTU

The data which forms the basis for this equation was obtained from NRC approved BWR rack analysis documentation and is provided in references 5.4, 5.14, 5.15, and 5.16. The data in these references are documented as bounding $k_{infinity}$ values for BWR assembly designs of various initial enrichments, assembly exposures, and assembly configurations. The equation development is provided in Attachment II. This assumption is based upon engineering judgement. This assumption is used in Section 6.2 and throughout Section 7.

4.3.7 The WP/repository design and performance parameters documented in reference 5.6 and 5.9 (i.e., Principle Isotope Burnup Credit (CDA, Key 009), the drift emplacement concept (CDA, Key 011), thermal loading of 80 to 100 MTU/acre (CDA, Key 019), criticality methods, WP degradation modes, etc.) are assumed to be representative of the current MGDS repository conditions and provide reasonable indication of the performance requirements for the WP designs in the repository environment. Reference 5.6 provides all references to the CDA (Ref. 5.9) and the specific CDA references are not repeated here. This assumption is based upon engineering judgement. This assumption is used throughout Section 7.

4.3.8 The cost penalty of $50,000 per commercial SNF assembly which is not directly handled by a WP system scenario is assumed to be a representative bounding estimate of the true cost

for requiring an additional option to handle these "non-standard" SNF assemblies (e.g., temporarily storing the assemblies to increase assembly age, designing additional criticality control materials, design modifications to a WP type, etc.). This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used in Section 4.1 and throughout Section 7.

4.3.9 All commercial SNF is assumed to fit into the basic WP SNF basket envelope developed in reference 5.6. There are two notable exceptions which must be accommodated in this analysis: 1) South Texas PWR SNF assemblies are designed for a 14 foot reactor core rather than the standard 12 foot reactor core. The South Texas PWR assemblies fit the standard PWR cross section but will require a longer WP length. 2) Big Rock Point BWR SNF assemblies are designed with an assembly square cross section of 6.52 inches rather than the standard 5.44 inch square cross section. The Big Rock Point Assemblies are also approximately half the length of the standard BWR assembly design.

Clearly, the South Texas PWR SNF will require a new WP design since these assemblies require a longer WP basket envelope and there are not enough of these long assemblies to justify the cost of fabricating all WPs with the additional length. Thus, specific accommodation of a South Texas SNF WP will be included in this analysis in order to capture the additional cost of this WP type. However, additional options to handle the Big Rock Point BWR SNF are available; such as (but not limited to) putting these assemblies into a standard PWR WP. Finally, there is a very small number of Big Rock Point BWR assemblies, and assuming for this analysis that they are handled as part of the standard BWR SNF waste stream will not significantly affect the results of this analysis. This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used throughout Section 7.

4.4 Codes and Standards

Not applicable.

5. References

5.1 *Yucca Mountain Site Characterization Project Q-List*, YMP/90-55Q, REV 4, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).

5.2 "Perform Waste Stream Analysis to Determine Design Basis Fuel," Document Identifier (DI) Number: BB0000000-01717-2200-00029 REV 02, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O).

for requiring an additional option to handle these "non-standard" SNF assemblies (e.g., temporarily storing the assemblies to increase assembly age, designing additional criticality control materials, design modifications to a WP type, etc.). This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used in Section 4.1 and throughout Section 7.

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Clearly, the South Texas PWR SNF will require a new WP design since these assemblies require a longer WP basket envelope and there are not enough of these long assemblies to justify the cost of fabricating all WPs with the additional length. Thus, specific accommodation of a South Texas SNF WP will be included in this analysis in order to capture the additional cost of this WP type. However, additional options to handle the Big Rock Point BWR SNF are available; such as (but not limited to) putting these assemblies into a standard PWR WP. Finally, there is a very small number of Big Rock Point BWR assemblies, and assuming for this analysis that they are handled as part of the standard BWR SNF waste stream will not significantly affect the results of this analysis. This assumption is based upon engineering judgement and experience of the LDE and the originating engineer for this design analysis. This assumption is used throughout Section 7.

4.4 Codes and Standards

Not applicable.

5. References

5.1 *Yucca Mountain Site Characterization Project Q-List*, YMP/90-55Q, REV 4, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).

5.2 "Perform Waste Stream Analysis to Determine Design Basis Fuel," Document Identifier (DI) Number: BB0000000-01717-2200-00029 REV 02, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O).

5.3 *Quality Assurance Requirements and Description*, DOE/RW-0333P REV 6, U.S. DOE OCRWM.

5.4 "Pilgrim Nuclear Power Plant Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-92925, U.S. Nuclear Regulatory Commission Docket Number: 50-293, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.5 CRWMS M&O Interoffice Correspondence LV.WP.TLL.02/97-026, "Transmittal of Preliminary Design Basis Fuel Data," From T.L. Lotz to File, February 10, 1997.

5.6 *Mined Geologic Disposal System Advanced Conceptual Design Report, Volume III of IV, Engineered Barrier Segment/Waste Package*, DI Number: B00000000-01717-5705-00027 REV 00, CRWMS M&O.

5.7 *Repository Design Requirements Document*, YMP/CM-0023, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.8 *Engineered Barrier Design Requirements Document*, YMP/CM-0024, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.9 *Controlled Design Assumptions Document*, DI Number: B00000000-01717-4600-00032 REV 04, CRWMS M&O.

5.10 *Mined Geological Disposal System Requirements Document*, DOE/RW-0404P (DI Number: B00000000-00811-1708-00002 REV 02), U.S. DOE OCRWM.

5.11 CRWMS M&O Interoffice Correspondence LV.WP.JAC.02/97-032, "Waste Package Cost Estimates," From J.A. Cogar to T.L. Lotz, February 13, 1997.

5.12 Software Qualification Report for the Spent Nuclear Fuel Decay Heat Function (SNFDHF) (CSCI: 20026 V1.0), DI Number: 20026-2003 REV 00, CRWMS M&O.

5.13 Software Life Cycle Plan for the Spent Nuclear Fuel Decay Heat Function (SNFDHF) (CSCI: 20026 V1.0), DI Number: 20026-2001 REV 00, CRWMS M&O.

5.14 "Proposed Modification to the Technical Specifications for the Pilgrim Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-93126, U.S. Nuclear Regulatory Commission Docket Number: 93-016, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.15 Lotz, T. L., "ATEA BWR Rack Scoping Analysis", Framatome Technologies Incorporated Document Number: 32-1257226-00, August, 1996.

5.16 "Duane Arnold Nuclear Power Plant Spent Fuel Pool Rack Design", HOLTEC Document Number: HI-92987, U.S. Nuclear Regulatory Commission Docket Number: 50-331, U.S. Nuclear Regulatory Commission (NRC), Washington, D.C.

5.17 CRWMS M&O Interoffice Correspondence LV.WP.TLL.04/97-069, "Transmittal of Waste Package Design Configuration Data," From T.L. Lotz to File, April 1, 1997.

6. Use of Computer Software

6.1 Scientific and Engineering Software

The GETHEAT program and its HEAT.DAT data file provided in the Spent Nuclear Fuel Decay Heat Function (SNFDHF) code system (Ref. 5.12) version (V) 1.0 (CSCI: 20026 V1.0) is used in this analysis. GETHEAT program with its HEAT.DAT data file is designed to calculate PWR and BWR SNF decay heat rates given the assembly burnup, decay time (i.e., age), and assembly average initial U235 enrichment. Thus, GETHEAT program is appropriate for use with the WPBIN00a program provided in Attachment I to determine SNF decay heat loads in order to evaluate waste package loading scenarios. The GETHEAT software is executed on a IBM compatible PC with the DOS 6.2 operating system. The software qualification of the GETHEAT software, including problems of the type analyzed in this report, is summarized in the Software Qualification Report for the SNFDHF code system (Ref. 5.12). The GETHEAT evaluations performed for this design analysis are fully within the range of the validation for the GETHEAT software used. Access to and use of the GETHEAT software for this analysis was granted by Software Configuration Management and performed in accordance with the Life Cycle Plan for the SNFDHF code system (Ref. 5.13) and the QAP-SI series procedures. Inputs and outputs to the GETHEAT software are included as attachments as described in the following design analysis.

6.2 Computational Support Software

The percent values of the commercial SNF waste stream handled, the number of WP of each type required, and the number of SNF assemblies not handled by a proposed WP system scenario were generated with the computer code WPBIN00a version (V) 00A and is classified as computational support software. WPBIN00a V00A is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures. WPBIN00a requires the data provided in assumptions 4.3.3, 4.3.5, 4.3.6, and 4.3.7 as inputs. Based upon the data provided in assumption 4.3.3, WPBIN00a determines commercial SNF assembly characteristics from GETHEAT (see Section 6.1), the equation from either assumption 4.3.5 (i.e, PWR SNF) or 4.3.6 (i.e, BWR SNF), and then determines which WP type in a WP scenario (WP scenario is based upon assumption 4.3.7) the SNF assembly can be loaded into and then tallies that assembly to the selected WP type. If the SNF assembly does not meet any of the WP type criteria, then the assembly is tallied into a non-standard SNF bin. Once each assembly in the waste stream has been tallied,WPBIN00a then summarizes the number of each WP type required and prints the final summary table.

The WPBIN00a code listing is provided in Attachment I, the output files with an input listing are listed in Attachment V, and provided in reference 5.17. The WPBIN00a code is simply an automation of a simple data manipulation process which can easily be checked by hand. The data is provided in this analysis and the references for the purpose of performing hand calculation checks. The data manipulation has been checked by hand and will be used in this analysis on that basis. The WPBIN00a code was utilized for the purpose of computational support software as it was intended. The WPBIN00a software was executed on an IBM PC compatible with a DOS 6.2 operating system.

The BWR $k_{infinity}$ data curve fit was performed in Microsoft's EXCEL Version 5.0 and is classified as computational support software. Microsoft's EXCEL Version 5.0 is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures and will not be qualified under the M&O procedures. EXCEL simply provides a framework to automate simple mathematical calculations which can easily be checked by hand or through alternate calculational methods. Based upon the data provided in assumption 4.3.6, EXCEL generates a simple curve via direct equation calculation. Once the proper equation coefficients for the equations are determined, EXCEL summarizes the numeric values at selected data points. The EXCEL spread sheet file is provided as Attachment II. The data points used are provided in this analysis for the purpose of performing hand calculation checks. The data manipulation has been checked by hand and will be used in this analysis on that basis. EXCEL was utilized for the purpose of computational support software as it was intended and it is appropriate for the use of generating a curve given an equation form. The EXCEL software was executed on an IBM PC compatible with a Windows 3.1 operating system.

The presentation graphics provided in Attachment III was generated with the computer code Harvard Graphics Version 2.0 and is classified as computational support software. Harvard Graphics Version 2.0 was executed on a IBM PC compatible with a Windows 3.1 operating system. Harvard Graphics Version 2.0 is not a controlled computer code and has not been qualified under the QAP-SI series of M&O procedures and will not be qualified under the M&O procedures. Harvard Graphics Version 2.0 simply provides a framework to create a graphical representation of data. No calculation or modification beyond cut and paste operations with tabular data from reference 5.5 and WPBIN00a software was performed in Harvard Graphics.

7. Design Analysis

Previous WPDD efforts have focused upon determining the performance characteristics of a WP with regard to Engineered Barrier System (EBS) and MGDS performance (Ref. 5.6). This involved determining performance requirements for criticality control, heat transfer, shielding, structural strength, and degraded mode performance with a nearly bounding commercial SNF assembly type. Thus, much of the assumed performance requirements and the cost data used in this analysis is based upon these documented results. However, these analyses did not provide the rationale for, nor identify, the required mix of WP types which will need to be licensed in order to cover 100% of the commercial SNF waste stream in an reasonable manner. This analysis is intended to perform this function using the WP performance data summarized in reference 5.6.

7.1 Design Basis Fuel (DBF)

It is likely that the license application for the waste package will be reviewed by the Nuclear Regulatory Commission using criteria similar to those already in place for dry cask storage systems. That is not to say the requirements placed upon the disposal device are the same as for storage casks, but that the topical safety analysis report (SAR) for the waste package should follow the standard format and content established for dry cask storage SARs. The *Standard Review Plan for Dry Cask Storage Systems* (NUREG-1536) states that:

> "Specifications must be provided for the spent fuel to be stored in the cask, such as, but not limited to, type of spent fuel (i.e., Boiling Water Reactor (BWR), Pressurized Water Reactor (PWR), both), maximum allowable enrichment of the fuel prior to any irradiation, burn-up (i.e., megawatt-days/Metric Ton Uranium), minimum acceptable cooling time of the spent fuel prior to storage in the cask (aged at least one year), maximum heat designed to be dissipated, maximum spent fuel loading limit, condition of the spent fuel (i.e., intact assembly or consolidated fuel rods), and the inert atmosphere requirements."

Due to the large variability in SNF characteristics, several separate WP designs will be required to accommodate all of the SNF planned for disposal in the first repository. It could be argued that there is a potential engineering solution to any SNF decay heat or criticality problem such that one design could accommodate all of the SNF assembly types. However, common sense and economics dictate that multiple WP designs be tailored to portions of the waste stream (that is, it is not cost effective to allow the most stressing 10% of the waste stream to drive the design for the other 90%). Therefore, a family of WP designs is required and each individual WP design must have a specifically designated design basis fuel. The purpose of this document is to develop rational WP design and DBF combinations supported by waste stream coverages, past WP analyses, and engineering judgement.

7.2 Waste Acceptance Issues

Due to the uncertainty in waste acceptance parameters, eight waste stream scenarios will be considered (see assumption 4.3.3):

Scenario W1: YFF10_DPC_NoISF_63

Take from reactor spent fuel pool the youngest fuel that is at least 10 years old (YFF10). Take from pool 5 - 10 year old fuel when older pool fuel is gone. Then take from dry storage oldest fuel first; which is stored and shipped using dual purpose canisters (DPC). No interim storage facility is used. Continue for first 63,000 MTUs of SNF.

Scenario W2: YFF10_DPC_ISF_63

Same as scenario W1, except that an Interim Storage Facility (ISF) begins DPC receipt starting in 2003. No SNF is shipped from the ISF to the repository until all of the reactor allocations have been met.

Scenario W3: YFF10_SPC_NoISF_63

Same as scenario W1, except that any dry storage SNF is stored using single purpose canisters (SPC).

Scenario W4: YFF10_SPC_ISF_63

Same as scenario W2, except that DPCs are used for reactor storage and to ship SNF to the ISF for the first two years, then SPCs are used for storage at the ISF.

Scenario W5: OFF_SPC_NoISF_63

Same as scenario W3, except that reactors ship spent fuel based on an oldest fuel first (OFF) strategy. Take from reactor spent fuel pool the oldest fuel first until only 5 year old or younger SNF remains, then take from dry storage oldest fuel first. Continue for first 63,000 MTUs of SNF.

Scenario W6: OFF_SPC_ISF_63

Same as scenario W5, except that DPCs are used for reactor storage prior to 2003 and to ship SNF to the ISF for two years starting in 2003, then SPCs are used for storage at the ISF. No spent fuel is shipped from the ISF to the repository until all of the reactor allocations have been met.

Scenario W7: YFF10_DPC_NoISF_87

Same as scenario W1, except that waste receipt is continued for the full 86,800 MTUs projected to be discharged from the existing reactor facilities (86,800 MTUs is beyond the current statutory limit for a single repository).

Scenario W8: YFF10_DPC_ISF_87

Same as scenario W2, except that waste receipt is continued for the full 86,800 MTUs projected to be discharged from the existing reactor facilities (86,800 MTUs is beyond the current statutory limit for a single repository).

Attachment III provides a graphical summary of each of the commercial waste stream scenarios. The data from reference 5.5 (assumption 4.3.3) was processed by the WPBIN00a software to generate the commercial SNF $k_{infinity}$ values, using the equations from either assumption 4.3.5 (i.e., PWR SNF) or 4.3.6 (i.e., BWR SNF), and SNF assembly heat rates based upon the GETHEAT software (Ref. 5.12). These WPBIN00a output files are listed in Attachment V, and provided in reference 5.17, as files case1.all, case2.all, case3.all, case4.all, case5.all, case6.all, case7.all, and case8.all for waste stream scenarios W1, W2, W3, W4, W5, W6, W7, and W8, respectively. The data was then put into Harvard Graphics to create each cumulative distribution plot and each histogram plot.

Notice that both the PWR (pp. 3, 4; Attachment III) and BWR (pp. 7, 8; Attachment III) $k_{infinity}$ plots show very little variation with respect to the different waste stream scenarios. This indicates that the criticality problem is relatively independent of the details of the waste stream delivery system. Waste stream scenarios W2, W5, and W8 appear to be representative of a lower, middle, and high range of waste stream characteristics with regard to criticality concerns. Waste streams W1, W3, W4, W6, and W7 fall within these three scenarios and will provide similar results.

The SNF assembly initial heat plots for PWR (pp. 1, 2; Attachment III) and BWR (pp. 5, 6; Attachment III) assemblies display a much greater sensitivity to the waste stream delivery system. This characteristic of the waste stream was not unexpected, since SNF assembly heat rates decay fairly quickly with cooling time. However, this makes selecting a WP system more difficult, since at this time each waste stream scenario must be considered as equally likely to be correct. Thus, tailoring a WP system to a specific waste stream scenario to reduce costs is not a realistically viable option. Thus, any WP system which is designed should be set up to handle any of these waste stream scenarios for a reasonable cost.

The data provided in Attachment III show that evaluating waste stream scenarios W2, W3, W5, and W8 will both bound and provide a reasonable estimate of the median for the given variations in waste stream characteristics. These waste stream scenarios will be evaluated further in this analysis.

7.3 Waste Package Performance Issues

The performance characteristics of WPs with regard to containment of waste, efficient use of material (i.e., packing density), criticality safety, thermal performance, predictability of degraded modes, and performance in degraded modes has been documented in analyses performed during the WP conceptual design (Ref. 5.6). These analyses provide a basis with which to determine the best WP design with regard to individual WP performance and the results of the conceptual design will be used to provide the first cut in determining WP SNF assembly capacities and how they should be combined into a WP system capable of emplacing the commercial SNF waste stream (see assumptions 4.3.7 and 4.3.9). The conceptual design efforts showed that the larger capacity WP designs were desirable from a cost and handling perspective, but the largest practical sizes which still meet the repository performance criteria limited the WP designs to capacities of 24 PWR assemblies or 44 BWR assemblies. Larger capacity WP designs will have significant difficulty meeting repository thermal and criticality performance requirements and present structural design difficulties during the degradation phase of the WP performance life (Ref. 5.6).

The conceptual design provides the following ranking for WP performance versus SNF assembly capacity:

Best performance characteristics:	21 PWR assembly capacity 12 PWR assembly capacity 44 BWR assembly capacity 24 BWR assembly capacity
Moderate performance characteristics:	24 PWR assembly capacity

All other WP designs showed significant problems concerning degraded mode performance and efficient use of materials (i.e., packing density). As the internal structures degraded and slumped, only the designs listed above provided predictable geometries, sufficient criticality control, and sufficient structural performance to keep the commercial SNF in an intact form. Thus, only WP systems comprised of the listed WP capacities will be considered in this analysis since these have the highest probability for meeting all of the repository performance criteria (Ref. 5.6).

The 24 PWR assembly capacity WP will be considered in this analysis to determine if it has a large cost advantage over the 21 PWR assembly capacity WP. However, if the cost advantage is not significant, then a WP system comprised of WPs from the best performance characteristics list will be selected instead based on the higher probability for meeting all of the repository performance criteria.

Additional performance constraints are discussed in the following sections.

7.3.1 Thermal Issues

The thermal load on the waste package (and consequently its temperature) is most directly determined by the rate of heat generation. Of course, both heat rate and waste package temperature change with time depending on the total repository thermal loading. However, heat at time of emplacement is the single strongest determining parameter for peak waste package temperature, which is a very important design parameter, constrained by the need to avoid cladding creep and mineral phase transformations at the emplacement drift wall. The performance parameter, heat at emplacement, is primarily a function of age at emplacement and burnup and provides a criteria for distinguishing between assembly thermal categories.

While the WP design basis fuel is specified on a per-assembly basis, the total WP heat load will impact the emplacement drift structures and the surrounding rock. Previous preliminary analyses (Ref. 5.6) have indicated that initial individual WP heat loads of around 18 kW can be tolerated assuming a reference repository thermal loading range of 80 to 100 MTU/acre. It may be possible to accept a higher initial heat, such as 19 kW; however, for other system interface issues, total initial WP heat loads could be limited to lower values (such as the 14.2 kW heat at emplacement limit indicated for the conceptual multi-purpose canister design). Note that the data provided in reference 5.6 show that the 19 kW WP total heat load has a significant risk of not meeting the repository thermal performance criteria for rock media temperatures if thermal loads in the 90 to 100 MTU/acre range are selected. A significant cost advantage must exist for this higher WP heat load to be selected and the additional design risk accepted. To determine the trending and costs with respect to the waste stream, three total WP initial heat loads will be considered: 14.2, 18, and 19 kW. Individual assembly heats have been rounded off to the nearest multiple of 10 watts.

Given the three maximum WP heat load conditions and the data provided in Attachment III, the following WP rated heat load options will be considered. The PWR SNF assembly portion of the waste stream is the most complicated to handle due to the higher heat load per assembly and larger assembly size as compared to the BWR SNF assemblies. The derated WP options are discussed further in Section 7.4. The derated configurations are selected based on maintaining a balanced (i.e., symmetrical) WP loading configuration. WP systems will be based on combinations of these WP types and use the given capacity and thermal rating. Each of the following scenarios is a combination of large and small PWR and BWR WPs, with the largest PWR WP heat total heat load limited to the stated value:

Scenario T1: Three PWR categories with maximum WP heat of 19 kW

Base options (watts)

0 < heat < 900	For 21 PWR (total 18.9 kW)
0 < heat < 900	For 12 PWR (total 10.8 kW)
0 < heat < 790	For 24 PWR (total 19.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

900 < heat < 1030	For 12 PWR (total 12.4 kW)
900 < heat < 1030	For 16 PWR (derated 21, 16.5 kW)
790 < heat < 950	For 20 PWR (derated 24, 19.0 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
1030 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
950 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)

Scenario T2: Two PWR categories with maximum WP heat of 19 kW

Base options (watts)

0 < heat < 900	For 21 PWR (total 18.9 kW)
0 < heat < 900	For 12 PWR (total 10.8 kW)
0 < heat < 790	For 24 PWR (total 19.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

900 < heat < 1370	For 12 PWR (total 16.4 kW)
900 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
790 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Scenario T3: Three PWR categories with maximum WP heat of 18 kW

Base options (watts)

0 < heat < 850	For 21 PWR (total 17.9 kW)
0 < heat < 850	For 12 PWR (total 10.2 kW)
0 < heat < 750	For 24 PWR (total 18.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

850 < heat < 1030	For 12 PWR (total 12.4 kW)
850 < heat < 1030	For 16 PWR (derated 21, 16.5 kW)
750 < heat < 900	For 20 PWR (derated 24, 18.0 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
1030 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
900 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)

Scenario T4: Two PWR categories with maximum WP heat of 18 kW

Base options (watts)

0 < heat < 850	For 21 PWR (total 17.9 kW)
0 < heat < 850	For 12 PWR (total 10.2 kW)
0 < heat < 750	For 24 PWR (total 18.0 kW)
0 < heat < 400	For 44 BWR (total 17.6 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

850 < heat < 1370	For 12 PWR (total 16.4 kW)
850 < heat < 1370	For 12 PWR (derated 21, 16.4 kW)
750 < heat < 1370	For 12 PWR (derated 24, 16.4 kW)
400 < heat < 520	For 24 BWR (total 12.5 kW)

Scenario T5: Three PWR categories with maximum WP heat of 14.2 kW

Base options (watts)

0 < heat < 670	For 21 PWR (total 14.1 kW)
0 < heat < 670	For 12 PWR (total 8.0 kW)
0 < heat < 590	For 24 PWR (total 14.2 kW)
0 < heat < 320	For 44 BWR (total 14.1 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Intermediate options (watts)

670 < heat < 1030	For 12 PWR (total 12.4 kW)
670 < heat < 880	For 16 PWR (derated 21, 14.1 kW)
590 < heat < 710	For 20 PWR (derated 24, 14.2 kW)
320 < heat < 520	For 24 BWR (total 12.5 kW)

Non-Standard Assembly options (watts)

1030 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
880 < heat < 1370	For 10 PWR (derated 21, 13.7 kW)
710 < heat < 1370	For 10 PWR (derated 24, 13.7 kW)

Scenario T6: Two PWR categories with maximum WP heat of 14.2 kW

Base options (watts)

0 < heat < 670	For 21 PWR (total 14.1 kW)
0 < heat < 670	For 12 PWR (total 8.0 kW)
0 < heat < 590	For 24 PWR (total 14.2 kW)
0 < heat < 320	For 44 BWR (total 14.1 kW)
0 < heat < 400	For 24 BWR (total 9.6 kW)

Non-Standard Assembly options (watts)

670 < heat < 1370	For 10 PWR (derated 12, 13.7 kW)
670 < heat < 1370	For 10 PWR (derated 21, 13.7 kW)
590 < heat < 1370	For 10 PWR (derated 24, 13.7 kW)
320 < heat < 520	For 24 BWR (total 12.5 kW)

7.3.2 Criticality Issues

The criticality performance parameter, $k_{infinity}$ (see assumption 4.3.4), and the WP loading scenarios developed for this analysis are based on advanced conceptual design (Ref. 5.6) analysis results. All of the WP designs considered assume that Principal Isotope Burnup Credit will be accepted by the NRC (see assumption 4.3.7). This means that each WP is designed with 5 mm thick carbon steel tubes around the fuel assemblies. When included, the neutron absorber plates are 7 mm thick borated SS-B6A and the absorber control rods are zirconium clad B_4C rods. It is also noted that there is no reason based on criticality potential to derate a WP or use a smaller WP for PWR SNF (i.e., derating for PWRs is only performed for thermal reasons, BWRs are derated as specified above). This is due to the fact that derating for criticality relies on increased neutron leakage to reduce the multiplication factor. However, this effect is reduced significantly when the WP internals degrade and is not sufficient for criticality control in large WPs. Thus, other options, such as control rods, are utilized (see Ref. 5.6).

All SNF assembly $k_{infinity}$ values are determined based upon assumption 4.3.5 or 4.3.6. The basis for each WP rated $k_{infinity}$ limit is provided in reference 5.6. The following WP rated heat load options will be considered. WP systems will be based on combinations of these WP types and use the given capacity and criticality rating.

Scenario C1: Three criticality control categories

Base options

$0 < k_\infty < 1.00$	PWR fuel requiring no neutron absorbers in the WP basket
$0 < k_\infty < 1.00$	BWR fuel requiring no neutron absorbers in the WP basket

Intermediate options

$1.00 < k_\infty < 1.13$	PWR fuel requiring neutron absorber plates in the WP basket
$1.00 < k_\infty < 1.37$	BWR fuel requiring neutron absorber plates in the WP basket

Non-Standard Assembly options

$1.13 < k_\infty < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.37 < k_\infty < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

Scenario C2: Two criticality control categories

Base options

$0 < k_\infty < 1.13$	PWR fuel requiring neutron absorber plates in the WP basket
$0 < k_\infty < 1.37$	BWR fuel requiring neutron absorber plates in the WP basket

Non-Standard Assembly options

$1.13 < k_\infty < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.37 < k_\infty < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

Scenario C3: Two criticality control categories (no absorber plate option)

Base options

$0 < k_\infty < 1.00$	PWR fuel requiring no neutron absorbers in the WP basket
$0 < k_\infty < 1.00$	BWR fuel requiring no neutron absorbers in the WP basket

Non-Standard Assembly options

$1.00 < k_\infty < 1.45$	PWR fuel requiring neutron absorber control rods in the assemblies
$1.00 < k_\infty < 1.54$	BWR fuel requiring thicker neutron absorber plates (24 BWR)

7.4 Waste Package Loading Issues

A secondary purpose of this analysis is to determine the cost effectiveness of derating the base WP option (for thermal reasons) versus utilizing a second smaller capacity waste package for the assemblies that could not be placed in the larger capacity base option disposal device. It is also desirable to investigate the impact of base option WP total capacity on system cost. To bound these possible options, the following loading scenarios are considered (see assumption 4.3.9):

Scenario L1:
- 21 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 44 BWR Base option
- 24 BWR Non-Standard option if needed

Scenario L2:
- 21 PWR Base option
- 16 PWR (derated 21) Intermediate option
- 12 PWR (derated 21) Non-Standard option if needed
- 21 PWR South Texas
- 44 BWR Base option
- 20 BWR (derated 44) Non-Standard option if needed

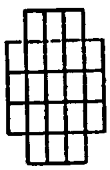
Scenario L3:
- 12 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 24 BWR Base option

Scenario L4:
- 24 PWR Base option
- 12 PWR Intermediate option
- 10 PWR (derated 12) Non-Standard option if needed
- 12 PWR South Texas
- 44 BWR Base option
- 24 BWR Non-Standard option if needed

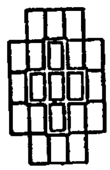
Scenario L5:
- 24 PWR Base option
- 20 PWR (derated 24) Intermediate option
- 12 PWR (derated 24) Non-Standard option if needed
- 24 PWR South Texas
- 44 BWR Base option
- 20 BWR (derated 44) Non-Standard option if needed

Scenario L6: Same as L5, but using small WP designs for Non-Standard option rather than a derated WP type.

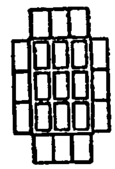
The following graphics depicts each WP Derating Options considered. The center assemblies in each WP are marked as blocked out in the derated WP.



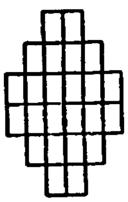
21 PWR



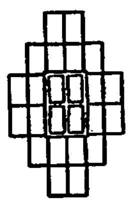
16 PWR
(derated 21)



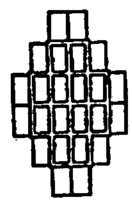
12 PWR
(derated 21)



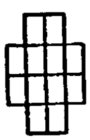
24 PWR



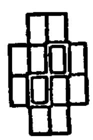
20 PWR
(derated 24)



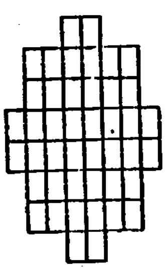
12 PWR
(derated 24)



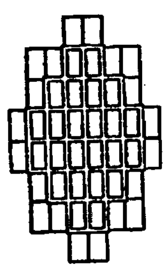
12 PWR



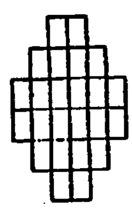
10 PWR
(derated 12)



44 BWR



20 BWR
(derated 44)



24 BWR

7.5 WP Unit Costs

The WP cost estimates used to determine the economies of differing WP designs are provided in Section 4.1 (see assumptions 4.3.1, 4.3.2, 4.3.8, and 4.3.9). To determine the cost differences between each of the scenario combinations, it is assumed that $10,000,000 is required to perform the design and licensing activities for each WP design option. This cost is a rough estimate used only to demonstrate the cost savings of minimizing the total number of different WP designs to be licensed. Additionally, if a WP system did not directly handle all of the SNF assemblies in the waste stream scenario, a $50,000 per assembly penalty was assessed to the WP system costs.

All cost figures are based upon 1996 dollars and this analysis does not account for the time value of money. The cost figures are used only to evaluate the relative differences between WP system scenarios and will not be representative of the true cost of the WP system. Finally, since at this time each of the waste stream scenarios have an equal probability of occurring, the evaluation of each WP system will be performed on the average cost. The average cost is based upon the total cost of each waste stream scenario equally weighted to determine the average.

7.6 Waste Package System Cases

All of the required data has now been identified in order to perform the WP system evaluations. Section 7.2 specified that the waste stream scenarios W2, W3, W5, and W8 provide a representative range for waste stream variability. Section 7.3 specified the range of WP capacity, WP thermal rating, and WP criticality rating of favorable candidate WP types. Section 7.4 identified the range of candidate WP systems which should be evaluated. Finally, Section 7.5 provides the cost basis with which to help evaluate the relative differences between each WP system.

The evaluation process is begun by selecting a WP loading scenario (i.e., L1, L2, L3, L4, L5, or L6), then selecting a WP thermal strategy (i.e., T1, T2, T3, T4, T5, or T6), and finally selecting a criticality strategy (i.e., C1, C2, or C3). Each combination of these three items determines the WP types which comprise a WP system. Each WP system is then evaluated with each of the four selected waste stream scenarios (i.e., W2, W3, W5, and W8) to determine the number of each WP type, the number of assemblies which can not be put into a WP type, and the associated costs. Thus, a matrix of WP systems to be considered for evaluation is then created.

However, some observations can be made concerning the WP systems generated:

1) Criticality scenario C3 should be the most expensive due to the increased criticality control material costs.

2) Thermal scenarios T5 and T6 increase the number of WP required since the low WP total heat load limit of 14.2 kW will force the use of smaller WP capacities. This will either

increase cost or increase the number of assemblies not handled by the WP system. Given the data in reference 5.6, there is no justification limiting the WP total heat load to a value below 18 kW.

3) Thermal scenarios T1 and T2 will not reduce the number of the non-standard WP type required enough to provide sufficient incentive to accept the additional risks of not meeting repository thermal performance criteria. Given the data in Attachment III, an increase in base WP thermal rating from 850 W/assembly to 900 W/assembly will alter the cumulative coverage results by less than 5%. Thus, there is little incentive to select a high risk WP design.

4) Derating large WPs for non-standard SNF assemblies is generally not cost effective unless there are very few SNF assemblies which the base WP design can not handle. Generally, given the constraints provided in Section 7.3 and the data in Attachment III, this situation will not occur.

Based on these observations, the WP system matrix for evaluation can be reduced to those WP systems which may provide some benefit. A few additional cases to confirm the observations used to reduce the evaluation matrix will also be included. Table 7.5-1 lists all of the WP system cases evaluated in this analysis.

Table 7.5-1 WP System Cases Evaluated

L1-T1-C1	L1-T1-C2	L1-T1-C3	L1-T2-C1	L1-T2-C2	L1-T2-C3	L1-T3-C1
L1-T3-C2	L1-T3-C3	L1-T4-C1	L1-T4-C2	L1-T4-C3	L1-T5-C1	L1-T6-C1
L2-T3-C1	L2-T4-C1	L3-T4-C1	L4-T4-C1	L5-T3-C1	L5-T4-C1	L6-T4-C1

7.7 Resulting Coverages

The tables provided in Attachment IV indicate the bins resulting from the loading, thermal, criticality, and waste stream scenarios described above. These results were generated with the WPBIN00a code in Attachment I and all input/output files are listed in Attachment V (see Ref. 5.17). For example, the first table (page 1, Attachment IV) indicates the WP designs and corresponding thermal and criticality ratings for the WP system for case L1-T1-C1 (loading scenario L1, thermal scenario T1, and criticality scenario C1). Each table reports the resulting coverages for each WP system for waste stream scenarios W2, W3, W5, and W8 and the calculated costs. Number (#) indicates the number of filled (last one partially filled) waste packages, or the number of leftover assemblies that could not be placed into any of the WP types for that WP system. Percentages indicate the percentage amount of assemblies held by each waste package type calculated for PWRs and BWRs separately.

Examining the results, the lowest average cost (those less than \$3.200 billion) WP systems are:

1) L1-T2-C1	Page 4, Attachment IV	\$3.101 Billion
2) L6-T4-C1	Page 21, Attachment IV	\$3.123 Billion
3) L4-T4-C1	Page 18, Attachment IV	\$3.140 Billion
4) L1-T4-C1	Page 10, Attachment IV	\$3.156 Billion
5) L1-T1-C1	Page 1, Attachment IV	\$3.163 Billion
6) L1-T3-C1	Page 7, Attachment IV	\$3.171 Billion
7) L2-T3-C1	Page 15, Attachment IV	\$3.198 Billion

Notice that the highest cost WP systems were those using the criticality scenario C3; therefore, reducing the number of these cases was justified. Generally, criticality scenario C1 was less costly than C2; however, C2 provides one base WP design which covers 90% or more of the total waste stream. The criticality scenario C2 also provides some additional margin for misloaded WP types and a smaller number of WP types required. However, the cost benefit of criticality scenario C1 is attractive if a viable WP system can be created with it.

The observations made in Section 7.6 concerning the thermal scenarios T5 and T6 were shown to be accurate. These WP systems were among the higher cost options. Also, those WP systems which utilized derated WP types generally required very few if any of the derated WPs and were generally higher cost WP systems. This point is illustrated by comparing cases L5-T4-C1 (p. 20, Attachment IV) and L6-T4-C1 (p. 21, Attachment IV) which differed only in the use of derated large WP versus using small WP designs. The WP system which depended upon derated WP types was the higher cost system.

The lowest four average cost WP systems differ on cost by 2% or less. The lowest cost WP system has a maximum WP total heat load of 19 kW. As discussed in Section 7.3.1, this presents a significant risk to the repository thermal performance goals as long as a high thermal loading strategy is to be proposed for NRC license. An estimated 2% reduction in WP costs is not significant enough to warrant accepting the risk of repository and/or a WP redesign effort.

The next two lowest cost WP systems are dependent upon a 24 PWR assembly capacity WP design. As discussed in Section 7.3, this WP design has a performance deficiency with regard to WP degraded mode performance when compared to the other WP types. The fourth lowest cost WP system is comprised of WP types which have been determined to have the best performance characteristics. Each of these three WP systems (items 2, 3, and 4 in the cost list) are based upon a WP thermal rating of 18 kW or less (i.e., thermal scenario T4), the criticality scenario C1, and are low risk for not meeting WP performance requirements on these points. The two low cost 24 PWR WP systems (loading scenarios L4 and L6) differ in cost by 1% or less from the 21 PWR WP system (loading scenario L1). An estimated 1% reduction in WP costs is not significant enough to warrant accepting the risk of repository and/or a WP redesign effort.

Thus, the best WP system to handle the waste stream variability and provide a high probability for meeting all of the repository WP performance criteria is the L1-T4-C1 WP system. Table 7.7-1 summarizes the WP system components and the waste stream coverages for each WP type. All of the WP types provided in Table 7.7-1are requried in order to emplace 100% of the commercial SNF waste stream in the repository.

Table 7.7-1 WP System L1-T4-C1 Waste Stream Coverage

Case L1-T4-C1		Heat Range (W)		Criticality Range		Coverage Range	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1375 to 1835	26.9 to 40.6%
21 PWR - absorber plates criticality - p1	2	0	850	1.00	1.13	2399 to 3596	53.1% to 58.1%
21 PWR - absorber rods (no abs. plates) criticality - p2	3	0	850	1.13	1.45	119 to 257	2.6% to 4.1%
12 PWR - no absorber, thermal - p1	4	850	1370	0.00	1.02	80 to 850	1.0% to 7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150 to 272	1.9% to 2.5%
44 BWR - no absorber base thermal & criticality	6	0	400	0.00	1.00	695 to 997	24.6% to 30.3%
44 BWR - absorber plates criticality - b1	7	0	400	1.00	1.37	1942 to 2704	68.2% to 74.6%
24 BWR - thick absorber plates thermal - option b1 criticality - b2	8	0	520	0.00	1.54	40 to 197	0.8% to 2.8%
Total WP Production Costs:		$3.156B Ave.				$2.873B to $4.020B	

8. Conclusions

As identified in Sections 2 and 4, this analysis is based on unqualified/unconfirmed input data and use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

This analysis is prepared by the Mined Geologic Disposal System Waste Package Development Department to set the capacity of the WP designs and the number of different types of WP design types which will be required to handle 100% of the anticipated commercial SNF waste stream. The objective of this evaluation is to determine: 1) the number of different types of WP needed, 2) the capacity of each WP type, 3) the SNF parameters which provide the limits for each WP type, and 4) provide a reasonable rationale that the selected system of WP types may be capable of disposing 100% of the anticipated commercial SNF waste stream to be shipped to the MGDS repository. This information will then determine the scope of the WP design efforts and provide goals for determining the design basis SNF fuel type for thermal, structural, and neutronics/criticality analysis.

The selected design basis WP system configuration is presented in Table 8-1 and the rationale supporting this selection is provided in Sections 7.2 through 7.7. Note, the 12 PWR assembly WP type can be designed to accept PWR assemblies with a 1500 W/assembly heat rate or less given a total WP heat load limit of 18 kW. This change will not significantly affect the WP coverage for the WP system reported in Table 8-1 and will provide additional capacity to handle non-standard PWR SNF assemblies. This is the WP system which is recommended for WP design efforts.

All of the WP types listed in Table 8-1 are requried in order to emplace 100% of the commercial SNF waste stream in the repository. Thus, all of the objectives of this design analysis have been met.

Table 8-1 Design Basis WP System Configuration Waste Stream Coverage

Case L1-T4-C1 (See Section 7.7) WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_min	k_max	Coverage Range #	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1375 to 1835	26.9 to 40.6%
21 PWR - absorber plates criticality - p1	2	0	850	1.00	1.13	2399 to 3596	53.1% to 58.1%
21 PWR - absorber rods (no abs. plates) criticality - p2	3	0	850	1.13	1.45	119 to 257	2.6% to 4.1%
12 PWR - no absorber thermal - p1	4	850	1370	0.00	1.02	80 to 850	1.0% to 7.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150 to 272	1.9% to 2.5%
44 BWR - no absorber base thermal & criticality	6	0	400	0.00	1.00	695 to 997	24.6% to 30.3%
44 BWR - absorber plates criticality - b1	7	0	400	1.00	1.37	1942 to 2704	68.2% to 74.6%
24 BWR - thick absorber plates thermal - option b1 criticality - b2	8	0	520	0.00	1.54	40 to 197	0.8% to 2.8%

9. Attachments

Attachments to this design analysis are summarized in Table 9-1. Each attachment is identified by a specific number, file name, date of file, and number of pages.

Table 9-1 List of Attachments

Attachment Number	Description	Date	Number of Pages
I	WPBIN00a Program source code listing (File Name: WPBIN00A.CPP)	2/13/97	5
II	BWR assembly $k_{infinity}$ data curve fit (File Name: BWRKINF.FIT)	2/19/97	4
III	Waste stream data plots for thermal and criticality parameters (File Name: WADATA.GPH)	2/20/97	8
IV	WP system coverage and costs table summaries (File Name: WPCOVER.TBL)	2/27/97	21
V	WPBIN00a input/output files stored on magnetic media (File Name: WADATA.TPE; see reference 5.17)	2/21/97	2

```
/*wpbin00a.cpp Program to tabulate statistics according to a standard,
 *regular, set of bins, or a special set of bins defined by limits on
 *a set of records.
 *This program uses the verified routines in for computing assembly
 *heat, the object modules for which are incorporated in the link
 *command, as described below.
 *The command for compiling only is \msvc\bin\cl /c /FPi87 /AH wpbin00a.cpp
 *The command for linking is
   \msvc\bin\link wpbin00a.obj heatmdh.obj gethtmdh.obj,,,,;
 *The executable will be wpbin00a.exe        */

#include <string.h>
#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <malloc.h>
#include <string.h>
#include <ctype.h>
#define MAIN
#include "heat.h"
#define YEARS 40
#define CRITS 85
#define BHEATS 100
#define PHEATS 200
#define MAXBINS 20
#define FIRSTPYR 2010

int stdhbin(char,float),stdcbin(float),spcbin(int,char,float,float);
float getfloat(char*,int,int);
float mcritsp[CRITS]={0},mheatsp[PHEATS]={0},mcumhp[PHEATS]={0},
    mcumcp[CRITS]={0},mcritsb[CRITS]={0},mheatsb[BHEATS]={0},
    mcumhb[BHEATS]={0},mcumcb[CRITS]={0},
    mbins[MAXBINS][YEARS];
long int count=0,ntotalb=0,ntotalp=0,nobins[5]={0};
//Heat h;              // Use this only for Quickwin application
int getint(char*,int,int),ncount=0,bincap[MAXBINS];
FILE *ferr;
long int ncritsp[CRITS]={0},nheatsp[PHEATS]={0},ncumhp[PHEATS]={0},
    ncumcp[CRITS]={0},ncritsb[CRITS]={0},nheatsb[BHEATS]={0},
    ncumhb[BHEATS]={0},ncumcb[CRITS]={0},assybpyr[YEARS]={0},
    nbins[MAXBINS][YEARS],npkgs[MAXBINS][YEARS],assyppyr[YEARS]={0},
    totalassy[MAXBINS]={0};
float minheat[MAXBINS],maxheat[MAXBINS],mink[MAXBINS],
        maxk[MAXBINS],mtupyr[YEARS]={0},mobins[5]={0},
        totalmtu[MAXBINS]={0},totalpkg[MAXBINS]={0};
char brectype[MAXBINS];

void main()
{int i,j,k,ndyr,npyr,yr,m,na,nh,nk,lastpyr=0,timelimit,atype,
   nbinrecs,ndx;
long int gtotalassy=0;
float age,b,heat,w,a,c,cumheat=0,mtupassy,avage=0,
      gtotalmtu=0,
```

```
      kinf,cumcrit=0, wtotalb=0,wtotalp=0,youngtotal=0,gtotalpkg=0;
  FILE *fout,*find,*finp;
  char buffer[300],type,inname[13],outname[13],title[50],rname[15],
     subtitle[50],outchar[3]={'b','p','s'};
  if ((finp=fopen("wpbin00a.in","r"))==NULL)
    {printf("Can't open input parameter file\n");exit(0);}
  fgets(buffer,100,finp); /*readthrough labels*/
  fgets(buffer,100,finp);
  sscanf(buffer,"%d %s %s %s %d",&nbinrecs,inname,outname,title,&timelimit);
  fgets(buffer,100,finp); //readthrough more labels
  for(i=0;i<nbinrecs;i++)
    {fgets(buffer,100,finp);
    sscanf(buffer,"%c %d %f %f %f %f\n",&brectype[i],&bincap[i],
      &minheat[i],&maxheat[i],&mink[i],&maxk[i]);}
  if ((find=fopen(inname,"r"))==NULL)
    {printf("Can't open input data file %s\n",inname);exit(0);}
  fout=fopen(outname,"w");
  ferr=fopen("junk.out","w");
  while(fgets(buffer,300,find)!=NULL)
    {w=getfloat(buffer,21,10);
    b=getfloat(buffer,51,10);
    ndyr=getint(buffer,71,8);
    npyr=getint(buffer,287,4);
    type=tolower(buffer[123]);
    na=getint(buffer,31,10);
    a=getfloat(buffer,41,10);
    strncpy(rname,buffer+1,11);
    rname[11]='\0';
    if((na>0)&&(npyr<=timelimit)&&(npyr>0)&&((type=='p')||(type=='b')))
      {j=npyr-ndyr;
      yr=npyr-FIRSTPYR;
      mtupyr[yr]+=w;
      if(type=='b')assybpyr[yr]+=na;
      else assyppyr[yr]+=na;
      if(j<10)
        {fprintf(ferr,"age=%d , mass= %f\n",j,w);
        youngtotal+=na;}
      if(npyr>lastpyr)lastpyr=npyr;
      avage+=na*j;
      j=(j>=YEARS)?YEARS-1:j;
      j=(j<1)?1:j;
      mtupassy=w/na;
      heat=mtupassy*h.GetHeat((float)j,(type=='p'?1:0),b,a);
      c=(j>40)?40:(float)j;
      if(type=='b')
        {ntotalb+=na;
        wtotalb+=w;}
      else
        {ntotalp+=na;
        wtotalp+=w;}
      b/=1000;
      if(type=='b')
        {kinf=.92601-.012598*b+.19901*a+9.49922e-5*b*b-.006702*a*a-.001243*a*b;
```

```
if((kinf>1.4)||(b<5))fprintf(ferr,"Nassy=%d burnup=%.2f kinf=%.3f Enrch=%.2f Dschg=%d %s\n",
     na,b,kinf,a,ndyr,rname);}
else
 kinf=1.06-.01*b-.002*c+.114*a+.00007081*b*b+.00007565*c*c
   -.007*a*a-.0002671*b*a-.0001145*b*c+.0002318*c*a+
   .000009366*b*c*a;
if(nbinrecs==0)
 {if(type=='b')
   {ncritsb[stdcbin(kinf)]+=na;
   nheatsb[stdhbin(type,heat)]+=na;
   mcritsb[stdcbin(kinf)]+=w;
   mheatsb[stdhbin(type,heat)]+=w;}
 else
   {ncritsp[stdcbin(kinf)]+=na;
   nheatsp[stdhbin(type,heat)]+=na;
   mcritsp[stdcbin(kinf)]+=w;
   mheatsp[stdhbin(type,heat)]+=w;}}
else
 {if(strcmp(rname,"SOUTH TEXAS")==0) type='s';
 ndx=spcbin(nbinrecs,type,heat,kinf);
 nbins[ndx][yr]+=na;
 mbins[ndx][yr]+=w;}}}
printf("Total assy %ld  Avg age %f  MTU B %f  MTU P %f  Final yr %d\n",
  ntotalp+ntotalb,avage/(ntotalp+ntotalb),wtotalb,wtotalp,lastpyr);
fprintf(fout,"%s\n",title);
if(nbinrecs==0) strcpy(subtitle,"Standard Table");
else sprintf(subtitle,"%d %s",nbinrecs,"Bins");
fprintf(fout,"%s\n",subtitle);
if(nbinrecs==0)
 {ncumhb[0]=nheatsb[0];
 for(i=1;i<BHEATS;i++) ncumhb[i]=nheatsb[i]+ncumhb[i-1];
 fprintf(fout,"\n\nBWR Heat Percentiles\n");
 fprintf(fout,"%10s %10s %10s %10s\n",
     "Watts/Assy"," Assy","Cum Assy","Percent");
 for(i=0;i<BHEATS-1;i++) fprintf(fout,"%10d %10ld %10ld %10.2f\n",
   (i+1)*10,nheatsb[i],ncumhb[i],(float)ncumhb[i]*100/ntotalb);
 fprintf(fout,"%10s %10ld %10ld %10.2f\n",
   "Above",nheatsb[BHEATS-1],ncumhb[BHEATS-1],
   (float)ncumhb[BHEATS-1]*100/ntotalb);
 fprintf(fout,"\n\nBWR Kinf Percentiles\n");
 fprintf(fout,"%12s %12s %12s %12s\n","     Kinf","     Assy"," CumAssy", "Percent");
 ncumcb[0]=ncritsb[0];
 for(i=1;i<CRITS;i++) ncumcb[i]=ncritsb[i]+ncumcb[i-1];
 for(i=0;i<CRITS-1;i++)
   {kinf=((float)i+1+75)/100;
   fprintf(fout,"%12.3f %12ld %12ld %12.2f\n",kinf,ncritsb[i],
          ncumcb[i],(float)ncumcb[i]*100/ntotalb);}
 fprintf(fout,"%12s %12ld %12ld %12.2f\n","Above",ncritsb[CRITS-1],
          ncumcb[CRITS-1],(float)ncumcb[CRITS-1]*100/ntotalb);
 ncumhp[0]=nheatsp[0];
 for(i=1;i<PHEATS;i++) ncumhp[i]=nheatsp[i]+ncumhp[i-1];
 fprintf(fout,"\n\nPWR Heat Percentiles\n");
 fprintf(fout,"%10s %10s %10s %10s\n",
```

```
"Watts/Assy"," Assy","Cum Assy","Percent");
for(i=0;i<PHEATS-1;i++) fprintf(fout,"%10d %10ld %10ld %10.2f\n",
 (i+1)*10,nheatsp[i],ncumhp[i],(float)ncumhp[i]*100/ntotalp);
fprintf(fout,"%10s %10ld %10ld %10.2f\n",
 "Above",nheatsp[PHEATS-1],ncumhp[PHEATS-1],
 (float)ncumhp[PHEATS-1]*100/ntotalp);
fprintf(fout,"\n\nPWR Kinf Percentiles\n");
fprintf(fout,"%12s %12s %12s %12s\n","    Kinf","    Assy"," CumAssy", "Percent");
ncumcp[0]=ncritsp[0];
for(i=1;i<CRITS;i++) ncumcp[i]=ncritsp[i]+ncumcp[i-1];
for(i=0;i<CRITS-1;i++)
 {kinf=((float)i+1+75)/100;
 fprintf(fout,"%12.3f %12ld %12ld %12.2f\n",kinf,ncritsp[i],
          ncumcp[i],(float)ncumcp[i]*100/ntotalp);}
fprintf(fout,"%12s %12ld %12ld %12.2f\n","Above",ncritsp[CRITS-1],
          ncumcp[CRITS-1],(float)ncumcp[CRITS-1]*100/ntotalp);
fprintf(fout,"\n\n%10s%10s%10s%10s\n","Year","MTU","B Assy","P Assy");
for(i=0;i<=timelimit-FIRSTPYR;i++) fprintf(fout,"%10d%10.2f%10ld%10ld\n",
 i+FIRSTPYR,mtupyr[i],assybpyr[i],assyppyr[i]);
fprintf(fout,"\n\nAverage age = %7.3f\n",avage/(ntotalb+ntotalp));}
else
 {for(i=0;i<nbinrecs;i++)
  {fprintf(fout,"\n\n\nType=%c Cap=%d Hmin=%.1f Hmax=%.1f Kmin=%.2f Kmax=%.2f\n\n",
    brectype[i],bincap[i],minheat[i],maxheat[i],mink[i],maxk[i]);
  fprintf(fout,"%12s%12s%12s%12s\n","Year","Num_Assy","Num_Pkgs","MTU");
  for(j=0;j<=lastpyr-FIRSTPYR;j++)
   {totalassy[i]+=nbins[i][j];
   totalmtu[i]+=mbins[i][j];
   totalpkg[i]+=(float)nbins[i][j]/bincap[i];
   fprintf(fout,"%12d%12ld%12.2f%12.2f\n",j+FIRSTPYR,nbins[i][j],
    (float)nbins[i][j]/bincap[i],mbins[i][j]);}
  gtotalassy+=totalassy[i];
  gtotalpkg+=totalpkg[i];
  gtotalmtu+=totalmtu[i];
  fprintf(fout,"\n%12s%12ld%12.2f%12.2f\n",
    "Bin Total",totalassy[i],totalpkg[i],totalmtu[i]);}
 for(i=0;i<3;i++)
  {for(j=0;j<=timelimit-FIRSTPYR;j++) nobins[i]+=nbins[nbinrecs+i][j];
  for(j=0;j<=timelimit-FIRSTPYR;j++) mobins[i]+=mbins[nbinrecs+i][j];
  gtotalassy+=nobins[i];
  gtotalmtu+=mobins[i];}
 fprintf(fout,"\n\nSummary Table\n");
 fprintf(fout,"%10s%10s%10s%10s%10s%10s\n","Type","Cap","Num_Assy",
   "PctType","Num_Pkg","MTU");
 for(i=0;i<nbinrecs;i++)
  fprintf(fout,"%10c%10d%10ld%10.2f%10.2f%10.2f\n",brectype[i],
   bincap[i],totalassy[i],
   (float)totalassy[i]*100/(brectype[i]=='b'?ntotalb:ntotalp),
   totalpkg[i],totalmtu[i]);
 for(i=0;i<3;i++)
  fprintf(fout,"%10c%10d%10ld%10.2f%10.2f%10.2f\n",outchar[i],
   1,nobins[i],(float)nobins[i]*100/(i==0?ntotalb:ntotalp),
   (float)nobins[i],mobins[i]);
```

```
 fprintf(fout,"\n%10s%20ld%20.2f%10.2f\n","Totals",gtotalassy,
      gtotalpkg,gtotalmtu);}
printf("Done \n");}

int stdhbin(char t, float ht)
{int n;
n=ht/10;
if((10*n-ht)==0)n--;
if(n<0) n=0;
else
 {if (t=='b') if(n>BHEATS-1) n=BHEATS-1;
 else if(n>PHEATS-1) n=PHEATS-1;}
return n;}

int stdcbin(float k)
{int n;
n=(int)(100*k-75);
if((100*k-75-n)==0)n--;
if(n<0) n=0;
 else if(n>CRITS-1) n=CRITS-1;
return n;}

int spcbin(int num,char t,float ht, float k)
{int found=0,i=0;
while((found==0)&&(i<num))
 {if((brectype[i]==t)&&
   (ht>minheat[i])&&(ht<=maxheat[i])&&
   (k>mink[i])&&(k<=maxk[i])) found=1;
 i++;}
if(found==1)return(i-1);
else
 {fprintf(ferr,"No bin for %c %f %f\n",t,ht,k);
 if(t=='p') num++;    //default adds 0 for t=='b'
 else if(t=='s') num+=2;
 return num;}}

float getfloat(char* string, int start, int length)
{char temp[20];
int i,j;
for(i=start;i<start+length;i++) temp[i-start]=string[i];
temp[length]='\0';
return(atof(temp));}

int getint(char* string, int start, int length)
{char temp[20];
int i,j;
for(i=start;i<start+length;i++) temp[i-start]=string[i];
temp[length]='\0';
return(atoi(temp));}
```

Feb 19 1997 Filename: bwrKinf.fit BBAA00000-01717-0200-00017 REV00 Attachment II - p. 1

	BWR Kinf Curve Versus Initial U235 Enrichment					
Assembly Average Burnup GWd/MTU	Lattice Average Initial E: 2.00%	Lattice Average Initial E: 2.50%	Lattice Average Initial E: 3.00%	Lattice Average Initial E: 3.50%	Lattice Average Initial E: 4.00%	Lattice Average Initial E: 4.50%
0	1.072	1.122	1.169	1.205	1.242	1.279
5	1.131	1.186	1.229	1.265	1.301	1.338
7.5	1.165	1.218	1.257	1.297	1.334	1.368
8.5	1.168					
10	1.148	1.235	1.283	1.333	1.366	1.398
12.5	1.122	1.202	1.270	1.347	1.389	1.426
15	1.094	1.173	1.241	1.310	1.381	1.433
17.5	1.061	1.140	1.208	1.277	1.348	1.401
20	1.034	1.108	1.173	1.240	1.311	1.365
25	0.982	1.105	1.114	1.177	1.242	1.290
30	0.927	0.995	1.054	1.115	1.178	1.225
35	0.882	0.945	1.000	1.056	1.114	1.157
40	0.845	0.904	0.955	1.007	1.061	1.100
45	0.809	0.866	0.915	0.965	1.017	1.055
50	0.782	0.835	0.880	0.927	0.975	1.010
55	0.754	0.806	0.850	0.895	0.942	0.976
60		0.781	0.828	0.868	0.911	0.942

Gd_2O_3 influenced range.

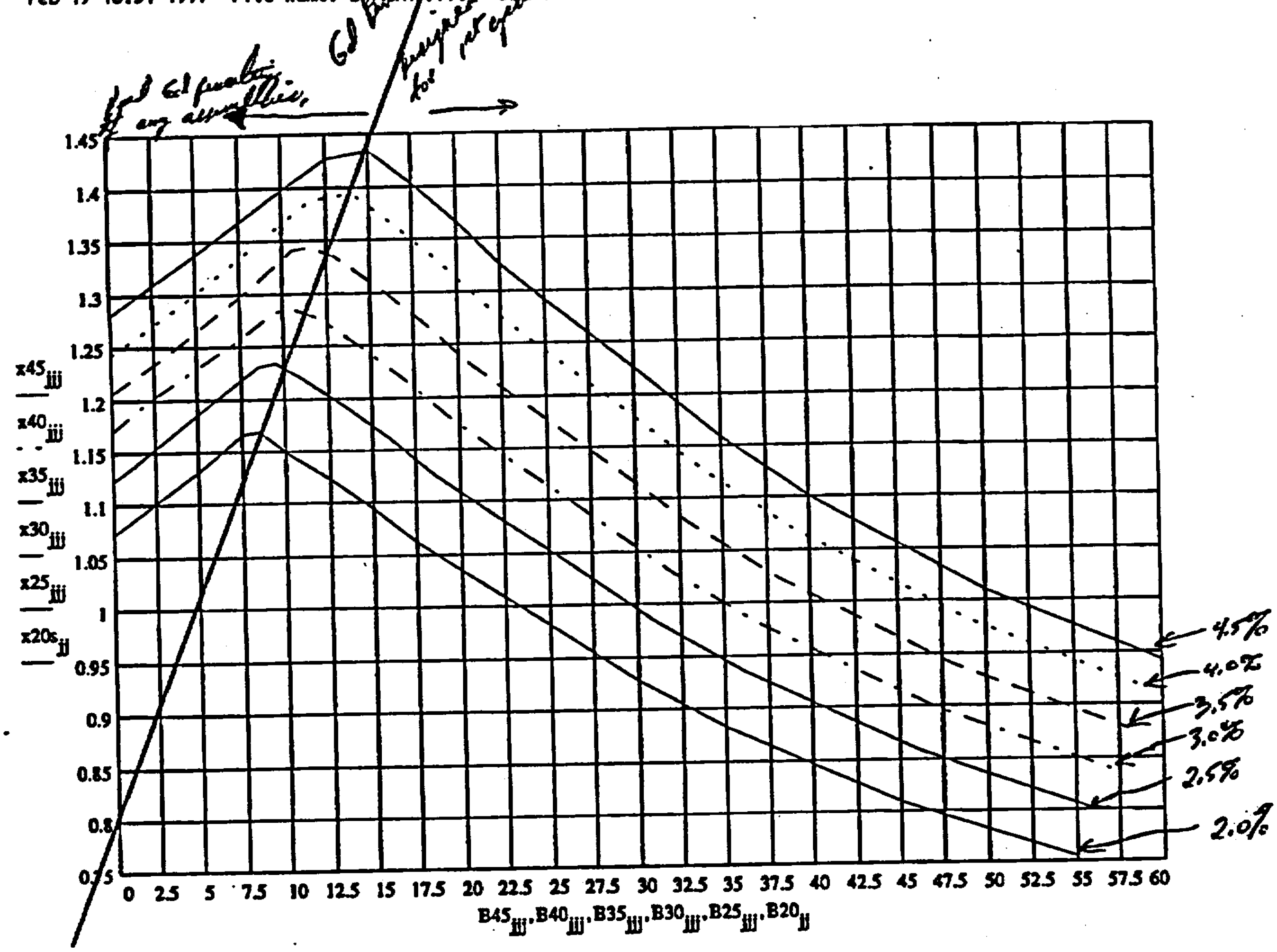
After Gd_2O_3 burnout range

Notes:
1) Curves are bounding with regard to assembly array and Gd2O3/U loading.
2) Curves are for time of discharge; use is conservative with if no cooling time is applied.
3) All values are based upon Holtec, Siemens, and ATEA rack designs for GE and Siemens BWR Fuel assmebly designs (i.e., from NRC license submittal data).
4) Gd burnout for all designs is in the 7.5 to 15 GWd/MTU burnup range, which is the designed end of first cycle. Any item to the left of the curve peak will need a GD penalty applied.

Data in table is from references 5.4, 5.14, 5.15, and 5.16. These values are all NRC reviewed values which are bounding for BWR assembly designs for each Burnup/U235 enrichment pair.

NOTE:
All hand written items are the work of the document originator.

DI: BBAA00000-01717-0200-00017 REV00
File Name: burkinf.fit



Graphical representation of the data in Table from page 1 of Attachment II. The design Gd burnout (i.e. end of cycle 1) is ~~shown~~ shown on the plot. The curve fit is to focus on the values to the right of ~~this~~ the Gd burnout line.

BWR Kinf Curve Versus Initial U235 Enrichment

Assembly Average Burnup GWd/MTU	Data (ref. 5.4, 5.14, 5.15, 5.16) Lattice Average Initial E: 2.00%	Lattice Average Initial E: 2.50%	Lattice Average Initial E: 3.00%	Lattice Average Initial E: 3.50%	Lattice Average Initial E: 4.00%	Lattice Average Initial E: 4.50%	Fit (Equation Values) Lattice Average Initial E: 2.00	Lattice Average Initial E: 2.50	Lattice Average Initial E: 3.00	Lattice Average Initial E: 3.50	Lattice Average Initial E: 4.00	Lattice Average Initial E: 4.50
0	1.07	1.12	1.17	1.21	1.24	1.28	1.30	1.38	1.46	1.54	1.61	1.69
5	1.13	1.19	1.23	1.27	1.30	1.34	1.22	1.31	1.38	1.46	1.53	1.60
7.5	1.17	1.22	1.26	1.30	1.33	1.37	1.19	1.27	1.35	1.42	1.49	1.55
8.5	1.17						1.18	1.26	1.33	1.40	1.47	1.54
10	1.15	1.24	1.28	1.33	1.37	1.40	1.16	1.23	1.31	1.38	1.45	1.51
12.5	1.12	1.20	1.27	1.35	1.39	1.43	1.12	1.20	1.27	1.34	1.41	1.47
15	1.09	1.17	1.24	1.31	1.38	1.43	1.09	1.17	1.24	1.31	1.37	1.43
17.5	1.06	1.14	1.21	1.28	1.35	1.40	1.06	1.14	1.21	1.27	1.34	1.40
20	1.03	1.11	1.17	1.24	1.31	1.37	1.03	1.11	1.17	1.24	1.30	1.36
25	0.98	1.11	1.11	1.18	1.24	1.29	0.98	1.05	1.11	1.18	1.23	1.29
30	0.93	1.00	1.05	1.12	1.18	1.23	0.93	1.00	1.06	1.12	1.17	1.23
35	0.88	0.95	1.00	1.06	1.11	1.16	0.89	0.95	1.01	1.06	1.12	1.17
40	0.85	0.90	0.96	1.01	1.06	1.10	0.85	0.91	0.96	1.01	1.06	1.11
45	0.81	0.87	0.92	0.97	1.02	1.06	0.81	0.87	0.92	0.97	1.02	1.06
50	0.78	0.84	0.88	0.93	0.98	1.01	0.78	0.83	0.88	0.93	0.97	1.01
55	0.75	0.81	0.85	0.90	0.94	0.98	0.75	0.81	0.85	0.90	0.94	0.97
60		0.78	0.83	0.87	0.91	0.94	0.73	0.78	0.83	0.87	0.90	0.94

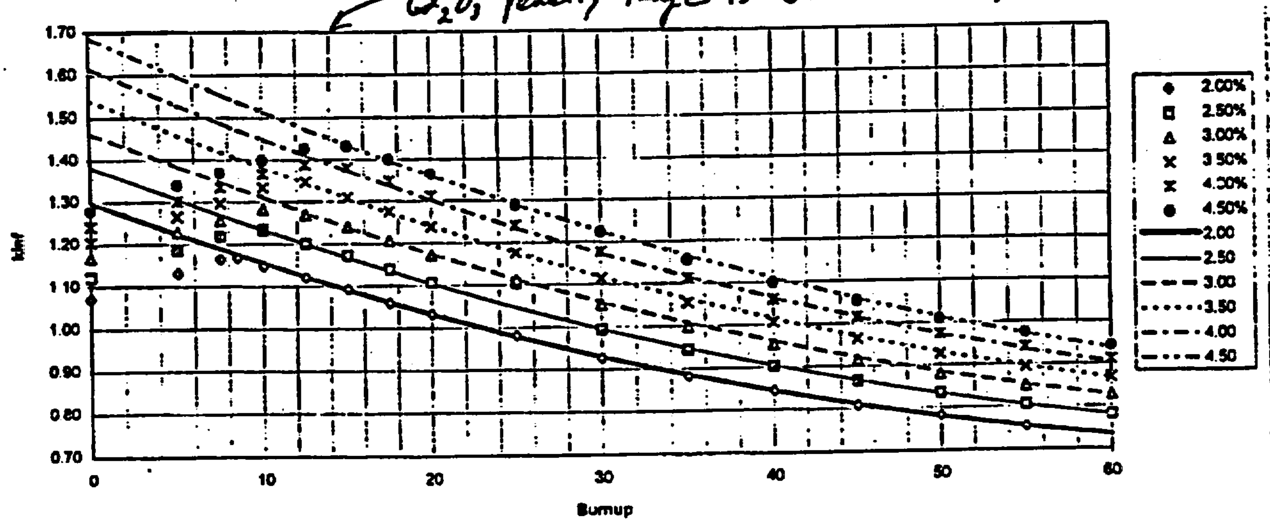
Gd_2O_3 penalty range

Fit range

Notes:
1) Curves are bounding with regard to assembly array and Gd2O3/U Loading.
2) Curves are for time of discharge; Use is conservative with if no cooling time is applied
3) All values are based upon Holtec, Siemens, and ATEA rack designs for GE and Siemens BWR Fuel assmebly designs. (I.e., from NRC license submittal data.)
4) Gd burnout for all designs is in the 7.5 to 15 GWd/MTU burnup range, which is the designed end of first cycle. Any item to the left of the curve peak will need a GD penalty applied.

BWR kinf Regression vs. Data

Gd_2O_3 penalty range is same as ref. 5.4, 5.14, 5.15, and 5.16.



SUMMARY OUTPUT			Valid Ranges			
			E (%)	B (GWd/MTU)	Line Fit	
Regression Statistics			2	8.5	8.38	
Multiple R	0.998732335		2.5	10	9.60	
R Square	0.997466278		3	10	10.81	
Adjusted R Square	0.997279975		3.5	12.5	12.02	
Standard Error	0.009203081		4	12.5	13.24	
Observations	74		4.5	15	14.45	
			6		18.10	
ANOVA			1		5.95	
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	5	2.267329287	0.453465857	5353.997068	8.38061E-87	
Residual	68	0.005759375	8.46967E-05			
Total	73	2.273088662				
(k)	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.926009985	0.018624601	49.7197212	3.39213E-55	0.888845193	0.963174776
B (b)	-0.012597677	0.000405282	-31.08372994	6.41499E-42	-0.013406404	-0.01178895
E (a)	0.199007692	0.011289601	17.62752225	4.65399E-27	0.176479658	0.221535727
B^2	9.49922E-05	5.36048E-06	17.72083358	3.46248E-27	8.42955E-05	0.000105689
E^2	-0.006702232	0.001751041	-3.827570527	0.000284176	-0.010196378	-0.003208087
BE	-0.001243395	8.5372E-05	-14.56443332	1.37392E-22	-0.001413752	-0.001073038
SUMMARY OUTPUT	Line Fit for Lower Burnup Limit as a Function of Enrichment					
Regression Statistics						
Multiple R	0.965016432					
R Square	0.931256713					
Adjusted R Square	0.914070892					
Standard Error	0.690065559					
Observations	6					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	25.80357143	25.80357143	54.1875	0.001814368	
Residual	4	1.904761905	0.476190476			
Total	5	27.70833333				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.523809524	1.108613974	3.178572169	0.033581044	0.445797307	6.601821741
X Variable 1	2.428571429	0.32991444	7.361215932	0.001814368	1.512580201	3.344562657

Fit only the Gd_2O_3 burnon Range.

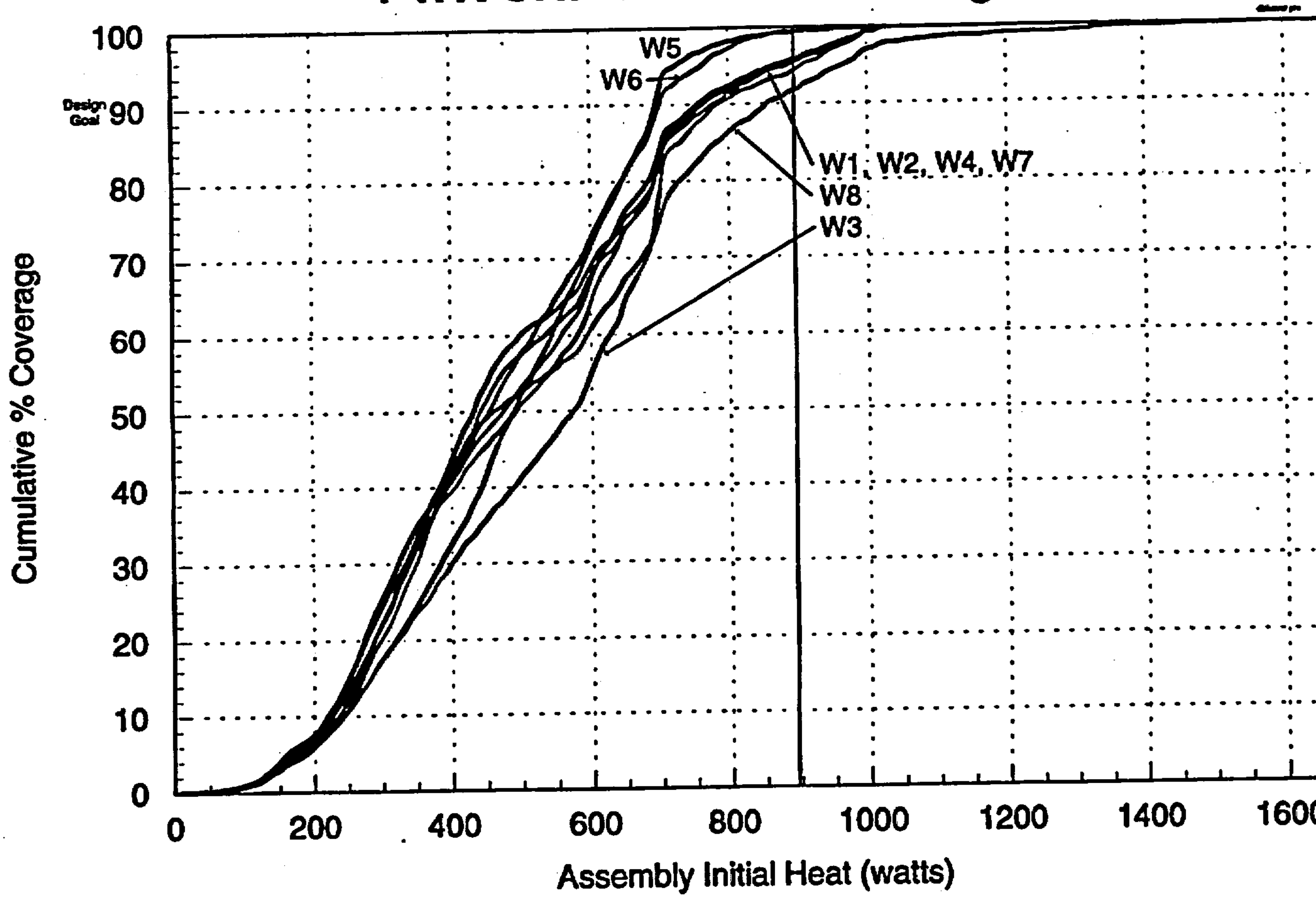
Fit Statistics indicate a Good to Excellent Curve Fit to the Data points.

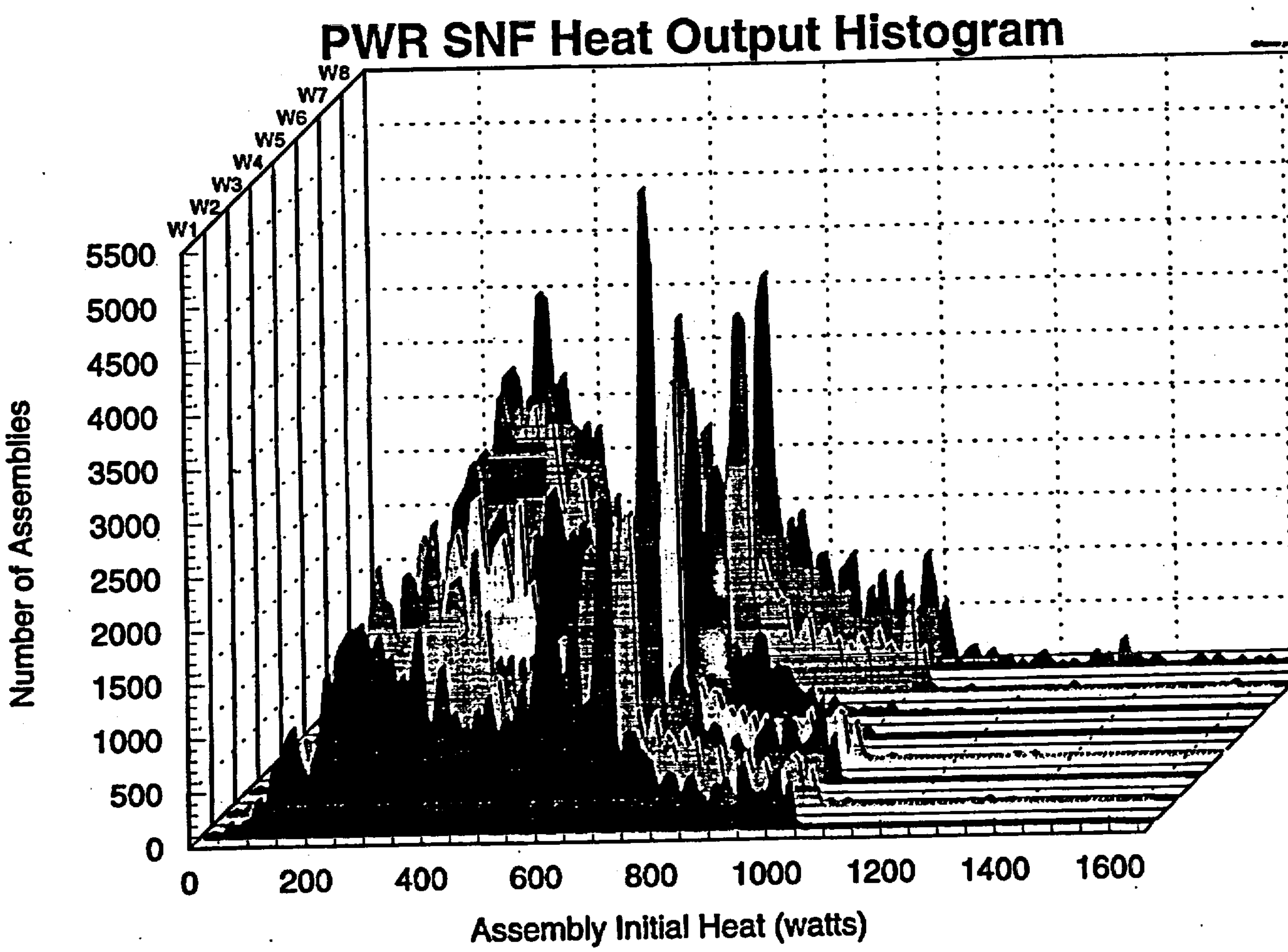
Result BWR K-inf equation:

$$K_{inf} = 0.92601 - (0.012598 \cdot b) + (0.19901 \cdot a) + (0.0000949922 \cdot b^2) - (0.006702 \cdot a^2) - (0.001243 \cdot b \cdot a)$$

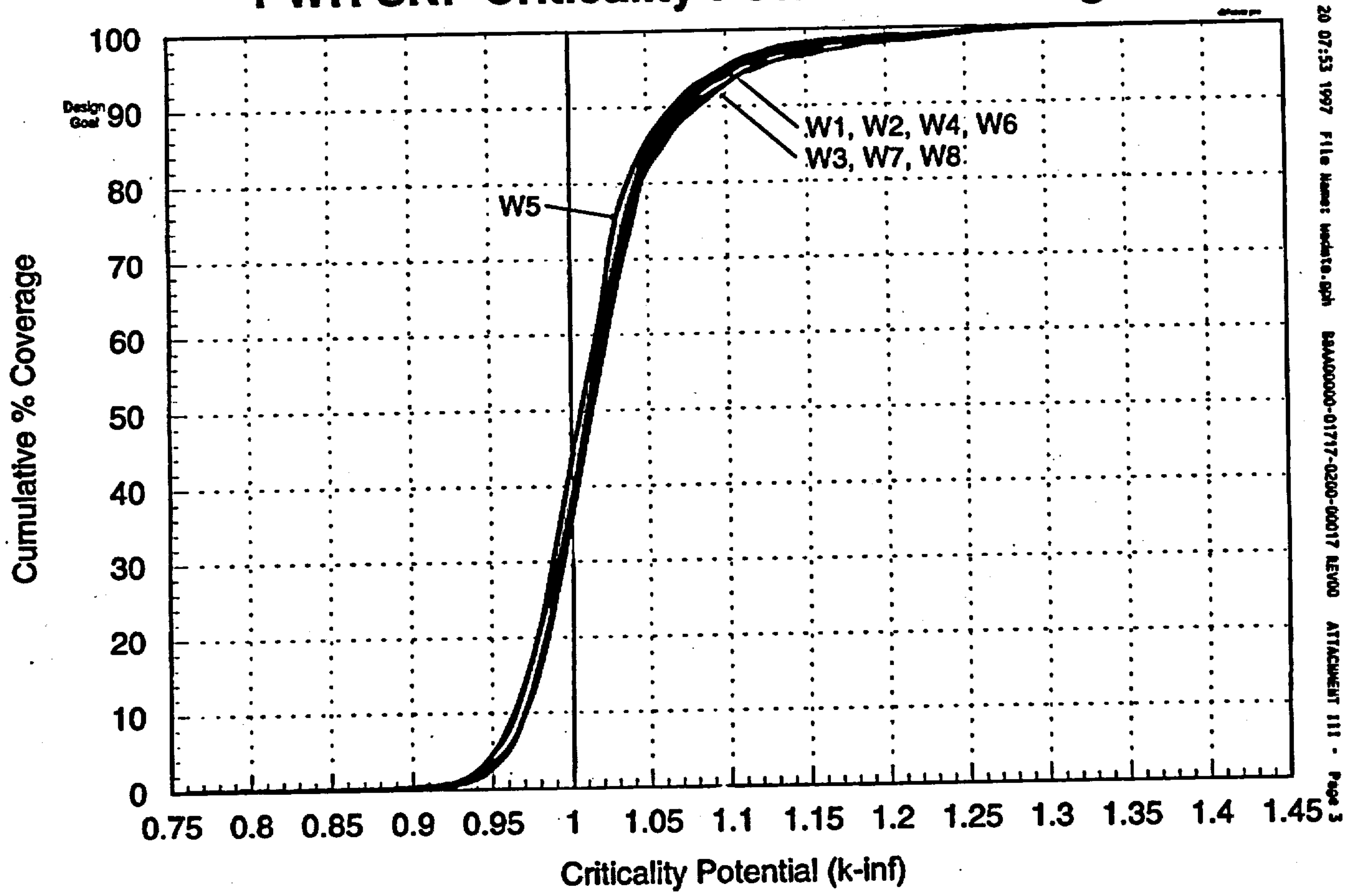
Where: a ≡ initial U235 enrichment (Assembly Average)
b ≡ assembly average burnup in GWd/MTU

PWR SNF Thermal Coverage

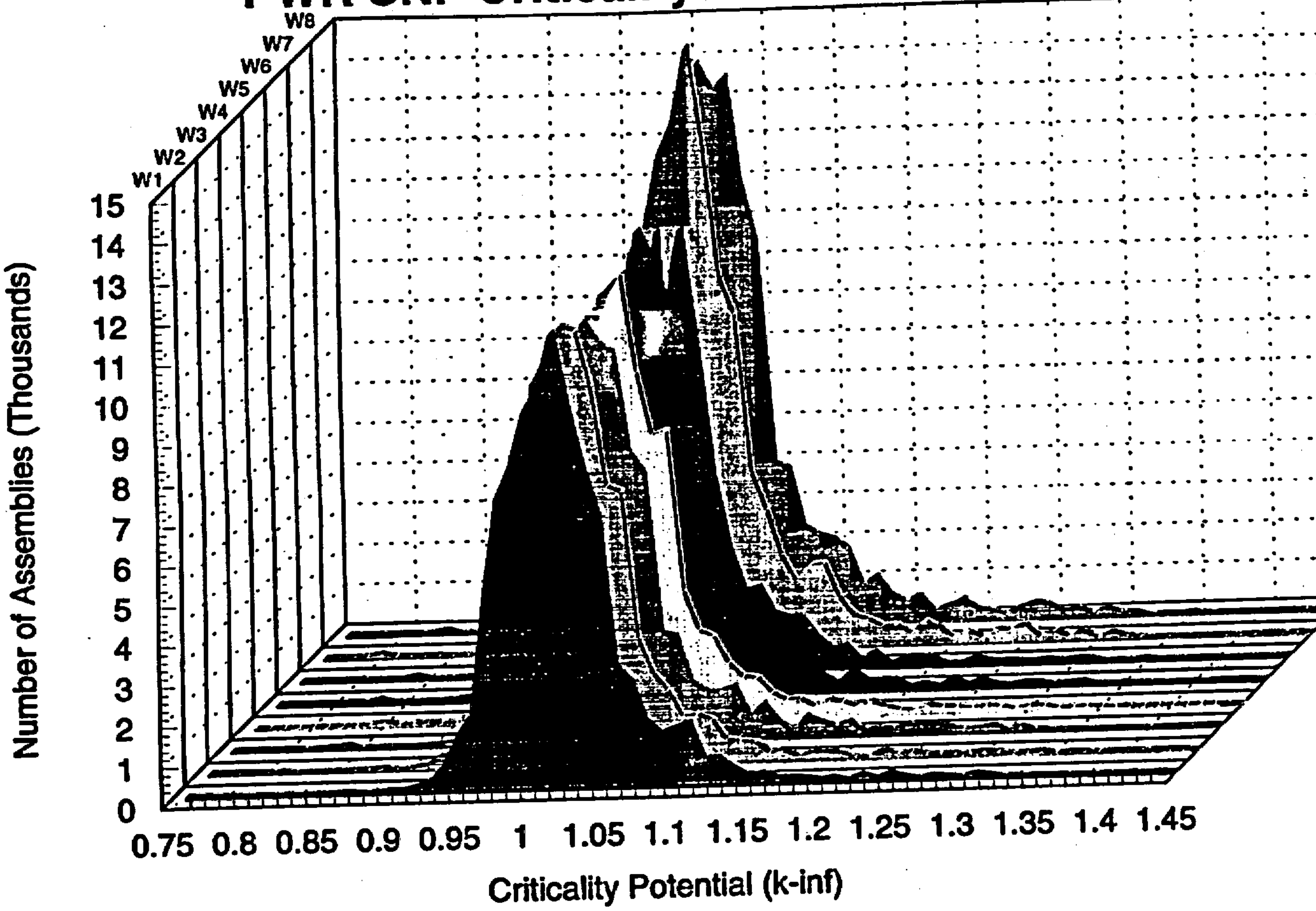



PWR SNF Heat Output Histogram
W1
W2
W3
W4
W5
W6
W7
W8
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Number of Assemblies
0
200
400
600
800
1000
1200
1400
1600
Assembly Initial Heat (watts)

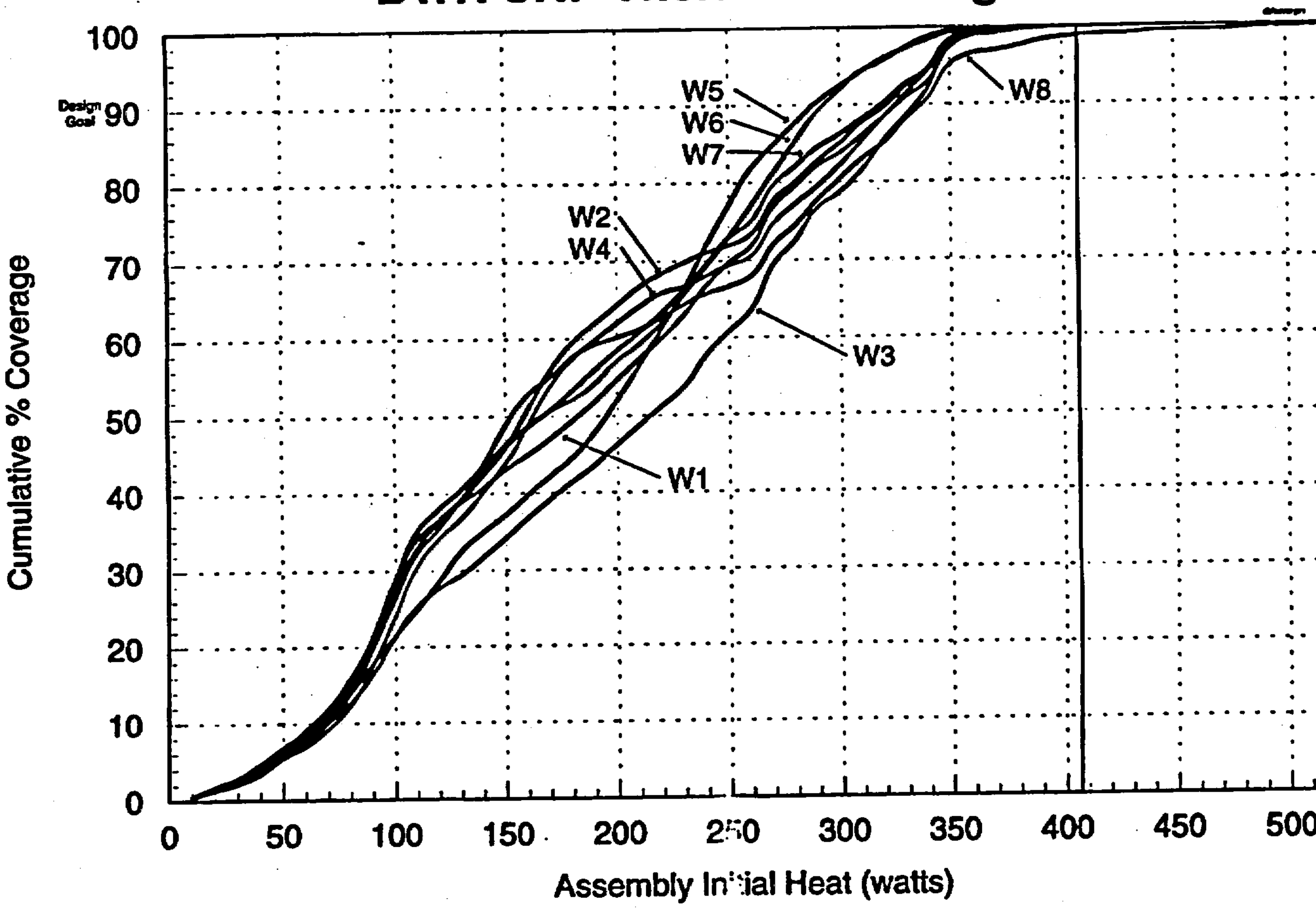
PWR SNF Criticality Potential Coverage



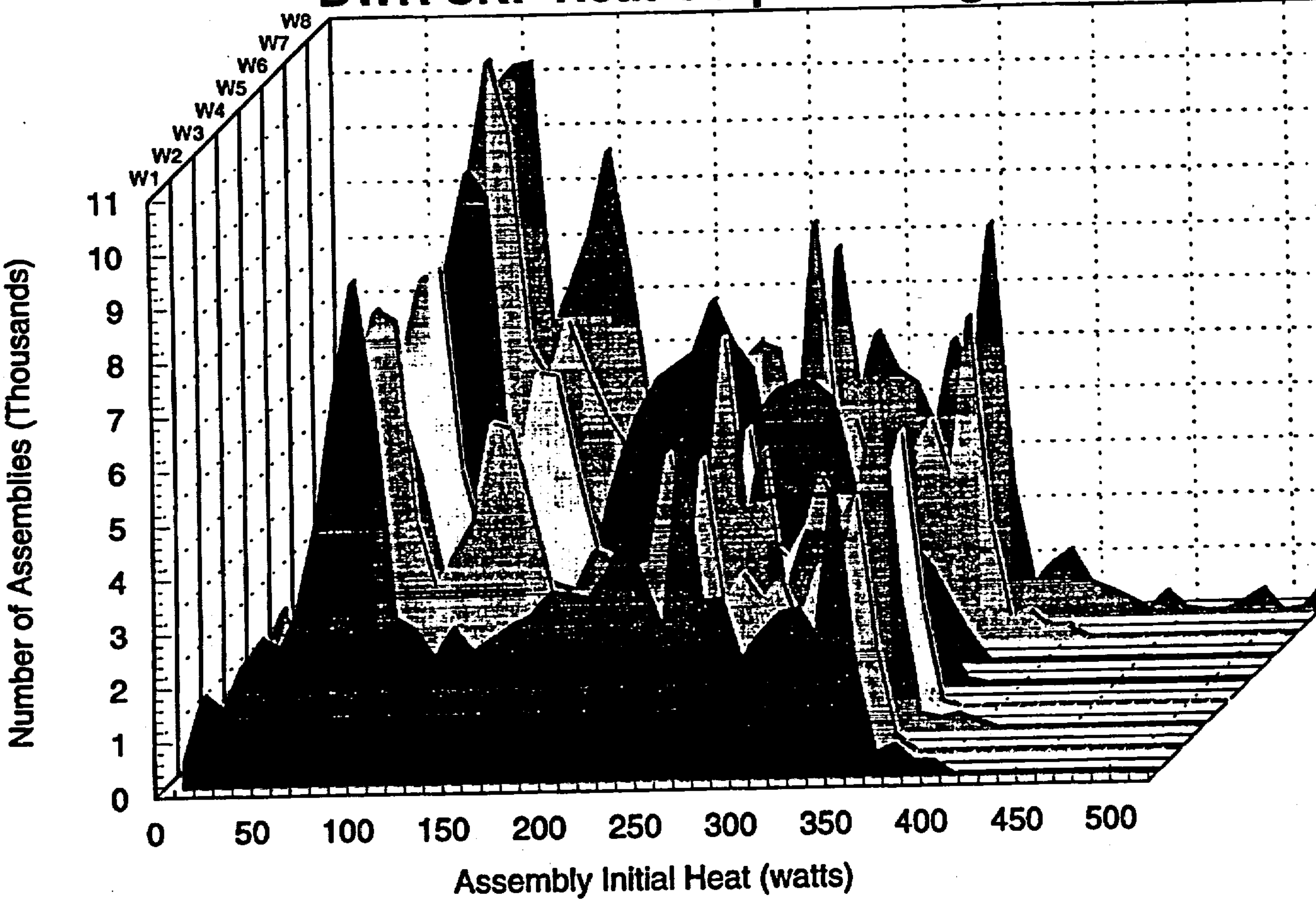
PWR SNF Criticality Potential Histogram



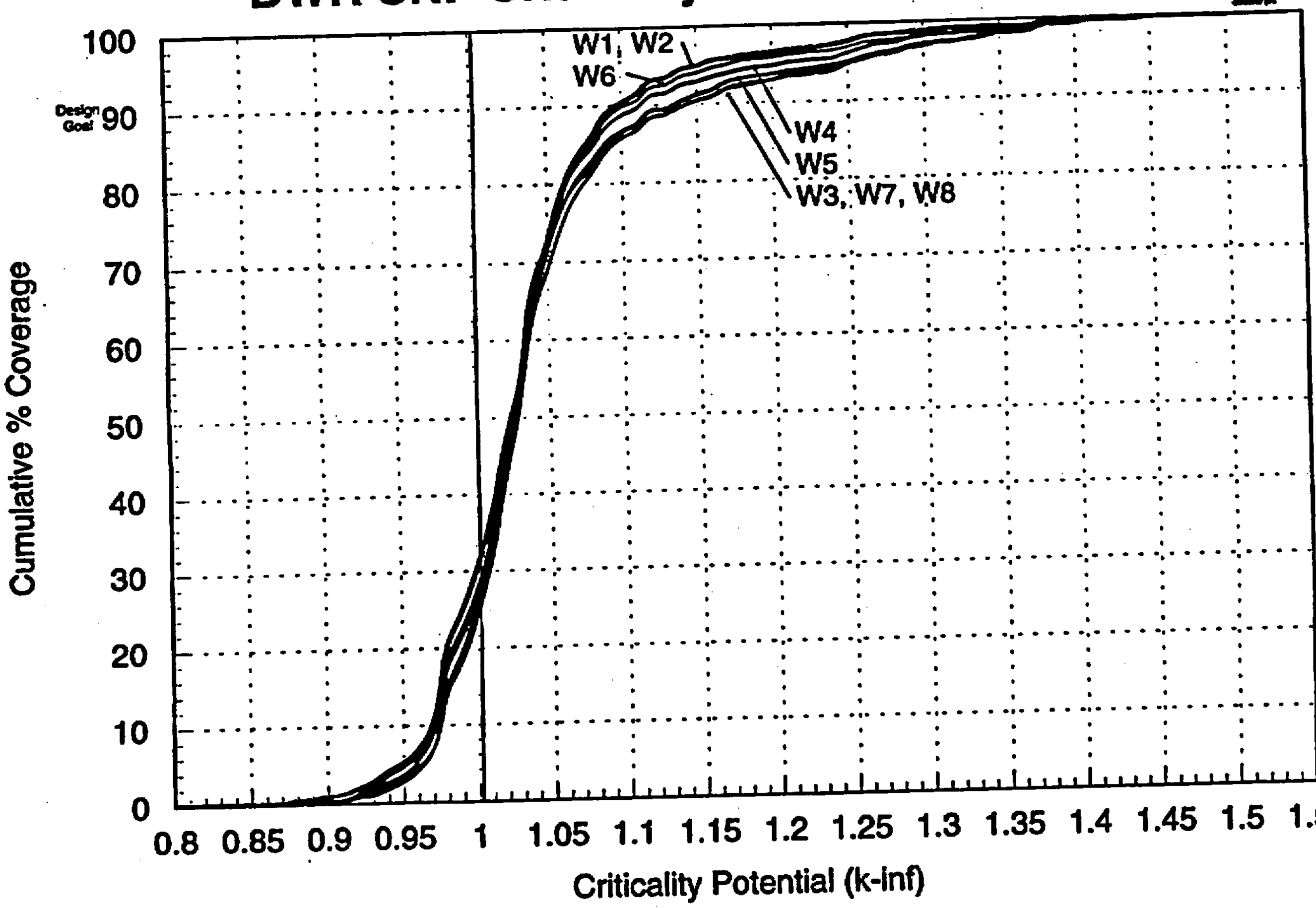
BWR SNF Thermal Coverage



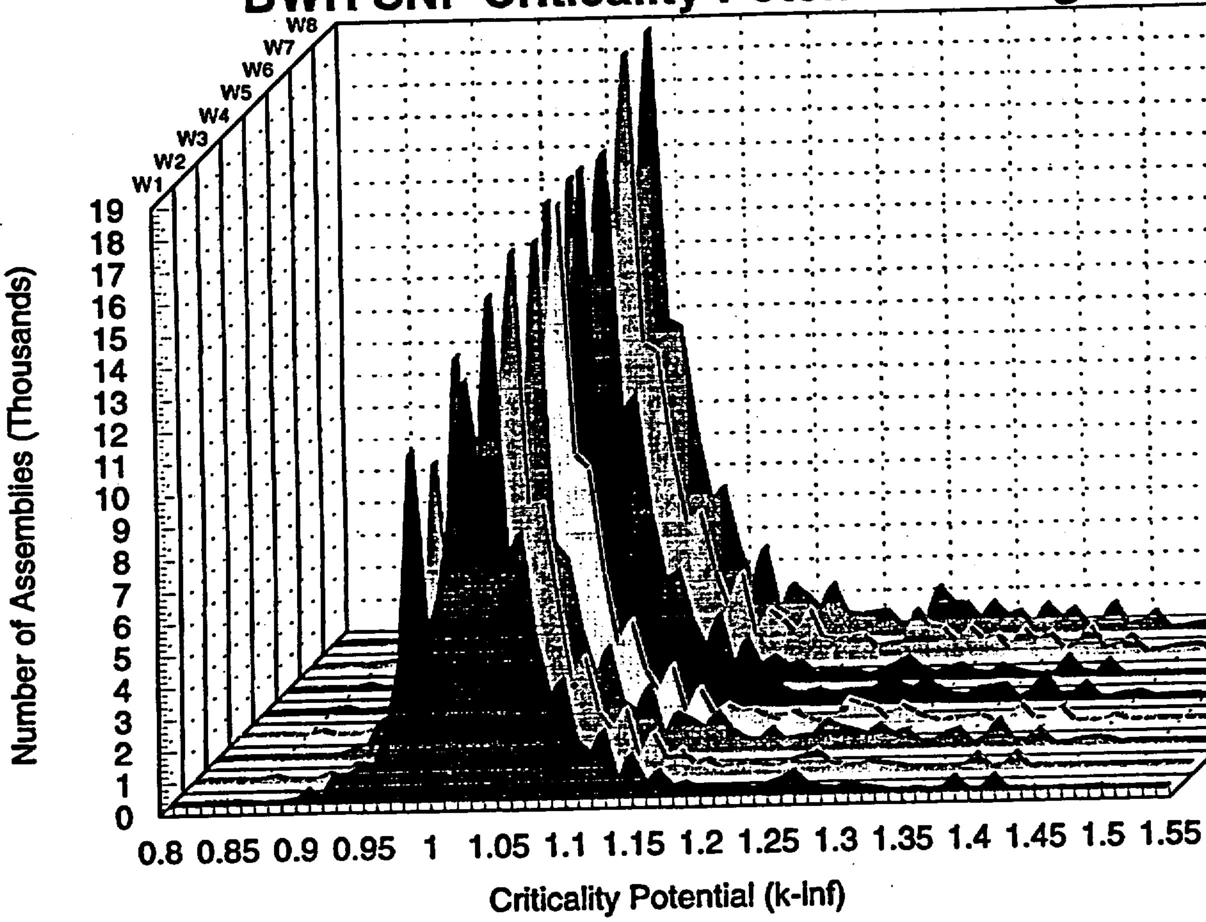
BWR SNF Heat Output Histogram



BWR SNF Criticality Potential Coverage



BWR SNF Criticality Potential Histogram



Case **L1-T1-C1** WP Types:	ID:	Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
		Hmin	Hmax	k_{∞}min	k_{∞}max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber plates criticality option p1	2	0	900	1.00	1.13	2644	58.4%	2613	57.8%	2401	53.1%	3637	58.0%
21 PWR - absorber rods criticality - option p2	3	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	900	1030	0.00	1.02	265	3.3%	347	4.4%	44	0.6%	502	4.6%
10 PWR (derated 12) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	2107 (655)	1.6%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.163B Ave.				$2.878B		$2.887B		$2.859B		$4.029B	

Case L1-T1-C2 WP Types:	ID:	Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
		Hmin	Hmax	k_∞min	k_∞max	#	%	#	%	#	%	#	%
21 PWR - absorber plates base thermal & criticality	1	0	900	0.00	1.13	4162	92.0%	4050	89.6%	4254	94.2%	5425	86.4%
21 PWR - absorber rods criticality - option p1	2	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	900	1030	0.00	1.15	265	3.3%	347	4.4%	44	0.6%	559	5.1%
10 PWR (derated 12) - abs. plates thermal - option p2	4	1030	1370	0.00	1.15	13	0.1%	0	0.0%	0	0.0%	189	1.4%
12 PWR - absorber plates base South Texas long WP	5	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	1060 (655)	0.8%
44 BWR - abosrber plates base thermal & criticality	6	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.365B Ave.				$3.060B		$3.083B		$3.068B		$4.249B	

Case L1-T1-C3		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber rods criticality - option p1	2	0	900	1.00	1.45	2763	61.1%	2799	61.9%	2554	56.5%	3894	62.0%
12 PWR - no absorber thermal - option p1	3	900	1030	0.00	1.02	265	3.3%	347	4.4%	44	0.6%	502	4.6%
10 PWR (derated 12) - no absorber thermal - option p2	4	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - no absorber base South Texas long WP	5	0	1030	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	111	1.0%
12 PWR - absorber rods South Texas long WP - option p1	6	0	1030	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	141	1.3%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	0 (0)	0.0%	1940 (488)	1.5%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	8	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.805B Ave.				$3.487B		$3.464B		$3.430B		$4.838B	

Case **L1-T2-C1** WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_∞min	k_∞max	W2 (YFF10-63) #	W2 %	W3 (YFF10-63) #	W3 %	W5 (OFF-63) #	W5 %	W8 (YFF10-87) #	W8 %
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber plates criticality - option p1	2	0	900	1.00	1.13	2644	58.4%	2613	57.8%	2401	53.1%	3637	58.0%
21 PWR - absorber rods criticality - option p2	3	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	900	1370	0.00	1.02	276	3.5%	347	4.4%	44	0.6%	629	5.7%
12 PWR - absorber plates base South Texas long WP	5	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	1694 (242)	1.3%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	7	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	8	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.101B Ave.				$2.867B		$2.877B		$2.657B		$4.002B	

Case L1-T2-C2		Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
WP Types:	ID:	Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - absorber plates base thermal & criticality	1	0	900	0.00	1.13	4162	92.0%	4050	89.6%	4254	94.2%	5425	86.4%
21 PWR - absorber rods criticality - option p1	2	0	900	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - absorber plates thermal - option p1	3	900	1370	0.00	1.15	276	3.5%	347	4.4%	44	0.6%	716	6.5%
12 PWR - absorber plates base South Texas long WP	4	0	1370	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	272	2.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	7 (7)	0.0%	647 (242)	0.5%
44 BWR - abosrber plates base thermal & criticality	5	0	400	0.00	1.37	2797	99.2%	2804	98.5%	2801	98.6%	3700	97.2%
24 BWR - thick absorber plates thermal & criticality - option b1	6	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.350B Ave.				$3.050B		$3.073B		$3.058B		$4.220B	

Case L1-T2-C3 WP Types:	ID:	Heat Range (W)		Criticality Range		W2 (YFF10-63)		W3 (YFF10-63)		W5 (OFF-63)		W8 (YFF10-87)	
		Hmin	Hmax	k_min	k_max	#	%	#	%	#	%	#	%
21 PWR - no absorber base thermal & criticality	1	0	900	0.00	1.00	1518	33.6%	1437	31.8%	1853	41.0%	1788	28.5%
21 PWR - absorber rods criticality - option p1	2	0	900	1.00	1.45	2763	61.1%	2799	61.9%	2554	56.5%	3894	62.0%
12 PWR - no absorber thermal - option p1	3	900	1370	0.00	1.02	276	3.5%	347	4.4%	44	0.6%	629	5.7%
12 PWR - no absorber base South Texas long WP	4	0	1370	0.00	1.00	89	1.1%	96	1.2%	93	1.2%	126	1.2%
12 PWR - absorber rods South Texas long WP - option p1	5	0	1370	1.00	1.45	62	0.8%	55	0.7%	58	0.7%	160	1.5%
1 PWR - (STx) Leftover assemblies not binned		All		All		0 (0)	0.0%	0 (0)	0.0%	0 (0)	0.0%	1527 (75)	1.2%
44 BWR - no abosrber base thermal & criticality	6	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997*	26.2%
24 BWR - thick absorber plates thermal & criticality - option b1	7	0	520	0.00	1.54	3895	75.4%	3640	69.7%	3794	72.8%	5153	73.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.791B Ave.				$3.477B		$3.454B		$3.420B		$4.812B	

Case **L1-T3-C1** WP Types:	ID:	Heat Range (W) Hmin	Hmax	Criticality Range k_∞min	k_∞max	W2 (YFF10-63) #	%	W3 (YFF10-63) #	%	W5 (OFF-63) #	%	W8 (YFF10-87) #	%
21 PWR - no absorber base thermal & criticality	1	0	850	0.00	1.00	1458	32.2%	1375	30.4%	1835	40.6%	1686	26.9%
21 PWR - absorber plates criticality - option p1	2	0	850	1.00	1.13	2630	58.1%	2599	57.5%	2399	53.1%	3596	57.3%
21 PWR - absorber rods criticality - option p2	3	0	850	1.13	1.45	119	2.6%	186	4.1%	153	3.4%	257	4.1%
12 PWR - no absorber thermal - option p1	4	850	1030	0.00	1.02	388	4.9%	479	6.1%	80	1.0%	723	6.6%
10 PWR (derated 12) - no absorber thermal - option p2	5	1030	1370	0.00	1.02	13	0.1%	0	0.0%	0	0.0%	153	1.2%
12 PWR - absorber plates base South Texas long WP	6	0	1030	0.00	1.13	150	1.9%	150	1.9%	150	1.9%	237	2.2%
1 PWR - (STx) Leftover assemblies not binned		All		All		73 (0)	0.1%	28 (0)	0.0%	7 (7)	0.0%	2464 (655)	1.9%
44 BWR - no abosrber base thermal & criticality	7	0	400	0.00	1.00	695	24.6%	863	30.3%	772	27.2%	997	26.2%
44 BWR - absorber plates criticality - option b1	8	0	400	1.00	1.37	2103	74.6%	1942	68.2%	2029	71.4%	2704	71.0%
24 BWR - thick absorber plates thermal - option b1 criticality - option b2	9	0	520	0.00	1.54	40	0.8%	81	1.5%	76	1.4%	197	2.8%
1 BWR Leftover assemblies not binned		All		All		0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total WP Production Costs:		$3.171B Ave.				$2.884B		$2.892B		$2.860B		$4.047B	

MOL.19980106.0331

CRWMS/M&O

Design Analysis Cover Sheet

Complete only applicable items.

(1.) QA: L

Page: 1 Of: 62

2. DESIGN ANALYSIS TITLE Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package			
3. DOCUMENT IDENTIFIER (Including Rev. No.) BBA000000-01717-0200-00057 REV 00			4. TOTAL PAGES 62
5. TOTAL ATTACHMENTS ~~4-Paper + 1 Tape~~ 4 Attachments	6. ATTACHMENT NUMBERS - NO. OF PAGES IN EACH I-4, II-3, III-1, IV-17		
	Printed Name	Signature	Date
7. Originator	John A. McClure (All but Sect. 7.2) James R. Worsham, III (Sect. 7.2)	John A McClure	9/15/97
8. Checker	John W. Davis (Sect. 1-7.2,7.4-9) James R. Worsham, III (Sect. 7.3-7.4	John W Davis P. Gottlieb (FOR J.R. WORSHAM)	9/15/97 9/15/97
9. Lead Design Engineer	Peter Gottlieb	Peter Gottlieb	9/15/97
10. Department Manager	Hugh A. Benton	[signature] FOR H.A. BENTON	9/15/97

11. REMARKS

Editorial change to Block 5 John A McClure 9/22/97

Hugh A. Benton 9/22/97

~~9902240056~~

Design Analysis Revision Record

Complete only applicable items.

(1.)

2. DESIGN ANALYSIS TITLE

Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package

3. DOCUMENT IDENTIFIER (Including Rev. No.)

BBA000000-01717-0200-00057 REV 00

4. Revision No.	5. Description of Revision
00	Initial Issue

Table of Contents

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1. Purpose

The purpose of this analysis is to evaluate the transient behavior and consequences of a worst case criticality event involving intact pressurized water reactor (PWR) spent nuclear fuel (SNF) in a degraded basket configuration inside a 21 PWR assembly waste package (WP). The objective of this analysis is to demonstrate that the consequences of a worst case criticality event involving intact PWR SNF are insignificant in their effect on the overall radioisotopic inventory in a WP.

2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the preliminary waste package (WP) design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the Mined Geologic Disposal System (MGDS) waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (Ref. 5.1, pp. 4, 15). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 *Classification of Permanent Items* evaluation. The responsible manager for the Waste Package Development Department has evaluated this activity in accordance with QAP-2-0, *Conduct of Activities*. The *Perform Criticality, Thermal, Structural, and Shielding Analyses* (Ref. 5.2) activity evaluation has determined that work associated with the commercial SNF waste package design task is subject to *Quality Assurance Requirements and Description* (QARD) (Ref. 5.3) requirements. As specified in NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents*, this activity is subject to QA controls.

Design inputs which are identified in this document are for the preliminary stage of the WP design process; all of these design inputs will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. Consequently, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as "to be verified" (TBV) in accordance with the appropriate procedures.

3. Method

An internal WP criticality is modeled in a manner analogous to transient phenomena in a nuclear reactor core. The light water reactor (LWR) transient analysis code, RELAP5/MOD3 (Ref. 5.4), is used to calculate the time evolution of the power level and other characteristics of a criticality involving PWR SNF. Reactivity tables based on changes in k_{eff} from a baseline configuration must be included in the RELAP5 input. The Monte Carlo N-Particle computer program, MCNP4A (Ref. 5.5), is used to calculate a baseline k_{eff} for criticality safety evaluations and to determine the change in reactivity from one configuration to another. MCNP4A does not have an associated cross section library with sufficient temperature dependent data to calculate the reactivity changes associated with fuel and moderator temperature changes required for this analysis. The SAS2H sequence of SCALE4.3 (Ref. 5.10) does have the necessary cross sections. SAS2H employs a one-dimensional (1-D) assembly-cell discrete-ordinates technique (XSDRNPM) for calculation of the multiplication factor (k_{eff}) for a configuration. A correction for finite dimensions can be made through use of various buckling terms. Initially, infinite MCNP cases were run with which to compare the results from infinite SAS2H cases in order to develop the appropriate SAS2H model to match MCNP results. Corrections were then made to the SAS2H model to account for finite dimensions using the appropriate buckling terms for inclusion in the models based on the baseline MCNP finite case. The resulting SAS2H model incorporating the buckling terms is then used for calculating temperature and density reactivity effects. The reactivity changes calculated by MCNP4A and SAS2H are used as input to RELAP5 to track the transient behavior of a criticality. The ORIGEN-S program in the SCALE4.3 code package is used to calculate the changes to the radioisotopic inventory as a result of the analyzed criticality events.

4. Design Inputs

4.1 Design Parameters

4.1.1 Spent Fuel Assembly Parameters

The fuel assembly which this calculation is based upon is the B&W 15X15 fuel assembly. The mechanical parameters for this assembly type are shown in Table 4.1-1. Note that inches are converted to centimeters exactly (2.54 cm/in.); this is not an indication of tolerance (accuracy), but is done for consistency between calculations using English and metric units. The theoretical density of natural UO_2 is 10.96 g/cm^3 (Ref. 5.10, Table M8.2.1). This information represents B&W fuel assembly dimensions prior to irradiation and is considered qualified data.

Table 4.1-1. Mechanical Parameters of B&W 15X15 Fuel Assembly

Parameter	Value	Units	Metric	Units	Radius (cm)	Reference
Fuel Rods	208	/assbly	208	/assbly	-	5.7, p. 2.1.2.2-6
Fuel Rods on a Lattice Side	15	/side	15	/side	-	5.7, p. 2.1.2.2-6
Guide Tubes	16	/assbly	16	/assbly	-	5.7, p. 2.1.2.2-6
Instrumentation Tubes	1	/assbly	1	/assbly	-	5.7, p. 2.1.2.2-6
Total Guide + Instrument Tubes	17	/assbly	17	/assbly	-	-
Clad/Tube Material	Zirc-4		Zirc-4		-	5.7, p. 2.1.2.2-6
Fuel Pellet OD	0.3686	inches	0.936244	cm	0.468122	5.7, p. 2.1.2.2-6
Fuel Stack Height	141.8	inches	360.172	cm	-	5.7, p. 2.1.2.2-6
Fuel Assembly Height	165.625	inches	420.6875	cm	-	5.8, p. 2A-8
Mass of U	1023	lb	464	kg	-	5.8, p. 2A-8
Mass of UO_2	1160.64	lb	526.38	kg	-	5.7, p. 2.1.2.2-6

Table 4.1-1. Mechanical Parameters of B&W 15X15 Fuel Assembly

Parameter	Value	Units	Metric	Units	Radius (cm)	Reference
Percent of Theoretical Density	95	%	95	%	-	5.7, p. 2.1.2.2-6
Fuel Clad OD	0.430	inches	1.0922	cm	0.5461	5.7, p. 2.1.2.2-6
Clad Thickness	0.0265	inches	0.06731	cm	-	5.7, p. 2.1.2.2-6
Fuel Clad ID*	0.377	inches	0.95758	cm	0.47879	-
Fuel Rod Pitch	0.568	inches	1.44272	cm	-	5.7, p. 2.1.2.2-6
Guide Tube OD	0.530	inches	1.3462	cm	0.6731	5.7, p. 2.1.2.2-6
Guide Tube Thickness	0.016	inches	0.04064	cm	-	5.7, p. 2.1.2.2-6
Guide Tube ID*	0.498	inches	1.26492	cm	0.63246	-
Instrumentation Tube OD	0.493	inches	1.25222	cm	0.62611	5.7, p. 2.1.2.2-6
Fuel Assembly Envelope	8.536	inches	21.68144	cm	-	5.7, p. 2.1.2.2-6
Displaced Volume per Fuel Assembly	4927	$inches^3$	0.081	m^3	-	5.9, p. II-3.6-98

* The inner diameters (IDs) above are calculated by subtracting 2 × thickness from the outer diameter (OD).

4.1.2 Intact Waste Package Geometry Parameters

The intact waste package geometry parameters used for this analysis are listed in Table 4.1-2 below. These are considered unqualified TBV information, as other WPD QAP-3-9 analyses being performed in parallel may result in design changes not reflected in these parameter values. Minor dimensional revisions from the listed values, if incorporated in the computational models used in this analysis, will have an insignificant effect on results from this analysis.

Table 4.1-2. Intact WP Dimensions

Component	Dimension	Reference
Outer barrier length (skirt edge to skirt edge)	533.5 cm	5.11, p. I-18
Outer barrier skirt length (both ends)	22.5 cm	5.11, p. I-18
Outer barrier lid thickness	11.0 cm	5.11, p. I-18
Outer barrier inner radii	73.1 cm	5.12, p. 8
Outer barrier outer radii	83.1 cm	5.12, p. 8
Gap between inner and outer lids	3.0 cm	5.11, pp. I-18 & I-19
Inner barrier length (overall)	463.5 cm	5.11, p. I-19
Inner barrier lid thickness	2.5 cm	5.11, p. I-19
Inner barrier inner radii	71.095 cm	5.12, p. 8
Inner barrier outer radii	73.095 cm	5.12, p. 8
Fuel cell tube thickness	0.5 cm	5.11, p. I-21
Fuel cell tube height	457.5 cm	5.11, p. I-21
Fuel cell tube outside width	23.64 cm	5.11, p. I-21

Table 4.1-2. Intact WP Dimensions		
Component	Dimension	Reference
Total displaced volume of single fuel cell tube	0.02117 m^3	5.11, p. VI-1
Criticality control plate thickness	0.7 cm	5.11, pp. I-29 to I-31
Criticality control plate height	113.38 cm	5.11, p. I-20
Total displaced volume of all criticality control plates	0.243 m^3	5.11, p. VI-1
Total displaced volume of guides and supports	0.259 m^3	5.11, p. VI-1

4.1.3 Material Properties

The atom densities for the SNF used are taken from a previous criticality analysis (Ref. 5.13, case r58h13f). Case r58h13f is the reference condition on which reactivity calculations are made and the RELAP5 cases are developed. The input for this case is included in Attachment I.

Table 4.1-3. Atom Densities for 4.9% Enriched B&W 15X15 SNF with 34 GWd/MTU and 25,000 Years Burnup (Ref. 5.13)

Isotope ID	Number Density
8016.50C	0.046947
42095.50C	4.794679E-05
44101.50C	4.354501E-05
43099.50C	4.284296E-05
45103.50C	2.608717E-05
47109.50C	3.714096E-06
60143.50C	3.74851E-05
60145.50C	2.799527E-05
62147.50C	1.138963E-05
62149.50C	1.455085E-07
62150.50C	1.043884E-05
62152.50C	4.59594E-06
63151.55C	8.136066E-07
63153.55C	3.93607E-06
64155.50C	1.686186E-07
92233.50C	3.326725E-07
92234.50C	1.018437E-05
92235.50C	5.531404E-04
92236.50C	1.774777E-04
92238.50C	2.174501E-02
93237.55C	4.392789E-05
94239.55C	7.906197E-05
94240.50C	3.440139E-06
94241.50C	2.761636E-12
94242.50C	7.012276E-06
95241.50C	8.639479E-11
95243.50C	1.386765E-07

4.2 Criteria

Requirements identified as TBD in the *Engineered Barrier Design Requirements Document* (EBDRD; Ref. 5.7) will not be carried to the conclusions of this analysis based on the rationale that the conclusions are for preliminary design, and will not be used as input in design documents supporting construction, fabrication, or procurement.

The criterion for this analysis is:

- The Engineered Barrier System shall be designed such that the probability and consequences of nuclear criticality provide reasonable assurances that the preformance objective of 10CFR60.112 is met [EBDRD 3.7.1.3.A, 3.3.1.G].

In addition, EBDRD 3.3.1.G indicates that "The Engineered Barrier Segment design shall meet all relevant requirements imposed by 10CFR60." The NRC has recently revised several parts of 10CFR60 which relate to the identification and analysis of design basis events (Ref. 5.9) including the criticality control requirement, which was moved to 60.131(h). These changes are not reflected in the current versions of the EBDRD or the CDA. The change to the criticality requirement simply replaces the phrase "criticality safety under normal and accident conditions" with "criticality safety assuming design basis events."

The criterion for this analysis, together with the wording in the current 10CFR60.131(h) can be summarized as: (1) Demonstration of the prevention of criticality, (2) Demonstration that the consequences of criticality (even if one did occur) are insignificant. This analysis is part of a continuing sequence which individually contribute to satisfying the second of these criteria in the following manner:

- The consequences of a criticality, particularly the increase in radionuclide inventory and transient overpressure and temperature, are shown to be insignificant under the range of conditions considered thus far.

- The severity of consequence (particularly increase in radionuclide inventory) will be used as input to the Total System Performance Assessment (TSPA) - Viability Assessment (VA) which, in turn, will demonstrate compliance with the performance objective of §60.112 (as specified in CDA Key assumption 60).

4.3 Assumptions

4.3.1 It is assumed that the nuclear reactor type model of a WP developed for RELAP5/MOD3 is an appropriate approximation to the criticality processes involving PWR SNF inside a waste package (TBV). The basis for this assumption is as follows:

RELAP5/MOD3 was developed for the U.S. Nuclear Regulatory Commission for simulations of transient phenomena in PWR systems such as loss of coolant (Ref. 5.4). The physical processes involving material behavior of PWR SNF within a waste package during a criticality event are similar to the situations for which RELAP5/MOD3 was developed to analyze. There is reasonable confidence in the capability of RELAP5/MOD3 to provide conservative results for the applications within this analysis.

Inherent in the assumption that RELAP5 provides an appropriate approximation for WP criticality events is also the assumption that the time dependent neutron population in the WP fuel assemblies can be represented by the point kinetics model. The basis for this assumption is the compact size of the fuel assembly array making the system tightly coupled neutronicly and preventing any spatially localized phase differences in the neutron amplitude.

This assumption is used in Sections 7.4 and 7.5.

4.3.2 It is assumed that the reactivity feedback mechanism for the point kinetics model can be represented by separable effects (TBV). The bases for this assumption are as follows:

(1) Doppler reactivity depends upon intrinsic fuel parameters with temperature being the only time dependent variable,

(2) moderator reactivity effects depend only upon the fluid density,

(3) no soluble poisons are modeled, and

(4) the settled iron oxide residue is not redistributed in the WP.

This assumption is used throughout Section 7.

4.3.3 The waste package is assumed to be filled with water at the start of the postulated reactivity driven scenarios. The basis for this assumption is that it is conservative and is developed as a scenario in previous probabilistic analyses (Ref. 5.18). This assumption is used in Sections 7.2, 7.3, and 7.4.

4.3.4 CDA assumption EBDRD 3.7.1.3.A has been used to replace TBVs in requirements applicable to this document. The bases for these assumptions are given in the CDA (Ref. 5.15). These assumptions are used in Section 4.2.

4.3.5 Water inflow to the degraded WP is assumed to be 20 m^3/year at ambient drift space conditions. The basis for this assumption is that this is the largest design basis flow rate for long term periods (300-20,000 years after emplacement) given by CDA Assumption TDSS

026. Climate models suggest that the long term infiltration rate could possibly increase by as much as a factor of 10. This assumption is used throughout Section 7.

4.3.6 The most reactive SNF disposed of in the absorber rod WPs have been excluded from consideration in this analysis since the absorber rod WP design will take credit for the long term presence of neutron absorber control rods (CDA Key 081).

4.4 Codes and Standards

Not Applicable. Neutronic design of the waste package is not controlled by codes and standards.

5. References

5.1 *Yucca Mountain Site Characterization Project Q-List*, YMP/90-55Q, REV 4, Yucca Mountain Site Characterization Project.

5.2 *QAP-2-0 Activity Evaluations*, ID No. WP-20, Perform Criticality, Thermal, Structural, and Shielding Analyses, Dated 8/3/97, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O).

5.3 *Quality Assurance Requirements and Description*, DOE/RW-0333P REV 7, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).

5.4 *RELAP5/MOD3 Code Manual*, NUREG/CR-5535, INEL-95/0174, Prepared by Idaho National Engineering Laboratory for the U.S. Nuclear Regulatory Commission, August 1995.

5.5 *Software Qualification Report for MCNP4A*, CSCI: 30006 V4A, Document Identifier Number (DI#): 30006-2003 REV 02, CRWMS M&O.

5.6 *Software Qualification Report for The SCALE Modular Code System Version 4.3*, CSCI: 30011 V4.3, DI#: 30011-2002 REV 01, CRWMS M&O.

5.7 *Preliminary Waste Form Characteristics Report Version 1.0*, UCRL-ID-108314 Rev 1, Lawrence Livermore National Laboratory, December 1994.

5.8 *Characteristics of Potential Repository Wastes*, DOE/RW-0184-R1, Volume 1, US DOE OCRWM, July 1992.

5.9 *Final Design Package - Babcock & Wilcox BR-100 - 100 Ton Rail/Barge Spent Fuel Shipping Cask*, Document No. 51-1203400-01, B&W Fuel Company, November 1991.

5.10 *SCALE 4.3*, RSIC Computer Code Collection, CCC-545, Oak Ridge National Laboratory, October 1995.

5.11 *Waste Package Design Basis Events*, DI#: BBA000000-01717-0200-00037 REV 00, CRWMS M&O.

5.12 *Probabilistic Criticality Consequence Evaluation*, DI#: BBA000000-01717-0200-00021 REV 00, CRWMS M&O.

5.13 *Criticality Evaluation of Degraded Internal Configurations for the PWR AUCF WP Designs*, DI#: BBA000000-01717-0200-00056 REV 00, CRWMS M&O.

5.14 *Engineered Barrier Design Requirements Document*, YMP/CM-0024, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.15 *Controlled Design Assumptions Document*, DI#: B00000000-01717-4600-00032 REV 04, ICN 02, CRWMS M&O.

5.16 *10 CFR Part 60; Disposal of High-Level Radioactive Wastes in Geologic repositories; Design Basis Events; Final Rule*, U.S. Nuclear Regulatory Commission, Federal Register, volume 61, Number 234, pp. 64257-64270, December 4, 1996.

5.17 Jensen, Peter J., et al, *Anticipated Transients Without Scram Analysis for the River Bend Station*, Proceedings: Fourth International RETRAN Conference, EPRI NP-4558-SR, p. 23-1, May 1986.

5.18 *Second Waste Package Probabilistic Criticality Analysis: Generation and Evaluation of Internal Criticality Configurations*, DI#: BBA000000-01717-0200-00005 REV 00, CRWMS M&O.

5.19 *Determination of WP Design Configurations*, DI#: BBAA00000-01717-0200-00017 REV 00, CRWMS M&O.

5.20 Duderstadt, James J., Hamilton, Louis J., *Nuclear Reactor Analysis*, John Wiley & Sons, New York, 1976.

5.21 *Third Waste Package Probabilistic Criticality Analysis: Methodology for Basket Degradation with Application to Commercial Spent Nuclear Fuel*, DI#: BBA000000-01717-0200-00049 REV 00, CRWMS M&O.

5.22 *Electronic Attachments for: BBA000000-01717-0200-00057 REV 00, Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package*, Colorado Backup Tape, RPC Batch Number MOY-970904-01, CRWMS M&O.

5.23 *Final Safety Analysis Report Three Mile Island Nuclear Station - Unit 1*, TMI-1/FSAR, April, 1996.

5.24 Idelchik, I. E, *Handbook of Hydraulic Resistance*, The State Scientific Research Institute for Industrial and Sanitary Gas Purification, Second Edition, Moscow, Russia.

6. Use of Computer Software

The calculation of nuclear reactivity of PWR SNF configurations was performed with the MCNP4A computer code, CSCI: 30006 V4A. MCNP4A calculates k_{eff} for a variety of geometric configurations with neutron cross sections for elements and isotopes described in the Evaluated Nuclear Data File version B-V (ENDF-B/V). MCNP4A is appropriate for the fuel geometries and materials required for these analyses. The calculations using the MCNP4A software were executed on Hewlett-Packard (HP) workstations. The software qualification of the MCNP4A software, including problems related to calculation of k_{eff} for fissile systems, is summarized in the Software Qualification Report for the Monte Carlo N-Particle code (Ref. 5.5). The MCNP4A evaluations performed for this design are fully within the range of the validation for the MCNP4A software used. Access to and use of the MCNP4A software for this analysis was granted by Software Configuration Management and performed in accordance with the QAP-SI series procedures. Inputs and outputs for the MCNP4A software are included as attachments (see Tables 9-1 and 9-2) as described in the following design analysis.

The calculation of nuclear reactivity of PWR SNF configurations was also performed with the SAS2H code sequence, which is a part of the SCALE 4.3 code system, CSCI: 30011 V4.3. SAS2H is designed for spent fuel depletion and reactivity calculations to determine spent fuel isotopic content. Thus, SAS2H and ORIGEN-S are appropriate for the fuel geometries and materials required for these analyses. The calculations using the SCALE4.3 software were executed on HP workstations. The software qualification of the SCALE4.3 software, including benchmark problems related to generation of isotope contents, is summarized in the Software Qualification Report for the SCALE Modular Code system (Ref. 5.6). The SAS2H evaluations performed for this design are fully within the range of the validation for the SAS2H software used. The associated 44GROUP cross section library was used for these calculations. Access to and use of the SAS2H software for this analysis was granted by Software Configuration Management and performed in accordance with the QAP-SI series procedures. Inputs and outputs for the SAS2H and ORIGEN-S are included as attachments (see Tables 9-1 and 9-2).

The transient simulation of criticality events is performed using RELAP5/MOD3. RELAP5/MOD3 has been installed on HP workstations and the 10 installation test cases (ans79.p, edhtrk.p, edhtrkd.p, edhtrkn.p, edrst.p, edstrip.p marpzd4.p pump2.p, typpwr.p, typpwrn.p) have been run successfully. These installation test cases are included on tape (Ref. 5.22). RELAP5/MOD3 has not been qualified according the QAP-SI-0. RELAP5/MOD3 was developed for the U.S. Nuclear Regulatory Commission for simulations of operational transients in PWR systems such as loss of coolant. The criticality events involving PWR SNF within a waste package are similar to the situations for which RELAP5/MOD3 was developed to analyze. There is reasonable confidence in the capability of RELAP5/MOD3 to provide conservative results for the applications within this analysis (TBV).

7. Design Analysis

7.1 Background

For postclosure, the low probability and consequences of a criticality must provide reasonable assurance that the performance objective of 10CFR60.112 is met. This analysis contributes to satisfying the above requirements for postclosure by determining the consequences of a criticality for PWR SNF within a waste package as measured by the effect on the repository and on the radioisotopic inventory. The probability of criticality events is addressed in a separate analysis.

In a probabilistic analysis (Ref. 5.21, Sections 4.1.2 and 4.1.3) it has been shown that the corrosion rate of the zircaloy cladding of the SNF is much slower than the corrosion rates of the two principal materials which make up the basket (carbon steel and borated stainless steel). Therefore, the basket materials will degrade while the SNF is still mostly intact. What is not known is the exact disposition of the basket material after it has degraded. The iron oxide is very insoluble and will tend to precipitate, but the distribution of the precipitate could range from: (1) collecting equally on all the available surfaces, to (2) settling into the configuration with the lowest gravitational energy, limited only by the maximum density of hydrated iron oxide. The parameters for these two alternatives, called the uniform and settled distributions, respectively, are described in some detail in a previous analysis (Ref. 5.13).

The uniform distribution means that the iron oxide is distributed throughout the waste package wherever there is water. The settled distribution has two different manifestations, depending on whether the basket is partially degraded or fully degraded. The settled distribution for the partial basket will fill the lower portion of each assembly cell with 1/21 of the total oxide formed thus far from the degradation of the carbon steel in the assembly tube basket structure and from the degradation of the borated stainless steel, but not from the carbon steel guides and supports. For the fully degraded basket, the settled distribution will fill the lower portion of the waste package with all of the iron oxide from the complete degradation of the basket, so that some of the assemblies are completely covered by iron oxide while others see no iron oxide at all. These two alternative configurations are described more fully in reference 5.13.

The design basis WP system configuration for 100% coverage of the projected PWR waste stream (Ref. 5.19, Table 8-1) includes five different types of PWR WPs. These types are identified as:

(1) 21 PWR no absorber WP,

(2) 21 PWR absorber plate WP,

(3) 21 PWR absorber rod WP,

(4) 12 PWR no absorber WP, and

(5) long 12 PWR absorber plate WP for South Texas fuel.

A previous analysis (Ref. 5.13) investigated the effects on k_{eff} of fuel burnup, enrichment, and decay time, as well as degradation of basket components. The most reactive fuel/WP configuration combination identified was in the 21 PWR absorber plate WP. The fuel designated for disposal in the no absorber plate WP is purposefully of very low reactivity and is subcritical in all configurations. The absorber rod WPs are precluded from criticality even with the otherwise very reactive fuel. The analysis of the absorber plate WP identified the most reactive SNF as ones having the following characteristics:

(1) an enrichment of 4.9%,

(2) a burnup of 34 GWd/MTU, and

(3) a flooded fuel-clad gap.

(Note that as a result of the analysis, the fuels designated for disposal with absorber rods could be adjusted to include all the fuel which can go critical in the absorber plate WP, thereby eliminating these critical configurations from consideration.) The most reactive configuration occurs with the basket fully degraded, the boron removed, the PWR assemblies are stacked together, and the iron oxide from the basket materials has accumulated at its highest reasonable density of 58% leaving one and a half rows of assemblies at the top of the stack in water alone free of oxidation products. This configuration is illustrated in Figure 7.1-1.

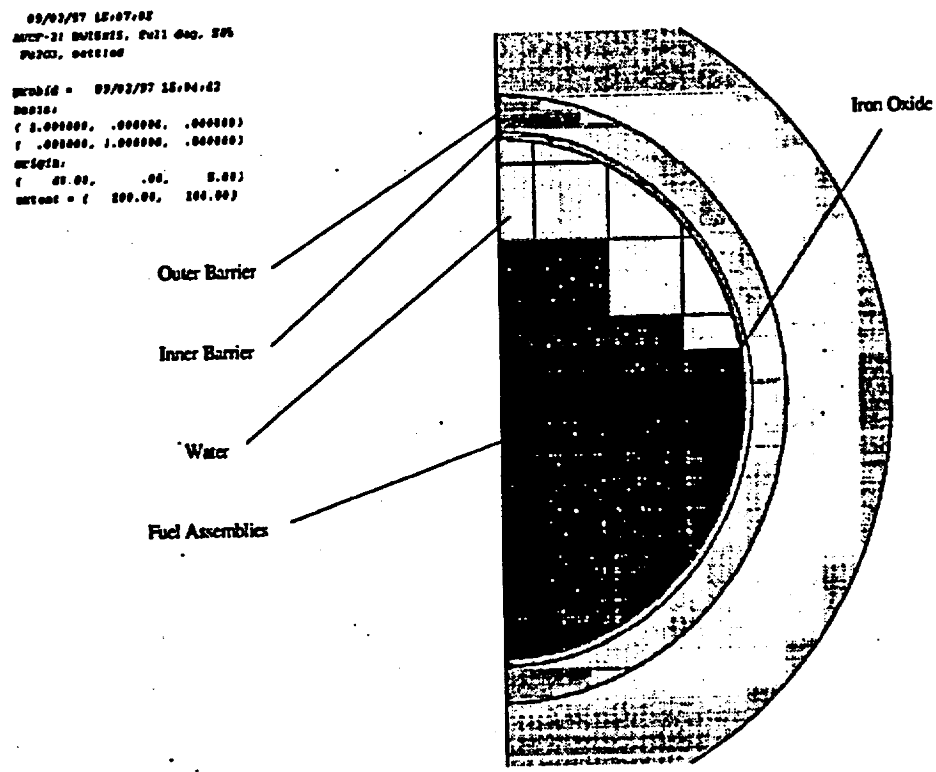

Figure 7.1-1. Base Configuration for Analysis of Stratified Degraded Waste Package

7.2 Neutronics Calculations and Reactivity Coefficients

The effects on reactivity due to changes in the system are shown to be separable into leakage effects and material effects in this section. Leakage effects are primarily dependant on boundary conditions such as water level in the waste package and must be calculated using finite waste package models. Material effects such as changes to fuel temperature, moderator temperature, or moderator density are primarily localized and can be approximated using infinite assembly models with a constant buckling (leakage) term.

Reactivity is defined as (Ref. 5.20, p. 222):

$$\rho = \frac{k_{eff} - 1.0}{k_{eff}}$$

and a change in reactivity ($\Delta\rho$) is defined as (Ref. 5.20, p. 222):

$$\Delta\rho = \rho_{Change} - \rho_{Base} = \frac{1}{k_{eff-Base}} - \frac{1}{k_{eff-Change}}$$

Thus, a positive reactivity change results when ρ_{Change} is greater than ρ_{Base}. In the RELAP5 input, ρ and $\Delta\rho$ are noted in terms of dollars ($) which is defined as (Ref. 5.20, p. 246):

$$\rho(\$) = \frac{\rho}{\beta_{eff}} \quad and \quad \Delta\rho(\$) = \frac{\Delta\rho}{\beta_{eff}}$$

where β_{eff} is the effective delayed neutron fraction. The value of the delayed neutron fraction for this analysis is given as (Ref. 5.23)

$$\beta_{eff} = 0.005$$

which is a conservative minimum value.

7.2.1 Reactivity Effect of Water Level in Waste Package

A separate analysis (Ref. 5.13, Table 7.4-10) investigated the effects of different configurations of iron oxide and water in the waste package. Results from that analysis are used here to provide the feedback due to changes in the water level within the waste package. The k_{eff} results for various water levels in the fifth (upper) row of assemblies for the 58% settled oxide case for fuel decayed for 25,000 years are listed in Table 7.2.1-1 below. For determination of feedback, only the nominal values are used (not adjusted by the standard deviation).

Table 7.2.1-1. Effects of Water Level on k_{eff}

Case ID	Water Height Relative to Top of Upper Row of Assemblies (cm)	k_{eff}
r58m13a1	+21.30	0.99656
r58m13a2	0.0	0.98569
r58m13aw	-12.98	0.92672
r58m13bw	-14.43	0.91801
r58m13cw	-15.87	0.91090
r58m13a3	-20.30	0.85541

In order to conservatively calculate the change in reactivity, the reference condition is taken at the water level even with the top of the assemblies (0.0 cm in Table 7.2.1-1). The negative effect of dropping to this level is neglected. The Δρs resulting from a drop in water level through the upper row of assemblies are listed in Table 7.2.1-2. The reactivity table for the RELAP5 model was extended on to -21.64 cm (lower edge of the assemblies) using the last reactivity value to define a zero level entry. Δρs for lower water levels are not required because the negative effect of dropping the water level to the bottom of the upper row is great enough to overwhelm the insertion postulated in this analysis.

Table 7.2.1-2. RELAP5 Reactivity Table for WP Water Level

Water Level Relative to Assembly Top (cm) - MCNP	Water Level Relative to Control Volume Bottom Elevation (ft) - RELAP5	$\$ = \Delta\rho/\beta_{eff}$
0	0.71	0.0
-12.98	0.28415	-12.911
-14.43	0.23657	-14.959
-15.87	0.18933	-16.660
-20.30	0.04399	-30.902
-21.64	0.0	-30.902

7.2.2 Reactivity Effect of Temperature and Density Changes

MCNP4A does not have an associated cross section library with sufficient temperature dependant data to calculate the reactivity changes required for this analysis. The SAS2H sequence of SCALE4.3 does have the necessary cross sections. SAS2H employs a one-dimensional (1-D) assembly-cell discrete-ordinates technique (XSDRNPM) for calculation of the multiplication factor (k_{eff}) for a configuration. A correction for finite dimensions can be made through use of buckling (leakage) correction terms. Initially, infinite MCNP cases were run with which to compare the results from infinite SAS2H cases in order to develop the appropriate SAS2H model to match MCNP results. Corrections were then made to the SAS2H model to account for finite dimensions using the appropriate buckling terms for inclusion in the SAS2H models based on the baseline MCNP finite case. The resulting SAS2H model incorporating the buckling terms is then used for calculating temperature and density reactivity effects.

7.2.2.1 SAS2H Setup and Model Development

The equation for the buckling (*B*) in the XSDRNPM-S computer software portion of the SAS2H code system is as follows (Ref. 5.10, Vol. 2, pp. F3.2.24-25):

$$B^2 = \left(\frac{\pi}{Axial\ length + f\,(0.710446)\,\lambda_m}\right)^2 + \left(\frac{\pi}{Radial\ length + f\,(0.710446)\,\lambda_m}\right)^2$$

This equation for the buckling of the three dimensional waste package models is based on the separability of the geometrical configuration into an axial coordinate and radial plane. The reflector effects are treated by the term:

$$\text{Reflector Effects} = f\,(0.710446)\,\lambda_m$$

where f is a factor greater or equal to 0.0, and λ_m is the effective neutron mean free path in the reflector region. The neutron mean free path is determined by the XSDRNPM internal calculations from the properties of the fuel region. The product of f and 0.710446 is a constant input to the SAS2H model to give the reflector effects indicated by the MCNP results. To determine the appropriate reflector effects constant ($f * 0.710446$), MCNP models of the waste package are evaluated. The k_{eff} values from MCNP and the k_∞ values from the SAS2H models are used to determine the SAS2H buckling values. The buckling values are then used to determine the constant, $f * 0.710446$. This process is performed in an iterative manner with the SAS2H model because the analytic solution of the equation involves multiple unknowns.

The separation of the independent neutron variables into an infinite assembly cell coupled with a buckling correction is assessed by first benchmarking the SAS2H infinite (∞) model (buckling = 0.0) with three MCNP k_∞ results. The MCNP k_∞ represents a fuel region with complete reflection on all finite surfaces. The complete reflection of the MCNP fuel model represents a buckling of 0.0, and a k_{eff} equal to k_∞.

The base finite MCNP model represents B&W 15X15 fuel assemblies, 4.9% U-235, 34,000 MWd/MTU burnup, and 25,000 years of isotopic decay. In the degraded state, within a waste package that has been breached by water, that has 58 percent iron oxide by volume settled in the bottom of the waste package, the MCNP k_{eff} is 1.0186 ± 0.0049 (Ref. 5.13, Table 7.4-7).

This MCNP model has two separate fuel regions: (1) the upper region of fuel in the waste package that has no iron oxide in the water, and (2) the lower region of fuel in the waste package that has 58% iron oxide in the water. The SAS2H infinite modeling must be able to produce the same k_∞ as the MCNP (within an insignificant deviation) for each independent fuel region. Note that the MCNP results are reported ±2σ (~ 95% confidence interval). Case output filenames which are included on tape (Ref. 5.22) are reported in parentheses beside or below the case results.

	MCNP-k_∞	SAS2H-k_∞	Δρ Difference
No Iron	1.20780 ± 0.00092 (INFH2O.O)	1.20693 (out.e49)	-0.00060
Iron	0.90595 ± 0.000186 (INFOX.O)	0.905533 (out.fe)	-0.00051

The above results show that the reactivity change between SAS2H and the MCNP reference k_∞ is between -5/10,000 and -6/10,000. This difference is quite insignificant and indicates that the separability of finite geometrical space and infinite cell - velocity space is generally valid using the SAS2H model with a buckling eigenvalue. A comparison of the SAS2H input with the MCNP input shows that the SAS2H pin cell and assembly cell has the same geometrical and material modeling as the MCNP pin and assembly lattice arrays.

The third SAS2H k_∞ model evaluation in comparison to MCNP was used to determine the SAS2H neutron flux and volume weighting of the upper fuel region with pure water and the lower fuel region with 58% iron oxide in water. The MCNP model used a square array of 16 fuel assemblies (4 by 4) with 12 containing 58% iron oxide in water and 4 containing pure water. This volume fraction of 0.25 pure water and 0.75 58% iron oxide in water is representative of the volume fraction of the 58 percent settled iron oxide in water model of the degraded waste package. The weighting of upper and lower regions was defined as follows:

$$k_\infty\text{(MCNP)} - \Delta\rho \text{ bias} = (x)\, k_\infty\text{(SAS2H pure water)} + (1 - x)\, k_\infty\text{(SAS2H 58\% iron oxide in water)}$$

The x is the combined flux and volume weighting factor, and the $\Delta\rho$ bias is defined by the $\Delta\rho$ difference in the table of iron and no iron k_∞ values. The parameters for the above equation are:

k_∞ (MCNP) = 1.12754 ± 0.00094 (INFLUX2O)
$\Delta\rho$ bias = -0.00055
k_∞ (SAS2H pure water) = 1.20693 (out.e49)
k_∞ (SAS2H 58% iron oxide in water) = 0.905533 (out.fe)
x = 0.71855

The comparison of MCNP and SAS2H results are shown in the following table:

	MCNP - k_∞	SAS2H - k_∞	$\Delta\rho$ Difference
Inf. Waste Package	1.12754 ± 0.00094 (INFLUX2O)	1.12684 (out.wpi)	-0.00055

The degraded waste package MCNP model, with a k_{eff} of 1.01860, has a pure water volume fraction of 0.254 and a 58% iron oxide in water volume fraction of 0.746. These volume fractions will only slightly affect the importance of the pure water region and the 58% iron oxide water region in comparison to the MCNP model with 0.25 pure water and 0.75 with 58% iron oxide in water. An increase in the weighting factor of the pure water region to:

x = 0.751311

was judged to be appropriate. This value is used in the final calculation (wp.out) as a weighting factor for the fraction of water in the moderator and (1-x) is the weighting factor for the fraction of 58% iron oxide/water mix in the moderator.

Axial Leakage Correction

The SAS2H axial buckling equation for the degraded waste package modeling is as follows (Ref. 5.10, Vol. 2, pp. F3.2.24-25):

$$B_{Axial}\ (SAS2H) = \frac{\pi}{Axial\ length + f\ (0.710446)\ \lambda_m}$$

with the assumption that the axial coordinate and radial plane may be separated by a constant buckling eigenvalue. The infinite cell SAS2H k_∞ results for the pure water in the upper region of the degraded waste package and the k_∞ results for the 58% iron oxide in water in the lower region of the degraded waste package indicated that the SAS2H separability modeling is valid. The flux-volume weighting of the upper and lower regions indicated that the importance of the upper region relative to the lower region is a factor greater than 2 to 1. Therefore, the pure water upper region was used to establish the constants for the theoretical reflector effects.

The pure water axial model of the degraded waste package was computed with MCNP and SAS2H. The MCNP modeling used reflective radial boundary conditions on the radial surfaces of the fuel. Thus, the boundary conditions represented an infinite radial model. The MCNP axial modeling however represented the appropriate geometry and compositions in the degraded waste package with appropriate boundary conditions at the end of the waste package outer metal surfaces. The SAS2H modeling used a radial buckling of zero ($B_{Radial} = 0.0$) to represent an infinite radial model. The SAS2H axial modeling represented the axial fuel length as 360.172 cm.

The solution of the reflector effects constant, ($f * 0.710446$), was iterative. However, the theoretical solution of $f = 2$ gave a very good comparison between the MCNP and SAS2H k_{eff}'s results as shown below:

$$\text{Reflector Effects Axial Constant} = f * 0.710446 = 1.420892$$

$$f = 2$$

	MCNP - k_{eff}'s	SAS2H - k_{eff}'s	Δρ Difference
Waste Package	1.20489 ± 0.00096 (INFH2OaO)	1.20430 (out.fin)	- 0.00041

The axial constant for the reflector effects on the buckling should be reduced somewhat to increase the axial leakage and reduce k_{eff}'s such that the Δρ difference was closer to - 0.00058 (the weighted bias). However, since the reflection effects constant is a combined axial and radial value, the above results are sufficient. Therefore, no additional correction is needed for the axial buckling other than entering the fuel length (360.172 cm) in the SAS2H input.

Radial Leakage Correction

In the 1-D SAS2H model, the radial leakage from the SNF configuration may be represented by either a cylinder or a square. Both options are investigated to identify the best. There are three theoretical equations that are appropriate to evaluate the radial buckling (Ref. 5.10, pp. F3.2.24-F3.2.25, Ref. 5.20, pp. 205-214) given by:

$$B_{Cylinder} = \frac{J_0(0)\ \textit{Bessel Function}}{\textit{Radius} + f_C\,(0.710446)\,\lambda_m}$$

$$B_{Square} = \frac{\left(\pi/2\right)^2}{Radial\ length + f_S\ (0.710446)\ \lambda_m}$$

$$B_{\substack{Separable \\ Square}} = \frac{\sqrt{2}\ \pi}{(2)\ Radial\ length + f_{SS}\ (0.710446)\ \lambda_m}$$

In the radial buckling for a cylinder, the radial length for the waste package model is the radius of a cylinder which has a planar area equal to the area of the 21 fuel assemblies in the degraded waste package. The width of the fuel lattice in the MCNP baseline degraded case (Attachment I) is 21.3 cm (10.65 X 2). The radius is given by:

$$Radius = \left\{ \frac{(21.3\ cm)^2\ 21}{\pi} \right\}^{1/2} = 55.0699\ \text{cm}$$

In the radial buckling for a square, the radial length for the waste package model is either the above radius or one-half the length of a square which has a planar area equal to the area of the fuel assemblies in the degraded waste package. This radial length is given by:

$$Radial\ length = \frac{\left\{ (21.3\ cm)^2\ 21 \right\}^{1/2}}{2} = 48.8044\ \text{cm}$$

In the radial buckling for a separable square, the radial length for the waste package model is the above radial length.

Reflector Effects

The three radial buckling equations were evaluated in combination with the axial buckling equation to determine the appropriate constant for the reflector effects on the combined axial and radial leakage for the degraded waste package. The SAS2H radial equation was used to determine the effective radial length with the reflector effects constant set to zero. For example, the effective radial length in the SAS2H radial buckling equation to reproduce the radial buckling of the separable square equation was determined as follows:

$$\frac{\pi}{\textit{Effective Radial Length}} = \frac{\pi}{\sqrt{2}\ \textit{Radial Length}}$$

where:

Effective Radial Length = 69.01988844 cm.

Iterations with the radial buckling equations and reflector effects constant in the SAS2H model in comparison to MCNP k_{eff} results indicated that the separable square radial buckling equation gave the more consistent overall results. The effective radial length is that shown above. The combined (axial and radial) reflector effects constant is given by:

Reflector Effects Constant $= f * 0.710446 = 0.875108$.

The comparison of the MCNP and SAS2H k_{eff} values shown below indicates that the iterative solution of the reflector effects constant (0.875108) is appropriately converged.

	MCNP - k_{eff}	SAS2H - k_{eff}	$\Delta\rho$ Difference
Waste Package	1.14053 ± 0.00052 (H2OH13FO)	1.13991 (out.wpn)	- 0.00048

Based on the results of the axial buckling evaluation of the reflector effects constant, it would be expected that f would be between 1 and 2 for the combined axial and radial reflector effects with a probable value nearer to 1. The above analysis results in an f of 1.23, which is consistent with expectations.

SAS2H Effective Radial Length of Fuel Stack

The last step in the development of a SAS2H model for the waste package reactivity coefficients is to determine the effective radial length. Ideally, the effective radial length for the degraded waste package with pure water and with 58% dense iron oxide and water in separate regions would be the effective radial length for the pure water region. If this were the situation, it would mean that the effects of the spatial flux shape could adequately be defined by the importance weighting of the two water regions. There would be no additional leakage effects. Such a situation would help to theoretically validate the separability model. Unfortunately, the SAS2H k_{eff} results, with an effective radial length of 69.0199 cm and a reflector constant of 0.875108 did not agree with the MCNP k_{eff}

(1.01860 ± 0.00486). To obtain agreement between the MCNP and SAS2H k_{eff} values, the SAS2H effective radial length had to be significantly decreased. The revised value is given by:

$$\text{Effective Radial Length (MCNP } k_{eff}) = 50.7843927 \text{ cm}$$

The decrease in the effective radial length significantly increased the radial leakage and decreased the k_{eff}. The iteration to determine the effective radial length of 50.7843927 cm gave the following SAS2H k_{eff} in comparison to MCNP:

	MCNP - k_{eff}	SAS2H - k_{eff}	$\Delta\rho$ Difference
Waste Package	1.01860 (Ref. 5.13)	1.01801 (out.wp)	- 0.00057

This agreement reflects the appropriate bias in the SAS2H k_∞ results.

Summary

With the buckling corrections developed in this section and the SAS2H assembly model giving the same k_∞ and k_{eff} results as MCNP, the SAS2H model is appropriate to evaluate reactivity changes in the degraded waste package fuel region. Three values are required for the buckling correction to the SAS2H model: (1) axial length (dz) = 360.172 cm; (2) reflector effects constant (bkl) = 0.875108; and (3) effective radial length (dy) = 50.7843927 cm.

7.2.2.2 SAS2H Reactivity Calculations

The reactivity effects of changes in the fuel temperatures and water densities are calculated with SAS2H to evaluate the RELAP5 functional relations between the thermodynamic state points and the respective reactivity values. The input file for the base SAS2H case (in.wp) is included as Attachment II. The RELAP5 model of reactivity used in this evaluation is based on two reactivity variables: (1) fuel temperature, and (2) water temperature-density. These two reactivity variables are treated as separable entities and combined in the RELAP5 model to define a total reactivity for the waste package.

The development of the RELAP5 reactivity input data included the dependent relationship between the fuel temperature and water temperature-density variables. The dependent effects were modeled using the following constraints and approximations:

(1) the fuel temperature would lead in time the water temperature-density,

(2) the water temperature effect on reactivity is insignificant compared to the water density,

(3) the water pressure effect on reactivity is insignificant compared to the water density,

(4) the onset of vapor (steam void fraction) formation would occur in the temperature range around 373 K (212°F), and

(5) the fuel temperature does not exceed 813 K (1004°F).

Steam void fractions in the 10 percent range were assumed to be caused by fuel temperatures of 543 K (518°F). Greater void fractions were assumed to be caused by fuel temperatures of 813 K (1004°F). Table 7.2.2.2-1 provides a case listing of 20 SAS2H calculations which are the bases for the RELAP5 reactivity values.

Table 7.2.2.2-1. SAS2H Reactivity Input for RELAP5

Case	k_{eff}	Fuel Temperature (K)	Water Density Factor
1 (out.wp)	1.01801	300	1.000
2 (out~1.122)	1.01712	323	1.000
3 (out~2.122)	1.01391	323	0.988
4 (out~2.212)	1.01212	373	0.988
5 (out~1.212)	1.00792	373	0.973
6 (out~1.320)	1.00599	433	0.973
7 (out~5.518)	1.00265	543	0.973
8 (out~4.518)	0.998466	543	0.958
9 (out~3.518)	0.993319	543	0.940
10 (out~2.518)	0.987415	543	0.920
11 (out~1.518)	0.981273	543	0.900
12 (out~9.100)	0.974209	813	0.900
13 (out~8.100)	0.966130	813	0.875
14 (out~7.100)	0.957650	813	0.850
15 (out~6.100)	0.948748	813	0.825
16 (out~5.100)	0.939397	813	0.800
17 (out~4.100)	0.929578	813	0.775
18 (out~3.100)	0.919256	813	0.750

19 (out-2.100)	0.908416	813	0.725
20 (out-1.100)	0.897022	813	0.700

7.2.3 Reactivity Insertion Scenario

As previously stated, the base finite MCNP model represents B&W 15X15 fuel assemblies with 4.9% U-235, 34,000 MWd/MTU burnup, and 25,000 years of isotopic decay. In the degraded state where a waste package has been breached by water and where the iron oxide has settled to the bottom of the waste package occupying 58 percent of the space by volume, the MCNP k_{eff} is 1.0186 with a standard deviation of ±0.0049 (Ref. 5.13, Table 7.4-7). This is the most reactive reasonable configuration possible in the absorber plate waste package. If the critical point is designated as a k_{eff} of 0.95, the maximum reactivity insertion possible is:

$$\frac{\Delta\rho}{\beta_{eff}} = \left[\frac{1}{0.95} - \frac{1}{1.0186}\right] \times \frac{1}{.005} = 14.18\$.$$

A change in reactivity value of this magnitude roughly corresponds to an insertion scenario involving the transition from a homogeneous distribution of iron oxide within the waste package to the stratified base configuration described above (Ref. 5.13, Table 7.4-9) or an increase in water level (Ref. 5.13, Table 7.4-10) for an SNF configuration not already completely submerged.

As will be demonstrated in the RELAP5 results, the magnitude of the insertion is not as important as the reactivity insertion rate. The negative reactivity effects of reduced water level in the package, increased fuel temperature and increased water temperature (decreased density) will eventually overwhelm any conceivable reactivity insertion mechanism. A significant transient criticality event can occur only when the balance of reactivity insertion and these negative counterbalancing effects exceed +1.0$ (prompt critical). If the insertion rate is sufficiently fast, the power level could be increasing by a factor of 2.7 (exponential period) on a time scale of a millisecond or less while the thermal changes are occurring on a time scale of a second or longer (Ref. 5.20, pp. 233-277). The greater the balance exceeds 1.0$ and the longer the duration, the greater will be the significance of the transient event in terms of the energy generated and its associated phenomena. This translates into a requirement for a relatively short insertion time (seconds) in order to achieve a prompt critical situation. The transition from a homogeneous to a stratified distribution of iron oxide within the waste package would, in general, be a slow process taking many days, months or years. Low probability events which conceivably could result in an insertion rate on a time scale of a second or minute would include:

(1) Increasing Ambient Episodic Focused Flow of water of 20 m^3 to 100 m^3 in one week (Ref. 5.15, CDA Assumption TDSS 026),

(2) Earthquake resulting in shaking of waste package and redistribution of iron oxide, and

(3) Rock fall resulting in shaking of waste package and redistribution of iron oxide.

The water level scenario (1) could insert reactivity on a minute time scale and the particle redistribution scenarios (2 and 3) could insert reactivity on a second or minute time scale depending on average particle size. Attachment III contains idealized terminal velocity (free fall, no impediment from other obstacles) calculations for particles sizes of 0.010 mm and 0.063 mm, which would take approximately 1 and 40 minutes, respectively, to fall to the bottom of the waste package. The typical crud particle size from metal oxidation is in the range of 0.0001 to 0.01 mm (Ref. 5.8, p. 2.6-6).

Based on these considerations, insertion times of 30 seconds and 3600 seconds were chosen for the RELAP5 calculations in order to demonstrate transient behavior for the criticality event.

7.3 RELAP5 Model Description

The purpose of this section is to describe the RELAP5 model used for the coupled neutronic-thermal-hydraulic analyses of a criticality event in a WP where the outer barrier has been compromised leading to a fully degraded basket assembly. The RELAP5 model of the WP, illustrated as a block diagram in Figure 7.3-1, consisted of 27 control volumes, 43 junctions, and 35 heat conductors. The spatial orientation of the WP is such that the cylindrical WP axis and long fuel assembly dimension are in the horizontal plane as shown in Figure 7.1-1. The model represents one-half of the WP cross-sectional cylinder since the system has left-right symmetry.

The RELAP5 code is designed to for use with fundamentally one-dimensional hydraulic systems but does include multi-dimensional flow representation under restricted conditions (Ref. 5.4). The RELAP5 model for the degraded WP contains flow connections in the two directions normal to the WP cylinder axis but not parallel to the axis. For this quasi-two dimensional model, the fuel bundles were modeled at one-fifth of the actual fueled length of 141.8 in. (Table 4.1-1) with appropriate adjustments to the model parameters. Fuel bundle and WP end fittings were excluded from the RELAP5 model. The principal elements of the model description include the geometric representation, flow connections, friction factors, and heat conductors. These elements are described in the following sections. Note that RELAP5 input quantities are specified in English units. A representative RELAP5 input file (r5wp2d.03c) is included in Attachment IV.

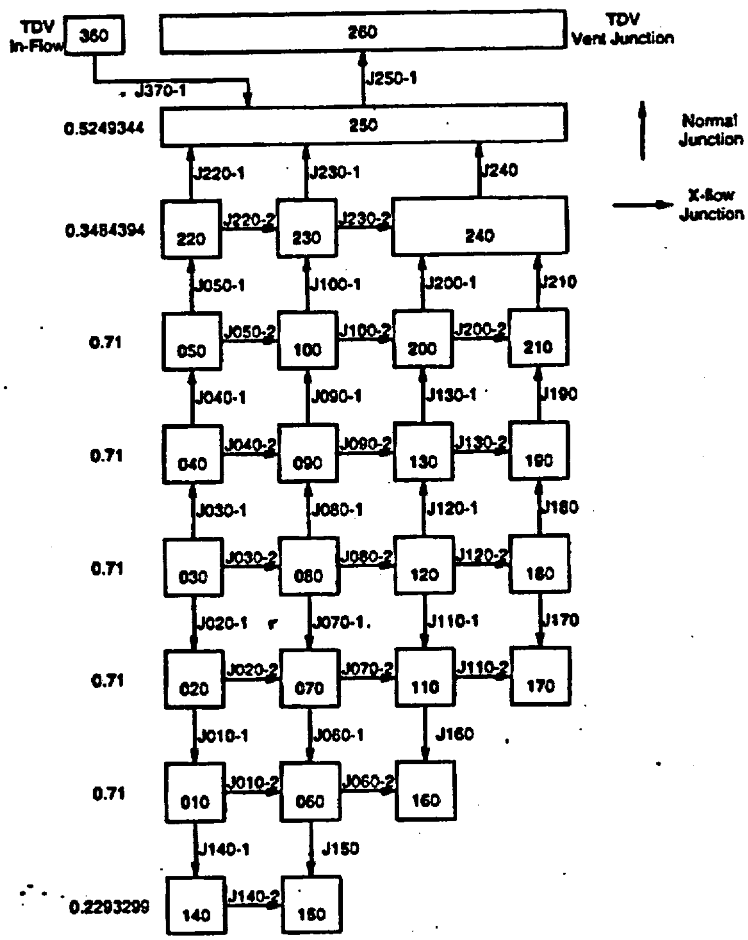

Figure 7.3-1. Block Diagram of RELAP5 Model

7.3.1 RELAP5 Model Geometry

The particular WP configuration modeled for the RELAP5 studies was the fully degraded basket condition with intact fuel assemblies. The iron oxide was assumed to have settled to the bottom of the WP covering the lower 3.5 rows of assemblies. The presence of oxide material was included in the development of the reactivity parameters but not specifically included in the hydrodynamic or thermodynamic modeling. The non-metal volume in each fuel assembly is represented by one RELAP5 control volume and the metal volume (fuel rods, guide tubes, and instrument tubes) modeled by heat conductors connected to the control volume. As stated previously, the WP is designed to hold fuel assemblies in a horizontal arrangement limiting the gravity contributions to volume pressures in the model to elevations of 21.6408 cm (0.568 in. pin cell pitch), the assembly width (Table 4.1-1). The control volume dimensions were assigned to produce the correct gravity pressure heads and fluid inventory. Dimensions of the water filled control vomunes around the WP periphery were derived by subtracting the area of the intersecting rectangular fueled cells from circular sector overlays with a radius of 71.32 cm (Drawing ID# BBAA00000-01717-2700-16004 Rev 00). The control volume dimensions for the model are listed in Table 7.3-1. The total volume contained in the control volumes is 16.051 ft^3 resulting in an initial inventory of 990.09 lb_m of water.

Control volumes representing SNF assemblies (heavily shaded rectangular areas in Figure 7.1-1) have IDs from 010010000 through 130010000 where control volumes 010010000-050010000 represent half assemblies. The remaining space in the WP interior (regions around the periphery and above the SNF assemblies in Figure 7.1-1) was described by the control volumes labeled 140010000-250010000. Two time-dependent control volumes (ID 260010000 and ID 360010000), representing the external boundary WP environment, complete the RELAP5 geometry setup. The block diagram of the RELAP5 model displayed in Figure 7.3-1, while not to scale, shows the relative control volume arrangement.

Initial conditions for the RELAP5 control volumes were specified as water filled at 122.0°F and 14.696 psia except for the time-dependent control volume (ID 260010000), representing the external environment, which was initialized as steam at 220.0°F and 14.696 psia to approximate a non-condensing gas environment.

Time-dependent volumes were included in the model to represent the drift space outside the WP where the out-flowing water inventory from the WP accumulates and to provide a low temperature flow path into the WP representing the drift flow leaking into the WP. Time dependent volumes are used as boundary conditions providing sinks and sources for the fluid inventory. Thermodynamic conditions in these control volumes are specified as functions of time and are not dependent upon the mass or enthalpy of connecting volumes.

Table 7.3-1. RELAP5 Control Volumes

Number ID*	Volume (ft^3)	Vertical Flow Area (ft^2)	Elevation (ft) (Center-line)	Pressure (psia)	Temperature (°F)
010010000	0.3516846	0.4953304	0.0	14.696	122.0
020010000	0.3516846	0.4953304	0.71	14.696	122.0
030010000	0.3516846	0.4953304	1.42	14.696	122.0
040010000	0.3516846	0.4953304	2.13	14.696	122.0
050010000	0.3516846	0.4953304	2.84	14.696	122.0
060010000	0.7033692	0.9906608	0.0	14.696	122.0
070010000	0.7033692	0.9906608	0.71	14.696	122.0

Table 7.3-1. RELAP5 Control Volumes

Number ID*	Volume (ft³)	Vertical Flow Area (ft²)	Elevation (ft) (Center-line)	Pressure (psia)	Temperature (°F)
080010000	0.7033692	0.9906608	1.42	14.696	122.0
090010000	0.7033692	0.9906608	2.13	14.696	122.0
100010000	0.7033692	0.9906608	2.84	14.696	122.0
110010000	0.7033692	0.9906608	0.71	14.696	122.0
120010000	0.7033692	0.9906608	1.42	14.696	122.0
130010000	0.7033692	0.9906608	2.13	14.696	122.0
140010000	0.2075716	0.9051223	-0.469665	14.696	122.0
150010000	0.2276341	0.9926054	-0.469665	14.696	122.0
160010000	0.7989270	1.125249	0.0	14.696	122.0
170010000	0.5438773	0.7660244	0.71	14.696	122.0
180010000	0.8980821	1.264904	1.42	14.696	122.0
190010000	0.8738187	1.230731	2.13	14.696	122.0
200010000	0.8633786	1.216026	2.84	14.696	122.0
210010000	0.7822260	1.101727	2.84	14.696	122.0
220010000	0.8633786	2.477844	3.36922	14.696	122.0
230010000	0.8633786	2.477844	3.36922	14.696	122.0
240010000	0.4918077	1.411458	3.36922	14.696	122.0
250010000	1.2517607	2.384604	3.80591	14.696	122.0
260010000	238.468	238.468	4.06837	14.696	220,0
360010000	238.468	238.468	3.54344	14.696	122.0

* First 3 digits correspond to the control volume labels in Figure 7.3-1.

7.3.2 RELAP5 Junction Description

The spatial orientation of the WP cylindrical axis is in the horizontal direction with the fuel assemblies stacked on their sides. The assemblies modeled for the MCNP analyses (Ref. 5.13) were B&W 15X15 assemblies with open pin arrays. This allows cross flow between assemblies since the internal WP structure is assumed to be fully degraded. The "normal" flow direction in the model (normal with respect to the one-dimensional hydraulic characteristic of the RELAP5 code) is vertical through the assemblies normal to the fuel rod long dimension. RELAP5 junctions define the cross sectional flow area between two control volumes which must intersect both volumes. These junctions are labeled as xxx010000 where xxx is the identifier of all junctions originating in a control volume. (Note that junction label prefixes "xxx" and control volume labels prefixes form independent sets.) A second flow direction was defined horizontally across the assemblies likewise normal to the fuel rod direction. The horizontal flow paths were modeled as junction "branch" components and labeled as xxx020000. Physical constraints on flow paths in the WP are incorporated into the junction flow areas and frictional loss coefficients.

In the development of the RELAP waste package model, form loss coefficients were included to treat the cross-flow between the flow channels. The fundamental expression for the cross-flow form loss coefficients is given by (Ref. 5.24):

$$\zeta = \psi A \, Re_{av}^{m}$$

where (ζ) is the loss coefficient,
(ψ) is a function of the angle of the flow (for 90° $\psi = 1$),
(A) is a function of the fuel rod pitch, and the hydraulic diameter,
(Re) is the average (av) Reynolds Number for the fluid conditions, and
(m) is a parameter to provide a best fit of the data.

Framatome has added two other terms, (1) a multiplier for the phase-flow characteristics, and (2) a multiplier for the number of cross-flow bundle-channels that are affected. The coefficient for highly voided regions that best matches data is 72. Sensitivity evaluations suggest that lower values would be appropriate at lower voids and flow velocities. However, for a range of Reynolds numbers (such as $3 \times 10^3 < Re < 10^5$ as noted by Idelchik), the value of 72 gives appropriate results.

All junction flow rates were initialized at zero (0) lb_m/sec except for junction 370000000 at 1.381×10^{-3} lb_m/sec at 122.0°F and 14.696 psia representing a drift inflow source of 20 m^3 per year. The junction parameters in the model are listed in Table 7.3-2.

Table 7.3-2. RELAP5 Junction Parameters

Junction ID*	Area (ft^2)	Orientation W.T. Horizontal (deg)	Connecting Volume IDs	Forward Loss Coefficient	Reverse Loss Coefficient	Choke Flag	Face Position (ft)
010010000	0.203838	90.0	01001000 02001000	72.0	72.0	no	0.355

Table 7.3-2. RELAP5 Junction Parameters

Junction ID*	Area (ft²)	Orientation W.T. Horizontal (deg)	Connecting Volume IDs	Forward Loss Coefficient	Reverse Loss Coefficient	Choke Flag	Face Position (ft)
010020000	0.407675	0.0	010010000 060010000	72.0	72.0	no	0.355
020010000	0.203883	90.0	020010000 030010000	72.0	72.0	no	1.065
020020000	0.407675	0.0	020010000 070010000	72.0	72.0	no	1.065
030010000	0.203883	90.0	030010000 040010000	72.0	72.0	no	1.775
030020000	0.407675	0.0	030010000 080010000	72.0	72.0	no	1.065
040010000	0.203838	90.0	040010000 050010000	72.0	72.0	no	2.485
040020000	0.407675	0.0	040010000 090010000	72.0	72.0	no	1.775
050010000	0.203838	90.0	050010000 220010000	72.0	72.0	no	3.195
050020000	0.407675	0.0	050010000 100010000	72.0	72.0	no	2.485
060010000	0.407675	90.0	060010000 070010000	72.0	72.0	no	0.355
060020000	0.407675	0.0	060010000 160010000	72.0	72.0	no	0.355
070010000	0.407675	90.0	070010000 080010000	72.0	72.0	no	1.065
070020000	0.407675	0.0	070010000 110010000	72.0	72.0	no	1.065
080010000	0.407675	90.0	080010000 090010000	72.0	72.0	no	1.775
080020000	0.407675	0.0	080010000 120010000	72.0	72.0	no	1.065
090010000	0.407675	90.0	090010000 100010000	72.0	72.0	no	2.485

Table 7.3-2. RELAP5 Junction Parameters

Junction ID*	Area (ft^2)	Orientation W.T. Horizontal (deg)	Connecting Volume IDs	Forward Loss Coefficient	Reverse Loss Coefficient	Choke Flag	Face Position (ft)
090020000	0.407675	0.0	090010000 130010000	72.0	72.0	no	1.775
100010000	0.407675	90.0	100010000 230010000	72.0	72.0	no	3.195
100020000	0.407675	0.0	100010000 200010000	72.0	72.0	no	2.485
110010000	0.407675	90.0	110010000 120010000	72.0	72.0	no	1.065
110020000	0.407675	0.0	110010000 170010000	72.0	72.0	no	1.065
120010000	0.407675	90.0	120010000 130010000	72.0	72.0	no	1.775
120020000	0.407675	0.0	120010000 180010000	72.0	72.0	no	1.065
130010000	0.407675	90.0	130010000 200010000	72.0	72.0	no	2.485
130020000	0.407675	0.0	130010000 190010000	72.0	72.0	no	1.775
140010000	0.203838	90.0	140010000 010010000	72.0	72.0	no	-0.355
140020000	0.541983	0.0	140010000 150010000	0.0	0.0	no	-0.355
150010000	0.407675	90.0	150010000 060010000	72.0	72.0	no	-0.355
160010000	0.407675	90.0	160010000 110010000	72.0	72.0	no	0.355
170010000	1.10807	90.0	170010000 180010000	0.0	0.0	no	1.065
180010000	1.33394	90.0	180010000 190010000	0.0	0.0	no	1.775
190010000	1.03803	90.0	190010000 210010000	0.0	0.0	no	2.485

Table 7.3-2. RELAP5 Junction Parameters

Junction ID*	Area (ft^2)	Orientation W.T. Horizontal (deg)	Connecting Volume IDs	Forward Loss Coefficient	Reverse Loss Coefficient	Choke Flag	Face Position (ft)
200010000	0.754086	90.0	200010000 240010000	0.0	0.0	yes	3.195
200020000	1.79585	0.0	200010000 210010000	0.0	0.0	yes	2.485
210010000	1.03803	90.0	210010000 240010000	0.0	0.0	yes	3.195
220010000	0.203838	90.0	220010000 250010000	0.0	0.0	yes	3.54344
220020000	0.823478	0.0	220010000 230010000	0.0	0.0	yes	3.195
230010000	0.407675	90.0	230010000 250010000	0.0	0.0	yes	3.54344
230020000	0.823478	0.0	230010000 240010000	0.0	0.0	yes	3.195
240010000	0.973291	90.0	240010000 250010000	0.0	0.0	yes	3.54344
250010000	0.107639	90.0	250010000 260010000	0.0	0.0	yes	4.06837
370010000	1.0	0.0	360010000 250010000	0.0	0.0	no	3.54344

* Digits 1-3 and 5 correspond to the "J" IDs in Figure 7.3-1.

7.3.3 RELAP5 Heat Conductor Description

Energy sources in RELAP5 models must be modeled with powered heat conductors connected to control volumes. In addition, non-powered heat conductors may be used to transport energy between disjoint fluid paths and/or into heat sinks. In order to properly model the thermal characteristics of conductors, the geometry is normally representative of individual components such as fuel rods. The overall fuel assembly energy balance is modeled by assigning the proper heat transfer area to the conductor. For the RELAP5 model of the WP, two sets of conductors describing the fuel pins and guide tubes were defined, one powered set representing the UO_2 fuel pellets (IDs 3301001 through 3301013) and one passive set representing the fuel rod cladding and guide tubes (IDs 3481001 through 3481013).

The conductor series 3301 and 3481 were connected respectively to control volumes 01001000 through 130010000 where the SNF assemblies are located. The fuel rods were modeled with independent pellet and clad conductors to simulate breached conditions with no gas gap between the fuel pellets and cladding and water is in contact with the UO_2 pellets. In this model, the fuel rod cladding was dissociated from the fuel pellet-to-water heat conduction path placing the pellets directly in contact with the control volume water mass. The cladding and guide tubes were in turn heated from secondary contact with the control volume water mass.

The outer containment shell of the WP was modeled with a set of nine passive heat conductors (IDs 3121001 through 3121009) representing large carbon steel heat sinks connected to the peripheral water filled control volumes (IDs 140010000 through 220010000).

Initial conditions for all heat conductors were 122.0°F.

Global energy sources in the RELAP5 program are defined by the time-dependent solution of point kinetics equations for the fission contribution to the energy generation coupled with (optionally) fission product and actinide radioactive decay energy. The global energy sources are distributed locally to powered heat conductors (IDs 3301001 through 3301013) through power factors which consist of nodal weights within conductors and overall weight factors among the conductors. For the RELAP5 WP model, the time-dependent power history represented one fuel assembly and the power factors were specified accordingly; 0.2 for one-fifth length full area assemblies and 0.1 for one-fifth length half area assemblies. Nodal power factors within conductors were given equal weighing.

The heat conductor descriptions for the RELAP5 model are listed in Table 7.3-3.

Table 7.3-3. RELAP5 Heat Conductor Specifications

Conductor ID	Geometry	Composition	Coordinate (ft) Left Right	Volume Connection	Initial Tempera-ture (°F)	Heat Transfer Area (ft^2)	Power Factor
3301001	Cylinder	UO_2	0.0 1.535833e-02	0 010010000	122.0	245.78667	0.1
3301002	Cylinder	UO_2	0.0 1.535833e-02	0 020010000	122.0	245.78667	0.1
3301003	Cylinder	UO_2	0.0 1.535833e-02	0 030010000	122.0	245.78667	0.1
3301004	Cylinder	UO_2	0.0 1.535833e-02	0 040010000	122.0	245.78667	0.1
3301005	Cylinder	UO_2	0.0 1.535833e-02	0 050010000	122.0	245.78667	0.1

Table 7.3-3. RELAP5 Heat Conductor Specifications

Conductor ID	Geometry	Composition	Coordinate (ft) Left Right	Volume Connection	Initial Temperature (°F)	Heat Transfer Area (ft^2)	Power Factor
3301006	Cylinder	UO_2	0.0 1.535833e-02	0 060010000	122.0	491.57333	0.2
3301007	Cylinder	UO_2	0.0 1.535833e-02	0 070010000	122.0	491.57333	0.2
3301008	Cylinder	UO_2	0.0 1.535833e-02	0 080010000	122.0	491.57333	0.2
3301009	Cylinder	UO_2	0.0 1.535833e-02	0 090010000	122.0	491.57333	0.2
3301010	Cylinder	UO_2	0.0 1.535833e-02	0 100010000	122.0	491.57333	0.2
3301011	Cylinder	UO_2	0.0 1.535833e-02	0 110010000	122.0	491.57333	0.2
3301012	Cylinder	UO_2	0.0 1.535833e-02	0 120010000	122.0	491.57333	0.2
3301013	Cylinder	UO_2	0.0 1.535833e-02	0 130010000	122.0	491.57333	0.2
3481001	Cylinder	Zr-4	1.570833e-02 1.791112e-02	010010000 010010000	122.0	265.875 531.750	0.0
3481002	Cylinder	Zr-4	1.570833e-02 1.791112e-02	020010000 020010000	122.0	265.875 531.750	0.0
3481003	Cylinder	Zr-4	1.570833e-02 1.791112e-02	030010000 030010000	122.0	265.875 531.750	0.0
3481004	Cylinder	Zr-4	1.570833e-02 1.791112e-02	040010000 040010000	122.0	265.875 531.750	0.0
3481005	Cylinder	Zr-4	1.570833e-02 1.791112e-02	050010000 050010000	122.0	265.875 531.750	0.0
3481006	Cylinder	Zr-4	1.570833e-02 1.791112e-02	060010000 060010000	122.0	265.875 531.750	0.0
3481007	Cylinder	Zr-4	1.570833e-02 1.791112e-02	070010000 070010000	122.0	265.875 531.750	0.0
3481008	Cylinder	Zr-4	1.570833e-02 1.791112e-02	080010000 080010000	122.0	265.875 531.750	0.0

Table 7.3-3. RELAP5 Heat Conductor Specifications

Conductor ID	Geometry	Composition	Coordinate (ft) Left Right	Volume Connection	Initial Temperature (°F)	Heat Transfer Area (ft^2)	Power Factor
3481009	Cylinder	Zr-4	1.570833e-02 1.791112e-02	090010000 090010000	122.0	265.875 531.750	0.0
3481010	Cylinder	Zr-4	1.570833e-02 1.791112e-02	100010000 100010000	122.0	265.875 531.750	0.0
3481011	Cylinder	Zr-4	1.570833e-02 1.791112e-02	110010000 110010000	122.0	265.875 531.750	0.0
3481012	Cylinder	Zr-4	1.570833e-02 1.791112e-02	120010000 120010000	122.0	265.875 531.750	0.0
3481013	Cylinder	Zr-4	1.570833e-02 1.791112e-02	130010000 130010000	122.0	265.875 531.750	0.0
3121001	Rectangular	Carbon Steel	0.0 190.0	140010000 0	122.0	1.73 0.0	0.0
3121002	Rectangular	Carbon Steel	0.0 190.0	150010000 0	122.0	1.73 0.0	0.0
3121003	Rectangular	Carbon Steel	0.0 190.0	160010000 0	122.0	1.73 0.0	0.0
3121004	Rectangular	Carbon Steel	0.0 190.0	170010000 0	122.0	1.73 0.0	0.0
3121005	Rectangular	Carbon Steel	0.0 190.0	180010000 0	122.0	1.73 0.0	0.0
3121006	Rectangular	Carbon Steel	0.0 190.0	190010000 0	122.0	1.73 0.0	0.0
3121007	Rectangular	Carbon Steel	0.0 190.0	200010000 0	122.0	1.73 0.0	0.0
3121008	Rectangular	Carbon Steel	0.0 190.0	210010000 0	122.0	1.73 0.0	0.0
3121009	Rectangular	Carbon Steel	0.0 190.0	220010000 0	122.0	1.73 0.0	0.0

7.3.4 RELAP5 Reactivity Tables

The feedback reactivity in the RELAP5 point kinetics model can be specified as direct time dependent tables (labeled as scram tables), weighted tables of fluid density vs reactivity, or through control system variables. The control system allows reactivity values to be more generally specified as functions of model variables.

The RELAP5 reactivity changes for fuel and moderator temperature effects are shown in Tables 7.3-4 and 7.3-5. The first parameter shown on Tables 7.3-4 and 7.3-5 is the 8 digit input line number beginning with the number 3 (30000000). The last 3 digits on these input lines identify the fuel temperature variables, 30000601 through 30000607, moderator density variables, 30000501 through 30000516, and the respective reactivities. The English units used here reflect the values used in the RELAP5 input.

The formulation of the reactivities for each input line is denoted as:

$$\rho\,(603) = \Delta\rho_{CB} + \rho\,(\mathrm{sum})$$

where ρ (603) is the input line number (603 for example), ρ (sum) is the summation of reactivities from the initial state point (122 °F), and:

$$\Delta\rho_{CB} = \frac{1}{k_{eff\text{ - }Base}} - \frac{1}{k_{eff\text{ - }Change}}$$

where C represents the change case number from Table 7.2.2.2-1 and B represents the base case number from the same table. Note that the cases listed in Table 7.2.2.2-1 include a number of branch cases (fuel temperature varied at constant density and density varied at constant fuel temperature). The constant parameter is listed the last column in Table 7.3-4 and Table 7.3-5.

Table 7.3-4. Average Fuel Temperature Versus Reactivity

RELAP5 Input Line #	Fuel Temperature (°F)	Δρ($)	Density (lb_m/ft^3)
30000601	32.0	+0.1719079	62.4279606
30000602	80.33	+0.1719079	62.4279606
30000603	122.0	+0.0	61.6903146
30000604	212.0	-0.3488604	61.6903146
30000605	320.0	-0.7295469	60.7424057
30000606	518.0	-1.3918144	60.7424057
30000607	1004.0	-2.8696928	56.1851645

Table 7.3-5. Moderator Density Versus Reactivity

RELAP5 Input Line #	Density (lb_m/ft^3)	$\Delta\rho$($)	Fuel Temperature (°F)
30000501	43.6995724	- 22.8341124	1004
30000502	45.2602714	-20.0375898	1004
30000503	46.8209705	-17.4413905	1004
30000504	48.3816695	-15.0255317	1004
30000505	49.9423685	-12.7766726	1004
30000506	51.5030675	-10.6782739	1004
30000507	53.0637665	-8.7187079	1004
30000508	54.6244655	-6.8856192	1004
30000509	56.1851645	-5.1688975	518
30000510	57.4337238	-3.9010990	518
30000511	58.6822830	-3.9010990	518
30000512	59.8121897	-1.6592902	518
30000513	60.7424057	-0.8234196	212
30000514	61.6903146	0.00	122
30000515	62.4279606	+0.6225345	122
30000516	65.0000000	+0.6225345	80.33

The initial state point is represented by fuel temperatures of 122°F and a corresponding density of 61.6903146 lb/ft³. There are interpolation control reactivity lines for ρ (601) and ρ (516). Temperatures less than 80.33°F {ρ (602)} cannot be attained. Therefore, 32°F is a dead-ended interpolation point:

$$\rho\,(601)_{32°F} = \rho\,(602)_{80.33°F.}$$

Likewise, water densities greater than 1.0 gm/cm³ or 62.4 lb/ft³ cannot be attained. Therefore, 65.0 lb/ft³ is a dead-ended interpolation point:

$$\rho\,(516)_{65.0\,lb/ft^3} = \rho\,(515)_{62.4\,lb/ft**3}.$$

The reactivity summation, ρ (sum), begins with the base reactivity for the initial state points and proceeds in the direction of increasing positive values or decreasing negative ones.

The formulations for the fuel temperature reactivity values are shown below. These expressions are straightforward. For example, if a positive reactivity increase is considered to have resulted from a fuel temperature decrease from 122°F to 80.33°F, the base case in Table 7.2.2.2-1 is #2 and the change case is #1. Consequently, the change in reactivity is $\Delta\rho_{1,2}$. The sum of all previous reactivities is zero because this is the first change from the base reactivity, which is zero at 122°F.

$$\rho(601) = \rho(602)$$
$$\rho(602) = \Delta\rho_{1,2} + \rho(603)$$
$$\rho(603) = 0.0 = \Delta\rho = \rho(603)$$
$$\rho(604) = \Delta\rho_{4,3} + \rho(603)$$
$$\rho(605) = \Delta\rho_{6,5} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(604) + \rho(603)$$

$$\rho(606) = \Delta\rho_{7,6} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(605) + \ldots$$

$$\rho(607) = \Delta\rho_{12,11} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(606) + \ldots$$

The formulations for the moderator density reactivity values are shown below. The format and evaluation follow the same pattern as that for the fuel temperatures discussed above.

$$\rho(516) = \rho(515)$$
$$\rho(515) = \Delta\rho_{2,3} + \rho(514)$$
$$\rho(514) = 0 = \Delta\rho = \rho(\text{sum})$$
$$\rho(513) = \Delta\rho_{5,4} + \rho(514)$$
$$\rho(512) = \Delta\rho_{8,7} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(513) + \rho(514)$$

$$\rho(511) = \Delta\rho_{9,8} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(512) + \ldots$$

$$\rho(510) = \Delta\rho_{10,9} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(511) + \ldots$$

$$\rho(509) = \Delta\rho_{11,10} + \rho(\text{sum})$$
$$\rho(\text{sum}) = \rho(510) + \ldots$$

$$\rho(508) = \Delta\rho_{13,12} + \rho(\text{sum})$$

ρ (sum) = Sum of previous ρ values

ρ (507) = $\Delta\rho_{14,13}$ + ρ (sum)
ρ (506) = $\Delta\rho_{15,14}$ + ρ (sum)
ρ (505) = $\Delta\rho_{16,15}$ + ρ (sum)
ρ (504) = $\Delta\rho_{17,16}$ + ρ (sum)
ρ (503) = $\Delta\rho_{18,17}$ + ρ (sum)
ρ (502) = $\Delta\rho_{19,18}$ + ρ (sum)
ρ (501) = $\Delta\rho_{20,19}$ + ρ (sum)

During the development of the model, it was noted that the reactivity was remaining high during the transient when the water level was decreasing down through the upper row of assemblies. Based on the results in Section 7.2.1 that this was a very large negative effect, it was recognized that this effect needed to be included. The control system input option was used to incorporate the results in Table 7.2.1-2 into the RELAP5 model. A control block was added to the input file to compute an average liquid level in the top row of fueled assemblies and adjacent fluid volumes having the same elevation. Reactivity is calculated from the table at the current liquid level using linear interpolation procedures based on the results in Section 7.2.1. The MCNP analyses for the sequence of water levels in the WP were evaluated from the top of the fuel assembly to -20.30 cm as indicated in Section 7.2.1. The reactivity table for the RELAP5 model was extended to -21.64 cm (lower edges of the assemblies) using the last reactivity value to define a zero level entry. This is a conservative approach since the k_{eff} of the system is strongly correlated with the water level at these conditions.

The inclusion of the control block for water level necessitated that the moderator density table be overridden. Note that this is conservative since the drop in moderator density is shown in Table 7.3-5 to always result in a negative change in reactivity.

7.4 Results of RELAP5 Analysis

All results in this section from RELAP5 calculations are TBV because the RELAP5/MOD3 code has not been qualified according QAP-SI-0 as indicated in Section 6.

The consequences of a large reactivity insertion in the WP, one where the insertion rate was on the order of minutes and the second where the rate was on the order hours, were investigated with the RELAP5 model. In particular, the scenarios investigated were a positive reactivity insertion of 14.18$ at a constant rate over 30 seconds and over 3600 seconds. These cases are labeled as r5wp2d.sht for the 30 second scenario and r5wp2d.lng for the 3600 second scenario. The short term (initial power excursion) transient responses in both cases were qualitatively similar, being dominated by the positive ramp reactivity insertion and negative Doppler feedback reactivity which terminated the initial power rise in each case prior to the introduction of significant negative void reactivity. The transient response of the WP system following termination of the initial power rise was controlled by the rate of energy addition affecting the rate and magnitude of the void formation and thus the time evolution of the void reactivity component. Ultimately, sufficient fluid inventory was lost from the WP (> 225 kg in either case) to sustain a large negative void reactivity component, keeping the system in a subcritical condition.

Maximum pressures in the WP system remained below 2.55e+05 Pa and maximum center line fuel rod temperatures remained below 570 K. Sufficient fluid inventory remained in the WP at the problem termination to redistribute the energy in the system and reducing the fuel rod temperatures to less than 373 K. Values of several key parameters from the RELAP5 analyses are summarized in Table 7.4-1.

Table 7.4-1. Summary of 14.18$ Ramp Reactivity Insertion Cases

Variable	30 second reactivity insertion case r5wp2d.sht	3600 second reactivity insertion case r5wp2d.lng
Peak fission power/assembly	9.47e+07 watts	8.76e+05 watts
Time of peak fission power	2.52 seconds	176.0 seconds
Total fission and decay heat power per assembly at time of fission power maximum	9.48e+07 watts	9.00e + 05 watts
Total energy into WP/assembly at termination time	5.16e+07 joules	8.15e+07 joules
Maximum volume pressure	2.544e+05 Pa	2.258e+05 Pa
Control volume where maximum pressure monitored	150010000	150010000
Peak mean fuel rod temperature	497.5 K	438.4 K
Time of peak pin temperature	4.18 seconds	633 seconds
Water inventory - Initial	450.04 kg	450.04 kg
Water inventory - Final	209.02 kg	219.29 kg
Incremental Burnup	1.6e-03 MWd/MTU	1.8 MWd/MTU
Termination time	1200 seconds	1800 seconds

The consequences of each reactivity insertion scenario were directly related in severity to the reactivity insertion rate in the flooded WP which is typical of transient reactivity events analyzed in reactor systems such as during Anticipated Transients Without Scram (ATWS) (Ref. 5.17), supporting the assumption that the RELAP5 code can adequately model the WP system. The total energy generated may be larger for slower insertion rate events as shown in Table 7.4-1 but is distributed over longer time periods than the more rapid insertion rate events. Within an essentially closed system such as the WP being analyzed, the energy generation can be considered as an adiabatic process since the time scales are too short for significant amounts of energy to be transferred into the WP barriers as heat sinks. Thus, although the detailed histories differ markedly, preliminary analysis indicates that the final state of the system is, at most, only weakly dependent upon reactivity insertion rates since the fission reaction terminates as soon as the WP is sufficiently voided. In this state, sufficient fluid inventory has been converted to steam (or a two-phase fluid) and expelled from the WP to preclude any short term return to criticality.

The time evolution of key parameters from the 30 second scenario are shown in Figure 7.4-1 through Figure 7.4-10, respectively, for assembly power, reactivity components, control volume pressures, WP fluid inventory, junction flow rates, and average fuel temperature. Two ranges are shown for several of the parameters, one showing a panoramic view of the parameter value over the total time period, and the second providing a higher resolution study over a limited time scale. In this scenario, the energy generation rate was sufficiently rapid during the initial power excursion to raise fuel temperatures (Figure 7.4-10) well into the range where void formation occurs generating the sharp pressure rise (Figure 7.4-5) and inventory loss (Figure 7.4-7). As shown in Figure 7.4-3, the large negative void reactivity component prevented any possible return to criticality in the WP system and the fission power level (Figure 7.4-1) asymptotically approaches the characteristic 79 second decay period of the longest lived delayed neutron precursor group (standard 6-group model).

The total system reactivity and its three components (positive ramp insertion, negative Doppler and void feedback) are given in Figure 7.4-3. This figure shows the early Doppler feedback reactivity which terminated the initial power excursion followed by the larger negative void reactivity which ultimately terminates the event. All values of the reactivity components have reached their asymptotic values by 30 seconds.

Maximum pressures in the WP system reach approximately 2.5e+05 Pa during the initial phases of the event as shown in Figure 7.4-4 and Figure 7.4-5, then return to near initial values. The lower final values reflect the gravity head from the reduced final fluid inventory as shown in Figure 7.4-6 and Figure 7.4-7.

The flow rate in the exit junction, ID 250010000, and junction IDs 230010000 and 230020000 are shown in Figure 7.4-8 over the total event period and in Figure 7.4-9 for an initial phase. The flow rate in the exit junction, ID 250010000, is limited by the choking model which controls the rate of inventory loss and pressure relief. The direction of flow for the exit junction is predominately outward

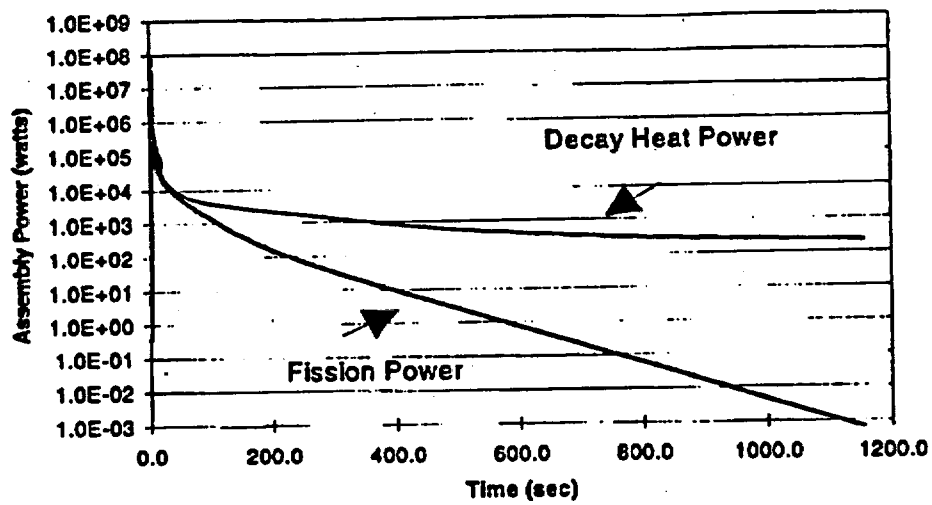

Figure 7.4-1. Assembly Power - 30 second Reactivity Insertion Scenario

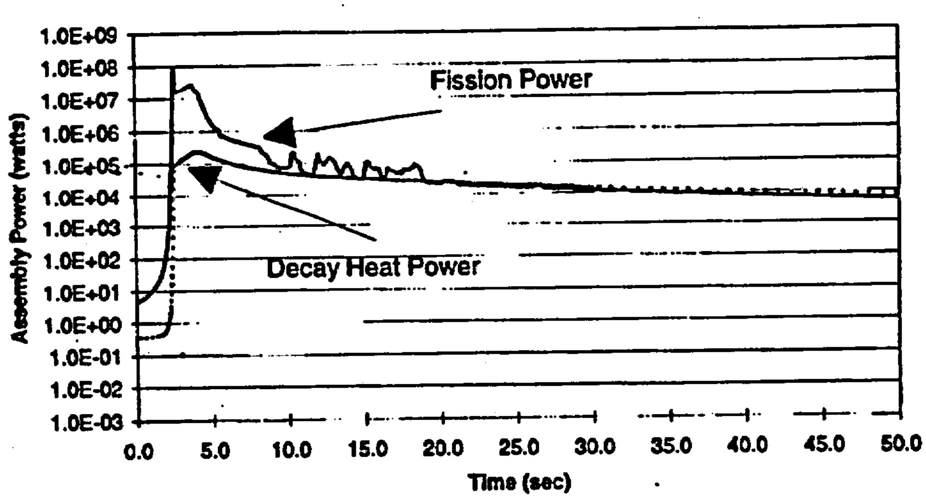

Figure 7.4-2. Assembly Power - 30 second Reactivity Insertion Scenario

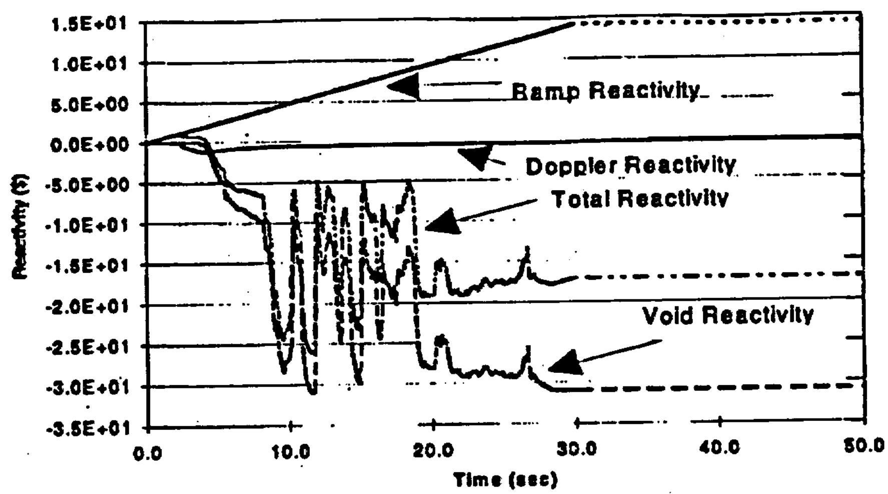

Figure 7.4-3. Reactivity Components - 30 second Reactivity Insertion Scenario

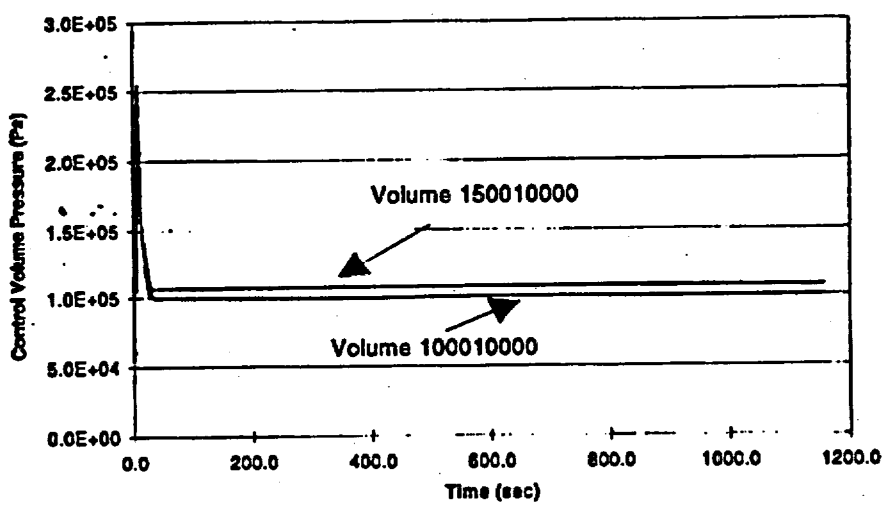

Figure 7.4-4. Volume Pressures - 30 second Reactivity Insertion Scenario

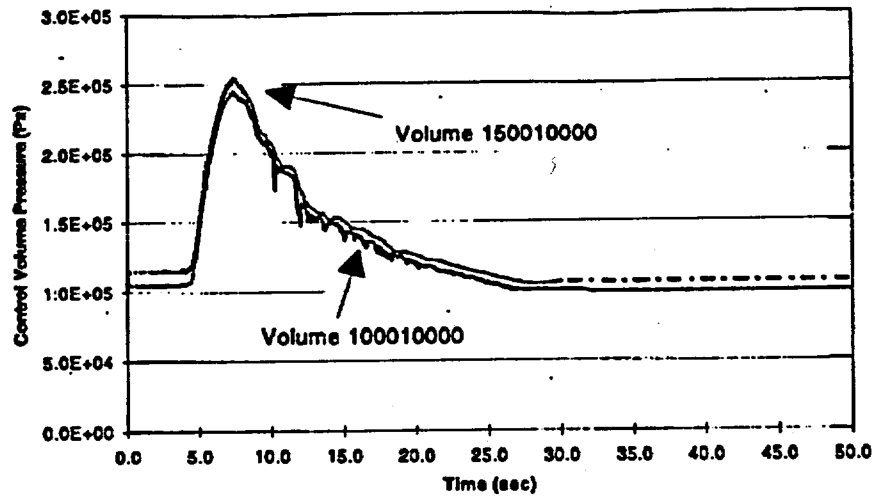

Figure 7.4-5. Volume Pressures - 30 second Reactivity Insertion Scenario

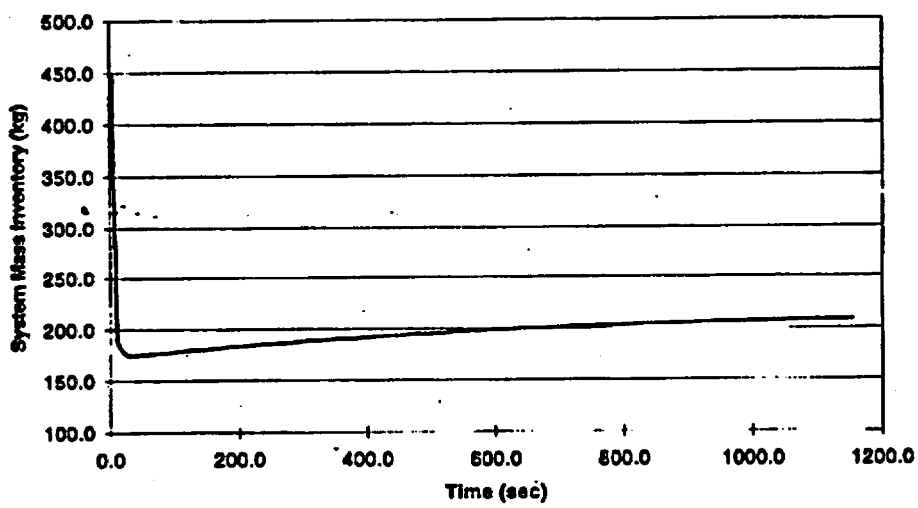

Figure 7.4-6. Waste Package Fluid Inventory - 30 second Reactivity Insertion Scenario

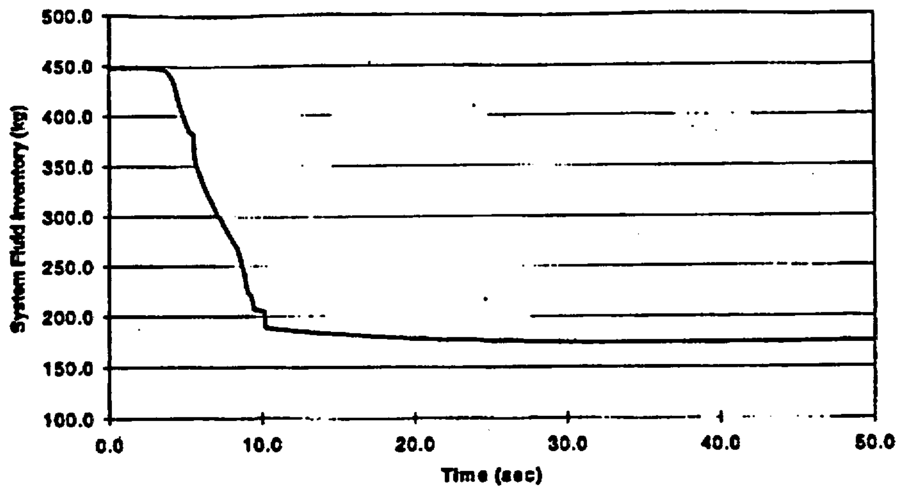

Figure 7.4-7. Waste Package Fluid Inventory - 30 second Reactivity Insertion Scenario

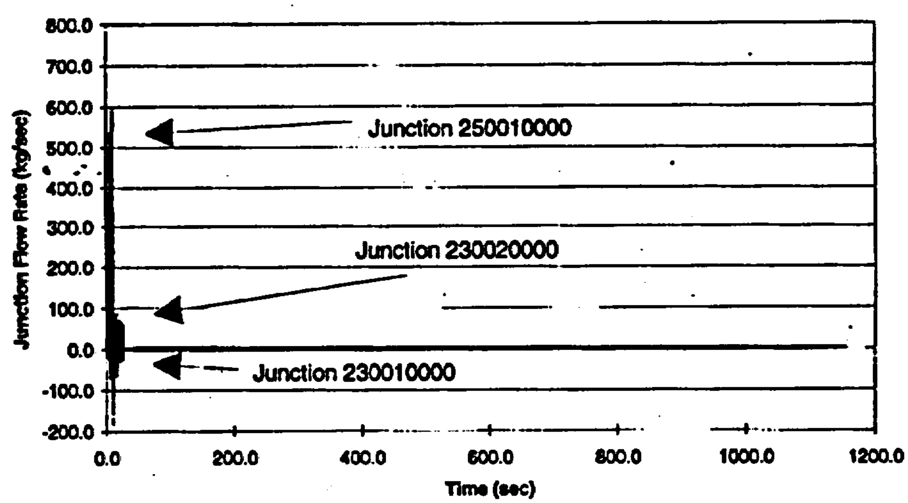

Figure 7.4-8. Junction Flow Rates - 30 second Reactivity Insertion Scenario

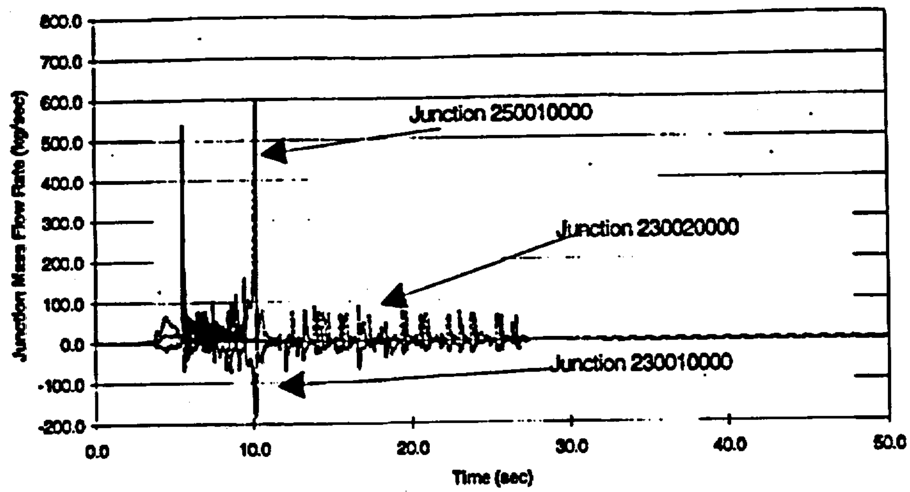

Figure 7.4-9. Junction Flow Rates - 30 second Reactivity Insertion Scenario

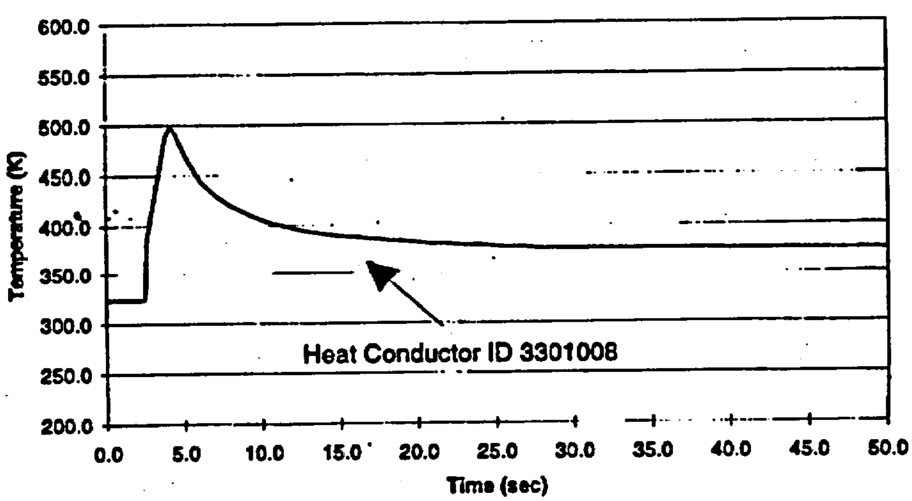

Figure 7.4-10. Average Metal Temperature - 30 second Reactivity Insertion Scenario

(inventory loss) with very low reverse mass flow rates since the external environment (Control Volume 260010000) was specified as water vapor. Interior junctions, as shown in these figures, may experience either positive or negative flow rates as the pressure distribution dictates. As stated previously, the system returns to a stable sub-critical configuration following the initial activity.

The much lower reactivity insertion rate in the 3600 second reactivity insertion scenario, and thus the energy generation rate, resulted in a less severe transient response than for the 30 second reactivity insertion scenario as listed in Table 7.4-1. The time evolution of key parameters from this scenario is shown in Figure 7.4-11 through Figure 7.4-20, respectively, for assembly power, reactivity components, control volume pressures, WP fluid inventory, junction flow rates, and average fuel temperature. Two ranges are shown, as above, for several of the parameters, one showing a panoramic view of the parameter value over the total time period, and the second providing a higher resolution study over a limited time scale. In the 3600 second reactivity insertion scenario, the power excursion is terminated by the negative Doppler reactivity (Figure 7.4-13) with fuel pin metal temperatures (Figure 7.4-20) at values where subcooled boiling can be initiated. The initial vapor generation was coincident with the initial WP inventory loss (Figure 7.4-15) but did not result in a prominent pressure surge as shown in Figure 7.4-16. During the 200-600 second time period in the scenario, negative reactivity from the void and Doppler effects was nearly equal to the positive ramp insertion reactivity, maintaining the power level (Figure 7.4-12). An increase in the vapor generation rate around 600 seconds into the scenario resulted in a pressure surge (Figure 7.4-16) and further inventory loss. As shown in Figure 7.4-13, the large negative void reactivity component prevents any possible return to criticality in the WP system and the fission power level (Figure 7.4-11) asymptotically approaches the characteristic 80 second decay profile. The inventory loss at this point is sufficient to prevent any possible return to critical conditions until the WP refills with water which has a time scale of years.

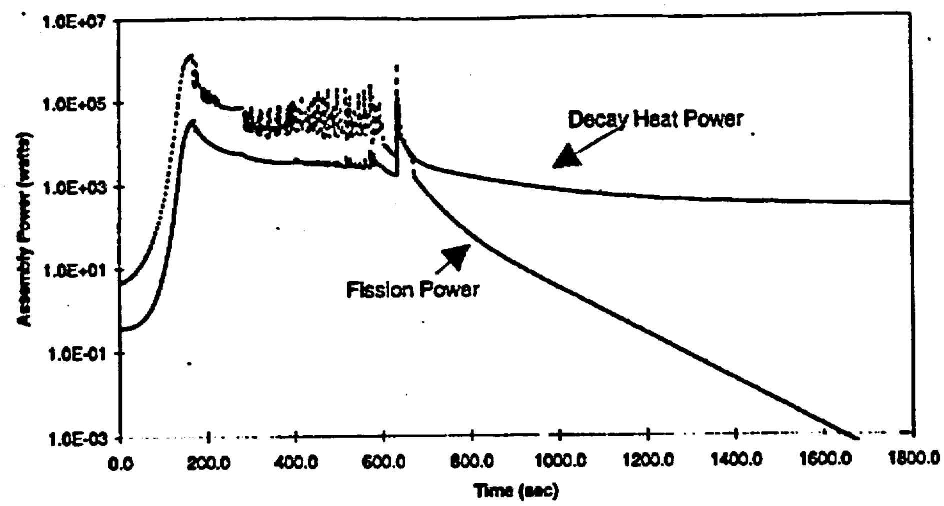

Figure 7.4-11. Assembly Power - 3600 second Reactivity Insertion Scenario

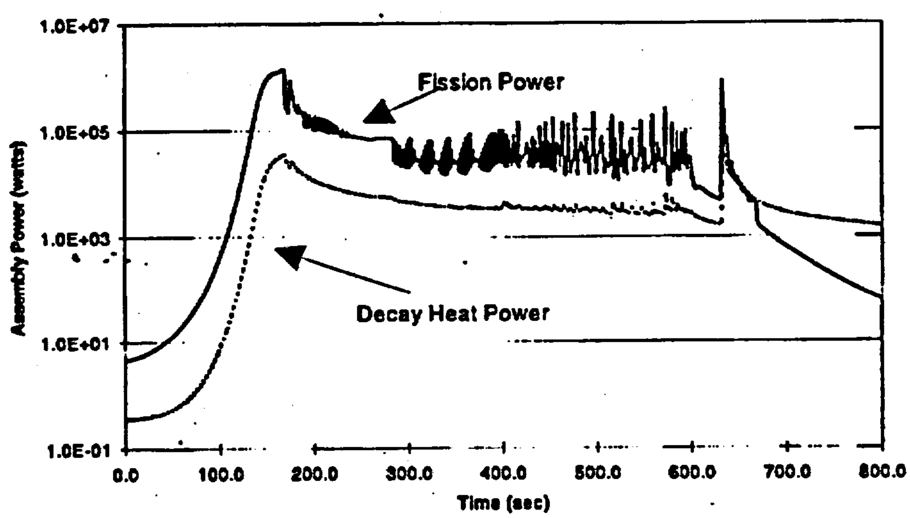

Figure 7.4-12. Assembly Power - 3600 second Reactivity Insertion Scenario

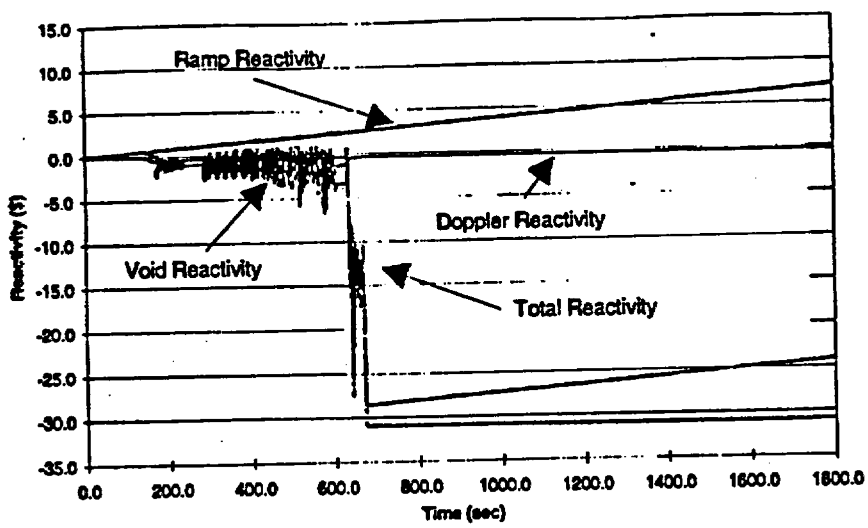

Figure 7.4-13. Component Reactivity - 3600 second Reactivity Insertion Scenario

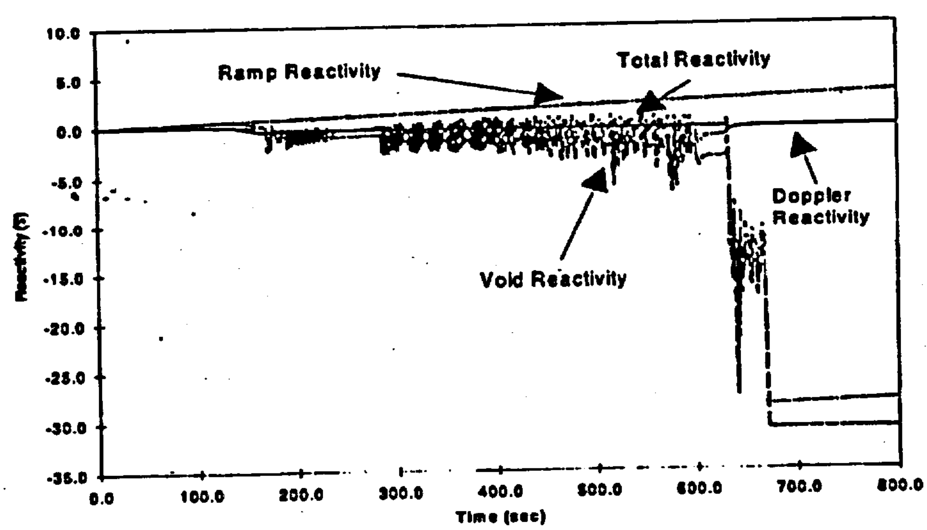

Figure 7.4-13. Component Reactivity - 3600 second Reactivity Insertion Scenario

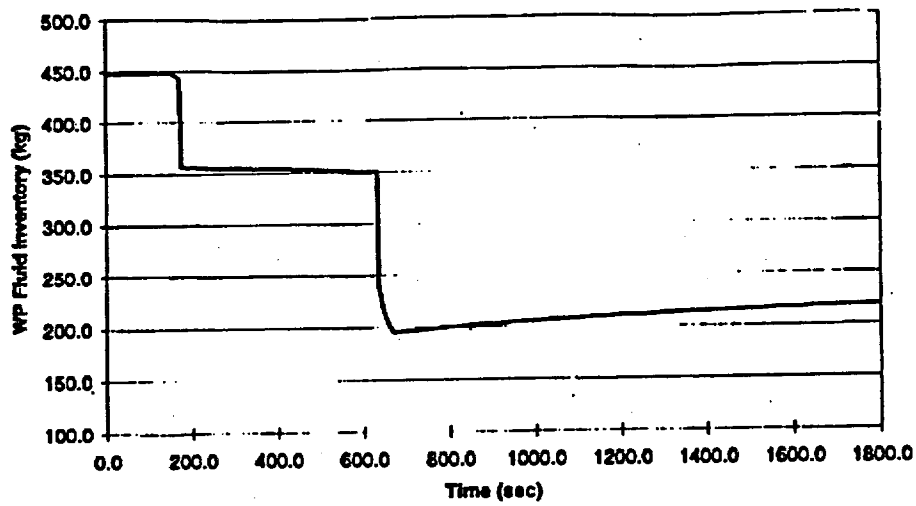

Figure 7.4-15. Waste Package Fluid Inventory - 3600 second Reactivity Insertion Scenario

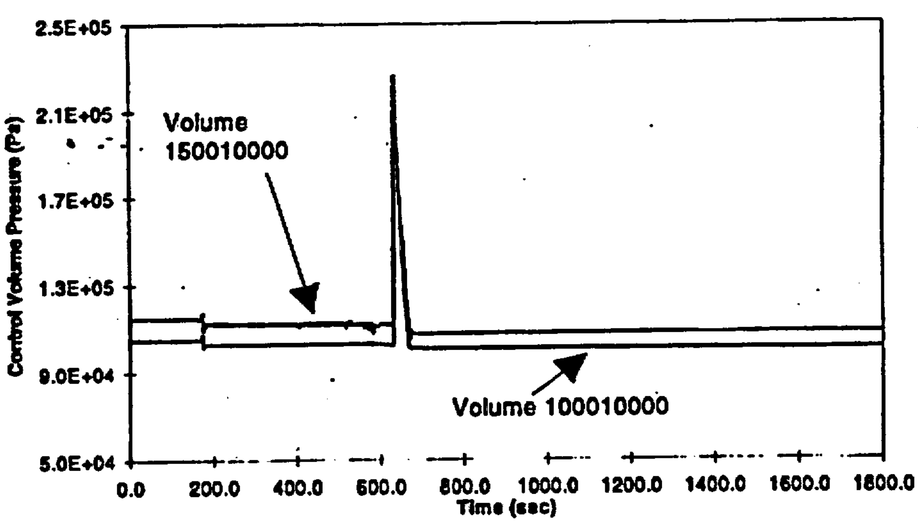

Figure 7.4-16. Volume Pressures - 3600 second Reactivity Insertion Scenario

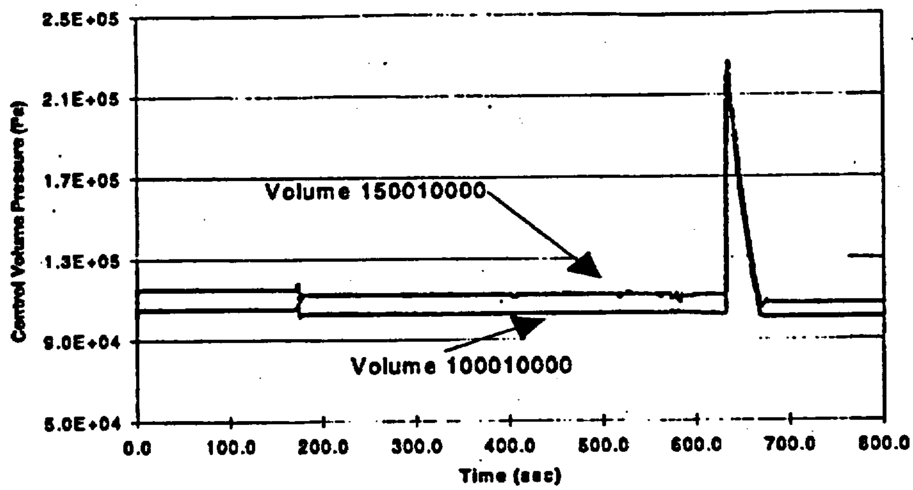

Figure 7.4-17. Volume Pressures - 3600 second Reactivity Insertion Scenario

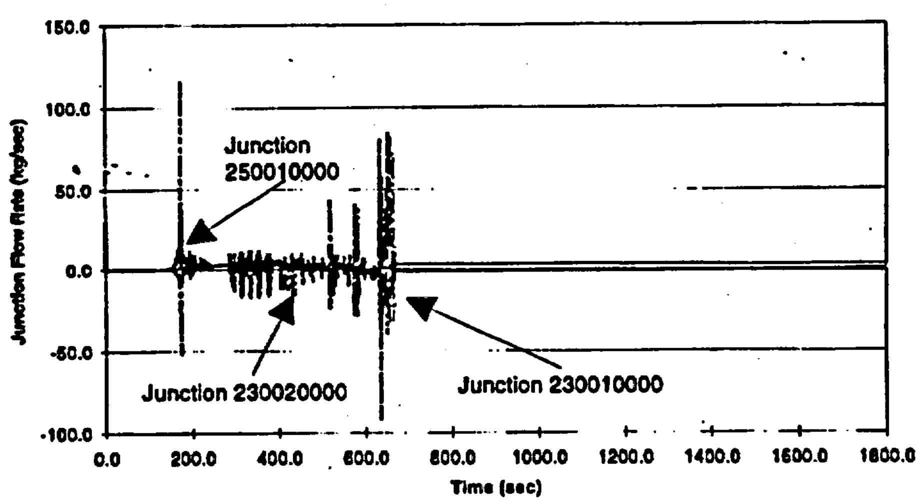

Figure 7.4-18. Junction Flow Rates - 3600 second Reactivity Insertion Scenario

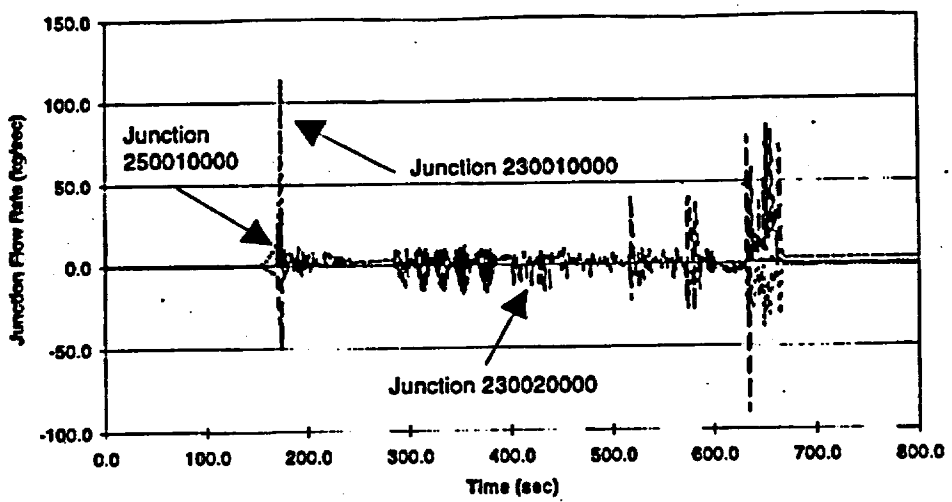

Figure 7.4-19. Junction Flow Rates - 3600 second Reactivity Insertion Scenario

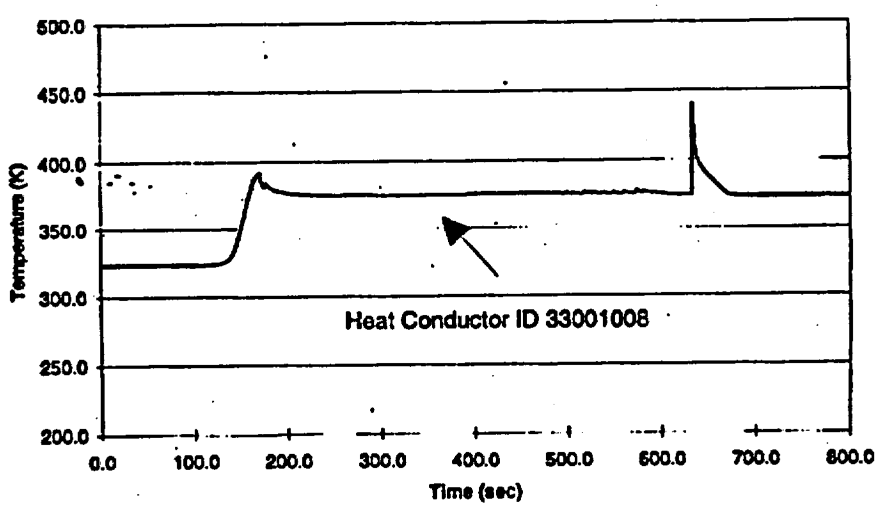

Figure 7.4-20. Average Metal Temperature - 3600 second Reactivity Insertion Scenario

7.5 Changes to the Radionuclide Inventory Due to Transient Criticality Event

To evaluate the effects of a criticality on the radionuclide inventory of a waste package, the code sequence SAS2H was run using the PWR criticality design basis fuel, power histories from the RELAP5 analyses, and a decay period of one year. The maximum decay period of one year was based on the short operating time of the criticality event which precludes formation of significant inventories of long lived isotopes. The transient fission power history and fuel temperature, listed in Table 7.5-1, for the SAS2H input files (short.inp, long.inp) were approximated by histograms derived from the graphical data shown in Section 7.4. Figure 7.4-1 and Figure 7.4-10 were the basis for the 30 second reactivity scenario histograms. Figure 7.4-11 and Figure 7.4-20 were the basis for the 3600 second reactivity insertion scenario histograms. The burnup calculated from these histograms (summation of time steps in days multiplied by power in MW and divided by 0.464 MTU) are only 1.6E-3 MWd/MTU and 1.8 MWd/MTU for the short and the long cases, respectively. The output of the SAS2H runs (short.out and long.out) list the radionuclide inventories in curies for the 30 second and 3600 second reactivity insertion scenarios, respectively. These values are compared in Table 7.5-2 to the initial radionuclide inventory for a 25,000 year decay period generated as part of a previous analysis (Ref. 5.13). The initial analysis contained 36 isotopes in the radionuclide inventory. For this analysis, only those isotopes whose inventories after one year decay differed from the original values by a minimum cutoff value ($\sim 10^{-20}$) are listed. As shown, small differences appear in the fission product activity but the principal radioactivity is due to the actinide decay which is not significantly altered by the criticality events.

Note that the input compositions for the short and long SAS2H runs are based on the MCNP criticality compositions which have been adjusted up to 96% of 10.96 g/cm^3 (theoretical density of natural UO_2). The 25,000 year decay case to which the results are compared has compositions based on a UO_2 density of 10.206. Therefore, the activities for the isotopes for which a composition was specified in the inputs for the long and short cases must be multiplied by 0.97 (10.206/10.5216) to be compared on the same basis.

Table 7.5-1. ORIGEN-S Input Parameters

Case	Power (MW)	Burn Time (days)	Fuel Temperature (K)
30 second Reactivity Scenario (short.out)			
	9.0	0.0000023	326.5
	50.0	0.0000023	383.2
	25.0	0.000015	469.3
	2.0	0.000023	455.4
	0.5	0.000069	422.1
	0.3	0.00046	388.8
3600 second Reactivity Scenario (long.out)	*	*	*
	0.5	0.00046	327.6
	1.0	0.00023	374.8
	0.5	0.00035	380.4
	0.07	0.0093	376.5
	0.03	0.0035	376.5
	0.01	0.001	373.2

Table 7.5-2. Radionuclide Inventory after One Year Decay Period

Isotope	Initial Activity (Ci) (Ref. 5.13)	30 second Reactivity Scenario (short.out) Increase (Ci)	3600 sec Reactivity Scenario (long.out) Increase (Ci)
Actinides	-	-	-
th229	3.71e-02	5.63e-06	5.63e-06
th230	2.60e-01	1.17e-05	1.17e-05
pa231	9.01e-03	5.20e-07	5.20e-07
u233	6.20e-02	-	-
u234	1.23e+00	-	-
u235	2.33e-02	-	-
u236	2.25e-01	-	-
u238	1.45e-01	-	-
np237	6.10e-01	-	-
pu238	0.00e+00	5.65e-04	6.27e-04
pu239	9.74e+01	-	-
pu240	1.56e+01	-	-
pu241	5.72e-03	-	-
pu242	5.57e-01	-	-
am241	5.95e-03	-	-
am243	5.59e-01	-	-
cm244	0.00e+00	1.22e-05	1.34e-05
Fission Products	-	-	-
tc99	6.02e+00	1.34e-02*	1.34e-02*
sm151	0.00e+00	1.22e-04	1.36e-04

* These values may be significantly overestimated as a result of roundoff to 3 digits in SAS2H.

8. Conclusions

All conclusions in this section from RELAP5 calculations are TBV because the RELAP5/MOD3 code has not been qualified according QAP-SI-0 as indicated in Section 6.

The criticality consequence analyses performed for the fully degraded internal structure of a 21 PWR WP loaded with 15X15 B&W SNF demonstrated that, based upon conservative assumptions, the system remains in a safe configuration following scenarios where 14.18$ of positive reactivity is added to the WP system over time scales of 30 to 3600 seconds. The 14.18$ reactivity value represents the maximum possible reactivity attainable in the WP designs as discussed in Section 7.2.3. The probability of these criticality scenarios will be addressed in separate analyses (TBD). The results of the preliminary analysis in Section 7.4 show that the PWR SNF WP system returns to a subcritical configuration with the fuel rod temperatures and WP internal pressures remaining well below levels which could melt fuel or generate more than minor effects on adjacent WP systems (e.g. humidity levels will temporarily increase in the drift environment). The results discussed in Section 7.4 also show that consequences of a reactivity insertion event decrease in severity as the insertion rate decreases. However, the final state of the system, where sufficient water is lost from the WP to maintain a subcritical state, depends primarily on the energy generated rather than the rate, since steam formation is the primary energy dissipation mechanism in the WP.

Consequently, criticality events in a WP will be restricted to localized incidents and not involve additional WPs or affect the overall integrity of the repository. The principal impact on the environment external to the WP experiencing a criticality event is the return of water in vapor form to the drift environment increasing the ambient humidity. This should not significantly impact the WP environment in an adverse manner since the presence of water in the environment is assumed initially. Although not considered in the RELAP5 model, condensation of the water vapor will prevent any significant over pressurization of adjacent WP modules since the drift environment is assumed to be 326.2 K. The criticality analysis of the WP (Ref. 5.13) showed that the system is subcritical unless the SNF in the WP is submerged in water. This criticality consequence analysis shows that sufficient water inventory is expelled from the WP to preclude any immediate return to a critical configuration. Flooding the WP to levels where criticality is again possible would require several years even at the most conservative flow rates forecast for the drift region.

Burnup from the transient reactivity scenarios was less than 2.0e-03 Mwd/MTU per scenario. The ORIGEN-S analysis of the scenarios showed that the radionuclide inventories in a WP had a negligible increase after a one year decay period which will have no significant effects on the WP or repository.

9. Attachments

The hardcopy attachments are listed in Table 9-1 below. Electronic attachments are provided on Colorado Trakker® tapes (Ref. 5.22) and are listed in Table 9-2 below for REV 00 Cases.

Table 9-1. Attachments of Supporting Documentation for Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package

Attachment Number	Description	Pages
I	Base MCNP Case (R58H13F)	4
II	Base SAS2H Case (IN.WP)	3
III	Terminal Velocity Calculation	1
IV	RELAP5 Input File (R5WP2D.03C)	17

Table 9-2. Attachments of Computer Outputs for Criticality Consequence Analysis

File Name	File Size (Bytes)	File Date	File Time of Day
ANS79.P	95,956	9/2/97	4:42p
EDHTRK.P	610,033	9/2/97	4:42p
EDHTRKD.P	605,830	9/2/97	4:42p
EDHTRKN.P	605,649	9/2/97	4:42p
EDRST.P	699,984	9/2/97	4:42p
EDSTRIP.P	7,743	9/2/97	4:42p
MARPZD4.P	693,794	9/2/97	4:42p
PUMP2.P	1,362,805	9/2/97	4:42p
TYPPWR.P	1,677,913	9/2/97	4:42p
TYPPWRN.P	1,679,245	9/2/97	4:43p
INFH2O.O	547,580	8/29/97	1:31p
INFOX.O	234,872	8/29/97	1:31p
OUT.E49	2,694,284	7/22/97	7:23p
OUT.FE	2,730,022	7/22/97	7:23p

Table 9-2. Attachments of Computer Outputs for Criticality Consequence Analysis

File Name	File Size (Bytes)	File Date	File Time of Day
INFLUX2O	556,209	8/29/97	1:31p
OUT.WP	2,738,210	8/29/97	1:23p
INFH2OaO	544,337	8/29/97	1:31p
OUT.FIN	2,694,880	8/19/97	7:46p
H2OH13FO	579,852	8/29/97	1:28p
OUT.WPN	2,694,372	7/22/97	7:59p
OUT.WP	2,738,210	8/29/97	1:23p
OUT~1.122	2,740,086	8/29/97	1:23p
OUT~2.122	2,740,107	8/29/97	1:23p
OUT~2.212	2,740,122	8/29/97	1:24p
OUT~1.212	2,740,122	8/29/97	1:23p
OUT~1.320	2,740,236	8/29/97	1:23p
OUT~5.518	2,740,464	8/29/97	1:24p
OUT~4.518	2,740,443	8/29/97	1:24p
OUT~3.518	2,738,807	8/29/97	1:24p
OUT~2.518	2,738,828	8/29/97	1:24p
OUT~1.518	2,738,828	8/29/97	1:23p
OUT~9.100	2,739,362	8/29/97	1:25p
OUT~8.100	2,739,341	8/29/97	1:25p
OUT~7.100	2,737,726	8/29/97	1:25p
OUT~6.100	2,737,684	8/29/97	1:25p
OUT~5.100	2,740,464	8/29/97	1:24p
OUT~4.100	2,737,726	8/29/97	1:24p
OUT~3.100	2,736,174	8/29/97	1:24p
OUT~2.100	2,736,153	8/29/97	1:23p
OUT~1.100	2,736,216	8/29/97	1:23p
R5WP2D.SHT	18,830,566	9/2/97	4:24p
R5WP2D.LNG	18,839,913	9/2/97	4:23p
SHORT.OUT	22,131,092	9/2/97	3:52p
LONG.OUT	22,136,053	9/2/97	3:46p

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c        Assembly Sub-lattices - 1/2 Model
1      0       1  3 -13 -20   FILL=1 (0 -74 0) IMP:N=1
c      ASSEMBLY LATTICE
5      1  -3.4592  -61  60 -63  62  IMP:N=1 LAT=1 U=1
       FILL=0:3 0:7 0:0  1 3R  56 56 1  1  56 56 56 1
                         56 56 56 1  59 59 59 60  57 57 58  58
                         58 3R   58 3R       $ 1/2 model
c      BARRIER CELLS
c      Basket Material-Lid Gap
76     8  -1.0000    1 -20  13  -14      IMP:N=1 $ 1/2 model
c      Inner Barrier
77     5  -8.4425    1   3  20 -21 -14  IMP:N=1 $ 1/2 model
c      Inner Lid
78     5  -8.4425    1  14 -15 -21       IMP:N=1 $ 1/2 model
c       Gap between Inner and Outer Barrier Lids
79     8  -1.0000    1  15 -16 -21       IMP:N=1 $ 1/2 model
c       Gap between Inner and Outer Barriers
80     8  -1.0000   21 -22   1   3 -16  IMP:N=1 $ 1/2 model
c      Outer Barrier
81     7  -7.8320   22 -24   1   3 -16  IMP:N=1 $ 1/2 model
c      Outer Barrier Lid
82     7  -7.8320    1 -24  16 -17       IMP:N=1 $ 1/2 model
c      12" of Water around Container
83     8  -1.0000   24 -25   1   3 -17  IMP:N=1 $ 1/2 model
c      12" of Water above Container
84     8  -1.0000   17 -19.  1 -25       IMP:N=1 $ 1/2 model
c      OUTSIDE WORLD
85     0  -1:-3:19:25  IMP:N=0  $ 1/2 model
c      WET w/ Fe2O3 PIN LATTICE
86     1  -3.4592  -26 27 -28  29  IMP:N=1 LAT=1  U=56
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                           56 2 4R 4 2 2R 4 2 4R 56
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                           57 3 14R 57
                           57 3 6R 7 3 6R 57
                           57 3 14R 57
                           57 3 3 5 3 3 5 3 2R 5 3 3 5 3 3 57
                           57 3 14R 57  57 3 2R 5 3 6R 5 3 2R 57
                           57 3 4R 5 3 2R 5 3 4R 57
                           57 3 14R 57  57 3 14R 57  57 16R
c      WET W/ Fe2O3 FUEL ROD
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90     4  -6.5600    -30  10 -11 IMP:N=1 U=2
91     1  -3.4592    -30  11      IMP:N=1 U=2
92     8  -1.0000     30 -31 -11 IMP:N=1 U=2
93     1  -3.4592     30 -31  11 IMP:N=1 U=2
94     4  -6.5600     31 -32 -11 IMP:N=1 U=2
95     1  -3.4592     31 -32  11 IMP:N=1 U=2
96     1  -3.4592     32          IMP:N=1 U=2
c      Wet FUEL ROD
97     2    6.982783E-02 -30 -10      IMP:N=1 U=3
98     4  -6.5600    -30  10 -11 IMP:N=1 U=3
```

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99    8  -1.0000    -30  11       IMP:N=1 U=3
100   8  -1.0000     30 -31 -11 IMP:N=1 U=3
101   8  -1.0000     30 -31  11 IMP:N=1 U=3
102   4  -6.5600     31 -32 -11 IMP:N=1 U=3
103   8  -1.0000     31 -32  11 IMP:N=1 U=3
104   8  -1.0000     32         IMP:N=1 U=3
c     WET w/ Fe2O3 CONTROL ROD/GUIDE TUBE
105   8  -1.0000  -33        IMP:N=1 U=4  $ No DCRA Rod
c     105   9  -7.8300  -33        IMP:N=1 U=4  $ DCRA Rod
106   1  -3.4592   33  -34  IMP:N=1 U=4
107   1  -3.4592   34  -35  IMP:N=1 U=4  $ No DCRA Cladding
c     107   4  -6.5600   34  -35  IMP:N=1 U=4  $ DCRA Cladding
108   1  -3.4592   35  -36  IMP:N=1 U=4
109   4  -6.5600   36  -37  IMP:N=1 U=4
110   1  -3.4592   37       IMP:N=1 U=4
c     Wet CONTROL ROD/GUIDE TUBE
111   8  -1.0000  -33        IMP:N=1 U=5  $ No DCRA Rod
c     111   9  -7.8300  -33        IMP:N=1 U=5  $ DCRA Rod
112   8  -1.0000   33  -34  IMP:N=1 U=5
113   8  -1.0000   34  -35  IMP:N=1 U=5  $ No DCRA Cladding
c     113   4  -6.5600   34  -35  IMP:N=1 U=5  $ DCRA Cladding
114   8  -1.0000   35  -36  IMP:N=1 U=5
115   4  -6.5600   36  -37  IMP:N=1 U=5
116   8  -1.0000   37       IMP:N=1 U=5
c     WET w/ Fe2O3 INSTRUMENTATION TUBE
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118   4  -6.5600   38 -39      IMP:N=1 U=6
119   1  -3.4592   39          IMP:N=1 U=6
c     Wet INSTRUMENTATION TUBE
120   8  -1.0000  -38          IMP:N=1 U=7
121   4  -6.5600   38 -39      IMP:N=1 U=7
122   8  -1.0000   39          IMP:N=1 U=7
c     WET w/ Partial Fe2O3 PIN LATTICE
123   1  -3.4592  -26 27 -28  29  IMP:N=1 LAT=1  U=59
      FILL -8:8 -8:8 0:0  59 16R  59 2 14R 59  59 2 14R 59
                          59 2 4R 4 2 2R 4 2 4R 59
                          59 2 2R 4 2 6R 4 2 2R 59  59 2 14R 59
                          59 2 2 4 2 2 4 2 2R 4 2 2 4 2 2 59
                          59 2 14R 59
                          59 2 6R 6 2 6R 59
                          59 3 14R 59
                          59 3 3 5 3 3 5 3 2R 5 3 3 5 3 3 59
                          59 3 14R 59  59 3 2R 5 3 6R 5 3 2R 59
                          59 3 4R 5 3 2R 5 3 4R 59
                          59 3 14R 59  59 3 14R 59  59 16R
c     Half Water/Half Fe2O3 LATTICE
124   8  -1.0000  -58 56 -59  66  IMP:N=1    U=60
125   1  -3.4592  -58 56 -66  57  IMP:N=1    U=60

c     SURFACE SPECIFICATIONS
1*    PX    0.0
3*    PZ    0.00
10    PZ  180.0860    $ TOP ACTIVE FUEL
11    PZ  201.2360    $ TOP FUEL HARDWARE
c     12   PZ  226.75      $ TOP TUBE - (Shielding Model)
13    PZ  228.75      $ TOP OF BASKET MATERIAL
14    PZ  229.25      $ TOP RING/WATER GAP
15    PZ  231.75      $ TOP INNER LID
16    PZ  234.75      $ TOP LID GAP
17    PZ  245.75      $ TOP OUTER LID
c     18   PZ  268.25      $ TOP SKIRT - (Shielding Model)
19    PZ  298.75      $ TOP REFLECTOR REGION
20    CZ   71.095     $ ID OF INNER BARRIER
21    CZ   73.095     $ OD OF INNER BARRIER
22    CZ   73.10      $ ID OF OUTER BARRIER
c     23   CZ   76.45      $ ID OF SKIRT LIP - (Shielding Model)
24    CZ   83.10      $ OD OF OUTER BARRIER
25    CZ  113.60      $ OD OF REFLECTOR REGION
c     PIN LATTICE BOUNDS
26    PX  0.72136
```

```
27   PX -0.72136
28   PY  0.72136
29   PY -0.72136
C     FUEL ROD
30   CZ  0.468122
31   CZ  0.478790
32   CZ  0.546100
C     CONTROL ROD/GUIDE TUBE
33   CZ  0.45340  $ 0.49022
34   CZ  0.46990  $ 0.50292
35   CZ  0.54610  $ 0.56007
36   CZ  0.62230  $ 0.63246
37   CZ  0.67310
C     INSTRUMENTATION TUBE
38   CZ  0.56007
39   CZ  0.62611
C    ASSEMBLY LATTICE BOUNDS Actual
56   PX  -11.95   $ UCF Intact Outside Tube ID
57   PY  -11.95
58   PX   11.95
59   PY   11.95
C    FUEL CELL LATTICE BOUNDS
60   PX  -10.65    $ ACTUAL 12.30
61   PX   10.65
62   PY  -10.65
63   PY   10.65
C    plane for half water/half oxide lattice cell
66   PY   0.72136

MODE  N
C     VOL   88J
KCODE   4000 1.01 10 400
C      MATERIAL SPECIFICATIONS
C         WATER AT 300 K d=3.4592 g/cc w/ 58% Fe2O3
M1     1001.50C  2.8089-2    8016.50C  4.8430-2  26000.55C 2.2924-2
MT1    LWTR.01T
C      e49b34.sum    25000  years decay
M2     8016.50C    .046947
      42095.50C   4.794679E-05
      44101.50C   4.354501E-05
      43099.50C   4.284296E-05
      45103.50C   2.608717E-05
      47109.50C   3.714096E-06
      60143.50C   3.74851E-05
      60145.50C   2.799527E-05
      62147.50C   1.138963E-05
      62149.50C   1.455085E-07
      62150.50C   1.043884E-05
      62152.50C   4.59594E-06
      63151.55C   8.136066E-07
      63153.55C   3.93607E-06
      64155.50C   1.686186E-07
      92233.50C   3.326725E-07
      92234.50C   1.018437E-05
      92235.50C   5.531404E-04
      92236.50C   1.774777E-04
      92238.50C   2.174501E-02
      93237.55C   4.392789E-05
      94239.55C   7.906197E-05
      94240.50C   3.440139E-06
      94241.50C   2.761636E-12
      94242.50C   7.012276E-06
      95241.50C   8.639479E-11
      95243.50C   1.386765E-07
C          Air d=0.001225 g/cc
M3     7014.50C  -0.80   8016.50C  -0.20
C          ZIRCALOY-4 d=6.56 g/cc
M4     8016.50C -0.0012  24000.50C -0.0010  26000.55C -0.0020
      40000.50C -0.9818  50000.35C -0.0140
C         ALLOY 625 d=8.4425 g/cc
```

```
M5    6000.50c -0.1000  13027.50c -0.4000  14000.50c -0.5000
     16032.50c -0.0150  22000.50c -0.4000  24000.50c -21.500
     25055.50c -0.5000  26000.55c -5.0000  28000.50c -58.000
     41093.50c -1.8200  42000.50c -9.0000  73181.50c -1.8200
     15031.50c -0.0150  27059.50c -0.9300
c       A516 CARBON STEEL d=7.832 g/cc
M7    6000.50c -0.00220  14000.50c -0.002750  15031.50c -0.00035
     16032.50c -0.00035  25055.50c -0.0090
     26000.55c -0.98535
c        WATER AT 300 K d=1.0000 g/cc
M8    1001.50c  2.    8016.50c  1.
MT8   LWTR.01T
c    TALLIES
PRINT
```

```
1         primary module access and input record ( scale driver - 95/03/29 - 09:06:37 )
-   module sas2h    will be called
     SAS2H: 4.9wt%, 34GWD/MTU, 25000yr, Waste-Pack Buckling Model
     '
     ' Iron (Fe2O3) rust in the water around the fuel pins  58 vol. %
     '
     ' Blending from MCNP = 0.751311 water + .248689 rusty water
     '
     ' B & W  15x15 fuel assembly, high temp burnup
     '
     44group     latticecell
     '
     '  MCNP input mixtures for fuel-pin-cell, assembly-cell, and waste package
     '
      o        1 0 4.694700-02 300.00 end
      u-233    1 0 3.326725-07 300.00 end
      u-234    1 0 1.018437-05 300.00 end
      u-235    1 0 5.531404-04 300.00 end
      u-236    1 0 1.774777-04 300.00 end
      u-238    1 0 2.174501-02 300.00 end
     np-237    1 0 4.392789-05 300.00 end
     pu-239    1 0 7.906197-05 300.00 end
     pu-240    1 0 3.440139-06 300.00 end
     pu-241    1 0 2.761636-12 300.00 end
     pu-242    1 0 7.012276-06 300.00 end
     am-241    1 0 8.639479-11 300.00 end
     am-243    1 0 1.386765-07 300.00 end
     mo-95     1 0 4.794679-05 300.00 end
     tc-99     1 0 4.284296-05 300.00 end
     ru-101    1 0 4.354501-05 300.00 end
     rh-103    1 0 2.608717-05 300.00 end
     ag-109    1 0 3.714096-06 300.00 end
     nd-143    1 0 3.748510-05 300.00 end
     nd-145    1 0 2.799527-05 300.00 end
     sm-147    1 0 1.138963-05 300.00 end
     sm-149    1 0 1.455085-07 300.00 end
     sm-150    1 0 1.043884-05 300.00 end
     sm-152    1 0 4.595940-06 300.00 end
     eu-151    1 0 8.136066-07 300.00 end
     eu-153    1 0 3.936070-06 300.00 end
     gd-155    1 0 1.686186-07 300.00 end
     kr-83     1 0 1-20        300.00 end
     kr-85     1 0 1-20        300.00 end
      y-89     1 0 1-20        300.00 end
     sr-90     1 0 1-20        300.00 end
     zr-93     1 0 1-20        300.00 end
     zr-94     1 0 1-20        300.00 end
     zr-95     1 0 1-20        300.00 end
     nb-94     1 0 1-20        300.00 end
     ru-106    1 0 1-20        300.00 end
     rh-105    1 0 1-20        300.00 end
     pd-105    1 0 1-20        300.00 end
     pd-108    1 0 1-20        300.00 end
     sb-124    1 0 1-20        300.00 end
     xe-131    1 0 1-20        300.00 end
     xe-132    1 0 1-20        300.00 end
     xe-135    1 0 1-20        300.00 end
     xe-136    1 0 1-20        300.00 end
     cs-134    1 0 1-20        300.00 end
     cs-135    1 0 1-20        300.00 end
     cs-137    1 0 1-20        300.00 end
     ba-136    1 0 1-20        300.00 end
     la-139    1 0 1-20        300.00 end
     pr-141    1 0 1-20        300.00 end
     pr-143    1 0 1-20        300.00 end
     nd-147    1 0 1-20        300.00 end
     ce-144    1 0 1-20        300.00 end
     pm-147    1 0 1-20        300.00 end
     pm-148    1 0 1-20        300.00 end
     eu-154    1 0 1-20        300.00 end
```

```
eu-155      1 0 1-20        300.00 end
'-----------------------------------------
'
'  Homogenized zirc-4 clad and water gap
'
' water - o  2 0 4.27077-03  300.00 end
' zirc4 - o  2 0 2.602667-04  300.00 end
'
 h          2 0 8.54154-03  300.00 end
 o          2 0 4.52929-03  300.00 end
cr          2 0 6.62716-05  300.00 end
fe          2 0 1.23407-04  300.00 end
zr          2 0 3.70866-02  300.00 end
arbm-sn  5.7221016 1  0  0  0  50000  100.0
            2 0.013999775   300.00 end
'
'  sn          2 0 4.06386-04  300.00 end
'------------------------------------------
'
'  Moderator around fuel pins and guide tubes
'
'     Assembly with iron
'
'   h           3  0  2.8089-02  300.00  end
'   o           3  0  4.8430-02  300.00  end
'   fe          3  0  2.2924-02  300.00  end
'
'     MCNP K-inf blended iron assembly
'
'  Contains (1-x) 58 vol% Fe2O3 water and x pure water
'  with x=0.734106 from blending equation
'
h           3  0  5.72276-02  300.00  end
o           3  0  3.71651-02  300.00  end
fe          3  0  5.70095-03  300.00  end
'
' 0 ppm boron
'------------------------------------------
'
'  Zirc-4
'
 o          4 0 2.98378-04  300.00 end
cr          4 0 7.59759-05  300.00 end
fe          4 0 1.41478-04  300.00 end
zr          4 0-4.25173-02  300.00 end
arbm-sn     6.5600  1  0  0  0  50000  100.0
            4 0.013999775   300.00 end
'
'  sn          4 0 4.65894-04  300.00 end
'------------------------------------------
'
'  Water region inside of the guide tubes
'
 o          5 0 3.34363-02  300.00 end
 h          5 0 6.68727-02  300.00 end
'
' 0 ppm boron
'------------------------------------------
'
end comp
'-------------------------------------------
'
'  fuel - pin - cell geometry:
'
'  Water - Zirc-4  homogenized for water in gap
'
'  MCNP assembly pitch = 10.65 + 10.65 = 21.30
'
'  21.30/15(pin-cells) = 1.42 pin-cell pitch
'
```

```
squarepitch  1.42000  0.936244  1   3  1.0922  2 0.936245 0 end
'
'  Standard pin-cell pitch = 1.44272
'
'  squarepitch  1.44272  0.936244  1   3  1.0922  2 0.936245  0 end
'
'  Standard gap with gas and standard clad
'
'  squarepitch  1.44272  0.936244  1   3  1.0922  2 0.95758  0 end
'-------------------------------------------------------------
'
'  Pin-cell buckling
'
more data   bkl=0.875108   dy=50.7843927
                           dz=360.172   end
'-------------------------------------------------------------
'
'  assembly and cycle parameters
'
'  guide tube region is different
'
npin/assm=208 fuelngth=360.172 ncycles=1 nlib/cyc=1
printlevel=7 inplevel=3 numztotal=6   end
5  0.453400       2 0.453401     3 0.622300
4  0.6736472448  3 0.8011492  500 2.9146084
'
'  Assembly buckling
'
bon   end
nit   end
xsd
SAS2H: 4.9wt%, 34GWD/MTU, 25000yr, Inf-Assem, No iron
x5=  1.0-4  1.0-4  1.0  0.0  0.0  0.875108
     50.7843927   360.172   0.0   1.0   1.0-3   0.75
   end
power=7.25 burn=1.0-20 down=1.0-20
   end
```

Size of small spherical particle required to fall 1 meter in 1 minute in water

Density of water at 120°F $\rho f := 988.8 \cdot \frac{kg}{m^3}$

Viscosity of water at 120°F $\mu := 5.62 \cdot 10^{-4} \cdot \frac{kg}{m \cdot sec}$

Density of Fe_2O_3 $\rho s := 5240 \cdot \frac{kg}{m^3}$

Terminal velocity as a function of diameter for small sphere's using Stoke's law (Re<=1)

$$Fd = m \cdot g - Fb$$

$$3 \cdot \pi \cdot \mu \cdot v \cdot D = \rho s \cdot \frac{4}{3} \cdot \pi \cdot \left(\frac{D}{2}\right)^3 \cdot g - \rho f \cdot g \cdot \frac{4}{3} \cdot \pi \cdot \left(\frac{D}{2}\right)^3$$

From Fox, R.W., McDonald, A.T., *Introduction to Fluid Mechanics*, 3rd Edition, John Wiley & Sons, 1985. p. 461

Solving for v yields

$$v(D) := \frac{1}{18} \cdot D^2 \cdot g \cdot \frac{(\rho s - \rho f)}{\mu} \qquad Re(D) := \frac{v(D) \cdot D \cdot \rho f}{\mu}$$

$$\frac{1 \cdot m}{v(.063 \cdot mm)} = 1.019 \cdot min \qquad Re(.063 \cdot mm) = 1.813$$

However, a 0.063 mm diameter sphere at terminal velocity slightly outside of the range of Stoke's law (drag will be slightly higher and particle will fall slightly slower than indicated).

Note that typical crud particle sizes are in the range of 0.1 to 10 microns per *Characteristics of Repository Wastes*, DOE/RW-0184 vol. 1, p. 2.6-6

$$\frac{1 \cdot m}{v(.010 \cdot mm)} = 40.441 \cdot min \qquad Re(.010 \cdot mm) = 7.251 \cdot 10^{-3}$$

```
= relap5/mod2  waste package (b & w  15 by 15  21 fa)
*-------------------------------------------------------
*
*
* ( this is /kappa/jrw/lv/relap/r5wp2d.in
*
* the input is a transition from tmi-1 power uprate lbloca
* to waste package (near field) criticality excursion consequences
* with 4.90 wt.% u-235 , 34,000 mwd/mtu burnup and  25,000 year decay
*
*  b & w   heavy isotope actinide contribution )
*
*
*----------------- base model description ---------------------
*
*     fti  document 32-1244460-00
*     by: ks pacheco
*
* the base deck for the tmi-1 model was taken from 2772base1.in
* contained in 32-1234886-00.  /kappa/ksp/tmipug/base/tmibase.in
*
*  21fa, 208-pins/fa, 16-guide tubes/fa, 1-instrument tube/fa
*       one-fifth length model - Power into Assembly is 5 Watts
*       for Full Length assemblies
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*   deck obtained from tuck w. (lynchburg) 07/31/97
*   07/31/97 modifiation - jam (lv)
*     delete most of the $$$ cards from deck
*     convert to mod3 format
*     junction control flag - change from 3xxxx to 0xxxx
*                             no horizontal stratification
*     heat structure cards ...8xx and ...9xx - CHF Changes
*                             MOD2 - 5 wds, MOD3 - 9 wds
*     add Time-Dependent Vol and Time-Dependent Junction to input
*     InFlow Conditions
*     Add Minor Edits.
*   Case 001 Using small time steps to make sure case runs ok
*   Case 002 Match Tuck Worsham's data (Fax memo - 08/04/97
*   Case 003 Use short time steps through power peak
*   Case 004 Add Doppler Weight Factors to activate Fuel Temp Feedback
*            B&W Relap5 has been modified to compute Doppler Weights
*            internally if none supplied.
*            Add Avg-Fuel Temp To Minor Edits
*            Add variable Void Weight Factors porportional to Control
*            Volume relative size
*   Case 005 Rerun Case C003 with Doppler Weights
*   Case 006 Add Reactivity Control Blocks to Edit Components to Case 004
*   Case 101 Switch to Implicit Numerics
*            Shorten time steps to avoid zero mass in control volumes
*            around 5.8 sec, turn on the choking model for junctions in
*            non-fuelled volumes.
*   Case 111 Similar to Case 101: reduce reactivity ramp by 50%;
*                                 increase refill rate by 50%;
*                                 change minor edits;
*                                 adjust minor edit frequencirs to 0.05 sec
*   Case 102 Try Case 101 with automatic T.S. control to cut down on
*            number of minor edit points
*            Redo case 102 to include fission and decay heat power,
*            add reactivity table vs mixture level
*   Case 102a review short T.S. case again
*        102b check for T.S. convergence (more stable than case 102a
*        102c check further for T.S. convergence
*        103a actually add mixture level calc - limit to top fuelled row
*             delete void reactivity table
*        103b 08/20/97 - revise case c103a and rerun
*             revise MCNP void reactivity table to use delta rho
*             and include all restart time steps, remove mixture level flgs
*        103c reinstate the mixture level model in vols 21001, 05001, 10001,
```

```
*            20001
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
100   new   transnt
101   run
* 101   inp-chk
102   british   british
105   150.  160.
*
*  noncondensible gas
110   "nitrogen"
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
* time step control
*      end      min      max     time  minor  major  restart
*      time     delt     time    step  edit   edit    point
*     (sec)    (sec)     step    optn  freq   freq    freq
*
*  Case 103a time steps
  201   0.1       1.0-8    1.0-4    07    100     1000     1000
  202   1.5       1.0-8    1.0-3    07    100     100      100
  203   4.0       1.0-8    5.0-5    07    1000    10000    10000
  204  20.0       1.0-8    5.0-5    07    10000   20000    20000
*
*  Case c103a.rst01 time steps
  205  30.0       1.0-8    5.0-5    07    10000   20000    20000
*
*  Case c103a.rst02 time steps
  206  40.0       1.0-8    1.0-4    07    1000    10000    10000
*
*  Case c103a.rst03 time steps
  207  80.0       1.0-8    1.0-4    07    1000    10000    10000
*
*  Case c103a.rst04 time steps
  208  360.0      1.0-8    1.0-3    07    1000    10000    10000
*
*  Case c103a.rst05 time steps
  209  1800.0     1.0-8    1.0-2    07    200     1000     1000
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*        general tables
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*  reactivity insertion
*
20200100   reac-t
20200101   0.0  0.0  30.0  14.18  1.0+10  14.18
*  20200101  0.0  0.0  30.0   7.09  1.0+10   7.09
*
*
*   average fuel temperature vs. reactivity
*
20200200   reac-t
*
*           fuel temp. K       reactivity, dollars     density lb/ft**3
*
20200201    273.16                +0.1719079
20200202    300.01                +0.1719079
20200203    323.16                 0.0
20200204    373.16                -0.3488604
20200205    433.16                -0.7295469
20200206    543.16                -1.3918144
```

```
20200207    813.16              -2.8696928
*
*  moderator density reactivity feedback
*
20200500  reac-t
*
*           density  kg/m**3    reactivity, dollars      fuel temp. f
*
20200501       701.470834          -22.8341124           *  1004
20200502       726.523364          -20.0375898           *  1004
20200503       751.575895          -17.4413905           *  1004
20200504       776.628425          -15.0255317           *  1004
20200505       801.680954          -12.7766726           *  1004
20200506       826.733484          -10.6782739           *  1004
20200507       851.786013          -08.7187079           *  1004
20200508       876.838543          -06.8856192           *  1004
20200509       901.891072          -05.1688975           *   518
20200510       921.933098          -03.9010990           *   518
20200511       941.975121          -02.6972060           *   518
20200512       960.112521          -01.6592902           *   518
20200513       975.044461          -00.8234196           *   212
20200514       990.260409           00.00                *   122
20200515      1002.101192          +00.6225345           *   122
20200516      1043.387881          +00.6225345           *    80.33
*
*
*     MCNP mixture level reactivity table (beta = 0.005)
*     Row 5 of fueled assemblies
*     Ref: W.D. reactor physics book + J. Massari Doc
*
*        Mixture level (ft)   Reactivity ($)
*
20201000  reac-t
*
20201001    0.0                 -30.902
20201002    0.04399             -30.902
20201003    0.18933             -16.660
20201004    0.23657             -14.959
20201005    0.28415             -12.911
20201006    0.71                  0.0
*
*...**...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*     minor edits
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*     pressure
*
301   "p"          150010000          * Vol Pressure
302   "p"          060010000          * Vol Pressure
303   "p"          070010000          * Vol Pressure
304   "p"          080010000          * Vol Pressure
305   "p"          090010000          * Vol Pressure
306   "p"          100010000          * Vol Pressure
307   "p"          250010000          * Vol Pressure
*
*     enthalpy
*
315   "hvmix"      090010000          * Vol Enthalpy
317   "hvmix"      250010000          * Vol Enthalpy
*
*
*     volume vapor generation/unit vol
*
321   "vapgen"     150010000          * Vol vapor gen rate
322   "vapgen"     060010000          * Vol vapor gen rate
```

```
323   "vapgen"     070010000           * Vol vapor gen rate
324   "vapgen"     080010000           * Vol vapor gen rate
325   "vapgen"     090010000           * Vol vapor gen rate
326   "vapgen"     100010000           * Vol vapor gen rate
*
*
*     Volume Mass
*
329   "tmass"      0                   * Fluid Inventory
330   "tmassv"     260010000           * Vol Mass
331   "tmassv"     150010000           * Vol Mass
332   "tmassv"     060010000           * Vol Mass
333   "tmassv"     070010000           * Vol Mass
334   "tmassv"     080010000           * Vol Mass
335   "tmassv"     090010000           * Vol Mass
336   "tmassv"     100010000           * Vol Mass
337   "tmassv"     220010000           * Vol Mass
338   "tmassv"     230010000           * Vol Mass
339   "tmassv"     240010000           * Vol Mass
340   "tmassv"     250010000           * Vol Mass
*
*     mass flow
*
341   "mflowj"     080010000           * Jun Flow
342   "mflowj"     080020000           * Jun Flow
343   "mflowj"     070010000           * Jun Flow
344   "mflowj"     070020000           * Jun Flow
345   "mflowj"     240010000           * Jun Flow
346   "mflowj"     230010000           * Jun Flow
347   "mflowj"     230020000           * Jun Flow
348   "mflowj"     250010000           * Jun Flow
349   "mflowj"     220010000           * Jun Flow
351   "mflowj"     220020000           * Jun Flow
352   "mflowj"     020010000           * Jun Flow
353   "mflowj"     020020000           * Jun Flow
*
*
*     average fuel temperature
*
361   "htvat"      3301008             * Avg Metal Temp
*
*   control variables
*
*   kinetics parameters
*
389   "rkfipow"    0            * "fission" "power"
390   "rkgapow"    0            * "decay heat" "power"
391.  "rkreac"     0            * "total" "reactivi"
392   "cntrlvar"   081          * "MCNP void Reactivity
393   "cntrlvar"   014          * "doppler reac
394   "cntrlvar"   056          * "void reactivity
395   "cntrlvar"   060          * "ramp reactivity
396   "cntrlvar"   065          * "total calc reac
397   "cntrlvar"   070          * "assembly energy
398   "cntrlvar"   075          * "Sum (Heat slab vapor gen rate)
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*   waste package
*
*
* modeling begins with central planar region
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
* bottom of cylinder
*
```

```
1400000   "bot-watr"  "branch"
*        no. of jun  jun cntrl
1400001   2           0
*        aflow(norm)  len       vol      angle(az) inclin  elev change
1400101    0.00       .2293299  .2075716  0.0   -90.0    -.2293299
*        wall rough  hyd dia   cntrl
1400102   4.1667-5    1.0+10    00
*        vol cntrl   press     temp
1400200   003         14.696    122.00
*        from vol    to vol    ajun '   k(f)   k(r)    jun cntrl
1401101   140000000 010010000  .2038375  72.0   72.0    01000
*        liq vel     vap vel   interface vel
1401201   0.0         0.0       0.0
*        from vol    to jun    ajun     k(f)   k(r)    jun cntrl
1402101   140000000 150000000  .5419829  0.0    0.0     01003
*        liq vel     vap vel   interface vel
1402201   0.0         0.0       0.0
*
* bottom side of cylinder
*
1500000   "bos-watr"  "branch"
1500001   1           0
1500101    0.00       .2293299  .2276341   0.0   -90.0    -.2293299
*                         cntrl (therm-off, mix-off, pack-on,
*                                vert strat-on,  interphase fric-pipe,
*                                wall-xdir, non-eq)
1500102   4.1667-5    1.0+10    0000000
1500200   003         14.696    122.00
1501101   150000000 060010000  .4076750  72.0   72.0    01000
1501201   0.0         0.0       0.0
*
* side of cylinder fuel level 1
*
1600000   "s1-watr"   "branch"
1600001   1           0
1600101    0.00       .71       .7989270   0.0   -90.0    -.71
1600102   4.1667-5    1.0+10    00
1600200   003         14.696    122.00
1601101   160000000 110010000  .4076750  72.0   72.0    01000
1601201   0.0         0.0       0.0
*
* side of cylinder fuel level 2
*
1700000   "s2-watr"   "branch"
1700001   1           0
1700101    0.00       .71          .5438773   0.0   -90.0   -.71
1700102   4.1667-5    1.0602200    00
1700200   003         14.696       122.00
1701101   170000000 180000000      1.1080708  0.0    0.0    01000
1701201   0.0         0.0          0.0
*
* side of cylinder fuel level 3
*
1800000   "s3-watr"   "branch"
1800001   1           0
1800101    0.00       .71          .8980821   0.0    90.0    .71
1800102   4.1667-5    2.1134025    00
1800200   003         14.696       122.00
1801101   180010000 190000000      1.3339422  0.0    0.0    01000
1801201   0.0         0.0          0.0
*
* side of cylinder fuel level 4
*
1900000   "s4-watr"   "branch"
1900001   1           0
1900101    0.00       .71          .8738187   0.0    90.0    .71
1900102   4.1667-5    2.0432176    00
1900200   003         14.696       122.00
1901101   190010000 210000000      1.0380308  0.0    0.0    01000
1901201   0.0         0.0          0.0
```

```
*
* side of cylinder - fuel level 5
*
2100000   "s5-watr"   "branch"
2100001   1           0
2100101    0.00       .71           .7822260   0.0    90.0    .71
2100102   4.1667-5    1.6252320     0100000
2100200   003         14.696        122.00
*  2101101   210010000 240000000      1.0380308  0.0    0.0    01000
   2101101   210010000 240000000      1.0380308  0.0    0.0    00000
2101201   0.0         0.0           0.0
*
* 21 fuel assemblies
*
* half symmetry gives 13 planar fuel areas
*
* modeling begins with central fuel length,
*
* center fuel column,  at the cylinder bottom
*
* hydraulic dia. based on flow around fuel-clad, guide tubes, inst. tube
*
*...**...**...**...**...**...**...**...**...**...**...**...*
*
* column  1
*
0100000   "fuel-010"  "branch"
0100001   2           0
0100101    0.00       .71           .3516846   0.0    -90.0   -.71
0100102   3.133-6     .04168514     00
0100200   003         14.696        122.00
0101101   010000000 020010000       .2038375   72.0   72.0    01000
0101201   0.0         0.0           0.0
0102101   010000000 060000000       .4076750   72.0   72.0    01003
0102201   0.0         0.0           0.0
*
0200000   "fuel-020"  "branch"
0200001   2           0
0200101    0.00       .71           .3516846   0.0    -90.0   -.71
0200102   3.133-6     .04168514     00
0200200   003         14.696        122.00
0201101   020000000 030000000       .2038375   72.0   72.0    01000
0201201   0.0         0.0           0.0
0202101   020000000 070000000       .4076750   72.0   72.0    01003
0202201   0.0         0.0           0.0
*
0300000   "fuel-030"  "branch"
0300001   2           0
0300101    0.00       .71           .3516846   0.0    90.0    .71
0300102   3.133-6     .04168514     00
0300200   003         14.696        122.00
0301101   030010000 040000000       .2038375   72.0   72.0    01000
0301201   0.0         0.0           0.0
0302101   030000000 080000000       .4076750   72.0   72.0    01003
0302201   0.0         0.0           0.0
*
0400000   "fuel-040"  "branch"
0400001   2           0
0400101    0.00       .71           .3516846   0.0    90.0    .71
0400102   3.133-6     .04168514     00
0400200   003         14.696        122.00
0401101   040010000 050000000       .2038375   72.0   72.0    01000
0401201   0.0         0.0           0.0
0402101   040000000 090000000       .4076750   72.0   72.0    01003
0402201   0.0         0.0           0.0
*
0500000   "fuel-050"  "branch"
0500001   2           0
0500101    0.00       .71           .3516846   0.0    90.0    .71
*                           cntrl (therm-off, mix-on, pack-on,
```

```
*                                       vert strat-on,  interphase fric-pipe,
*                                       wall-xdir, non-eq)
0500102    3.133-6    .04168514          0100000
0500200    003         14.696            122.00
0501101    050010000 220000000           .2038375  72.0    72.0    01000
0501201    0.0        0.0                0.0
0502101    050000000 100000000           .4076750  72.0    72.0    01003
0502201    0.0        0.0                0.0
*
*...**...**...**...**...**...**...**...**...**...**...**...*
*
* column  2
*
0600000    "fuel-060"  "branch"
0600001    2          0
0600101     0.00      .71               .7033692   0.0    -90.0    -.71
0600102    3.133-6    .04168514          00
0600200    003         14.696            122.00
0601101    060000000 070010000           .4076750  72.0    72.0    01000
0601201    0.0        0.0                0.0
0602101    060000000 160000000           .4076750  72.0    72.0    01003
0602201    0.0        0.0                0.0
*
0700000    "fuel-070"  "branch"
0700001    2          0
0700101     0.00      .71               .7033692   0.0    -90.0    -.71
0700102    3.133-6    .04168514          00
0700200    003         14.696            122.00
0701101    070000000 080000000           .4076750  72.0    72.0    01000
0701201    0.0        0.0                0.0
0702101    070000000 110000000           .4076750  72.0    72.0    01003
0702201    0.0        0.0                0.0
*
0800000    "fuel-080"  "branch"
0800001    2          0
0800101     0.00      .71               .7033692   0.0     90.0     .71
0800102    3.133-6    .04168514          00
0800200    003         14.696            122.00
0801101    080010000 090000000           .4076750  72.0    72.0    01000
0801201    0.0        0.0                0.0
0802101    080000000 120000000           .4076750  72.0    72.0    01003
0802201    0.0        0.0                0.0
*
0900000    "fuel-090"  "branch"
0900001    2          0
0900101     0.00      .71               .7033692   0.0     90.0     .71
0900102    3.133-6    .04168514          00
0900200    003         14.696            122.00
0901101    090010000 100000000           .4076750  72.0    72.0    01000
0901201    0.0        0.0                0.0
0902101    090000000 130000000           .4076750  72.0    72.0    01003
0902201    0.0        0.0                0.0
*
1000000    "fuel-100"  "branch"
1000001    2          0
1000101    0.00       .71               .7033692   0.0     90.0     .71
1000102    3.133-6    .04168514          0100000
1000200    003         14.696            122.00
1001101    100010000 230000000           .4076750  72.0    72.0    01000
1001201    0.0        0.0                0.0
1002101    100000000 200000000           .4076750  72.0    72.0    01003
1002201    0.0        0.0                0.0
*
*...**...**...**...**...**...**...**...**...**...**...**...*
*
* column  3
*
1100000    "fuel-110"  "branch"
1100001    2          0
1100101     0.00      .71               .7033692   0.0    -90.0    -.71
```

```
1100102    3.133-6    .04168514       00
1100200    003         14.696         122.00
1101101    110000000 120000000       .4076750  72.0    72.0    01000
1101201    0.0        0.0             0.0
1102101    110000000 170000000       .4076750  72.0    72.0    01003
1102201    0.0        0.0             0.0
*
1200000    "fuel-120"  "branch"
1200001    2          0
1200101     0.00      .71            .7033692   0.0    90,0    .71
1200102    3.133-6    .04168514       00
1200200    003         14.696         122.00
1201101    120010000 130000000       .4076750  72.0    72.0    01000
1201201    0.0        0.0             0.0
1202101    120000000 180000000       .4076750  72.0    72.0    01003
1202201    0.0        0.0             0.0
*
1300000    "fuel-130"  "branch"
1300001    2          0
1300101     0.00      .71            .7033692   0.0    90.0    .71
1300102    3.133-6    .04168514       00
1300200    003         14.696         122.00
1301101    130010000 200000000       .4076750  72.0    72.0    01000
1301201    0.0        0.0             0.0
1302101    130000000 190000000       .4076750  72.0    72.0    01003
1302201    0.0        0.0             0.0
*
* water - column  3
*
*...**...**...**...**...**...**...**...**...**...**...**...*
*
2000000    "ts-watr"   "branch"
2000001    2          0
2000101     0.00      .71            .8633786   0.0    90.0    .71
2000102    4.1667-5    1.0+10        0100000
2000200    003         14.696        122.00
*  2001101    200010000 240000000    .7540857    0.0     0.0    01000
   2001101    200010000 240000000    .7540857    0.0     0.0    00000
2001201    0.0        0.0            0.0
*  2002101    200000000 210000000    1.7958536   0.0     0.0    01003
   2002101    200000000 210000000    1.7958536   0.0     0.0    00003
2002201    0.0        0.0            0.0
*
* top of cylinder
*
*
* three water columns
*
*
2200000    "c1-watr"   "branch"
2200001    2          0
2200101     0.00      .3484394       .8633786   0.0    90.0    .3484394
2200102    4.1667-5    1.0+10        00
2200200    003         14.696        122.00
*  2201101    220010000 250000000    .2038375    0.0     0.0    01000
   2201101    220010000 250000000    .2038375    0.0     0.0    00000
2201201    0.0        0.0            0.0
*  2202101    220000000 230000000    .8234784    0.0     0.0    01003
   2202101    220000000 230000000    .8234784    0.0     0.0    00003
2202201    0.0        0.0            0.0
*
2300000    "c2-watr"   "branch"
2300001    2          0
2300101     0.00      .3484394       .8633786   0.0    90.0    .3484394
2300102    4.1667-5    1.0+10        00
2300200    003         14.696        122.00
*  2301101    230010000 250000000    .4076750    0.0     0.0    01000
   2301101    230010000 250000000    .4076750    0.0     0.0    00000
2301201    0.0        0.0            0.0
*  2302101    230000000 240000000    .8234784    0.0     0.0    01003
```

```
  2302101   230000000 240000000    .8234784   0.0    0.0   00003
2302201   0.0       0.0          0.0
*
2400000   "c3-watr"   "branch"
2400001   1          0
2400101    0.00     .3484394    .4918077   0.0    90.0    .3484394
2400102   4.1667-5  1.6908844   00
2400200   003         14.696     122.00
* 2401101   240010000 250000000    .9732914   0.0    0.0   01000
  2401101   240010000 250000000    .9732914   0.0    0.0   00000
2401201   0.0       0.0          0.0
*
* top plenum
*
2500000   "tp-watr"   "branch"
2500001   1          0
2500101    0.00     .5249344    1.2517607   0.0    90.0    .5249344
2500102   4.1667-5  1.3256083   00
2500200   003         14.696     122.00
* 2501101    250010000 260000000    .1076391   0.0    0.0   01000
  2501101    250010000 260000000    .1076391   0.0    0.0   00000
2501201   0.0       0.0          0.0
*
* outside of waste package,
*
* drift at 14.696 psia
*
2600000   "drift"      "tmdpvol"
2600101   238.46  1.0  0.0  0.0  90.0  1.0  1.0e-6  0.0  0010
2600200   003
2600201   0.0          14.696      220.00
*
* drift inflow volume
*
3600000    "gnd-watr"  "tmdpvol"
3600101    238.46  1.0  0.0  0.0  90.0  1.0  1.0e-6 0.0  0010
3600200    103
3600201    0.0     14.696      122.0
*
* Time-Dependent Junction for inflow
*
3700000    "in-flow"  "tmdpjun"
3700101    360010000    250000000     1.0
3700200    1             0
3700201    0.0          -1.381e-3     0.0        0.0
*  3700201    0.0           2.762e-3     0.0        0.0
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
***
***
***                  heat structure input
***
***
***
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*     waste package wall
*
13121000   9   20   1   1   0.0
13121100   0   2
13121101   10.0      19
13121201   6   19
13121301   0.0 19
13121400   0
13121401   122. 20
13121501   140010000    10000000    1      1    1.73  9
13121601   0               0         0      1    1.73  9
13121701   0   0.0   0.0   0.0   9
* 13121801   0   0.0   0.0   0.0   9
* 13121901   0   0.0   0.0   0.0   9
```

```
  13121801   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  9
  13121901   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  9
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*    fuel assembly clad, guide tubes, & inst-tube in fuel region
*
13481000   13    3    2    1    0.01570833
13481100   0     1
13481101   2     0.01791112
13481201   5     2
13481301   0.0   2
13481400   0
13481401   122.  3
*                                  225   *2.3633333 = 531.75  ft
*                                  112.5*2.3633333 = 265.875 ft
13481501   010010000  10000000      1     1     265.8750   5
13481502   060010000  10000000      1     1     531.7500   13
13481601   010010000  10000000      1     1     265.8750   5
13481602   060010000  10000000      1     1     531.7500   13
13481701   0   0.0   0.0   0.0   13
* 13481801   0   0.0   0.0   0.0   13
* 13481901   0   0.0   0.0   0.0   13
  13481801   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  13
  13481901   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  13
*  13481801   0   0.05360754   0.05360754   0.0   13
*  13481901   0   0.04701465   0.04701465   0.0   13
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*    fuel assembly pellets - water in gap region
*
13301000   13    10   2    1    0.0
13301100   0     1
*  13301101   6    0.01535833   1    0.01570833  2   0.01791667
13301101   9    0.01535833
*  13301201   3    6    -4    7    -5    9
13301201   3    9
*  13301301   1.0   6    0.0   7    0.0   9
13301301   1.0   9
13301400   -1
13301401   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301402   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301403   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301404   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301405   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301406   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301407   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301408   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301409   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301410   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301411   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301412   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301413   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301501   0   0    0     0     0.0   13
*
* length of fuel pin = #pins/ass'y * 141.8/(5 * 12)
*                    = 208 * 2.363 = 491.57333
*
13301601   010010000  10000000      1     1     245.78667   5
13301602   060010000  10000000      1     1     491.57333   13
13301701   1000      0.1        0.0        0.0   5
13301702   1000      0.2        0.0        0.0   13
* 13301801   0        0.0        0.0        0.0   13
* 13301901   0        0.05492351 0.05492351 0.0   13
13301801    0.0   10.0     10.0   0.0   0.0    0.0    0.0    1.0    13
13301901    0.0   10.0     10.0   0.0   0.0    0.0    0.0    1.0    13
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
```

```
***
***
***   reactor vessel heat structures
***
***
*
*
*     lower plenum of reactor vessel
*
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
* heat structure composition type
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* fuel   ( uo2 )
*
20100300  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* gap    (hot channel)
*
20100400  "tbl/fctn"  3         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* clad   ( zr-4)
*
20100500  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* base metal  ( carbon steel )
*
20100600  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* cladding  ( stainless steel )
*
20100700  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*$$$ *$$$ *
*$$$ *$$$ * gap    (avg channel)
*$$$ *$$$ *
*$$$ *$$$ 20100900  "tbl/fctn"  3         1
*$$$ *
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*     heat structure thermal conductivities
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*     fuel     ( uo2 )
*
20100301    70.0    1.237e-3     200.0     1.237e-3
20100302   400.0    1.022e-3     800.0     0.745e-3
20100303  1200.0    0.592e-3    1600.0     0.492e-3
20100304  2000.0    0.430e-3    2400.0     0.395e-3
20100305  2800.0    0.383e-3    3200.0     0.367e-3
20100306  3600.0    0.370e-3    4000.0     0.380e-3
20100307  4400.0    0.405e-3    5000.0     0.470e-3
*
*    gap      ( bol )
*
20100401  "helium"     0.989748
```

```
20100402 "nitrogen"   0.008098
20100403 "oxygen"     0.002153
20100404 "krypton"    0.000000
20100405 "xenon"      0.000002
*
*    clad  .  (zr-4)
*
20100501     70.0  2.333e-3    200.0  2.333e-3    400.0  2.458e-3
20100502    800.0  2.805e-3   1200.0  3.278e-3   1600.0  3.805e-3
20100503   1800.0  4.112e-3   2000.0  4.445e-3   2100.0  4.667e-3
20100504   2200.0  4.945e-3   2800.0  7.000e-3
*
*    thermal conductivity    base metal   ( carbon steel )
*
20100601  0.0       .00728    2000.0    .00728
*
*    thermal conducitvity    cladding   ( stainless steel )
*
20100701  0.0       .00311    2000.0    .00311
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*     heat structure volumetric heat capacities
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
* volumetric heat capacity  fuel     ( uo2 )
*
20100351     77.0  33.8    200.0  40.62    400.0  43.87
20100352    600.0  45.82   800.0  47.12   1000.0  48.10
20100353   1200.0  48.88  1600.0  49.92   2000.0  50.37
20100354   2400.0  51.35  2800.0  53.62   3200.0  58.17
20100355   3600.0  66.30  4000.0  78.97   4400.0  90.80
20100356   4800.0  99.12  5100.0  101.40
*
* volumetric  heat  capacity   gap   (hot channel)
*
20100451  32.0   0.000075   5400.0   0.000075
*
* volumetric  heat  capacity   clad
*
20100551    32.0   28.346  1062.0   33.232   1140.0   35.432
20100552  1480.0   35.432  1510.0   49.440   1530.0   56.440
20100553  1560.0   58.916  1590.0   61.800   1610.0   66.332
20100554  1620.0   76.220  1650.0   80.340   1680.0   78.28
20100555  1700.0   74.16   1780.0   35.432   3000.0   35.432
*
* volumetric  heat  capacity   base metal   (carbon steel)
*
20100651  0.0       64.4      2000.0    64.4
*
* volumemetric heat capacity   cladding   (stainless steel)
*
20100751  0.0       64.4      2000.0    64.4
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*
*       general tables
*
*
*...**...**...**...**...**...**...**...**...**...**...**...**...*
*
*  test power insertion
*
* 20200100  power
* 20200101  0.0  0.0  5.0  0.0  25.0  1.0-2
*
```

```
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*        control varialbes
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* 20547400  "hcpwr"   "constant"  3.15e6
* 20547400  "hcpwr"   "function"  3.15e4  0.0  0
* 20547401  time  0  1
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
***
***
***                reactor kinetics
***
***
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*  power in watts per assembly
*
30000000  "point"   "separabl"
30000001 "gamma-ac"  5.00000  .00000 .28637e+03   1.0  1.0
30000002  "ans73"   0.0   1.0
30000301  0.3230  0.000491  0.2910  0.00000341
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*  general table for waste package reactivity insertion  ttt = 1
*
30000011  1
30000012  10081
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*  moderator density reactivity feedback
*
*  beff = 0.005
*
*           density  lf/ft**3    reactivity, dollars     fuel temp. f
*
30000501      43.6995724         -22.8341124         *  1004
30000502      45.2602714         -20.0375898         *  1004
30000503      46.8209705         -17.4413905         *  1004
30000504      48.3816695         -15.0255317         *  1004
30000505      49.9423685         -12.7766726         *  1004
30000506      51.5030675         -10.6782739         *  1004
30000507      53.0637665         -08.7187079         *  1004
30000508      54.6244655         -06.8856192         *  1004
30000509      56.1851645         -05.1688975         *   518
30000510      57.4337238         -03.9010990         *   518
30000511      58.6822830         -02.6972060         *   518
30000512      59.8121897         -01.6592902         *   518
30000513      60.7424057         -00.8234196         *   212
30000514      61.6903146          00.00              *   122
30000515      62.4279606         +00.6225345         *   122
30000516      65.0000000         +00.6225345         *    80.33
*
*  control volume weighting  - modified from Original deck with uniform weights
*
30000701   010010000   0   .02191015   0.0
30000702   020010000   0   .02191015   0.0
30000703   030010000   0   .02191015   0.0
30000704   040010000   0   .02191015   0.0
30000705   050010000   0   .02191015   0.0
30000706   060010000   0   .04382030   0.0
30000707   070010000   0   .04382030   0.0
30000708   080010000   0   .04382030   0.0
30000709   090010000   0   .04382030   0.0
```

```
30000710    100010000   0   .04382030   0.0
30000711    110010000   0   .04382030   0.0
30000712    120010000   0   .04382030   0.0
30000713    130010000   0   .04382030   0.0
30000714    140010000   0   .01293183   0.0
30000715    150010000   0   .01418173   0.0
30000716    160010000   0   .04977361   0.0
30000717    170010000   0   .03388387   0.0
30000718    180010000   0   .05595103   0.0
30000719    190010000   0   .05443940   0.0
30000720    200010000   0   .05378898   0.0
30000721    210010000   0   .04873313   0.0
30000722    220010000   0   .05378898   0.0
30000723    230010000   0   .05378898   0.0
30000724    240010000   0   .03063990   0.0
30000725    250010000   0   .07798541   0.0
*
30000501
30000502
30000503
30000504
30000505
30000506
30000507
30000508
30000509
30000510
30000511
30000512
30000513
30000514
30000515
30000516
30000701
30000702
30000703
30000704
30000705
30000706
30000707
30000708
30000709
30000710
30000711
30000712
30000713
30000714
30000715
30000716
30000717
30000718
30000719
30000720
30000721
30000722
30000723
30000724
30000725
*---**---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*   average fuel temperature vs. reactivity
*
*
*          fuel temp. f      reactivity, dollars     density lb/ft**3
*
30000601    32.0             +0.1719079              *  62.4279606
30000602    80.33            +0.1719079              *  62.4279606
30000603   122.0              0.0                    *  61.6903146
30000604   212.0             -0.3488604              *  61.6903146
30000605   320.0             -0.7295469              *  60.7424057
```

```
30000606   518.0              -1.3918144        * 60.7424057
30000607  1004.0              -2.8696928        * 56.1851645
*
*
*
*  heat structure weighting - (added to deck - B&W code does weights
*                              internally)
*
30000801  3301001  0  .04762000  0.0
30000802  3301002  0  .04761900  0.0
30000803  3301003  0  .04761900  0.0
30000804  3301004  0  .04761900  0.0
30000805  3301005  0  .04761900  0.0
30000806  3301006  0  .09523800  0.0
30000807  3301007  0  .09523800  0.0
30000808  3301008  0  .09523800  0.0
30000809  3301009  0  .09523800  0.0
30000810  3301010  0  .09523800  0.0
30000811  3301011  0  .09523800  0.0
30000812  3301012  0  .09523800  0.0
30000813  3301013  0  .09523800  0.0
*
*   Control Blocks
*
20500000  999
20500100  cntrlvar   function  0.04762  0.0    0
20500101  htvat      3301001   002
20500200  cntrlvar   function  0.04761  0.0    0
20500201  htvat      3301002   002
20500300  cntrlvar   function  0.04761  0.0    0
20500301  htvat      3301003   002
20500400  cntrlvar   function  0.04761  0.0    0
20500401  htvat      3301004   002
20500500  cntrlvar   function  0.04761  0.0    0
20500501  htvat      3301005   002
20500600  cntrlvar   function  0.095238 0.0    0
20500601  htvat      3301006   002
20500700  cntrlvar   function  0.095238 0.0    0
20500701  htvat      3301007   002
20500800  cntrlvar   function  0.095238 0.0    0
20500801  htvat      3301008   002
20500900  cntrlvar   function  0.095238 0.0    0
20500901  htvat      3301009   002
20501000  cntrlvar  function  0.095238 0.0   0
20501001  htvat     3301010   002
20501100  cntrlvar  function  0.095238 0.0   0
20501101  htvat     3301011   002
20501200  cntrlvar  function  0.095238 0.0   0
20501201  htvat     3301012   002
20501300  cntrlvar  function  0.095238 0.0   0
20501301  htvat     3301013   002
20501400  cntrlvar  sum       1.0      0.0   0
20501401  -6.63322e-5  1.0  cntrlvar 1 1.0  cntrlvar 2  1.0    cntrlvar 3
20501402        1.0  cntrlvar 4  1.0    cntrlvar 5    1.0    cntrlvar 6
20501403        1.0  cntrlvar 7  1.0    cntrlvar 8    1.0    cntrlvar 9
20501404        1.0  cntrlvar 10 1.0    cntrlvar 11   1.0    cntrlvar 12
20501405        1.0  cntrlvar 13
*
*
20502000  cntrlvar  function   0.02191015  0.0   0
20502001  "rho"     010010000  005
20502100  cntrlvar  function   0.02191015  0.0   0
20502101  "rho"     020010000  005
20502200  cntrlvar  function   0.02191015  0.0   0
20502201  rho      030010000  005
20502300  cntrlvar  function   0.02191015  0.0   0
20502301  rho      040010000  005
20502400  cntrlvar  function   0.02191015  0.0   0
20502401  rho      050010000  005
20502500  cntrlvar  function   0.0438203   0.0   0
```

```
20502501   rho        060010000  005
20502600   cntrlvar   function   0.0438203    0.0    0
20502601   rho        070010000  005
20502700   cntrlvar   function   0.0438203    0.0    0
20502701   rho        080010000  005
20502800   cntrlvar   function   0.0438203    0.0    0
20502801   rho        090010000  005
20502900   cntrlvar   function   0.0438203    0.0    0
20502901   rho        100010000  005
20503000   cntrlvar   function   0.0438203    0.0    0
20503001   rho        110010000  005
20503100   cntrlvar   function   0.0438203    0.0    0
20503101   rho        120010000  005
20503200   cntrlvar   function   0.0438203    0.0    0
20503201   rho        130010000  005
20503300   cntrlvar   function   0.01293183    0.0    0
20503301   rho        140010000  005
20503400   cntrlvar   function   0.01418173    0.0    0
20503401   rho        150010000  005
20503500   cntrlvar   function   0.04977361    0.0    0
20503501   rho        160010000  005
20503600   cntrlvar   function   0.03388387    0.0    0
20503601   rho        170010000  005
20503700   cntrlvar   function   0.05595103    0.0    0
20503701   rho        180010000  005
20503800   cntrlvar   function   0.05443940    0.0    0
20503801   rho        190010000  005
20503900   cntrlvar   function   0.05378898    0.0    0
20503901   rho        200010000  005
20504000   cntrlvar   function   0.04873313    0.0    0
20504001   rho        210010000  005
20504100   cntrlvar   function   0.05378898    0.0    0
20504101   rho        220010000  005
20504200   cntrlvar   function   0.05378898    0.0    0
20504201   rho        230010000  005
20504300   cntrlvar   function   0.03063990    0.0    0
20504301   rho        240010000  005
20504400   cntrlvar   function   0.07798541    0.0    0
20504401   rho        250010000  005
*
20505000   cntrlvar   sum        1.0       0.0   0
20505001   0.0   1.0   cntrlvar 20   1.0   cntrlvar 21   1.0    cntrlvar 22
20505002         1.0   cntrlvar 23   1.0   cntrlvar 24   1.0    cntrlvar 25
20505003         1.0   cntrlvar 26   1.0   cntrlvar 27   1.0    cntrlvar 28
20505004         1.0   cntrlvar 29   1.0   cntrlvar 30   1.0    cntrlvar 31
*
20505500   cntrlvar   sum        1.0       0.0   0
20505501   0.0   1.0   cntrlvar 32   1.0   cntrlvar 33   1.0    cntrlvar 34
20505502         1.0   cntrlvar 35   1.0   cntrlvar 36   1.0    cntrlvar 37
20505503         1.0   cntrlvar 38   1.0   cntrlvar 39   1.0    cntrlvar 40
20505504         1.0   cntrlvar 41   1.0   cntrlvar 42   1.0    cntrlvar 43
20505505         1.0   cntrlvar 44
*
20505600   cntrlvar   sum        1.0       0.0   0
20505601   0.1185681    1.0   cntrlvar 50   1.0   cntrlvar 55
*
20506000   cntrlvar   function    1.0    0.0   0
20506001   time       0          001
20506500   cntrlvar    sum         1.0    0.0  0
20506501   0.0  1.0  cntrlvar 14  1.0   cntrlvar 56  1.0  cntrlvar  60
*
20507000   cntrlvar   integral    1.0    0.0    0
20507001   rktpow     0
*
20507500   cntrlvar   sum    6.22971e-2    0.0    0
20507501   0.0      1.0  htgamw  312100100  1.0  htgamw  312100200
20507502            1.0  htgamw  312100300  1.0  htgamw  312100400
20507503            1.0  htgamw  312100500  1.0  htgamw  312100600
20507504            1.0  htgamw  312100700  1.0  htgamw  312100700
20507505            1.0  htgamw  312100900
```

```
*
*               scale factor = 1/area sum
20508000   cntrlvar  sum   0.26289886    0.0     0
20508001   0.0     0.3516846 voidf  050010000  0.7033692  voidf 100010000
20508002           0.8633786 voidf  200010000  0.7822260  voidf 210010000
*
20508100   cntrlvar  function  1.0    0.0    0
20508101   cntrlvar  80        010
. * end of data
```