OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Complete Only Applicable Items

This is a placeholder page for records that cannot be scanned.

2. Record Date	3. Accession Number
12/04/2001	MOL.20020102.0190
4. Author Name(s)	**5. Author Organization**
PATRICIA BERNOT EMMA PARKER	N/A

6. Title/Description
EQ6 CALCULATION FOR CHEMICAL DEGRADATION OF ENRICO CODISPOSAL WASTE PACKAGE: EFFECTS OF UPDATED DESIGN AND RATES

7. Document Number(s)	8. Version Designator
CAL-EDC-MD-000015	REV. 00

9. Document Type	10. Medium
REPORT	OPTIC/PAPER

11. Access Control Code
PUB

12. Traceability Designator
DC# 28752

13. Comments
THIS IS A ONE-OF-A-KIND DOCUMENT DUE TO THE COLORED GRAPHS ENCLOSED AND CAN BE LOCATED THROUGH THE RPC.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
CALCULATION COVER SHEET

1. QA: QA
Page: 1 of: 119

2. Calculation Title
EQ6 Calculation for Chemical Degradation of Enrico Fermi Codisposal Waste Packages: Effects of Updated Design and Rates

3. Document Identifier (including Revision Number)
CAL-EDC-MD-000015 REV 00

4. Total Attachments	5. Attachment Numbers – Number of pages in each
3	I–11, II-2, III-2 compact discs

	Print Name	Signature	Date
6. Originator	Patricia Bernot Emma Parker		11/28/01
7. Checker	Sara Arthur	Sara E. Arthur	11-29-01
8. Lead	Susan LeStrange	Susan L LeStrange	12/04/01

Remarks

Revision History

10. Revision No.	11. Description of Revision
REV00	Initial Issue

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1. PURPOSE

The Monitored Geologic Repository (MGR) Waste Package Project of the BSC Management and Operating Contractor for the Department of Energy's Office of Civilian Radioactive Waste Management performed calculations to provide input for disposal of spent nuclear fuel (SNF) from the Enrico Fermi Reactor owned by the DOE (Ref. 9). The Fermi SNF has been considered for disposal at the proposed Yucca Mountain site. Because of the high content of fissile materials in the SNF, the waste package (WP) design required special consideration of the amount and placement of neutron absorbers, and the possible transport of absorbers and fissile materials over geologic time. If there is a breach in the WP, water will enter and infiltrate the WP. This water would be able to moderate neutrons, increasing the likelihood of a criticality event within the WP. Also, infiltrating water may in time gradually leach the fissile components from the WP and separate them from the neutron absorbers. Such phenomena would affect the neutronics of the system.

This study presents calculations of the long-term geochemical behavior of WPs containing one DOE disposal container and five high-level waste (HLW) glass pour canisters (GPCs) arranged according to the codisposal concept (Ref. 14). The specific study objectives were to determine:

- The extent to which criticality control material suggested for this WP design will remain in the WP after corrosion/dissolution of the initial WP configuration (such that it can be effective in preventing criticality).
- The extent to which fissile uranium (U) will be carried out of the degraded WP by infiltrating water (such that internal criticality is no longer possible, but the possibility of external criticality may be enhanced).
- The nominal chemical composition and amounts of minerals and other solids left in the WP. These may be used for the criticality evaluations of the WP design, and to suggest the range of parametric variations for additional evaluations.

The chemical compositions (and subsequent criticality evaluations) of the simulations are calculated for time periods up to ~670,000 years. This longer time frame is closer to the one million year time horizon recommended by the National Academy of Sciences to the Environmental Protection Agency for performance assessment related to a nuclear repository (Ref. 31). However, it is important to note that after 100,000 years, most of the materials of interest (fissile and absorber materials) will have either been removed from the WP, reached a steady state, or been transmuted. The sketch of the WP in Attachment II is a potential design of the type considered in this calculation.

Besides fissile materials, the calculation included the element gadolinium (Gd) with a high neutron absorption cross section, which is included in the DOE canister along with the Enrico Fermi fuel to reduce the possibility for criticality. The results of this calculation will be used to ensure that the type and amount of criticality control material used in the WP design will prevent criticality both internally and externally.

The scope of this study is to repeat several cases from a previous calculation (Ref. 32). This requirement is due to updates in the reaction rates of several WP components and the redesign of

the WP to include a 316NG Stainless Steel sleeve inside of the Alloy-22 containment (Attachment II). The case numbers and identifications, which correspond to the previous study, are detailed below in the results.

This calculation also includes calculation of the "source term" for external criticality. The source term provides input for descriptions of the chemistry effluent solutions from the WPs as they degrade. Particular attention is paid to the concentrations of fissile enrichments of U in the effluent. These source terms will then be used in future external transport and accumulation analyses.

This document has been prepared according to Administrative Procedure AP-3.12Q, REV0, ICN 4 (Ref. 29), *Calculations*, and is subject to the Quality Assurance Requirements and Description (QARD) Document (Ref. 30) requirements. This calculation has been prepared in accordance with the *Technical Work Plan for: Department of Energy Spent Nuclear Fuel Work Packages* (Ref.17).

2. METHOD

The method used for this calculation involves the following steps:

- Use of the qualified and modified version of the EQ3/6 reaction-path code (as described in Section 4) for tracing the degradation of the WP. The software estimates the concentrations remaining in the aqueous solution and the composition of the precipitated solids. (EQ3NR is used to determine a starting fluid composition for EQ6 reaction-path calculations.
- Use of "solid-centered flow-through" mode (SCFT) in EQ6; in this mode, an increment of aqueous "feed" solution is added continuously to the WP system, and a like volume of the existing solution is removed, simulating a continuously-stirred tank reactor. This mode is discussed in Section 4.
- Determination of fissile material concentrations in solution as a function of time (from the output of EQ6 simulated reaction times up to ~670,000 years).
- Calculation of the amount of U released from the WP as a function of time (U loss reduces the chance of criticality within the WP).
- Determination of the concentration of the neutron absorber Gd in solution as a function of time (from the output of EQ6 over times up to ~670,000 years).
- Calculation of the amount of neutron absorber retained within the WP as a function of time.
- Determination of composition and amounts of reaction-product solids (precipitated minerals or corrosion products, and unreacted package materials).
- Comparison of the former calculation (Ref. 32) with this calculation that incorporates the new WP design and degradation rates of WP components.
- Determination of fissile U content in solution for source term calculations.

This calculation used version 7.2bLV (Ref. 21) of EQ6. The User's Manual for 7.2bLV (Ref. 36) provides a detailed description of the code. The code retains the solid-centered flow-through (SCFT) mode developed in the previous Addendum to EQ6 (Ref. 37) and is complete, mathematically correct and technically adequate for the application. Further detail on the specific methods employed for each step is available in Section 5 of this calculation.

With regard to the development of this calculation, the control of the electronic management of data was evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Information* (Ref. 38). The evaluation (Ref. 17) determined that current work processes and procedures are adequate for the control of electronic management of data for this activity.

3. ASSUMPTIONS

All assumptions are for preliminary design; and are used throughout Section 5 and 6.

3.1 It is assumed that the solutions that drip into the WP will have the major ion composition of J-13 well water as given in (Ref. 15 [DTN: MO0006J13WTRCM.000]) for ~670,000 years. The rationale for this assumption is that the groundwater composition is controlled largely by transport through the host rock, over pathways of hundreds of meters, and the host rock composition is not expected to change substantially over 10^6 years. The assumption that the J-13 well water can approximate the water entering the WP implicitly assumes that any effects of contact with the engineered materials in the drift will be minimal after a few thousand years. For a few thousand years after waste emplacement, the composition may differ because of perturbations resulting from reactions with engineered materials and from the thermal pulse. These are not taken into account in this calculation because the outer shell and inner liner are not expected to breach until after that perturbed period. Therefore, the early perturbation is not relevant to the calculations reported in this document.

3.2 It is assumed that an aqueous solution fills all voids within the WP. The rationale for this assumption is that it provides the maximum degradation rates of WP components with the potential for precipitation of radionuclides within the WP or the flushing of radionuclides from the WP, and is therefore conservative. This assumption is justified by recent evaluations of codisposal WPs which show that degradation of the WP materials (specifically, HLW glass and steel) overwhelms the native chemistry of the incoming water. (Ref. 4, Figures 5-3 through 5-20 of show pH values between 3 and 10 in the WP).

3.3 It is assumed that the density of the incoming water is 1.0 g/cm^3. The rationale for this assumption is that for dilute solutions, the density is extremely close to that of pure water and that any differences are insignificant with respect to other uncertainties in the data and calculations. Moreover, this value is used only initially in EQ3/6 to convert concentrations of dissolved substances from parts per million to molality.

3.4 It is assumed that water will circulate freely enough in the partially degraded WP that all degraded solid products will react with each other through the aqueous solution medium. The rationale for this assumption is that it provides the most rapid aqueous degradation and is, therefore, conservative.

3.5 It is assumed that 25°C thermodynamic data can be used for the calculations. Though the initial breach of the WP may occur when the contents are at temperatures ≥ 50°C (Ref. 5, Figures 3-20 through 3-22), at times > 25,000 years, the WP temperatures are likely to be close to 25°C.

3.6 In general it is assumed that chromium (Cr) and molybdenum (Mo) will oxidize fully to chromate (or dichromate) and molybdate, respectively. This assumption is based on the available thermodynamic data (Ref. 3, "data0.ymp"), which indicate that in the presence of air, the Cr and Mo would both oxidize to the VI valence state. Laboratory observation of the corrosion of Cr and Mo containing steels and alloys, however, indicates that any

such oxidation would be extremely slow. In fact, oxidation to the VI state may not occur at a significant rate with respect to the time frame of interest, or there may exist stable Cr(III) solids that substantially lower aqueous Cr concentration. For the present analyses, the assumption is made that, over the times of concern, oxidation will occur. The rationale for this assumption is that by allowing the Cr and Mo to oxidize, the pH of the system will be lowered, allowing for the removal of neutron absorbers and retention of fissile materials.

3.7 It is assumed that gases in the WP solution remain in equilibrium with the ambient atmosphere outside the WP. In other words, contact of WP fluids with the gas phase in the repository is assumed to be sufficient to maintain equilibrium with the carbon dioxide (CO_2) and oxygen (O_2) present, whether or not this is the normal atmosphere in open air or rock gas that seeps out of the adjacent tuff. Moreover, the specific partial pressures of CO_2 and O_2 of the ambient repository atmosphere are set to, respectively, $10^{-3.0}$ and $10^{-0.7}$ atm. The rationale for choosing the O_2 partial pressure is that it is equivalent to that in the atmosphere (Ref. 40, p. F-210). The rationale for choosing the CO_2 partial pressure is to reflect the observation that J-13 well water appears to be in equilibrium with above-atmospheric CO_2 levels (Ref. 39, Table 7).

3.8 It is assumed that precipitated solids that are deposited remain in place, and are not mechanically eroded or entrained as colloids in the advected water. The rationale for this assumption is that it conservatively maximizes the amount of fissile material deposited inside the WP.

3.9 It is assumed that the corrosion rates used in this calculation encompass rates for microbially assisted degradation, and that the degradation rates will not be controlled principally by microbes (Ref. 5, p. 3-84). The rationale for this assumption is (1) corrosion rates measured under environmental conditions inherently include exposure to microbes, and (2) the lack of organic nutrients available for microbial corrosion will limit the involvement of microbes. Microbes can act as catalysts but this catalytic effect is not expected to significantly change the types of solids formed in the WP.

3.10 It is assumed that sufficient decay heat is retained within the WP over times of interest to cause convective circulation and mixing of the water inside the WP. The rationale for this assumption is the analysis in Reference 8, Attachment VI.

3.11 It is assumed that the rate of entry of water into, as well as the rate of egress from, a WP is equal to the rate at which water drips onto the WP. The rationale for this assumption is that for most of the time frame of interest, i.e., long after the outer barriers become largely degraded, it is more reasonable to assume all or most of the dripping water will enter the degraded WP than to assume a significant portion will instead be diverted around the remains. However, the calculations include scenarios with very low drip rates, which effectively simulate diversion of the bulk of the water striking the WP.

3.12 It is assumed that the most insoluble solids for a fissile radionuclide will form, i.e., equilibrium will be reached. The rationale for this assumption is conservatism; the

highest chance of internal criticality occurs when the fissile solids have lowest solubility, and are thus retained in the WP.

3.13 For any WP components that were described as "304" stainless steel, without indication of the carbon grade, the alloy was assumed to be the low-carbon equivalent (see Section 5.1.1 for nomenclature). The rationale of this assumption is that, in general, the carbon in the steel is totally insignificant compared to the carbon supplied by the fixed CO_2 fugacity of the EQ3/6 calculation, and to the constant influx of carbonate via the incoming water.

3.14 It is assumed that the reported alkalinity in analyses of J-13 well water corresponds to bicarbonate (HCO_3^-) alkalinity. Contributors to alkalinity in J-13 well water, in addition to bicarbonate, potentially include borate, phosphate, and silicate. However, at pH less than 9, the contribution of silicate will be small, and in any case the concentrations of all three of these components in J-13 well water are small. Fluoride or nitrate do not contribute to alkalinity unless a sufficiently low pH is reached. The rationale for this assumption is the observation that the calculated electrical neutrality, using the assumption, is zero within the analytical uncertainty, as it should be. The same assumption is implicitly made in Reference 15 (DTN: MO0006J13WTRCM.000).

3.15 A number of minor assumptions have been made about the geometry of the Enrico Fermi codisposal WP. These assumptions are outlined and referenced in the spreadsheet "Fermi_Fuel_kz.xls" (Ref. 1), and are also discussed in Section 5.1. The bases for these assumptions are to represent the WP geometry with the greatest accuracy and where inadequate information is available to choose among competing representations of WP geometry, the choice that appears to lead to greatest conservatism is always chosen.

3.16 It is assumed that the high-level waste glass composition is as given in Reference 16, Attachment I, p. I-7, and that the density of the HLW glass is 2.85 g/cm^3 (Ref. 43, p. 2.2.1.1-4). The rationale for this assumption is that the references cited above are the most recent and comprehensive sources available to provide this information.

3.17 Zircaloy and Zr corrosion kinetics studies (Ref. 6) revealed these materials to be resistant against chemical and biological corrosion. These studies on corrosion of Zircaloy-clad SNF indicate growth of oxide films for a time span of a million years to be about 7.6E-03 millimeter (0.3 mil). It was also assumed that the Zr cladding would breach soon after it comes in contact with water. The basis for this assumption is justified since it is conservative and accounts for any cladding that is damaged during storage, shipping, or packing.

3.18 It is assumed that the molecular weight of all "special reactants" (steel, glass, etc) is equal to 100g/mole. The rationale for this assumption is that it simplifies conversion of WP material compositions (often available in weight percent) to moles for EQ6 input files. By using this molecular weight for all special reactants, calculation of masses in WPs is simple and straightforward.

3.19 It is generally assumed that only the inside surface area of the 316NG liner is greatly exposed to degradation within the WP. The basis for this assumption is that after breach,

water is expected to fill the inside of the WP. This is also more conservative for internal criticality since more U is retained within the WP if only the inner surface area is taken into account.

3.20 If the outer shell of the WP comes into contact with water within the WP, it will react so slowly that it will have an insignificant effect on the chemistry of the WP solution. The basis for this assumption is that Alloy 22 corrodes very slowly compared to other reactants in the WP (Ref. 13). At the rate which soluble corrosion products are likely to be flushed from the WP, any input from the outer shell would have negligible effects on the chemistry.

3.21 The general composition and density of $GdPO_4$ was taken to be the same as that for the mineral monazite ($(Ce,La,Nd,Th)PO_4$). The rationale is that since there is no data on $GdPO_4$, monazite properties could be used to bound characteristics of $GdPO_4$ since Gd is also a lanthinide and should have similar properties to the actinide and lanthinides occurring in monazite.

3.22 It is assumed that the degradation rate of $GdPO_4$ is the same as that for quartz. The rationale for this assumption is that little is known about $GdPO_4$ degradation, only that it is relatively slow. For the purposes of this study, quartz dissolution rate is used since it is also known to be slow and is also well documented (Ex. Refs. 58 and 59).

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

This section describes the computer software used in the calculation.

Table 1. Computer Software Used in this Calculation

Software Name	Version	Software Tracking Number (Qualification Status)	Description and Components Used	Input and Output Files [a] (Included in Attachment I)
EQ3/6	7.2b	Qualified LLNL:UCRL-MA-110662 EQ3/6, Ref. 42	EQ3NR: a speciation-solubility code	input: *.3i pickup: *.3p output: *.3o
			EQPT: a data file preprocessor	input: data0.* output: data1.*
EQ6	7.2bLV	Qualified 10075-7.2bLV-00 EQ6, Ref. 21	EQ6: a reaction path code which models water/rock interaction or fluid mixing in either a pure reaction progress mode or a time mode	input: *.6i pickup: *.6p output: *.6o *.elem_aqu.txt *.elem_min.txt *.elem_tot.txt *.min_info.txt *.bin
ASPRIN	1.0	Qualified 10487-1.0-00 ASPRIN, Ref. 45	ASPRIN: performs post-processing of numerical information (from an output data file created by EQ6), to calculate isotopic inventories for elements of interest	input: *.bin (from EQ6) output: *.txt
MS EXCEL	Version 97 SR-2	Commercial off-the-shelf software: Exempt in accordance with AP-SI.1Q (Ref. 25), Section 2.1.	Excel: used in this document for graphical representation and arithmetical manipulations	input: *.elem_*.txt output: *.xls
PP	NA	Ref. 2. Used solely for visual display or graphical representation: Exempt in accordance with AP-SI.1Q (Ref. 25), Section 2.1.2.	PP: a plotting tool used for graphical representation	input: *.bin (from EQ6) output: *.wmf

[a] Files are explained in more detail in Attachment I.

The software products were run on a standard PC and all applicable products were obtained from Software Configuration Management (SCM). The software was appropriate for the application and was used within the range of validation in accordance with AP.SI-1Q.

The EQ6 software was used within its range of validation. However, some runs simulated periods of high ionic strength (1 to ~4). While EQ6 is capable of handling high ionic strengths, there is no qualified Yucca Mountain Project (YMP) thermodynamic database with corrections for high ionic strength. To address this issue, several sensitivity tests were performed using

other thermodynamic databases that have corrections for high ionic strength (Ref. 24, Sec. 5.1.2). The results show that calculations at high ionic strength, using the "data0.ymp" database (Ref. 3), overestimate the solubility of Pu and U, which is conservative with respect to external accumulations of these elements.

4.2 MODELS

The mathematical model *Defense High Level Waste Glass Degradation* was used for degradation rate expressions for dissolution of glass immersed in water. Both the earlier version of the model (Ref. 28, Equations 7 and 8) and the most recent version of the model (Ref. 46, Equations 7 and 8) were used in the calculations. The earlier version of the model was used in Sections 6.1 and 6.2 of this document. Two sensitivity cases were performed with the more recent model to check the effects of the new rate on U retention and source term calculations. The results are presented in Section 6.3.

The model does not have a Model Warehouse Data Tracking Number. The use of the model in the current calculation is justified, since the purpose of the model is to describe the degradation of HLW glass in a flooded WP.

5. CALCULATION

The calculations begin with selection of data for compositions, amounts, surface areas, and reaction rates of the various components of Fermi WPs. These quantities are converted to the form required for entry into EQ6. For example, weight percentages of elements or component oxides are converted to moles of elements per 100g of WP component; degradation rates in μm/y are converted to moles/(cm^2·s), etc. The final part of the input to EQ6 consists of the composition of incoming water (Section 5.1.3) together with a rate of influx to the WP that corresponds to suitably chosen percolation rates into a drift and drip rate (Section 5.1.4) into a WP. The EQ6 output provides the results of the chemical degradation calculations for the WP or components thereof. In selected cases, the degradation of the WP is divided into phases. In the first of these cases, degradation of HLW glass takes place before breach of the DOE canister and subsequent exposure of the Fermi fuel to water. The second scenario assumes that all WP components are breached except for the GPCs. The results include the compositions and amounts of solid products and of elements dissolved in solution. Details of the results are presented in Section 6.

When "time" or "years" are discussed in the calculation, this refers to the time or years after the WP has been breached, allowing water to enter. In all tables from this document, the number of digits reported does not necessarily reflect the accuracy or precision of the calculation. In most tables, two to four digits after the decimal place have been retained to prevent round-off errors in subsequent calculations.

5.1 CALCULATION INPUTS

5.1.1 WP Materials and Performance Parameters

This section (Section 5) provides a brief overview of the physical and chemical characteristics of Fermi WPs, and describes how the WP is represented in the EQ6 inputs. With the exception of the addition of the 316NG stainless steel inner sleeve, all the WP internals in this calculation are the same as the previous calculation (Ref. 32). The conversion of the WP physical description into parameters suitable for the EQ6 input files is performed by the spreadsheets "Fermi-IA-2001.xls" and "UenrichFermi.xls" (Attachment III). Additional details of the description may be found in Reference 9 (Section 3.1) and the references cited therein.

Material nomenclature used throughout this document includes: UNS N06625 and SA-240 S30403 (hereafter referred to as 304L), SA-516 (hereafter referred to as A516), SA-240 S31603 (hereafter referred to as 316L), and SA-240 S31603 nuclear grade stainless steel (hereafter referred to as 316NG stainless steel).

5.1.2 Physical and Chemical Form of the Enrico Fermi WP

It is convenient to consider the Enrico Fermi WP as several structural components:

- The outer shell constructed of Alloy 22.
- The inner sleeve (also called liner) constructed of 316NG stainless steel.

- The "outer web", a carbon steel (A516) structural basket designed to hold the HLW glass pour canisters (GPCs) in place.
- The 5 GPCs, which consist of 304L canisters, filled with solidified HLW glass.
- A centrally located 316L stainless steel DOE canister with an internal 316L stainless steel basket.
- Filler material: A516 carbon steel and $GdPO_4$ shot
- The individual fuel assemblies
- The Al alloy shipping canisters.

The normalized moles (defined as 100 grams/mole for all components) and the normalized surface area of the 316NG inner sleeve were calculated in file "Fermi-IA-2001.xls" sheet "EDA2" (Attachment III). The term "normalized" means that the total moles and surface area for each component are divided by a normalization factor, which is the void volume of the WP. The normalization is necessary because EQ6 calculations are based on 1 liter of aqueous solution. The void volume was calculated to be 4102 liters (Ref. 47, Table 5-4). The normalized moles and surface area of the remaining components were calculated in file "Fermi-IA-2001.xls", sheet "normal" (Attachment III). Some of these initial values come from Reference 9 (Section 3.1) and spreadsheet "Fermi_Fuel_Kz.xls" in Reference 1, which is the electronic media for Reference 32.

Table 2 provides the normalized moles, surface areas, and densities for all of the major components in the Enrico Fermi codisposal WPs.

Table 3 provides a summary of the compositions of the principal alloys used in the calculations, along with a range of degradation rates. In the new calculation, the degradation rate for the A516 carbon steel is set to an average number for all runs. This average rate lies in between the average and high rates of the previous calculation. The "low" and "average" rates for the stainless steels are comparable to the "average" and "high" rates used in the earlier calculations (Ref. 32) (with corrections made for a molecular weight of 100g/mole in the current calculation). The "high" rates added to this calculation come from the *Waste Package Degradation Process Model Report* (Ref. 19, Fig. 3-15) and are much higher than the highest rate of 1 μm/y used in the previous calculation (new rates are converted to EQ6 input format in Attachment III of Ref. 50).

Table 4 gives the simplified molar composition of the HLW glass used in the calculations. Several minor changes were made to these basic compositions to increase the efficiency of the calculations and to decrease the EQ6 run time. Principally, minor elements in the HLW glass, and other package materials compositions were removed or merged with chemically similar elements (e.g., Li was merged with Na in the glass composition). If the HLW glass composition is simplified, it can be entered as a "psuedo–mineral", GlassSRL, in the database. Entering the glass as a mineral reactant allows EQ6 to apply a pH-dependent degradation rate using the Transition State Theory formalism (Ref. 35, Section 3.3.3). Since neptunium (Np) and plutonium (Pu) made up only 1.1% of the total actinide content of the HLW glass, they were combined with

U to further simplify the composition. EQ6 estimates of Pu and U loss from the WP are not greatly affected by the changes made to the elemental compositions of the HLW glass.

A pH-dependent rate for HLW glass degradation was derived from Reference 28 and Reference 46, Section 6.2.3.3, Equations 7 and 8. The glass rate based on Reference 28 is taken from Table 3 of Reference 20. The glass rate based on Reference 46 was normalized in "HLWglass-2001.xls" (Attachment III). The first rate mechanism (described with k_1) in Table 4 is dominant at pH values above 7, while the second rate mechanism (described with k_2) is dominant at pH values below 7. The high glass degradation rate constants in Table 4 are those predicted at 50°C, while the moderate rate constants are those derived for degradation at 25°C (Refs. 28 and 46, Sec. 6.2.3.3, Eq. 7 and 8).

All "rates" given in Table 3 through Table 6 are rate constants ($mol/cm^2 \cdot s$) which EQ6 multiplies by the normalized surface area (in cm^2) to derive a rate in moles per second for each WP component. Therefore, the true degradation rate of all WP components is highly dependent on surface area.

Table 5 summarizes the composition of the fuel used in this calculation. New rates come from Reference 48, Section 3.2.2 (converted to EQ6 format in "Fermi-IA-2001.xls", Attachment III).

Table 2. Properties of Materials in Enrico Fermi Codisposal WP

EQ6 Parameter	*V*	ρ	m_i	*sk*
Reactant	**Molar Volume (cm^3/mol)** [n]	**Density (g/cm^3)**	**Initial Moles** [o]	**Surface Area** [p] **(cm^2)**
HLW Glass	35.09	2.85[g]	21.82[d]	1228.5[b]
Fresh U-Mo	5.739	17.242[j]	1.227186[a]	75.123[f]
$GdPO_4$ Shot	20.00	5.00[l]	0.035135[e] (0.07027)[e]	84.2552[e] (168.5104)[e]
A516 Shot	12.739	7.85[h]	1.783567[e] (1.67655)[e]	2724.2515[e] (2639.996)[e]
A516 Outer Web	12.739	7.85[h]	9.269[d]	120.0[d]
A516 Impact Plates	12.739	7.85[h]	0.2110[d]	1.615[d]
304L Glass Pour Canister	12.59	7.94[i]	5.494[d]	141.5[d]
316L DOE SNF Canister	12.53	7.98[i]	0.8592[d]	22.67[d]
316L Basket	12.53	7.98[i]	0.9226[a]	55.440[f]
316NG Inner Shell	12.53	7.98[i]	27.51[c]	57.305346[c]
Al Alloy Shipping Canister	36.90	2.71[k]	0.209885[a]	55.4971[f]
J-13 Water	N/A	1.0[m]	N/A	N/A

Source: [a] Ref. 1, spreadsheet "Fermi_Fuel_kz.xls", recalculated for molecular weight of 100g/mol in spreadsheet "Fermi-IA 2001.xls" (Attachment III).
[b] A HLW glass fracture factor of 21 (Ref. 49, p. 6-79) was used to adjust the values of HLW glass surface area from Ref. 47, Table 5-4 in spreadsheet "Fermi-IA-2001.xls" (Attachment III).
[c] Calculated in "Fermi-IA-2001.xls", sheet "EDA2" (Attachment III) from SK0200 REV 04 (Attachment II).
[d] Ref. 47, Table 5-4
[e] Calculated in "Fermi-IA-2001.xls" (Attachment III), parentheses are for values when the $GdPO_4$ content is doubled in Section 6.3.1.1
[f] Ref. 1, spreadsheet "Fermi_Fuel_kz.xls"
[g] Ref. 43 (Based on range of HLW glass densities, p. 2.2.1.1-4)
[h] Ref. 33 (p. 9)
[i] Ref. 23 (p.7, Table XI)
[j] Ref. 32, Table 5-4
[k] Ref. 32, Table 5-2
[l] Ref. 57, p. 413 (average density of monazite, See Assumption 3-21)
NOTES: [m] The density of a dilute solution is assumed to be 1.0 (Assumption 3.3).
[n] Molar volume calculated by dividing the molecular weight (100g/mole) by density.
[o] To determine mass (g) of each reactant, multiply the normalized moles by 100 g/mole and multiply by the normalization factor of 4102 liters.
[p] To determine the true surface area (cm^2) of each reactant, multiply the normalized area by the normalization factor of 4102 liters.

Table 3. Steels Composition and Degradation Rates

Element	A516 Carbon Steel		304L Stainless Steel		316L Stainless Steel		316NG Stainless Steel		Al Alloy	
	wt%[a]	Moles/ 100g[h]	wt%[b]	Moles/ 100g[h]	wt%[c]	Moles/ 100g[h]	wt%[d]	Moles/ 100g[h]	wt%[l]	Moles/ 100g[m]
C	0.28	0.0233	0.03	0.002498	0.03	0.00250	0.02[j]	0.001665	0	0
Mn	1.045	0.0190	2.00	0.036405	2.00	0.03640	2.00	0.036405	0.15	0.00273
P	0.035	0.00113	0.045	0.001453	0.045	0.00145	0.045	0.001453	0	0
S	0.035	0.00109	0.03	0.000936	0.03	0.00094	0.03	0.000936	0	0
Si	0.29	0.0103	0.75	0.026704	1.00	0.03560	1.00	0.035606	0.6	0.02136
Cr	0	0	19.00	0.36541	17.00	0.32694	17.00	0.326948	0.195	0.00375
Ni	0	0	10.00	0.17039	12.00	0.20446	12.00	0.204464	0	0
Mo	0	0	0	0	2.50	0.02606	2.50	0.026058	0	0
N	0	0	0.10	0.007139	0.10	0.00714	0.08[j]	0.005712	0	0
Fe	98.3	1.76	68.045	1.2184	65.295	1.16924	65.325	1.169756	0.7	0.01253
Zn	0	0	0	0	0	0	0	0	0.25	0.00382
Cu	0	0	0	0	0	0	0	0	0.275	0.00433
Mg	0	0	0	0	0	0	0	0	1.00	0.04114
Ti	0	0	0	0	0	0	0	0	0.15	0.00313
Al	0	0	0	0	0	0	0	0	96.68	3.58319
Total	100	1.8148	100	1.8294	100	1.8107	100	1.8090	100	3.6716
Rate	**µm/y**	**Moles/ $(cm^2 \cdot s)^k$**	**µm/y**	**Moles/ $(cm^2 \cdot s)^k$**	**µm/y**		**Moles/ $(cm^2 \cdot s)^k$**		**Moles/ $(cm^2 \cdot s)^l$**	
Low	Same as Avg	Same as Average	0.1[f]	2.52E-14	0.1[f]		2.53E-14		Same as Average	
Avg	72[e]	1.79E-11	1[n]	2.52E-13	1[n]		2.53E-13		2.54E-13	
High	Same as Avg	Same as Average	34[g]	8.656E-12	2[g]		5.056E-13		Same as average	

Source: [a] Ref. 44 (p. 321, Table 1)
[b] Ref. 34. (p. 3, Table 1)
[c] Ref. 41 (p. 2, Table 1)
[d] Ref. 41 (p.2, Table 1, 316 stainless steel base for 316NG)
[e] Ref. 27 (pp. 2.2-96 through 2.2-98)
[f] Ref. 26 (pp. 11-13)
[g] Ref. 19 (Eq. 3-14 derived from Figure 3-15, 50th percentile value)
[h] Ref. 50 (Attachment III)
[i] Ref. 18 (p. 603), converted to EQ6 format in Ref. 20 (Table 4)
[j] Ref. 52 (p. 931)
[k] Converted to values appropriate for input into EQ6 in Ref. 50 (Table 5-2)
[l] Ref. 51 (p. 373)
[m] Converted to values appropriate for input into EQ6 in "Fermi-IA-2001.xls" (Attachment III)
NOTE: [n] The average steel degradation rate was taken as 10 times the low rate.

Table 4. Simplified Glass Composition and Degradation Rates

Element	Moles/ 100g [a]	Comment
O	2.7038	
U	0.0078	
Np	0	Merged with U (~0.1% of actinides)
Pu	0	Merged with U (Pu ~1% actinides)
Ba	0.0011	
Al	0.0863	
S	0.0040	
Ca	0.0162	
P	0.0005	
Cr	0	Merged with Al (overwhelmed by steel Cr; Cr_2O_3 similar to Al_2O_3)
Ni	0	Merged with Fe
Pb	0	Merged with Ba (both form insoluble $CrO_4^=$ compounds in EQ6 runs)
Si	0.7765	
Ti	0	Merged with Si (TiO_2 similar to SiO_2)
B	0.2912	
Li	0	Merged with Na
F	0.0017	
Cu	0	Merged with Fe
Fe	0.1722	
K	0.0752	
Mg	0.0333	
Mn	0	Merged with Fe
Na	0.5767	
Cl	0	Removed (overwhelmed by Cl in in-dripping water)

Total Degradation Rate = $k_1[H+]^{-0.04} + k_2[H+]^{0.6}$ (moles/cm^2·s)			
Low Rate Constant (k_1)	liter/(cm2·s)	8.858E-19[b]	8.858E-19[c]
High Rate Constant (k_1)	liter/(cm2·s)	1.076E-17[b]	1.076E-17[c]
Low Rate Constant (k_2)	liter/(cm2·s)	7.976E-13[b]	1.115E-11[c]
High Rate Constant (k_2)	liter/(cm2·s)	4.874E-12[b]	1.354E-10[c]

Source: [a] Simplified composition based on Ref. 16 (Attachment I, p. I-7). This is the composition added to the "data0.ymd" for the pseudo-mineral GlassSRL. One mole = 100g HLW glass.
[b] Ref. 28; (Section 6.2.3, Equations 7 and 8); Converted to inputs for EQ6 in Ref. 20 (Table 3)
[c] Ref. 46: (Section 6.2.3, Equations 7 and 8); Converted to inputs for EQ6 in spreadsheet "HLWglass-2001.xls" (Attachment III)

Table 5. Fermi Fuel Composition and Degradation Rates

Element	Composition	
	wt%[a]	Moles/100g
U	89.74	0.37701008
Mo	10.26	0.1069492
Rate	**moles/(cm^2·s)[b]**	**Basis**
Low	3.4601E-17	Extrapolation of temperature dependent rate regression of Ref. 48 to 25°C
High	3.4601E-13	10,000 times low rate (according to Ref. 48)

NOTE: [a] Ref. 32, Table 5-4
[b] Ref. 48, Section 3.2.2, recalculated in "Fermi-IA-2001.xls", sheet "rates" (Attachment III)

For the Enrico-Fermi fuel type, the Gd is added to the WP as $GdPO_4$ shot which is mixed with A516 carbon steel shot inside the 316L stainless steel basket structure within the DOE canister. Table 6 gives the composition of the $GdPO_4$ shot used in this calculation.

Table 6. $GdPO_4$ Shot Composition and Degradation Rates

Element	Wt%[a]	Moles/100g[b]
P	12.280	0.3964772
O	25.374	1.5859082
Gd	62.346	0.3964771
Rate	**Moles/(cm^2·s)**	**Basis**
Low	1.40E-16[c]	Quartz degradation rate
Medium	2.52E-14[d]	304L stainless steel degradation rate
High	1.798E-11[d]	A516 carbon steel degradation rate

Source: [a] Taken as similar to composition of monazite ($(Ce,La,Nd,Th)PO_4$), Ref. 57 (p. 413)
[b] Calculated in "Fermi-IA-2001.xls", sheet "compositions"
[c] Ref. 58 (Figure 2) and Ref. 59 (Tables I and III), converted to values appropriate for use in EQ6 in "Fermi-IA-2001.xls", Sheet "rates" (Attachment III) (See Assumption 3-22).
NOTE: [d] Due to the uncertainty in the degradation rate of $GdPO_4$, the low rate (based on quartz) was used in all EQ6 runs. The medium and high rates were used in sensitivity cases to test how dependent Gd retention is on the degradation rate.

5.1.3 Chemical Composition of Incoming Water

It was assumed that the water composition entering the WP would be the same as that for water from well J-13 (Assumption 3.1). This water has been analyzed repeatedly over a span of at least 20 years (Ref. 15, DTN: MO0006J13WTRCM.000). The composition of J-13 well water as used in this calculation has been adjusted slightly (see Assumptions 3.7 and 3.15). The concentration of Si (as listed in Ref. 15) had to be converted into a concentration in terms of SiO_2(aq) for input into EQ3NR. The conversion was accomplished by the following:

$$[SiO_2(aq)] = [Si] \times M_{SiO_2} / M_{Si}$$

where the square brackets indicate concentration (mg/liter), M indicates molecular weight, and the subscripts indicate the particular species.Based on the molecular weights of Si and O in Reference 12 and the concentration of Si in Reference 15, the concentration for SiO_2(aq) is:

$$(28.5 \text{ mg/liter}) \times (28.0855 + 2 \times 15.9994) / (28.0855) = 60.97 \text{ mg/L}$$

Table 7 and Table 8 contain the EQ3NR input file constraints for J-13 well water composition and the EQ6 input file elemental molal composition for J-13 well water used for this calculation.

The "Basis Species" column of Table 7 lists the chemical species names recognized by EQ3NR and EQ6. Since some of the components of J-13 well water, as analyzed (Ref. 15, DTN: MO0006J13WTRCM.000) are in a different chemical form than the species listed in this column, these components must be substituted or "switched" with the basis species for input into EQ6 and are listed in the "Basis Switch" column. Basis species listed as "Trace" in the "Basis Switch" column are not found in J-13 well water, as analyzed (Ref. 15), but are in the composition of other WP components and must be input at a trace concentration for numerical stability in EQ6 calculations.

Table 7. EQ3NR Input File Constraints for Incoming Water Composition

Basis Species	Basis Switch	Concentration [a]	Units
redox		-0.7 [c]	log fO_2
Na+		45.8	mg/L
SiO_2(aq)		60.97	mg/L
Ca++		13.0	mg/L
K+		5.04	mg/L
Mg++		2.01	mg/L
H+		8.1 [b]	pH
HCO_3-	CO_2(g)	-3 [c]	log fCO_2
F-		2.18	mg/L
Cl-		7.14	mg/L
NO_3-	NH_3(aq)	8.78	mg/L
SO_4--		18.4	mg/L
Al+++	Trace	1.000E-16	Molality
Mn++	Trace	1.000E-16	Molality
Fe++	Trace	1.000E-16	Molality
$B(OH)_3$(aq)	Trace	1.000E-16	Molality
HPO_4--	Trace	1.000E-16	Molality
Ba++	Trace	1.000E-16	Molality
CrO_4--	Trace	1.000E-16	Molality
Cu++	Trace	1.000E-16	Molality
Gd+++	Trace	1.000E-16	Molality
MoO_4--	Trace	1.000E-16	Molality
Ni++	Trace	1.000E-16	Molality
Pu++++	Trace	1.000E-16	Molality
$Ti(OH)_4$(aq)	Trace	1.000E-16	Molality
UO_2++	Trace	1.000E-16	Molality
Zn++	Trace	1.000E-16	Molality

Source: [a] Ref. 15 (A trace concentration (1.000E-16 molal) is added for elements that are not in J-13 well water as analyzed, but are in the composition of the WP components, to ensure numerical stability in EQ3/6 runs.)
NOTES: [b] If log (fCO2) = –3, then EQ3NR calculates pH = 8.1 (Ref. 39, Table 7). See Assumption 3.7.
[c] (Ref. 40, p. F-210) See Assumption 3.7.

The values in Table 7 were run through EQ3 to provide the values to be used in the EQ6 file (Table 8).

Table 8. EQ6 Input File Elemental Molal Composition for Incoming Water

Element	Mole/Kg	Element	Mole/Kg
O	5.55E+01	Mg	8.27E-05
Al	1.00E-16	Mn	1.00E-16
B	1.00E-16	Mo	1.00E-16
Ba	1.00E-16	N	1.42E-04
Ca	3.24E-04	Na	1.99E-03
Cl	2.01E-04	Ni	1.00E-16
Cr	1.00E-16	S	1.92E-04
F	1.15E-04	Si	1.02E-03
Fe	1.00E-16	U	1.00E-16
C	2.07E-03	K	1.29E-04
H	1.11E+02	Gd	1.00E-16
P	1.00E-16		

NOTE: [a] These values are output from EQ3NR for input into EQ6 input files.

5.1.4 Drip Rate of Incoming Water

It is assumed (Assumption 3.11) that the drip rate onto a WP is the same as the rate at which water flows through the WP. The drip rate is taken from a correlation between percolation flux and drip rate, also called mean seep flow rate (Ref. 10, Figure 3.2-15). A range of drip rates was chosen. Specifically, values of 0.0015, 0.015, and 0.15 m^3/year were used for most cases, corresponding to percolation fluxes ranging from about 10 mm/year to 80 mm/year. The value of 10 mm/year corresponds to a high infiltration rate for the present-day climate and 80 mm/year corresponds to about twice the high infiltration rate for the glacial-transition climate (Ref. 10, Table 3.2-2). [Table 3.2-2 of Ref. 10 gives values of net infiltration rate, rather than percolation flux; however, they are equal at the potential repository level (Ref. 10, Section 3.2.3.4, p. 3-33)].

Table 9. Drip Rate Values for Input to EQ6

Drip Rate (m^3/year)	Drip Rate (normalized for EQ6 input) (moles/s)[a]
0.0015	1.16E-11
0.015	1.16E-10
0.15	1.16E-09

NOTE: [a] The values of drip rate in units of m^3/year are multiplied by 1000 liters/m^3, divided by 1 liter/mole, divided by 365.25 days/year, divided by 86,400 s/day, and divided by 4102 liters of void volume in the WP.

5.1.5 Densities and Molecular Weights of Solids

EQ6 calculates total mineral volumes, using the molar volume values (V0PrTr) embedded in the EQ3/6 data0 file ("data0.ymd", Attachment III). The mineral volumes are printed to EQ6 output files with endings such as "elem_min.txt" and "min_info.txt". The mineral volumes are used to calculate corrosion product density ("S+A.xls" and "S+A sensitivity.xls", Attachment III) for Section 6 of this report. For many solids that are in the EQ6 database, the molar volumes are not available. These solids are flagged in the database with fictitious molar volumes of "500". Version 7.2bLV of EQ6 ignores the minerals with a molar volume of "500" when it calculates the total mineral volume. For the current study, the data0 file contains valid molar volume entries for the solids that comprise the vast bulk of the volume, such as hematite, nontronite, trevorite, and pyrolusite. Molar volumes have also been added for several minerals as outlined in Section 5.1.7; therefore, the error in the density calculations due to a lack of molar volumes for the minor minerals is minimal.

5.1.6 Atomic Weights

Atomic weights were taken from Reference 11 and Reference 12.

5.1.7 Thermodynamic Database

The thermodynamic database used for the EQ6 calculations, "data0.ymd", (Attachment III) is a slightly altered version of the qualified database "data0.ymp" (Ref. 3). Adjustments made to the database do not negatively impact the calculations. For further explanation of changes to the database, see Reference 50, Section 5.1.7, and Reference 53, Section 5.1.7.

The database used in Reference 32 was "data0.nuc". Several changes have been made to the qualified database (Ref. 3), which were not in the "nuc" database. Some of these include changes to U bearing minerals such that those with questionable thermodynamic data were removed. The Log K was also changed for several minerals including soddyite. This has the net effect of allowing different U minerals to form in the WP for the current calculation than those formed in Reference 32.

5.1.8 Data Conversion

The data presented in Section 6 are transformed into EQ3/6 format by converting weight percents into moles per 100g; normalizing surface areas, volumes, and moles to one liter reactive water in the system; and converting rate constants to moles/(cm^2·s). In Section 6, the "moles" in plots are for the sub-sampled (one liter fluid) EQ6 system for all EQ6 solid special reactants. To obtain the actual mass (g) of a reactant in the WP, multiply *plotted* moles by (100 g/mole)·(4102 liters void space in the WP). To obtain the actual mass of a mineral in the WP, multiply *plotted* moles by (mineral molecular weight)·(4102 liters void space in the WP). The mineral molecular weights are given in the EQ3/6 database ("data0.ymd"), which is included in the electronic file distribution for this document (Attachment III).

5.1.9 Suppressed Minerals

The following minerals were suppressed (not allowed to form) in **all** EQ6 runs:

Quartz	Celadonite	Dolomite-ord
Tridymite	Dolomite	Annite
Muscovite	Dolomite-dis	Phlogopite
$BaZrO_3$	$CaZrO_3$	

The micas (muscovite, annite, and phlogopite) and celadonite are high temperature minerals that, although thermodynamically favored to form at the low 25°C temperature expected for the proposed repository, rarely do. Dolomite growth is also rarely seen at 25°C, so it was also suppressed. The more stable quartz and tridymite were suppressed because repository waters are often supersaturated with respect to quartz, suggesting that if it is growing near the repository horizon, it is doing so slowly. The Zr minerals are carryovers from the previous calculation (Ref. 32). $BaZrO_3$ was removed from the current database due to suspicions about data quality. $CaZrO_3$ remains in the database but is still suppressed because it is not known to form at low temperatures

In several runs, the iron (Fe) mineral hematite (Fe_2O_3) was suppressed to observe the effects that the precipitation of the most thermodynamically stable Fe mineral has on the loss of materials from the WP.

5.2 EQ6 CALCULATIONS

5.2.1 Scenarios Considered

The rationale for selection of scenarios in EQ6 simulations is to provide conservative criticality assessments of solubility and transport of fissile materials (i.e., U compounds) and criticality control materials (Gd, the neutron absorber) from the WP. An internal criticality event is possible if fissile material remains behind in the WP while neutron absorbers are flushed out.

The "*Disposal Criticality Analysis Methodology Topical Report*" document defines the internal and external degradation scenarios for disposal criticality analysis (Ref. 22, pp. 3-8 through 3-16). The internal degradation configurations are based on the assumption that groundwater drips onto the upper surface of the WP and penetrates it. Groundwater accumulates inside the WP, which could dissolve and flush the SNF from the WP. The following is a summary of three groups of degradation configurations from Reference 22:

- WP internals degrade faster than the waste forms
- WP internals degrade at the same rate as the waste form
- WP internals degrade slower than the waste forms.

The WP internals include all components within the WP, except SNF. The waste forms refer to Enrico Fermi SNF and HLW glass. The above configurations set the framework in which EQ6

scenarios could be developed.

The proposed criticality control material (Gd) is incorporated into $GdPO_4$ shot. Degradation of the $GdPO_4$ shot is expected to yield varied amounts of (1) aqueous (dissolved) Gd and (2) a solid Gd phosphate, possibly $GdPO_4 \cdot 10H_2O$. Gadolinium phosphate is sparingly soluble in neutral solutions, though the solubility does increase at low and high pH (Ref. 4, Section 5.3.1). Formation of $GdPO_4 \cdot 10H_2O$ is expected to be the controlling solid phase because of the amount of phosphate from degrading stainless steel and HLW glass. Dissolution of solid Gd carbonates and phosphates, at high pH, is also enhanced by dissolved carbonate. Uranium is also quite soluble in the alkaline, carbonate-rich solutions produced when HLW glass degrades. Thus the matrix of EQ6 calculations should include scenarios that may yield both low pH and high pH conditions, particularly high pH with high dissolved carbonate.

Low-pH conditions are likely to occur when the stainless steel of the inner sleeve degrades separately from the HLW glass. To obtain sustained, low-pH conditions it is generally necessary to break the degradation process into two stages. The first stage involves an early breach of the 304L stainless steel canisters holding the HLW glass, followed by fast degradation of the HLW glass and removal of the alkaline components during a period of relatively high drip rate. In the second stage, the 316L DOE canister holding the fuel assemblies is allowed to breach, exposing some portion of the fuel to acid conditions. To keep the pH low, the drip rate must be reduced for the second stage.

Another way to sustain a low pH is to assume that the DOE canister is breached and the 304L GPCs are not. The first stage involves early breach of the DOE SNF canister. The degradation of the stainless steels causes the pH to drop below neutral. During the second stage, the 304L GPCs breach and the degradation of the HLW glass causes the pH to rise.

Thus, the reaction scenarios can be divided into two general categories:

Single-Stage Cases – in these calculations, all reactants (steels, HLW glass, and fissile materials) are *exposed* simultaneously to the water in the WP. Because the reaction rates of the materials in the WP may vary greatly, all materials do not necessarily *degrade* simultaneously. These cases correspond to an extreme where the fuel is exposed to degradation immediately. These cases result in the highest dissolved radionuclide levels, and might provide the most conservative estimate of fissile material loss.

Two-Stage Cases – Involve breaking up the case into stages where different components are degraded separately from one another.

Scenario I – In the first stage, the A516 outer web (basket) and the GPCs (HLW glass and 304L steel) are first exposed to water, until the HLW glass is completely degraded and its alkalinity largely flushed out of the system. The first stage is actually run twice; once up to approximately three times as long as is required to degrade the HLW glass, in order to locate the true pH minimum; and it is run a second time, just to the commencement of the low-pH plateau, to create an EQ6 pickup file for the second stage. This repetitive process ensures that the maximum acidity will be achieved in the second stage. In the second stage, the contents of the DOE canister are added as reactants. The aim of the Type I two-stage runs is to force a "conservative" condition of high acidity, by degrading the HLW glass rapidly, before all the acid-producing

steel is degraded. The early HLW glass degradation and flushing requires very high HLW glass degradation rates; the total effective rate of the HLW glass is further increased by considering cracks as part of the total surface area. These high HLW glass degradation rates, if used with a slow flush rate, can produce unreasonably high ionic strengths (>1); such high ionic strengths are beyond the applicability of EQ3/6's "B-Dot" activity coefficient corrections.

Scenario II - In the first stage all of the WP components are exposed to degradation except for the HLW glass. Once the GPCs are approximately 2/3 consumed, stage two begins with the addition of the HLW glass to the system. The aim of the Scenario II cases is to force a condition of high acidity by excluding the HLW glass from the system in stage one. The high acidity causes most of the U in the system to precipitate out of solution into minerals. When stage two begins and the glass starts to degrade, the pH of the system will rise to basic levels causing the U minerals to dissolve. Since most of the U in solution is from the fuel, the enrichment fraction of the solution during this time period should be very high. In the extremely acidic condition (pH of 3 to 4) during the first stage, Gd minerals are unstable, and dissolve causing loss of Gd from the WP.

5.2.2 EQ6 Case Nomenclature

This study included 20 single-stage cases (including 3 source term cases) and 8 two-stage cases (including 3 source term cases), with varied combinations of steel, HLW glass, and fuel degradation rates with differing water fluxes. The names for the EQ6 input files, corresponding to each run, consists of the file name with the extension ".6i". For example, the EQ6 input file name for Case 1 is nm1x1321.6i. These input files are included in Attachment III. Each EQ6 run has associated tab-delimited text files, also included in Attachment III. Most of the important run conditions could be inferred from the root-file name. For most cases, the root-filename is evaluated from left to right, as follows:

The first character "n" indicates Enrico Fermi DOE Owned Fuel

The second character has different meanings:

- "c" indicates that the log fCO_2 = -2 (log fCO_2 = -3 in all other cases)
- "m" for minor constituents of J-13 water taken as trace (for all cases that have another symbol for the second character, minor constituents are still set to trace)
- "g" indicates that hematite has been suppressed.
- "t" indicates that the total surface area of the 316NG liner was exposed to degradation instead of the usual assumption that only the inside is significantly exposed to degradation.
- "A" indicates the $GdPO_4$ degradation rate is the same as A516 carbon steel
- "L" indicates the $GdPO_4$ degradation rate is the same as 304L stainless steel

The third character is "1" for one-stage runs and first stage of a two-stage run. "2" indicates the second stage of two-stage runs.

The fourth character has different meanings:

- "n" indicates that the new glass rate from Reference 46 has been used (all other cases use the glass rate indicated in Reference 28).
- "d" indicates that the mass of the $GdPO_4$ in the WP was doubled.
- Because of the size of some files, the runs had to be divided among several input files to obtain a time of 6.34E+05 years. The fourth character indicates the subdivision by:
  - "x" first part
  - "y" second part
  - "z" third part

The fifth character is "1", "2", or "3" corresponding to "low", "average", and "high" steel degradation rates respectively.

The sixth character is "3" or "4" indicating a "low" or "high" pH-dependent glass degradation rate respectively. No glass exposed to the system is indicated with a "0".

The seventh character is indicative of the degradation rate of the fuel. "2" indicates the "low" degradation rate given in Table 5, and "3" indicates the "high" rate. No fuel exposed to the system is indicated with a "0".

The eighth character in the block indicates the choice of water flush rate, with "1", "2", and "3" indicating 0.0015 m^3/y, 0.015 m^3/y, and 0.15 $m^3/$ respectively.

6. RESULTS

6.1 SUMMARY OF RESULTS

Technical product input information requiring confirmation may affect this document. Subsequent revisions will reflect any document changes occurring as a result of completing confirmation activities. A review of the DIRS database will confirm the status of the technical product input information.

6.1.1 Gd and U Retention: One-stage Runs

Table 10 through Table 12 summarize the total percentage of Gd and U moles retained at the end of the one-stage EQ6 runs and compare cases that are similar to those in Reference 32. Several new cases (e.g., those with fast steel rates) have no equivalent in the older calculation (Ref. 32).

Table 10. Summary of Gd Retention[e] for One-stage EQ6 Runs

Case	File Name	File Name (Previous Study)[c]	Gd Retention ~250,000 Years (Previous Study)[c]	Gd Retention ~250,000 Years[d]	Length of Run (Years)	Gd Retention at End of Run[a]
1	nm1x1321	-----[b]	-----	-----	634,350	100.00%
2	nm1x1331	N07_1111	99.50%	99.80%	634,370	99.77%
3	nm1(xy)1333	N06_1113	99.53%	97.20%	411,730	96.55%
4	nm1x2331	N10_2111	97.70%	99.60%	669,380	99.56%
5	nm1x2422	-----	-----	-----	633,780	99.66%
6	nm1x2432	N12_2212	99.97%	99.50%	633,780	99.34%
7	nm1{xyz}3323	-----	-----	-----	633,780	95.53%
8	nm1{xyz}3333	-----	-----	-----	622,460	94.64%
9	nm1{xyz}3433	-----	-----	-----	618,580	95.98%
10	ng1{xyz}3323	-----	-----	-----	633,780	95.42%

NOTES: [a] Gd retention calculated at ~634,000 years in "fermi-losses.xls" (Attachment III).
[b] All blank spaces represent no applicable data or not directly correlative.
[c] From Ref. 32 (Table 5-9).
[d] Calculated in "losses-oldtime.xls" (Attachment III).
[e] Retention of Gd is presented in percentage of total initial moles retained within the WP.

All cases run for this calculation predicted more than 94.5% Gd retention in the WP. As the drip rate increases, the loss of Gd also increases, but only slightly (up to 5%). For more information on effects of reactant rates on Gd loss, see Reference 53 (Section 6.2.8.1). The increased phosphorus (P) from the inner sleeve allows Gd retention even at lower pH values due to the formation of $GdPO_4 \cdot 10H_2O$, a very low solubility compound. In comparable cases, Gd retention (at 250,000 years) closely parallels the older runs in Reference 32, Table 5-9. Since the cases from the older calculation were run out to only 250,000 years, it is unclear as to whether the levels of Gd in the WP would have remained high, or more losses would have been predicted over a longer time frame.

When the "data0.nuc" database was used in Reference 32, the major Gd mineral to form during the degradation of the $GdPO_4$ shot was less hydrated than the Gd mineral that forms when "data0.ymd" (Ref. 3) is used ($GdPO_4 \cdot H_2O$ versus $GdPO_4 \cdot 10H_2O$). Reference 54, Section 6.8.3 shows that this difference in $GdPO_4$ hydration has no effect on Gd retention within the WP.

Table 11. Summary of Intact Fuel and Glass in WP for One-stage EQ6 Runs

Case	File Name	Length of Run (Years)	% Fuel Left in the WP at End of Run[a]	% of Total U moles in the Fuel[a]	% of Glass in the WP at End of Run[a]
1	nm1x1321	634,350	95.76%	70.01%	46.33%
2	nm1x1331	634,370	0.00%	0.00%	48.36%
3	nm1(xy)1333	411,730	0.00%	0.00%	0.00%
4	nm1x2331	669,380	0.00%	0.00%	0.00%
5	nm1x2422	633,780	95.76%	70.01%	0.00%
6	nm1x2432	633,780	0.00%	0.00%	0.00%
7	nm1{xyz}3323	633,780	95.76%	70.01%	0.00%
8	nm1{xyz}3333	622,460	0.00%	0.00%	0.00%
9	nm1{xyz}3433	618,580	0.00%	0.00%	0.00%
10	ng1{xyz}3323	633,780	95.76%	70.01%	0.00%

NOTES: [a] Calculated in spreadsheet "fermi-losses.xls" (Attachment III).

Table 12. Summary of U Retention[e] for One-stage EQ6 Runs

Case	File Name	File Name (Previous Study)[c]	U Retention ~250,000 Years (Previous Study)[c]	U Retention ~250,000 Years[d]	Length of Run (Years)	U Retention at End of Run[a]
1	nm1x1321	-----[b]	-----	-----	634,350	99.82%
2	nm1x1331	N07_1111	86.03%	99.83%	634,370	99.60%
3	nm1(xy)1333	N06_1113	7.43%	75.43%	411,730	69.68%
4	nm1x2331	N10_2111	7.40%	0.00%	669,380	0.00%
5	nm1x2422	-----	-----	-----	633,780	70.61%
6	nm1x2432	N12_2212	39.00%	0.00%	633,780	0.00%
7	nm1{xyz}3323	-----	-----	-----	633,780	70.01%
8	nm1{xyz}3333	-----	-----	-----	622,460	46.97%
9	nm1{xyz}3433	-----	-----	-----	618,580	0.00%
10	ng1{xyz}3323	-----	-----	-----	633,780	71.07%

NOTES: [a] U retention calculated in "fermi-losses.xls" (Attachment III).
[b] All blank spaces represent no applicable data or not directly correlative.
[c] From Ref. 32 (Table 5-9).
[d] Calculated in "losses-oldtime.xls" (Attachment III).
[e] Retention of U is presented in percentage of total initial moles retained within the WP.

Retention of U ranges from 99.82% to 0.00 (at the end of the one-stage runs). Uranium retention stems primarily from the formation of 5 major U-bearing minerals including: $(UO_2)_3(PO_4)_2 \cdot 6H_2O$; α-uranophane $(Ca(UO_2SiO_3OH)_2 \cdot 5H_2O)$; $CaUO_4$; schoepite $(UO_3 \cdot 2H_2O)$; and Na-boltwoodite $(NaUO_2SiO_3OH \cdot 1.5H_2O)$. In the previous study (Ref. 32), soddyite $((UO_2)_2SiO_4 \cdot 2H_2O)$ is the only major U bearing mineral reported in the calculation, though haiweeite $(Ca(UO)_2(Si_2O_5)_3 \cdot 5H_2O)$, and $Na_4UO_2(CO_3)_3$ were probably also present as minor U minerals (Ref. 32, Section 5.1.7). The differences in U retention in the U-bearing minerals formed have to do with 3 changes made from the previous calculation. The first, and probably most important, change is the addition of the 316NG liner which significantly affects the chemistry (most notably, pH) of the system, especially at slower steel degradation rates, compared to the previous calculation. The second change is the database used in this calculation ("data0.ymd") which is a slightly altered version of the qualified database "data0.ymp" (Ref. 3). The previous calculation used the unqualified database "data0.nuc" (Attachment III). A third change worth mentioning is that the new calculation uses a pH dependent glass degradation rate.

Due to the large number of cases prepared for this calculation, only figures and tables for representative cases are presented in this calculation. The times used in all tables are indicative of periods of interest due to low or high pH, significant changes in aqueous U or Gd concentration, or when major components are completely degraded.

The results of Case 1 (nm1x1321), shown in Figure 1 and Table 13 and Table 14, demonstrate the consequences of WP degradation with a slow steel rate, slow pH dependant glass rate, slow fuel rate, and 0.0015 m^3/y drip rate. The consequences include: changes in pH, variations in the dissolved U content of the water flushed from the WP, and the formation of solubility-controlling and space-filling materials and solid solutions. The pH of the system decreases with steel degradation followed by a slight increase when the 316L from the DOE canister and basket as well as the 304L from the GPCs are exhausted. Since the HLW glass is degrading slowly, the alkalinity from the glass is insufficient to neutralize the pH until all the steel is consumed at around 600,000 years when the 316NG liner is exhausted. The Mg and Ca carbonate minerals formed from the dissolution of HLW glass do not fully neutralize the acid produced from steel corrosion until this point. The steel degradation causes lower pH conditions due to the oxidation of the Cr and Mo released upon steel degradation. Since pH remains low for an extended time, much of the HLW glass (46.33%) remains intact.

Figure 1 also shows the concentration of aqueous U and the prominent mineral phases of this element. Phosphates, associated with increased phosphorus from the degradation of the 316NG liner, dominate in this case. Uranium retention is high (99.82%) because not only are conditions conducive to U-mineral formation, but 95.75% of the fuel (70% total U) and 46% of the glass (12.5% total U) remains intact. This accounts for 82.5% of the total U in the WP.

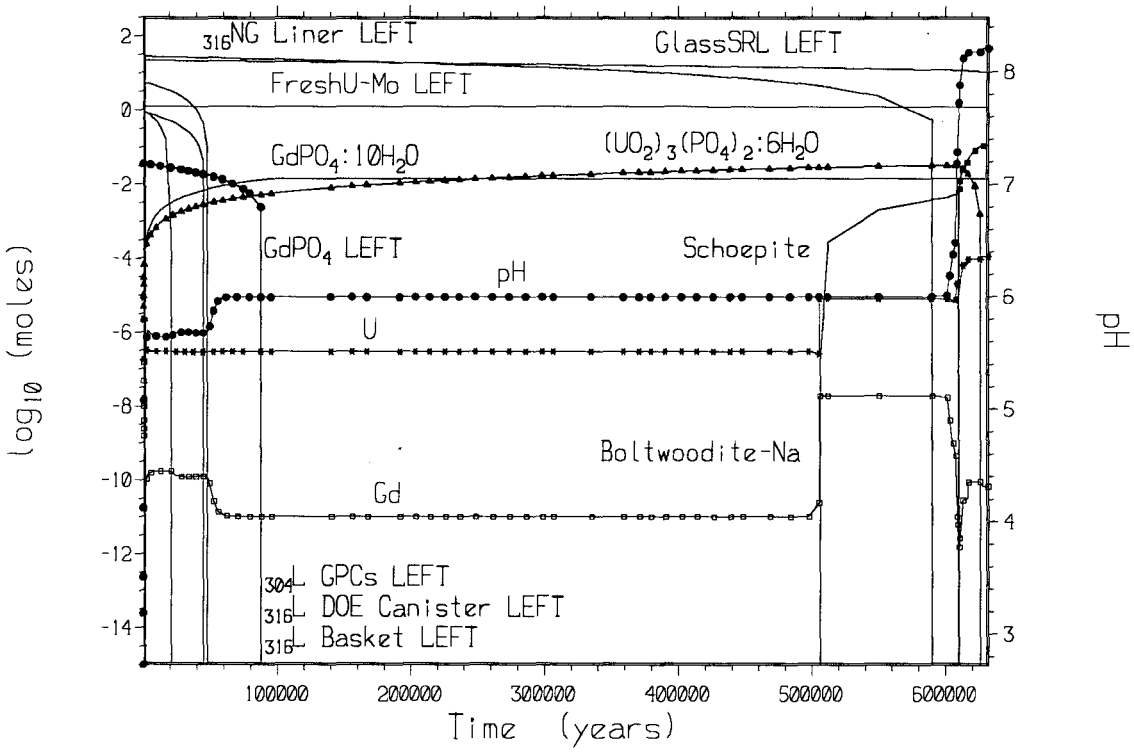

Figure 1. Case 1 (nm1x1321): WP Materials, Minerals, and Aqueous U

Table 13. Case 1 (nm1x1321): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years				
	20844	505630	550280	610290	634350
O	6.79E+02	1.81E+03	1.91E+03	2.03E+03	2.08E+03
Al	2.13E+01	3.99E+01	4.16E+01	4.40E+01	4.75E+01
B	4.91E-15	6.55E-14	2.31E-13	0.00E+00	1.31E-09
Ba	6.40E-02	1.26E+00	1.37E+00	1.52E+00	1.75E+00
Ca	3.54E-01	7.03E+00	7.65E+00	8.46E+00	9.58E+00
Cl	0.00E+00	0.00E+00	0.00E+00	3.11E-15	0.00E+00
Cr	2.42E-02	4.78E-01	5.20E-01	1.80E-11	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	0.00E+00	0.00E+00	6.14E-03	7.47E-02
Fe	1.42E+03	3.19E+03	3.33E+03	3.49E+03	3.51E+03
Gd	4.84E-01	2.19E+00	2.19E+00	2.19E+00	2.19E+00
H	1.94E+00	6.19E+00	6.58E+00	8.22E+00	7.83E+00
C	1.26E-13	0.00E+00	0.00E+00	1.33E-01	1.53E-01
P	6.67E-01	2.11E+00	2.22E+00	2.34E+00	1.91E+00
K	0.00E+00	5.67E+00	6.20E+00	7.19E+00	1.10E+01
Mg	7.37E-02	5.55E+00	6.06E+00	6.79E+00	7.94E+00
Mn	2.10E+01	7.26E+01	7.67E+01	8.14E+01	8.14E+01
Mo	8.47E-01	1.68E+01	1.83E+01	1.98E+01	1.17E+01
N	0.00E+00	0.00E+00	0.00E+00	4.16E-16	0.00E+00
Na	0.00E+00	7.37E-01	7.98E-01	2.42E+00	1.70E+01
Ni	5.85E+00	1.44E+02	1.57E+02	1.72E+02	1.72E+02
S	0.00E+00	0.00E+00	0.00E+00	3.33E-13	0.00E+00
Si	1.70E+01	2.22E+02	2.40E+02	2.65E+02	2.98E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	9.51E-01	1.94E+01	2.10E+01	2.33E+01	2.61E+01
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**529**	**1353**	**1420**	**1504**	**1532**
Density (g/cm^3)	**5.04**	**4.71**	**4.70**	**4.67**	**4.62**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 14. Case 1 (nm1x1321): Solution Composition in Molality

Element	Years				
	20844	**505630**	**550280**	**610290**	**634350**
Al	1.03E-05	2.23E-06	2.16E-06	3.26E-08	1.14E-07
B	1.51E-02	1.31E-02	1.30E-02	1.80E-02	5.28E-02
Ba	8.96E-07	4.65E-07	4.65E-07	6.48E-08	5.81E-09
Ca	9.29E-05	1.14E-04	1.14E-04	5.63E-04	1.69E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	2.09E-01	4.09E-02	4.09E-02	9.73E-03	3.15E-07
Cu	2.84E-07	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	2.03E-04	1.91E-04	1.91E-04	1.39E-13	2.35E-14
Fe	1.01E-11	4.42E-12	4.42E-12	1.17E-12	1.16E-12
Gd	1.69E-10	2.37E-11	1.84E-08	1.46E-12	6.72E-11
C	4.03E-05	5.28E-05	5.36E-05	8.70E-04	3.43E-03
P	1.59E-05	1.28E-05	3.44E-08	1.87E-05	1.44E-03
K	4.02E-03	2.66E-03	2.66E-03	1.83E-03	2.03E-03
Mg	2.08E-03	2.81E-04	2.81E-04	1.33E-04	4.59E-04
Mn	1.34E-10	1.61E-11	1.61E-11	6.14E-15	7.43E-16
Mo	6.66E-03	2.35E-03	2.35E-03	3.98E-04	9.29E-03
N	4.27E-03	8.56E-04	8.56E-04	1.62E-04	1.42E-04
Na	3.18E-02	2.77E-02	2.77E-02	1.93E-02	2.96E-02
Ni	1.00E-01	1.20E-02	1.20E-02	4.53E-06	3.75E-07
S	9.66E-04	4.88E-04	4.88E-04	4.49E-04	9.17E-04
Si	5.66E-05	5.66E-05	5.66E-05	4.22E-05	3.96E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	2.89E-07	2.53E-07	7.73E-06	1.16E-05	1.08E-04
Zn	1.81E-07	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**5.64**	**6.00**	**6.00**	**7.65**	**8.21**

Case 2 (nm1x1331), shown in Figure 2 and Table 15 and Table 16, demonstrates the consequences of WP component degradation when the conditions of Case 1 are combined with a fast fuel degradation rate. There is little effect on pH and the retention of Gd and U change very little. The major difference is that the density of the "sludge" formed in the WP increases slightly due to the increased amount of heavy elements added to the system by the completely degraded fuel. Once again, nearly half of the HLW glass remains intact due to the sustained low pH during most of the run.

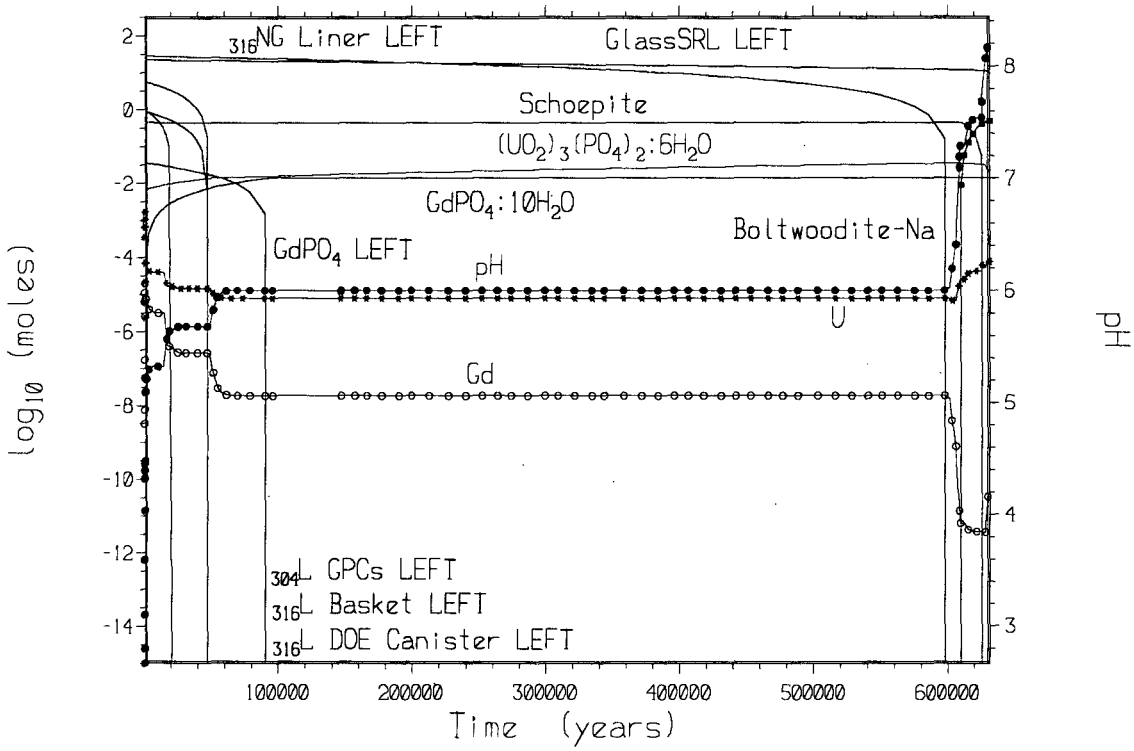

Figure 2. Case 2 (nm1x1331): WP Materials, Minerals, and Aqueous U

Uranium retention for Case 2 (at 250,000 years) is 13% (total U) higher than Case 3 (N07_1111) of Reference 32. This is due to the early rise in pH to almost 9 at 100,000 years in old Case 3. Since U minerals are highly soluble at higher pH values, more U (in the form of stable carbonate and hydroxyl complexes in solution) is lost from the WP. The addition of the 316NG liner in the current calculation keeps the pH low (around 6) until late in the run. Because of this lower pH, more U-bearing minerals are able to form and the U is retained in the WP.

Table 15. Case 2 (nm1x1331): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	28306	91461	628190	634370
O	7.61E+02	9.81E+02	2.09E+03	2.10E+03
Al	2.18E+01	2.43E+01	4.56E+01	4.65E+01
B	2.86E-13	6.92E-13	1.40E-11	0.00E+00
Ba	9.57E-02	2.58E-01	1.63E+00	1.69E+00
Ca	5.39E-01	1.42E+00	9.03E+00	9.30E+00
Cl	0.00E+00	0.00E+00	0.00E+00	1.16E-12
Cr	3.62E-02	9.76E-02	0.00E+00	8.05E-14
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	0.00E+00	4.03E-02	5.75E-02
Fe	1.51E+03	1.89E+03	3.50E+03	3.50E+03
Gd	6.53E-01	2.12E+00	2.19E+00	2.19E+00
H	3.60E+00	4.39E+00	1.02E+01	9.79E+00
C	0.00E+00	0.00E+00	1.42E-01	1.47E-01
P	8.00E-01	1.35E+00	2.56E+00	2.49E+00
K	0.00E+00	7.97E-01	9.00E+00	9.94E+00
Mg	8.77E-03	7.78E-01	7.31E+00	7.61E+00
Mn	2.36E+01	3.47E+01	8.14E+01	8.14E+01
Mo	1.29E+00	3.41E+00	1.88E+01	1.73E+01
N	0.00E+00	0.00E+00	0.00E+00	8.43E-15
Na	0.00E+00	2.29E-01	1.02E+01	1.42E+01
Ni	2.89E+00	1.91E+01	1.68E+02	1.68E+02
S	0.00E+00	0.00E+00	0.00E+00	2.02E-10
Si	2.29E+01	5.21E+01	2.80E+02	2.89E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.11E+02	1.13E+02	1.30E+02	1.30E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**600**	**762**	**1552**	**1559**
Density (g/cm^3)	**5.02**	**4.95**	**4.65**	**4.64**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 16. Case 2 (nm1x1331): Solution Composition in Molality

Element	Years			
	28306	**91461**	**628190**	**634370**
Al	8.48E-06	2.16E-06	5.45E-08	1.00E-07
B	1.48E-02	1.31E-02	3.12E-02	4.84E-02
Ba	8.16E-07	4.64E-07	1.49E-08	6.65E-09
Ca	1.43E-04	1.15E-04	5.70E-05	2.02E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.72E-01	4.09E-02	8.77E-06	7.34E-07
Cu	1.49E-08	1.00E-16	1.00E-16	1.00E-16
F	2.01E-04	1.91E-04	3.08E-12	2.04E-14
Fe	9.10E-12	4.42E-12	1.14E-12	1.15E-12
Gd	2.54E-07	1.84E-08	1.85E-12	3.32E-11
C	4.22E-05	5.36E-05	1.51E-03	2.91E-03
P	2.41E-08	3.44E-08	1.95E-05	8.88E-04
K	3.96E-03	2.66E-03	9.10E-04	1.98E-03
Mg	1.56E-03	2.81E-04	3.34E-05	2.11E-04
Mn	1.05E-10	1.60E-11	1.52E-15	7.97E-16
Mo	3.87E-03	2.32E-03	1.05E-03	6.16E-03
N	3.45E-03	8.56E-04	1.42E-04	1.42E-04
Na	3.13E-02	2.77E-02	5.68E-03	2.10E-02
Ni	7.88E-02	1.20E-02	1.03E-06	4.36E-07
S	8.53E-04	4.88E-04	6.20E-04	8.57E-04
Si	5.68E-05	5.66E-05	4.25E-05	4.01E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.40E-05	7.73E-06	5.25E-05	7.54E-05
Zn	1.32E-08	1.00E-16	1.00E-16	1.00E-16
pH	**5.68**	**6.00**	**7.91**	**8.16**

Case 3 (nm1(xy)1333), shown in Figure 3 and in Table 17 and Table 18, demonstrates WP component degradation for the same conditions as Case 2, except with a drip rate 100 times faster. There is a strong effect on pH and U retention. When drip rate increases, pH rises since the acid released during the degradation of the steel will be flushed out of the WP. As the pH increases, the degradation of the HLW glass also increases allowing for a slightly basic (rather than slightly acidic) solution inside the WP. The higher pH in this case (~8.1) compared to that of Case 2 (~6.4) allows the loss of 30% more total U from the WP. The effect on Gd retention is minor. The $GdPO_4 \cdot 10H_2O$, although very stable, undergoes slightly more dissolution as the fluid within the WP changes from acidic to alkaline conditions at around 50,000 years. The result is 3% more loss of the total Gd in the package.

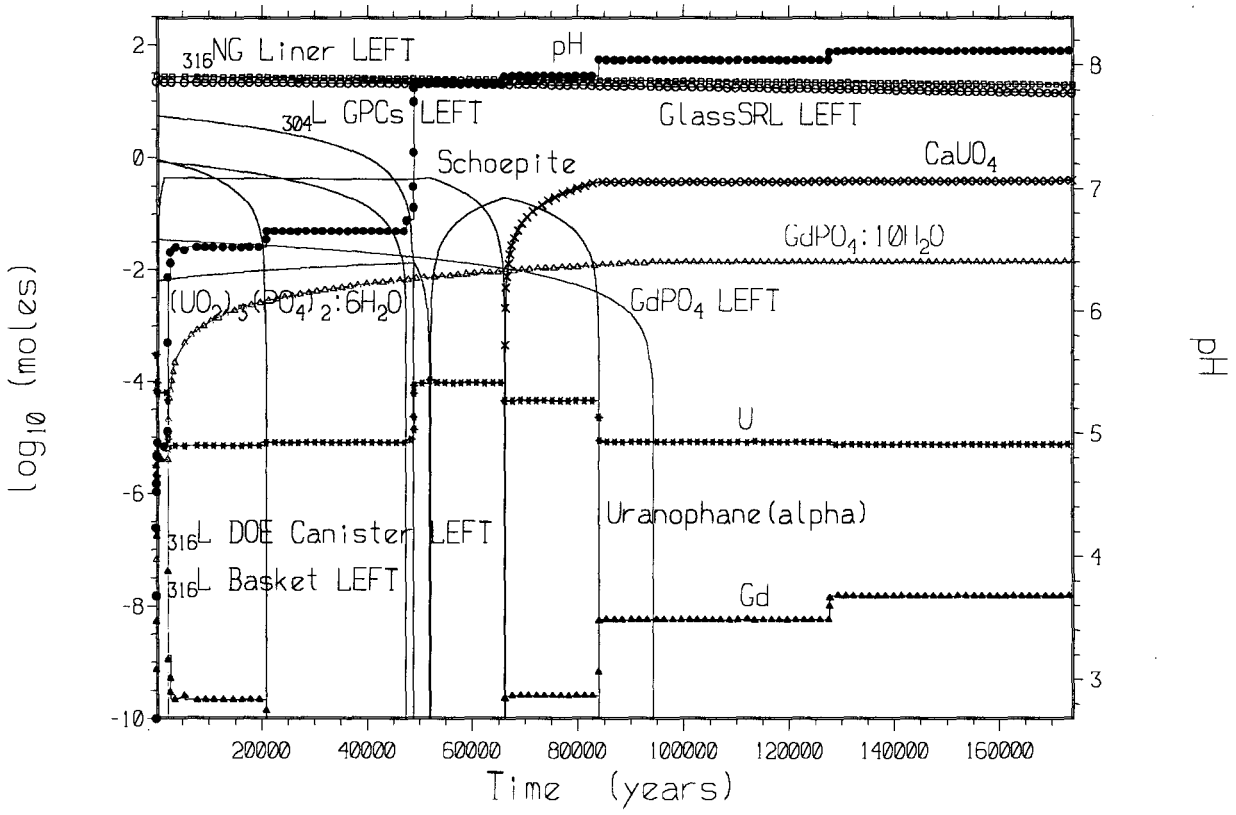

Figure 3. Case 3 (nm1{xy}1333): WP Materials, Minerals, and Aqueous U

Uranium retention for Case 3 (at 250,000 years) is 68%, total U, higher than Case 2 (N06_1113) of Reference 32 due primarily to the early rise in pH to 8.4 at approximately 50,000 years in old Case 2. The slightly lower pH (8.1) for Case 3 of the current calculation allows more U to remain in minerals, thus, more U is retained within the WP. The slightly lower pH is due to the presence

of the degrading 316NG liner. Like the other stainless steels, the oxidation of Cr and Mo released from the 316NG liner helps keep the pH slightly lower, even with the high flush rate.

Table 17. Case 3 (nm1{xy}1333): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years				
	2905	23280	52034	174160	411730
O	5.88E+02	7.68E+02	9.79E+02	1.56E+03	2.71E+03
Al	2.04E+01	2.13E+01	2.28E+01	3.89E+01	7.10E+01
B	0.00E+00	6.41E-15	0.00E+00	5.46E-14	0.00E+00
Ba	4.59E-15	0.00E+00	2.28E-02	1.06E+00	3.14E+00
Ca	1.07E+00	2.63E+00	6.78E+00	3.70E+01	6.52E+01
Cl	9.85E-14	0.00E+00	0.00E+00	0.00E+00	8.67E-16
Cr	2.17E-09	0.00E+00	0.00E+00	0.00E+00	1.52E-12
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	9.39E-13	0.00E+00	1.68E-01	2.40E-01	3.84E-01
Fe	1.15E+03	1.45E+03	1.76E+03	2.20E+03	3.04E+03
Gd	1.79E-02	4.91E-01	1.16E+00	2.14E+00	2.12E+00
H	4.23E+00	4.69E+00	5.34E+00	8.01E+00	1.92E+01
C	9.73E-12	0.00E+00	2.00E-03	9.30E-02	2.75E-01
P	4.27E-01	7.21E-01	1.05E+00	1.59E+00	2.30E+00
K	2.64E-13	0.00E+00	3.18E-18	0.00E+00	1.90E-15
Mg	1.07E-02	0.00E+00	3.54E-01	4.77E+00	7.79E+00
Mn	1.31E+01	2.19E+01	3.11E+01	4.23E+01	6.40E+01
Mo	1.22E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-16
N	1.84E-13	0.00E+00	1.14E-18	0.00E+00	8.04E-16
Na	1.27E-12	0.00E+00	8.53E-02	2.43E+00	2.42E-14
Ni	2.75E-01	2.36E+01	5.63E+01	1.23E+02	2.53E+02
S	1.38E-11	0.00E+00	1.74E-18	0.00E+00	1.60E-13
Si	9.04E+00	4.10E+01	8.73E+01	3.66E+02	8.98E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.09E+02	1.08E+02	1.05E+02	9.27E+01	1.05E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**463**	**595**	**746**	**1090**	**1764**
Density (g/cm^3)	**4.99**	**4.90**	**4.81**	**4.34**	**3.97**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 18. Case 3 (nm1{xy}1333): Solution Composition in Molality

Element	Years				
	2905	23280	52034	174160	411730
Al	3.17E-08	1.64E-08	5.17E-08	6.44E-08	1.03E-15
B	1.41E-04	1.52E-04	3.94E-04	4.81E-04	1.00E-16
Ba	5.34E-07	5.72E-07	1.37E-08	5.33E-09	1.16E-08
Ca	3.36E-04	2.65E-04	1.50E-05	2.60E-04	3.53E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	2.09E-03	1.70E-03	4.09E-04	4.09E-04	4.09E-04
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.16E-04	1.16E-04	1.16E-04	1.17E-04	1.14E-04
Fe	1.92E-12	1.70E-12	1.14E-12	1.15E-12	1.14E-12
Gd	2.18E-10	9.29E-11	3.00E-11	1.53E-08	7.29E-09
C	9.19E-05	1.12E-04	1.47E-03	2.24E-03	1.49E-03
P	8.30E-08	1.12E-07	4.46E-07	2.55E-09	2.31E-09
K	1.65E-04	1.68E-04	2.31E-04	2.53E-04	1.29E-04
Mg	1.49E-04	1.00E-04	7.77E-06	1.35E-04	1.84E-04
Mn	8.09E-13	4.24E-13	1.42E-15	6.79E-16	1.23E-15
Mo	1.99E-04	4.55E-05	3.26E-05	3.26E-05	3.26E-05
N	1.83E-04	1.74E-04	1.49E-04	1.49E-04	1.49E-04
Na	2.27E-03	2.29E-03	2.93E-03	2.97E-03	1.99E-03
Ni	6.05E-04	3.17E-04	9.80E-07	3.78E-07	8.28E-07
S	1.99E-04	1.98E-04	1.98E-04	1.99E-04	1.93E-04
Si	5.12E-05	5.02E-05	4.49E-05	3.94E-05	1.92E-04
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	7.17E-06	8.19E-06	1.12E-04	7.50E-06	2.32E-06
Zn	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**6.52**	**6.66**	**7.90**	**8.12**	**7.94**

Case 4 (nm1x2331), shown in Figure 4 and in Table 19 and Table 20, demonstrates the general consequences of applying an average steel degradation rate to Case 2. In the EQ6 scenarios, higher steel and glass degradation rates must be combined with faster flushing rates or high ionic strengths can occur which are outside the valid range for the qualified EQ6 database (Ref. 3). Case 4 has a maximum ionic strength of 3.15 at around 5000 years, which is above the maximum valid ionic strength of 1.00. Sensitivity tests (Ref. 24, Section 5.1.2) have shown that at ionic strengths between 1.00 and 4.00, the "data0.ymp" (Ref. 3) database overestimates the solubility of Pu and U, which is conservative for external criticality. Cases that simulate ionic strength above 4.00 should not be used.

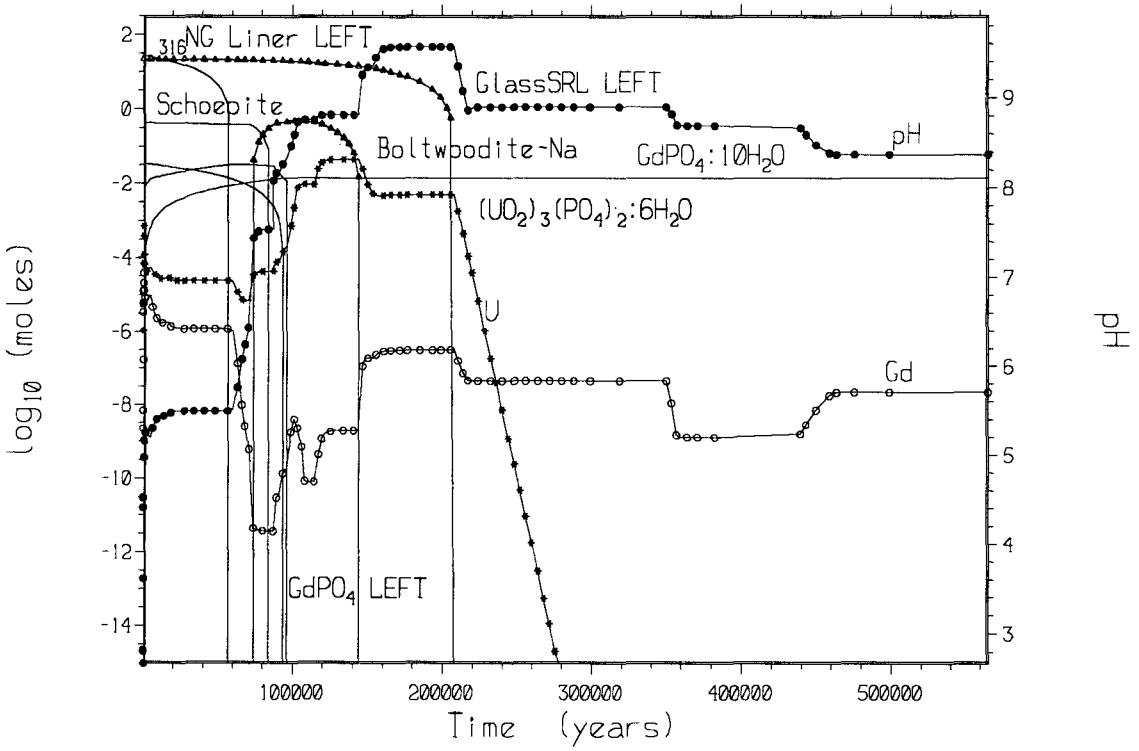

Figure 4. Case 4 (nm1x2331): WP Materials, Minerals, and Aqueous U

In cases such as this, where the steel degrades quickly and the glass slowly, the pH of the system becomes acidic until all steel within the WP is exhausted. Afterwards, the pH becomes basic and peaks while the glass is degrading. Since the pH peaks at around 9.6 for several thousand years, all U is lost from the WP. Some U is retained in runs having slow glass degradation and high drip rates since both parameters help keep the pH from exceeding 8.5.

Uranium retention for Case 4 (at 250,000 years) is 0.00% compared to 7.40% in Case 6 (N10_2111) of Reference 32. Both cases show a marked rise in pH at around 10,000 years when

the stainless steels are fully degraded. However, Case 6 (Ref. 32) has a constant HLW glass degradation rate compared to the pH dependant rate used in Case 4 of the current calculation. As mentioned before, when the pH increases, the rate of glass degradation also increases. For this reason, the pH in Case 4 peaks at 9.6 at 164,000 years. The pH in old Case 6 doesn't reach 9.0 until 250,000 years. Before this point, it remained at 8.4 for almost 90,000 years. The earlier high pH value in Case 4 causes more U to be lost from the WP earlier than the equivalent case (N10_2111) in Reference 32.

Table 19. Case 4 (nm1x2331): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	87597	115700	357970	669380
O	1.72E+03	1.81E+03	2.39E+03	2.39E+03
Al	2.51E+01	3.10E+01	7.11E+01	7.11E+01
B	1.35E-10	0.00E+00	0.00E+00	0.00E+00
Ba	3.11E-01	6.89E-01	3.29E+00	3.29E+00
Ca	1.73E+00	3.49E+00	1.58E+01	1.70E+01
Cl	0.00E+00	4.97E-13	4.55E-16	0.00E+00
Cr	0.00E+00	2.59E-19	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	3.27E-02	1.04E-01	1.57E-01	1.57E-01
Fe	3.41E+03	3.44E+03	3.60E+03	3.60E+03
Gd	2.03E+00	2.18E+00	2.18E+00	2.18E+00
H	5.72E+00	5.29E+00	1.22E+01	1.17E+01
C	2.72E-02	5.02E+00	2.88E-01	1.66E+00
P	2.39E+00	9.37E-01	1.20E+00	1.20E+00
K	2.71E+00	9.53E+00	5.13E+01	4.54E+01
Mg	1.33E+00	3.33E+00	1.74E+01	1.74E+01
Mn	8.14E+01	8.14E+01	8.14E+01	8.14E+01
Mo	1.55E+00	2.82E-17	0.00E+00	0.00E+00
N	0.00E+00	2.09E-17	1.14E-18	0.00E+00
Na	9.31E+00	2.82E+01	1.36E+01	7.14E+00
Ni	2.41E+01	2.41E+01	2.41E+01	2.41E+01
S	0.00E+00	8.27E-11	1.94E-14	0.00E+00
Si	8.32E+01	1.38E+02	5.16E+02	5.19E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.14E+02	1.05E+02	0.00E+00	0.00E+00
Zn	0.00E+00	0.00E+00	0.00E+00	4.95E-13
Total (Kg)	**1337**	**1387**	**1658**	**1656**
Density (g/cm^3)	**4.99**	**4.96**	**4.28**	**4.29**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Given that the pH reached 9 in the previous Case 6, the U present at 250,000 years should escape the WP in a few more thousand years. Therefore, the outcome of the two cases is identical, but the time it takes to reach 100% loss of U is different.

Table 20. Case 4 (nm1x2331): Solution Composition in Molality

Element	Years			
	87597	115700	357970	669380
Al	2.45E-08	4.27E-07	2.06E-07	9.62E-08
B	2.90E-02	8.69E-02	1.00E-16	1.00E-16
Ba	8.45E-08	8.18E-10	4.61E-10	1.70E-09
Ca	2.62E-05	6.52E-07	3.72E-06	8.57E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	8.67E-06	1.14E-10	1.00E-16	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	4.58E-06	5.81E-04	1.15E-04	1.15E-04
Fe	1.18E-12	1.29E-12	1.24E-12	1.17E-12
Gd	3.71E-12	8.03E-11	1.30E-09	2.16E-08
C	6.56E-04	4.03E-02	8.68E-03	3.99E-03
P	1.85E-06	1.09E-04	1.10E-06	7.67E-09
K	6.31E-04	1.15E-03	8.31E-04	1.70E-03
Mg	1.52E-05	6.94E-05	2.93E-05	1.07E-04
Mn	8.17E-15	9.56E-16	6.96E-16	4.65E-16
Mo	2.30E-03	9.63E-07	1.00E-16	1.00E-16
N	1.42E-04	1.42E-04	1.42E-04	1.42E-04
Na	6.67E-03	7.99E-02	8.87E-03	2.78E-03
Ni	5.98E-06	4.24E-08	3.02E-08	1.18E-07
S	5.90E-04	1.38E-03	1.92E-04	1.92E-04
Si	4.67E-05	5.14E-05	4.45E-05	3.96E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	4.26E-05	9.23E-03	1.00E-16	1.00E-16
Zn	1.00E-16	1.00E-16	1.01E-15	1.27E-18
pH	**7.54**	**8.75**	**8.69**	**8.37**

Case 6 (nm1x2432), shown in Figure 5 and in Table 21 and Table 22, demonstrates the consequences of WP degradation with an average steel, fast fuel, and average drip rate combined with a high pH-dependent HLW glass degradation rate.

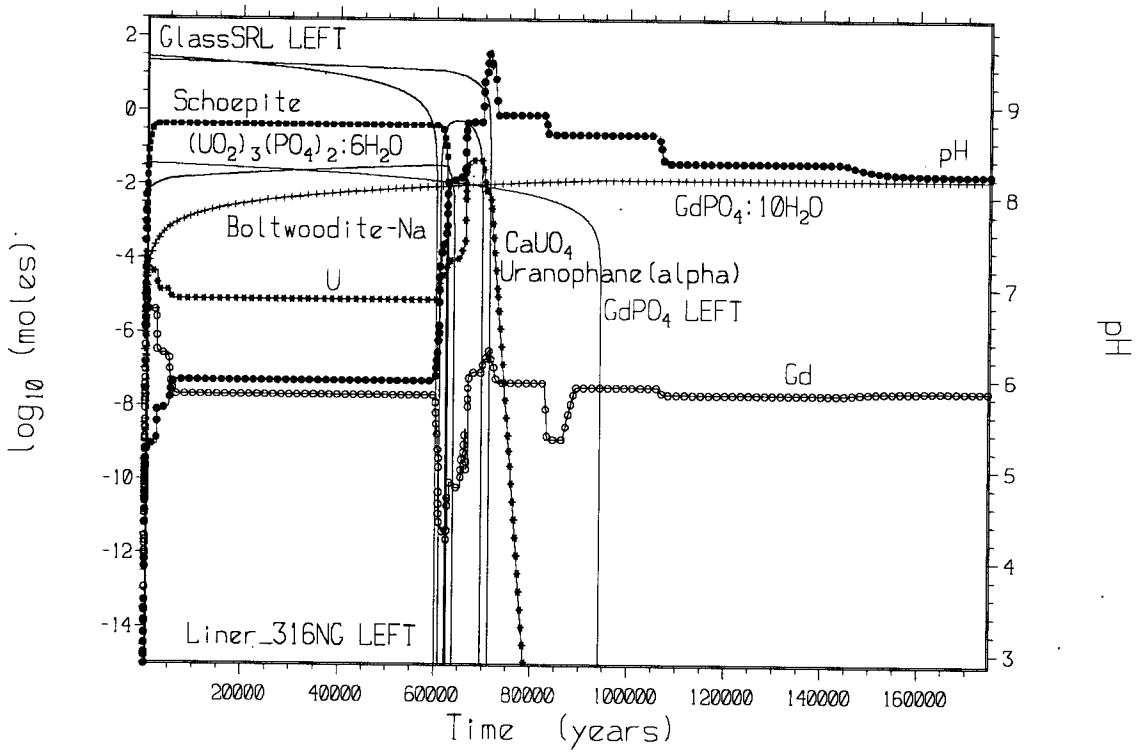

Figure 5. Case 6 (nm1x2432): WP Materials, Minerals, and Aqueous U

Once again, the pH is slightly acidic until all of the steel is degraded at 60,000 years. After this point, the pH increases from ~6.0 to ~9.6 over a period of 10,000 years. At this point, all of the HLW glass is degraded and, eventually, all U is lost from the WP due to the high solubility of U-minerals at the higher pH values.

Case 6 and Case 8 (Ref. 32) differ greatly. Case 6 from the current calculation loses all U from the WP within 80,000 years. On the other hand, Case 8 retains 39% of the U after 250,000 years. Again, the pH dependent versus independent rates of HLW glass degradation become a factor. For Case 6, all the fuel is degraded before the pH peak. At this pH peak, the HLW glass is also fully degraded. Prior to this point, all the U was in U-bearing minerals which are unstable at high pH values. As soon as the pH rose to around 8.8 the minerals dissolved and all the U was flushed from the WP. The constant glass rate in Case 8 (N12_1212, Ref. 32) also caused a pH high of 9.6, however, this occurred at only 1000 years into the run. After this point the pH drops rapidly to below 8 where U minerals can form. At the point where the pH drops, the fuel is still degrading, so about 1/3 of the U is retained within the WP.

Table 21. Case 6 (nm1x2432): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years					
	9360	62473	83355	107530	354250	633780
O	9.72E+02	2.05E+03	2.43E+03	2.43E+03	2.45E+03	2.49E+03
Al	2.38E+01	4.35E+01	7.11E+01	7.11E+01	7.11E+01	7.11E+01
B	3.52E-13	1.28E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba	2.23E-01	1.49E+00	3.28E+00	3.28E+00	3.28E+00	3.28E+00
Ca	1.30E+00	8.47E+00	1.71E+01	1.81E+01	2.27E+01	2.59E+01
Cl	0.00E+00	0.00E+00	4.05E-16	1.63E-17	0.00E+00	1.92E-18
Cr	8.46E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	3.70E-02	2.22E-01	2.22E-01	2.22E-01	2.22E-01
Fe	1.89E+03	3.49E+03	3.60E+03	3.60E+03	3.60E+03	3.60E+03
Gd	2.10E-01	1.44E+00	1.93E+00	2.18E+00	2.18E+00	2.18E+00
H	4.04E+00	9.71E+00	1.25E+01	1.26E+01	1.29E+01	1.32E+01
C	0.00E+00	1.31E-01	2.87E-01	7.06E-01	2.87E-01	2.87E-01
P	9.79E-01	2.40E+00	1.46E+00	1.51E+00	1.51E+00	1.51E+00
K	6.63E-01	8.32E+00	3.59E+01	3.33E+01	0.00E+00	0.00E+00
Mg	6.71E-01	6.82E+00	1.64E+01	1.65E+01	1.55E+01	1.40E+01
Mn	3.49E+01	8.14E+01	8.14E+01	8.14E+01	8.14E+01	8.14E+01
Mo	3.11E+00	1.78E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
N	0.00E+00	0.00E+00	1.14E-18	3.80E-18	0.00E+00	0.00E+00
Na	1.69E-01	9.96E+00	2.20E+01	8.71E+00	7.95E+00	7.14E+00
Ni	1.54E+01	1.52E+02	1.52E+02	1.52E+02	1.52E+02	1.52E+02
S	0.00E+00	0.00E+00	1.71E-14	2.13E-15	0.00E+00	4.35E-18
Si	4.74E+01	2.61E+02	5.21E+02	5.23E+02	5.48E+02	5.76E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.13E+02	1.28E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn	0.00E+00	0.00E+00	0.00E+00	4.35E-13	0.00E+00	0.00E+00
Total (Kg)	**758**	**1530**	**1699**	**1697**	**1701**	**1717**
Density (g/cm^3)	**4.96**	**4.67**	**4.29**	**4.30**	**4.30**	**4.28**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 22. Case 6 (nm1x2432): Solution Composition in Molality

Element	Years					
	9360	62473	83355	107530	354250	633780
Al	2.18E-06	5.28E-08	2.06E-07	9.61E-08	7.16E-08	7.16E-08
B	1.21E-02	3.65E-02	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ba	4.82E-07	1.61E-08	4.61E-10	1.70E-09	5.56E-09	5.56E-09
Ca	1.12E-04	6.23E-05	3.72E-06	8.56E-05	2.47E-04	2.47E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	4.09E-02	4.28E-05	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.85E-04	2.99E-12	1.15E-04	1.15E-04	1.15E-04	1.15E-04
Fe	4.56E-12	1.14E-12	1.24E-12	1.17E-12	1.14E-12	1.14E-12
Gd	2.03E-08	1.83E-12	1.30E-09	2.16E-08	1.54E-08	1.54E-08
C	5.28E-05	1.46E-03	8.68E-03	3.99E-03	2.11E-03	2.11E-03
P	3.35E-08	1.84E-05	1.10E-06	7.67E-09	2.21E-09	2.21E-09
K	2.48E-03	9.42E-04	8.31E-04	1.70E-03	1.29E-04	1.29E-04
Mg	2.43E-04	3.63E-05	2.93E-05	1.07E-04	1.43E-04	1.43E-04
Mn	1.74E-11	1.62E-15	6.96E-16	4.65E-16	6.93E-16	6.93E-16
Mo	2.38E-03	9.90E-04	1.00E-16	1.00E-16	1.00E-16	1.00E-16
N	8.56E-04	1.42E-04	1.42E-04	1.42E-04	1.42E-04	1.42E-04
Na	2.58E-02	5.88E-03	8.87E-03	2.78E-03	2.03E-03	2.03E-03
Ni	1.30E-02	1.11E-06	3.02E-08	1.18E-07	3.95E-07	3.95E-07
S	4.74E-04	6.93E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04
Si	5.72E-05	4.24E-05	4.45E-05	3.96E-05	3.86E-05	3.86E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	7.80E-06	4.97E-05	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Zn	1.00E-16	1.00E-16	7.89E-16	3.63E-18	1.00E-16	1.00E-16
pH	**5.98**	**7.90**	**8.69**	**8.37**	**8.10**	**8.10**

Case 8 (nm1{xyz}3333), shown in Figure 6 and Table 23 and Table 24, demonstrates the effects of WP component degradation using the highest steel degradation rate, slow pH-dependent glass degradation rate, fast fuel rate, and fast flushing rate.

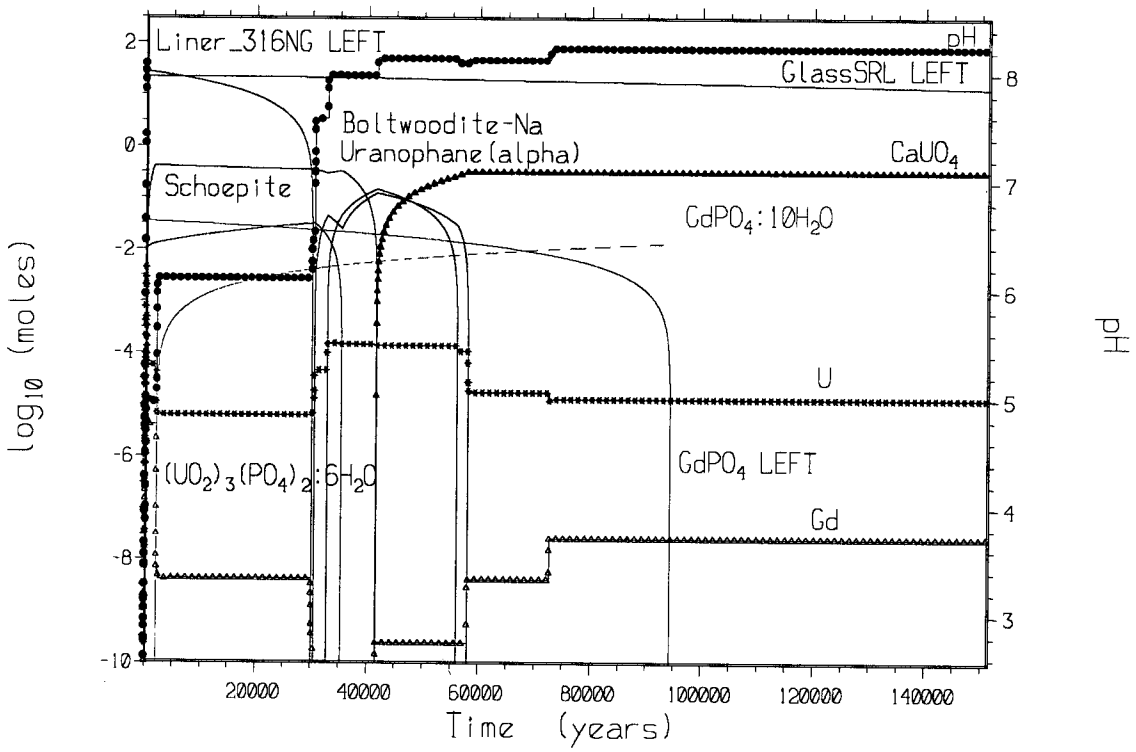

Figure 6. Case 8 (nm1{xyz}3333): WP Materials, Minerals, and Aqueous U

The pH levels for Case 8 are similar to those described for Case 3. However, retention of U and Gd are slightly different. Case 8 predicts only 47% U retention compared to Case 3 where 69.7% U retention was predicted. This may be due to the earlier rise of pH to above 8 at approximately 30,000 years in Case 8 whereas the pH did not rise to this level in Case 3 until almost 50,000 years. Therefore, more U is lost from the WP earlier in Case 8 than in Case 3 due to the early rise in pH.

Though the difference between the other cases presented is slight, Case 8 had the largest Gd loss (6.36%) among all the single stage runs.

Since the high steel degradation rates are new to this calculation there is no corresponding case to Case 8 in the previous calculation (Ref. 32).

Table 23. Case 8 (nm1{xyz}3333): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years					
	2134	3065	32806	41643	72654	151520
O	8.43E+02	8.73E+02	1.69E+03	1.72E+03	1.82E+03	2.12E+03
Al	1.97E+01	1.97E+01	2.10E+01	2.21E+01	2.66E+01	3.91E+01
B	4.69E-18	5.86E-19	1.32E-14	9.96E-18	0.00E+00	0.00E+00
Ba	0.00E+00	0.00E+00	1.27E-02	8.48E-02	3.75E-01	1.19E+00
Ca	8.42E-01	1.02E+00	7.77E+00	1.22E+01	2.57E+01	4.61E+01
Cl	0.00E+00	0.00E+00	0.00E+00	9.61E-19	1.92E-18	9.61E-19
Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	5.15E-19	1.89E-01	3.96E-01	4.01E-01	4.19E-01
Fe	1.72E+03	1.78E+03	3.40E+03	3.41E+03	3.42E+03	3.48E+03
Gd	1.98E-03	2.36E-02	7.13E-01	9.18E-01	1.64E+00	2.13E+00
H	3.44E+00	3.37E+00	5.19E+00	5.59E+00	4.55E+00	8.11E+00
C	0.00E+00	1.13E-12	1.11E-03	7.42E-03	3.28E-02	4.43E+00
P	8.06E-01	8.53E-01	2.10E+00	2.12E+00	2.29E+00	2.47E+00
K	0.00E+00	3.18E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mg	0.00E+00	0.00E+00	7.30E-01	1.73E+00	4.70E+00	7.69E+00
Mn	3.01E+01	3.20E+01	8.14E+01	8.14E+01	8.14E+01	8.14E+01
Mo	2.02E+00	2.44E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
N	0.00E+00	0.00E+00	0.00E+00	7.59E-19	7.59E-19	1.14E-18
Na	0.00E+00	0.00E+00	3.29E-04	3.38E+00	3.81E+00	2.33E+00
Ni	3.95E-04	4.85E-01	1.06E+01	1.05E+01	1.05E+01	1.05E+01
S	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Si	1.57E+01	1.79E+01	8.35E+01	1.03E+02	1.76E+02	3.72E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.06E+02	1.06E+02	1.04E+02	9.39E+01	7.60E+01	7.69E+01
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.02E-16	1.55E-11
Total (Kg)	**669**	**692**	**1320**	**1333**	**1378**	**1525**
Density (g/cm^3)	**5.07**	**5.07**	**5.00**	**4.96**	**4.85**	**4.54**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 24. Case 8 (nm1{xyz}3333): Solution Composition in Molality

Element	Years					
	2134	3065	32806	41643	72654	151520
Al	5.42E-07	3.68E-07	5.61E-08	8.86E-08	6.80E-08	6.82E-08
B	1.49E-04	1.29E-04	3.52E-04	4.61E-04	5.10E-04	5.44E-04
Ba	5.62E-07	4.88E-07	1.13E-08	4.59E-09	3.23E-09	2.96E-09
Ca	1.46E-04	2.11E-04	1.11E-05	1.68E-05	1.93E-04	1.78E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.14E-02	8.17E-03	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.16E-04	1.16E-04	3.30E-08	1.17E-04	1.17E-04	1.18E-04
Fe	3.79E-12	3.35E-12	1.14E-12	1.15E-12	1.15E-12	1.15E-12
Gd	7.14E-09	4.11E-09	2.75E-12	2.46E-10	2.64E-08	2.68E-08
C	5.46E-05	5.78E-05	1.61E-03	2.62E-03	2.86E-03	2.99E-03
P	3.52E-08	3.88E-08	8.10E-06	1.64E-07	2.59E-09	2.86E-09
K	1.67E-04	1.62E-04	2.20E-04	2.48E-04	2.61E-04	2.69E-04
Mg	9.97E-05	9.75E-05	6.45E-06	9.74E-06	1.11E-04	1.02E-04
Mn	9.51E-12	6.46E-12	1.20E-15	6.18E-16	5.23E-16	5.07E-16
Mo	8.98E-04	5.31E-04	2.80E-04	1.00E-16	1.00E-16	1.00E-16
N	3.55E-04	2.84E-04	1.42E-04	1.42E-04	1.42E-04	1.42E-04
Na	2.29E-03	2.25E-03	2.68E-03	3.26E-03	2.90E-03	3.09E-03
Ni	7.13E-03	4.84E-03	8.11E-07	3.25E-07	2.28E-07	2.09E-07
S	2.26E-04	2.17E-04	1.96E-04	1.98E-04	1.99E-04	1.99E-04
Si	5.68E-05	5.68E-05	4.50E-05	4.31E-05	3.99E-05	4.02E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	6.50E-06	6.29E-06	1.27E-04	1.39E-04	1.13E-05	1.33E-05
Zn	1.00E-16	1.00E-16	1.00E-16	1.00E-16	9.08E-17	1.78E-17
pH	**6.05**	**6.12**	**7.94**	**8.14**	**8.22**	**8.24**

6.1.2 Gd and U Retention: Two-Stage Runs

For the two-stage runs, the glass and the fuel are degraded separately from one another. In cases 11 and 12, the first stage simulates all the WP components being exposed to degradation except what is inside the DOE canister. The second stage begins when the DOE canister is allowed to breach. In the Scenario I two-stage runs, this corresponds to a pH low. For Cases 13 through 15, the first stage assumes that all package components except the glass pour canisters are breached and exposed to degradation to account for the possibility that the DOE canister was damaged during loading. The second stage then begins when the GPCs are 2/3 degraded and assumed to be breached. All values in section 6.1.2 are calculated in "fermi-losses.xls" (Attachment III)

6.1.2.1 Scenario I Two-stage Runs

Table 25 summarizes the retention values for Scenario I two-stage cases. Retention of U ranges from 27.20% to 94.21%. Like the one-stage runs, the retention of U in the WP stems from the formation of $(UO_2)_3(PO_4)_2 \cdot 6H_2O$, schoepite $(UO_3 \cdot 2H_2O)$, Na-boltwoodite $(NaUO_2SiO_3OH \cdot 1.5H_2O)$, α-uranophane $(Ca(UO_2SiO_3OH)_2 \cdot 5H_2O)$, and $CaUO_4$. Soddyite $((UO_2)_2SiO_4 \cdot 2H_2O)$ was once again the most abundant U mineral reported in the two-stage runs of Reference 32.

Gd retention is very high, 99.99% to 100%. The only Gd mineral formed is $GdPO_4 \cdot 10H_2O$.

Table 25. Gd and U Retention[c] for Scenario I Two-Stage EQ6 Runs

Case	Case ID	Length of Run (Years)	Gd Retention[a]	U Retention[a]
11	nm1x1403	33,979	-----	0.00%
	nm2{xy}1031	635,630	100.00%	72.80%
12	nm1x1303	33,999	-----	99.99%
	nm2x1332	633,860	96.89%	94.21%
Case[b]	**Case ID[b]**	**Length of Run (Years)[b]**	**Gd Retention[b]**	**U Retention[b]**
16	N17A1203	5,002	-----	0.00%
	N17{B,C}1011	500,050	99.93%	72.62%
17	N18A1103	5,005	-----	99.28%
	N18{B,C,D}1012	106,340	99.65%	80.91%

Sources: [a] Calculated in "fermi-losses.xls" (Attachment III)
[b] Ref. 32, Table 5-9, values re-calculated in "oldfermi-recalc.xls" (Attachment III)
[c] Retention of Gd and U is presented in percentage of total initial moles retained within the WP.

Figure 7 and Table 26 and Table 27 show the results of the first stage of Case 11 (nm1x1403). The pH of the system increases to above 8.8 in the first few years of degradation due to the fast glass degradation rate. This plateau continues for approximately 15,000 years until the glass is completely exhausted. At this point the pH slowly drops to 6.61 over a period of 19,000 years as the steel within the WP continues to degrade. During the initial plateau of high pH, all of the U from the degraded HLW glass is lost from the WP.

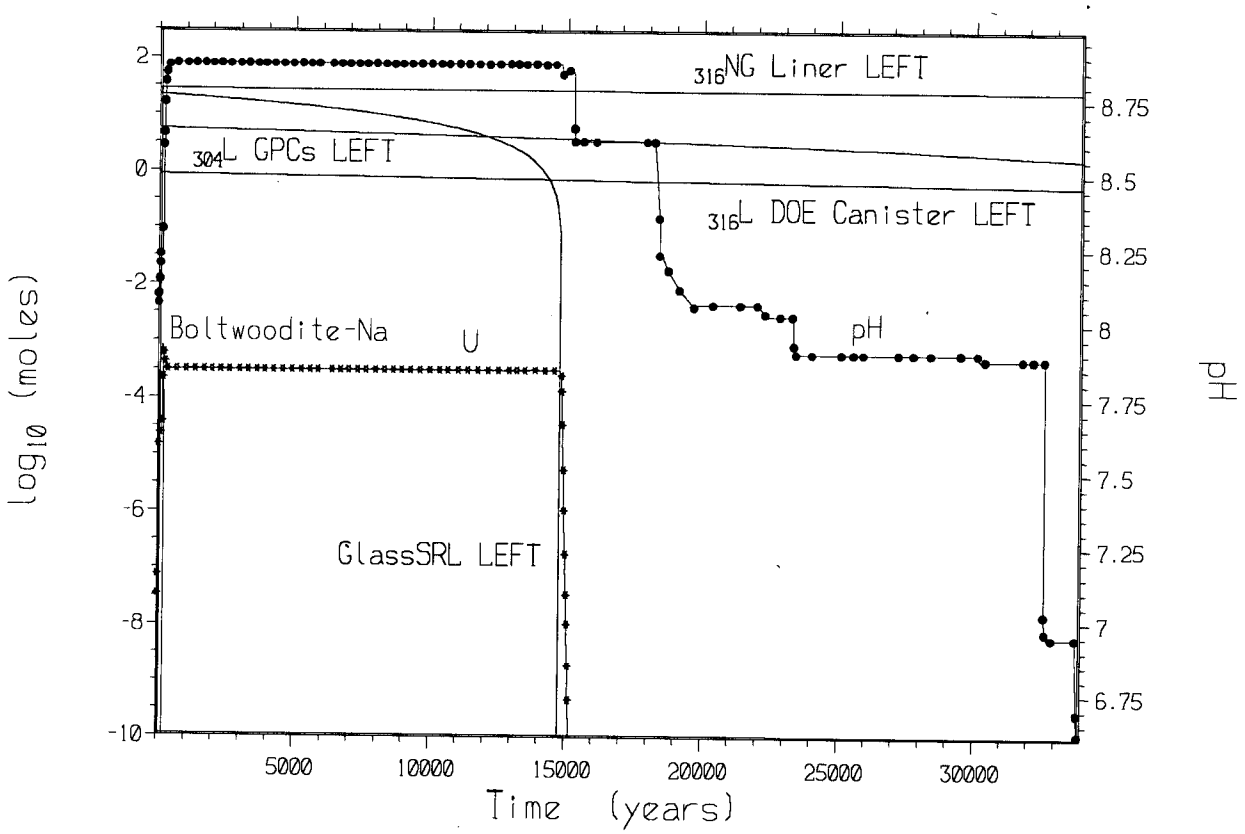

Figure 7. Case 11 (1st Stage: nm1x1403): WP Materials, Minerals, and Aqueous U

This is very close to what is seen in the first stage of Case 16 (Ref. 32). In old Case 16, the pH plateau is shorter-lived than in Case 11 of this calculation, only ~900 years, but the end result is the same. All U, from degraded HLW glass, in the first stage of old Case 16, is lost from the WP. This is when the first stage of Case 16 was ended. Case 11 of the current calculation is carried to a pH minimum at 34,000 years.

Table 26. Case 11 (1st Stage: nm1x1403): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	226	15072	15889	33979
O	4.10E+02	1.31E+03	1.32E+03	1.41E+03
Al	4.76E-01	5.08E+01	5.08E+01	5.08E+01
B	1.91E-11	3.19E-18	0.00E+00	0.00E+00
Ba	3.09E-02	3.30E+00	3.30E+00	3.29E+00
Ca	2.47E-01	2.09E+01	2.12E+01	1.04E+01
Cl	0.00E+00	0.00E+00	2.88E-18	0.00E+00
Cr	0.00E+00	0.00E+00	0.00E+00	1.20E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	1.81E-02	1.09E-01	1.10E-01	1.38E-01
Fe	9.16E+02	1.29E+03	1.30E+03	1.50E+03
Gd	0.00E+00	0.00E+00	0.00E+00	0.00E+00
H	1.13E-01	9.80E+00	1.03E+01	1.08E+01
C	2.10E-02	7.76E+00	6.96E+00	0.00E+00
P	8.83E-02	5.33E-01	5.39E-01	6.75E-01
K	1.91E-01	2.14E+01	2.03E+01	0.00E+00
Mg	1.73E-01	1.85E+01	1.85E+01	1.47E+01
Mn	9.76E+00	1.47E+01	1.50E+01	2.11E+01
Mo	0.00E+00	3.25E-18	6.50E-19	0.00E+00
N	0.00E+00	0.00E+00	3.80E-19	0.00E+00
Na	2.94E-01	2.73E+01	2.06E+01	0.00E+00
Ni	4.03E-01	2.69E+01	2.83E+01	6.02E+01
S	0.00E+00	0.00E+00	8.69E-19	2.93E-02
Si	7.39E+00	4.95E+02	4.96E+02	5.17E+02
Ti	4.44E-14	2.64E-12	2.79E-12	5.95E-12
U	6.36E-10	4.09E-17	0.00E+00	0.00E+00
Zn	1.64E-14	3.55E-12	3.74E-12	0.00E+00
Total (Kg)	**328**	**805**	**807**	**879**
Density (g/cm^3)	**5.20**	**3.68**	**3.68**	**3.83**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 27. Case 11 (1st Stage: nm1x1403): Solution Composition in Molality

Element	Years			
	226	15072	15889	33979
Al	1.49E-15	1.18E-07	8.35E-08	1.98E-08
B	9.81E-03	4.96E-07	1.00E-16	1.00E-16
Ba	4.17E-10	2.62E-10	6.70E-10	1.02E-06
Ca	3.94E-05	1.95E-05	4.72E-05	2.39E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.61E-03	1.61E-03	1.61E-03	1.61E-03
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.46E-04	1.13E-04	1.13E-04	1.13E-04
Fe	1.28E-12	1.31E-12	1.22E-12	1.77E-12
Gd	1.00E-16	1.00E-16	1.00E-16	1.00E-16
C	1.29E-02	1.34E-02	7.41E-03	1.01E-04
P	4.58E-08	1.23E-07	3.11E-08	4.03E-07
K	1.82E-03	1.56E-03	9.95E-04	1.29E-04
Mg	7.15E-06	1.73E-05	4.09E-05	1.08E-04
Mn	8.58E-16	1.02E-15	6.20E-16	5.34E-13
Mo	3.90E-05	3.90E-05	3.90E-05	3.90E-05
N	1.72E-04	1.72E-04	1.72E-04	1.72E-04
Na	1.94E-02	1.66E-02	1.06E-02	1.99E-03
Ni	2.58E-08	1.62E-08	4.47E-08	3.98E-04
S	3.84E-04	1.96E-04	1.96E-04	2.02E-04
Si	2.51E-04	5.12E-05	4.68E-05	5.09E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	6.01E-04	1.33E-08	1.00E-16	1.00E-16
Zn	1.32E-18	5.68E-19	1.11E-18	1.00E-16
pH	**8.77**	**8.85**	**8.61**	**6.61**

Figure 8 and Table 28 and Table 29 show the results of the second stage of Case 11 (nm2{xy}1031). Since the HLW glass is completely degraded at this point, and its alkalinity largely washed from the WP, the pH of the solution within the WP remains low for the remainder of the run. Since the pH remains low, all of the U within the package during this stage (from Fermi fuel) is retained as the U minerals described earlier. There is no effect on the retention of Gd and 100% remains in the WP as $GdPO_4 \cdot 10H_2O$.

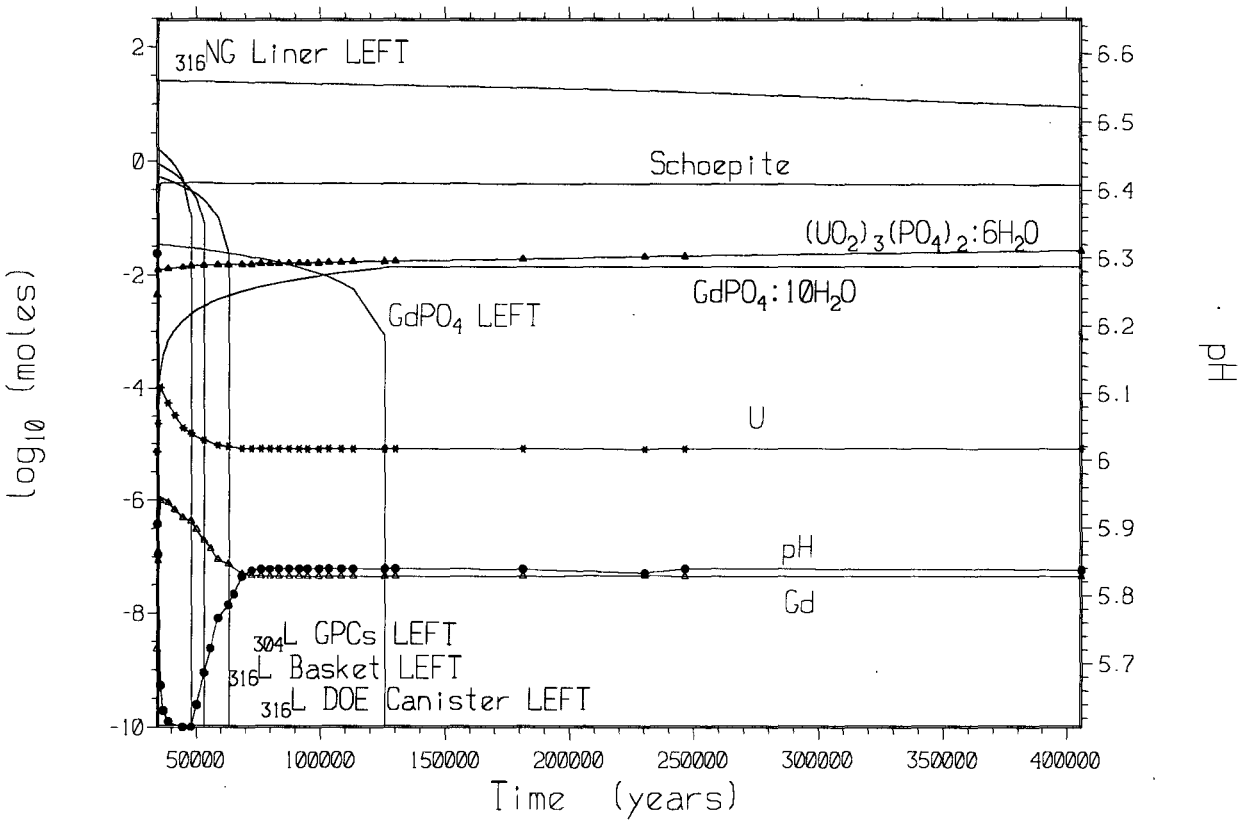

Figure 8. Case 11 (2nd Stage: nm2{xy}1031): WP Materials, Minerals, and Aqueous U

Even though the second stage of Case 16 from Reference 32 begins much sooner than that for current Case 11, the results are basically the same. After the beginning of the second stage, the pH drops rapidly so that most of the U is retained within the WP. Both Case 11 and old Case 16 retain slightly more than 72% of the total U (which, in both cases, is solely from the degraded U/Mo Fermi fuel).

Table 28. Case 11 (2nd Stage: nm2{xy}1031): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	33979	78235	442710	635630
O	1.42E+03	1.72E+03	2.24E+03	2.47E+03
Al	5.08E+01	7.11E+01	7.10E+01	7.10E+01
B	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba	3.29E+00	3.29E+00	3.27E+00	3.26E+00
Ca	1.04E+01	1.05E+01	1.18E+01	1.25E+01
Cl	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr	1.19E+00	1.24E+00	1.24E+00	1.15E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	1.39E-01	0.00E+00	0.00E+00	0.00E+00
Fe	1.52E+03	2.04E+03	3.13E+03	3.60E+03
Gd	2.33E-06	1.03E+00	2.19E+00	2.19E+00
H	1.08E+01	1.38E+01	1.42E+01	1.49E+01
C	0.00E+00	3.31E-12	1.89E-12	0.00E+00
P	6.80E-01	1.18E+00	2.16E+00	2.49E+00
K	2.12E-18	0.00E+00	0.00E+00	0.00E+00
Mg	1.47E+01	1.49E+01	1.51E+01	1.52E+01
Mn	2.12E+01	3.35E+01	6.69E+01	8.14E+01
Mo	0.00E+00	8.34E+00	8.75E+00	7.44E+00
N	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Na	9.97E-18	0.00E+00	0.00E+00	0.00E+00
Ni	6.02E+01	5.49E+01	5.07E+01	4.84E+01
S	3.49E-02	0.00E+00	0.00E+00	5.37E-02
Si	5.17E+02	5.23E+02	5.43E+02	5.52E+02
Ti	6.71E-06	3.15E-02	3.15E-02	3.15E-02
U	7.33E-03	1.10E+02	1.10E+02	1.10E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**884**	**1124**	**1528**	**1705**
Density (g/cm^3)	**3.84**	**4.02**	**4.26**	**4.33**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 29. Case 11 (2nd Stage: nm2{xy}1031): Solution Composition in Molality

Element	Years			
	33979	**78235**	**442710**	**635630**
Al	1.43E-08	1.32E-06	1.03E-06	4.54E-08
B	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ba	1.04E-06	6.92E-07	7.78E-07	1.03E-05
Ca	3.91E-05	7.87E-05	9.55E-05	3.33E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.79E-03	4.10E-02	4.11E-02	1.81E-04
Cu	1.93E-07	1.72E-11	1.00E-16	1.00E-16
F	6.64E-05	1.15E-04	1.15E-04	1.15E-04
Fe	2.01E-12	5.98E-12	6.55E-12	2.04E-12
Gd	1.60E-12	4.52E-08	4.14E-08	2.96E-10
C	8.35E-05	4.71E-05	5.47E-05	8.39E-05
P	1.69E-05	2.75E-08	3.21E-08	7.11E-08
K	1.29E-04	1.29E-04	1.29E-04	1.29E-04
Mg	1.78E-05	2.88E-05	3.51E-05	1.89E-05
Mn	9.86E-13	3.48E-11	3.52E-11	1.05E-12
Mo	4.81E-05	3.23E-03	3.25E-03	1.51E-03
N	1.73E-04	8.57E-04	8.56E-04	1.42E-04
Na	1.99E-03	1.99E-03	1.99E-03	1.99E-03
Ni	7.36E-04	2.62E-02	2.64E-02	7.90E-04
S	1.97E-04	3.09E-04	3.09E-04	2.05E-05
Si	5.68E-05	6.58E-05	7.48E-05	5.68E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	2.94E-07	8.21E-06	8.84E-06	6.80E-06
Zn	1.71E-07	1.17E-11	1.00E-16	1.00E-16
pH	**6.47**	**5.84**	**5.86**	**6.46**

Figure 9 and Table 30 and Table 31 show the results of the first stage of Case 12 (nm1x1303). Case 12 has the same parameters as Case 11 except that the glass now has a slow pH dependant degradation rate. In the first stage, the pH remains slightly below neutral (~6.7) for most of the run. Since the pH remains low, most of the U (96.89%) is kept inside the WP due to U mineral formation and the intact portion of the HLW glass remaining in the WP. As shown in Section 6.1.1 of this report, the fast drip rate allows some U to escape from the WP, but most is retained.

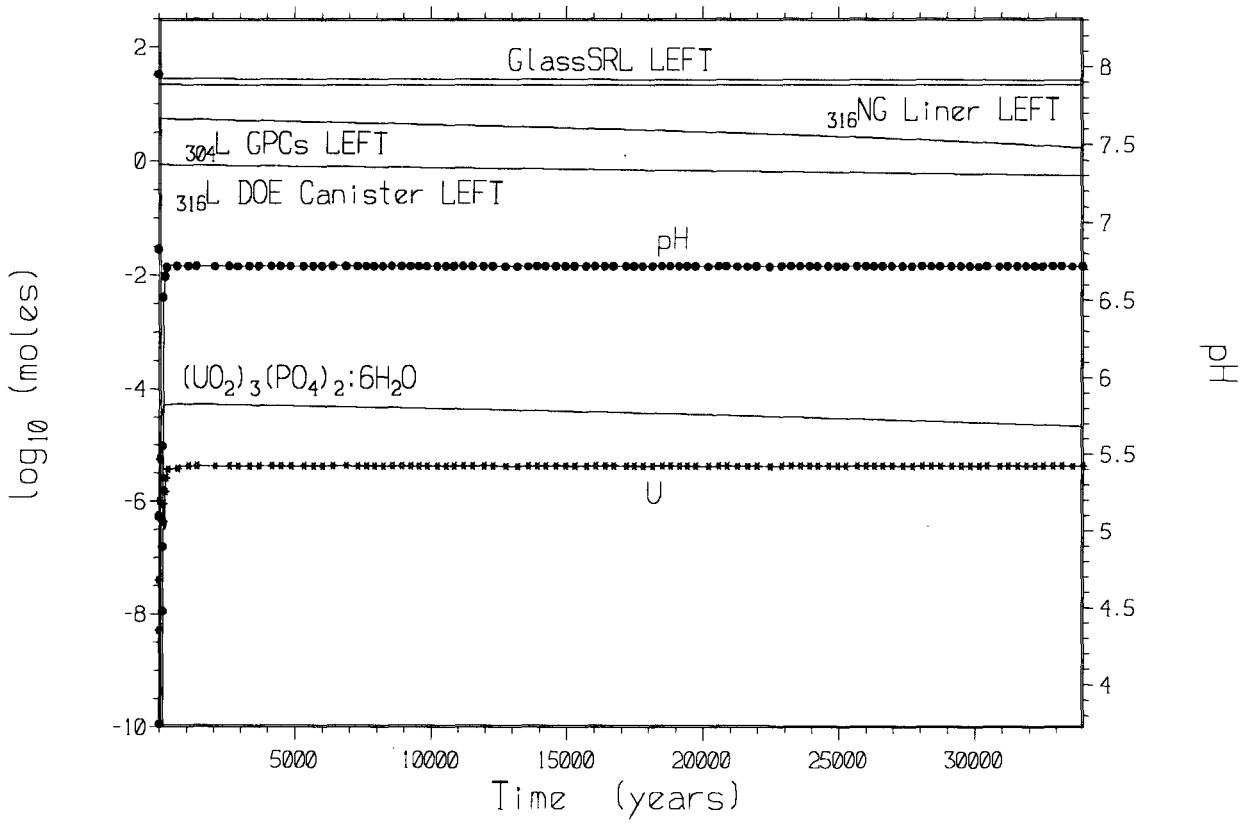

Figure 9. Case 12 (1st Stage: nm1x1303): WP Materials, Minerals, and Aqueous U

The first stage of Case 17 of Reference 32 also shows high retention of U (99.28%).

Table 30. Case 12 (1st Stage: nm1x1303): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years		
	136	968	33999
O	4.02E+02	4.08E+02	6.46E+02
Al	4.79E-02	8.78E-02	1.60E+00
B	0.00E+00	7.07E-14	3.31E-14
Ba	3.25E-03	2.06E-03	0.00E+00
Ca	0.00E+00	1.01E-01	1.76E+00
Cl	0.00E+00	0.00E+00	0.00E+00
Cr	0.00E+00	7.81E-04	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	3.38E-03	5.49E-02
Fe	9.13E+02	9.23E+02	1.30E+03
Gd	0.00E+00	0.00E+00	0.00E+00
H	1.32E-02	2.05E-02	3.62E-01
C	1.18E-13	0.00E+00	0.00E+00
P	2.80E-03	1.99E-02	2.70E-01
K	0.00E+00	0.00E+00	0.00E+00
Mg	0.00E+00	0.00E+00	0.00E+00
Mn	9.73E+00	1.00E+01	2.11E+01
Mo	5.33E-03	0.00E+00	0.00E+00
N	0.00E+00	0.00E+00	0.00E+00
Na	0.00E+00	0.00E+00	0.00E+00
Ni	0.00E+00	1.01E+00	4.31E+01
S	7.59E-04	0.00E+00	0.00E+00
Si	3.33E+00	4.52E+00	5.13E+01
Ti	2.86E-14	1.74E-13	5.96E-12
U	3.22E-02	3.91E-02	1.52E-02
Zn	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**324**	**328**	**504**
Density (g/cm^3)	**5.26**	**5.23**	**4.98**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 31. Case 12 (1st Stage: nm1x1303): Solution Composition in Molality

Element	Years		
	136	968	33999
Al	2.67E-05	4.52E-15	4.51E-15
B	1.43E-03	1.56E-04	1.57E-04
Ba	1.23E-07	9.26E-07	5.92E-07
Ca	4.05E-04	2.99E-04	2.99E-04
Cl	2.01E-04	2.01E-04	2.01E-04
Cr	1.60E-03	1.61E-03	1.61E-03
Cu	1.00E-16	1.00E-16	1.00E-16
F	1.23E-04	1.13E-04	1.13E-04
Fe	1.51E-09	1.61E-12	1.61E-12
Gd	1.00E-16	1.00E-16	1.00E-16
C	3.40E-05	1.22E-04	1.23E-04
P	2.08E-03	2.40E-07	2.39E-07
K	4.99E-04	1.69E-04	1.69E-04
Mg	2.47E-04	1.01E-04	1.01E-04
Mn	3.77E-07	3.17E-13	3.16E-13
Mo	2.52E-05	3.90E-05	3.90E-05
N	1.72E-04	1.72E-04	1.72E-04
Na	4.83E-03	2.30E-03	2.30E-03
Ni	8.26E-04	2.37E-04	2.36E-04
S	2.23E-03	1.98E-04	1.98E-04
Si	1.87E-04	1.87E-04	1.87E-04
Ti	0.00E+00	0.00E+00	0.00E+00
U	7.39E-06	4.27E-06	4.27E-06
Zn	1.00E-16	1.00E-16	1.00E-16
pH	**3.72**	**6.72**	**6.72**

Figure 10 and Table 32 and Table 33 show the results of the second stage of Case 12 (nm2x1332). The pH dips for a short time from the addition of the new steels within the DOE canister, but recovers again to a level of approximately 6.5. The pH remains at this level until all of the steel is gone at 600,000. For the next 34,000 years, the pH rises to above 8.25. During this period, 2.5% more (total U) is washed from the WP.

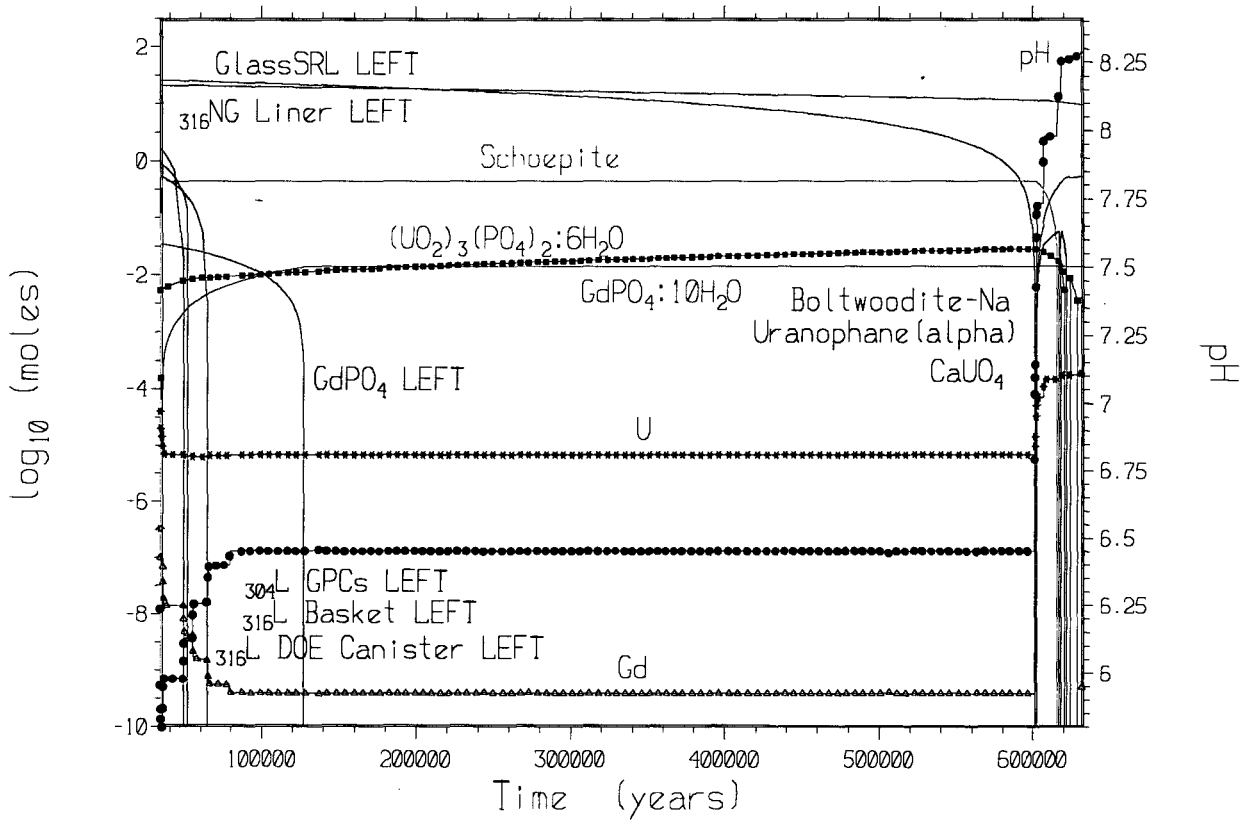

Figure 10. Case 12 (2nd Stage: nm2x1332): WP Materials, Minerals, and Aqueous U

The second stage of Case 17 of Reference 32 shows much greater losses of U than Case 12 (19% loss versus 6% loss). Because of the constant HLW glass degradation rate, the pH is able to rise above 7.8 in old Case 17. This is not enough to wash much of the U from the WP, but fewer and less stable U minerals exist at this pH level, allowing more U complexes to exist in solution so that more U can be flushed from the WP

Gadolinium retention remains high for both cases since both $GdPO_4 \cdot 10H_2O$ (from "data0.ymd") and $GdPO_4 \cdot H_2O$ (from "data0.nuc") are both very stable minerals.

Table 32. Case 12 (2nd Stage: nm2x1332): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	34000	80732	608930	633860
O	6.57E+02	1.01E+03	2.19E+03	2.25E+03
Al	1.60E+00	2.37E+01	4.53E+01	4.91E+01
B	5.86E-19	6.92E-14	3.18E-12	0.00E+00
Ba	1.98E-05	1.02E-01	1.35E+00	1.59E+00
Ca	1.78E+00	3.47E+00	1.27E+01	1.49E+01
Cl	9.61E-19	0.00E+00	0.00E+00	7.25E-14
Cr	0.00E+00	3.88E-02	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	5.58E-02	0.00E+00	7.23E-02	2.99E-01
Fe	1.32E+03	1.85E+03	3.50E+03	3.51E+03
Gd	3.70E-06	1.08E+00	2.19E+00	2.19E+00
H	3.63E-01	5.45E+00	1.11E+01	1.12E+01
C	8.33E-13	0.00E+00	1.18E-01	1.39E-01
P	2.76E-01	8.02E-01	2.23E+00	1.89E+00
K	0.00E+00	0.00E+00	4.37E-01	3.91E+00
Mg	2.35E-03	9.49E-01	7.20E+00	8.66E+00
Mn	2.13E+01	3.37E+01	8.14E+01	8.14E+01
Mo	6.50E-19	5.36E-03	0.00E+00	0.00E+00
N	0.00E+00	0.00E+00	0.00E+00	2.49E-15
Na	9.97E-18	0.00E+00	3.03E+00	1.98E+01
Ni	4.31E+01	4.51E+01	2.29E+02	2.29E+02
S	4.62E-06	0.00E+00	0.00E+00	4.72E-12
Si	5.14E+01	7.84E+01	3.57E+02	3.95E+02
Ti	1.06E-05	3.15E-02	3.15E-02	3.15E-02
U	2.79E-02	1.11E+02	1.25E+02	1.24E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**512**	**772**	**1600**	**1635**
Density (g/cm^3)	**4.98**	**4.85**	**4.57**	**4.50**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 33. Case 12 (2nd Stage: nm2x1332): Solution Composition in Molality

Element	Years			
	34000	80732	608930	633860
Al	3.96E-14	5.38E-08	6.10E-08	1.24E-07
B	1.57E-04	1.37E-03	4.29E-03	5.67E-03
Ba	4.50E-07	6.02E-07	9.48E-09	2.60E-09
Ca	1.48E-05	2.86E-04	9.37E-06	1.52E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.63E-03	4.09E-03	2.28E-15	1.00E-16
Cu	3.07E-07	1.00E-16	1.00E-16	1.00E-16
F	6.28E-05	1.23E-04	3.59E-08	1.45E-04
Fe	2.04E-12	2.09E-12	1.14E-12	1.16E-12
Gd	1.15E-12	3.92E-10	2.78E-12	6.03E-10
C	8.25E-05	8.42E-05	1.77E-03	3.81E-03
P	9.08E-05	7.21E-08	9.43E-06	1.63E-07
K	1.70E-04	4.83E-04	3.91E-04	4.77E-04
Mg	6.98E-06	1.11E-04	5.48E-06	8.73E-06
Mn	1.06E-12	1.22E-12	1.03E-15	4.97E-16
Mo	5.35E-05	3.11E-04	1.82E-07	1.00E-16
N	1.73E-04	2.13E-04	1.42E-04	1.42E-04
Na	2.30E-03	4.71E-03	2.45E-03	5.07E-03
Ni	7.85E-04	9.13E-04	6.74E-07	1.80E-07
S	4.67E-04	2.22E-04	2.50E-04	2.69E-04
Si	1.87E-04	5.28E-05	4.51E-05	4.33E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	4.08E-07	6.84E-06	1.45E-04	1.89E-04
Zn	2.71E-07	1.00E-16	1.00E-16	1.00E-16
pH	**6.46**	**6.45**	**7.98**	**8.29**

6.1.2.2 Scenario II Two-stage Runs

Table 34 summarizes the retention values for Scenario II two-stage runs. There are no equivalent cases in Reference 32.

Table 34. Gd and U Retention for Scenario II Two-stage EQ6 Runs

Case	Case ID	Length of Run (Years)	Gd Retention	U Retention
13	nm1x1023	59,892	-----	99.71%
	nm2{xyz}1323	633,370	98.32%	82.97%
14	nm1x1033	59,897	-----	95.08%
	nm2{xy}1303	431,980	95.89%	68.08%
15	nm1x1032	59,928	-----	98.11%
	nm2{xy}1302	633,780	87.01%	93.30%

NOTE: Retention of Gd and U is presented in percentage of total initial moles retained within the WP.

Cases 13 and 14 are exactly the same except that Case 13 has a slow fuel degradation rate and Case 14 has a fast fuel degradation rate. We have seen previously (Section 6.1.1) that the U retention for cases with the slow fuel degradation rate will be higher than those for the fast fuel rate since most (>95%) of the fuel remains intact. Gadolinium retention remains high for both cases. The "corrosion products" and "WP solution composition" tables are also very similar. For this reason, since the case with a fast fuel degradation rate would be more reactive in terms of criticality, only tables and figures for Cases 14 and 15 are presented in this section

Figure 11 and Table 35 and Table 36 show the results of the first stage of Case 14 (nm1x1033). During the first 2,800 years, the pH remains below 5. During this period, the amount of Gd in solution is high and a 3% (total Gd) loss occurs. After this point, the pH rises and hovers around neutral until the end of the run. It is only at this point that the mineral $GdPO_4 \cdot 10H_2O$ is able to form. Although $GdPO_4 \cdot 10H_2O$ is a very stable mineral, its stability decreases with decreasing pH and it is not able to form until the pH reaches a level above 6.0. Uranium is just the opposite, being more unstable in minerals at higher pH values. Though the pH has not risen above 8.5, the level is high enough to keep some of the U in solution and a 5% loss of U is seen over the next 56,000 years.

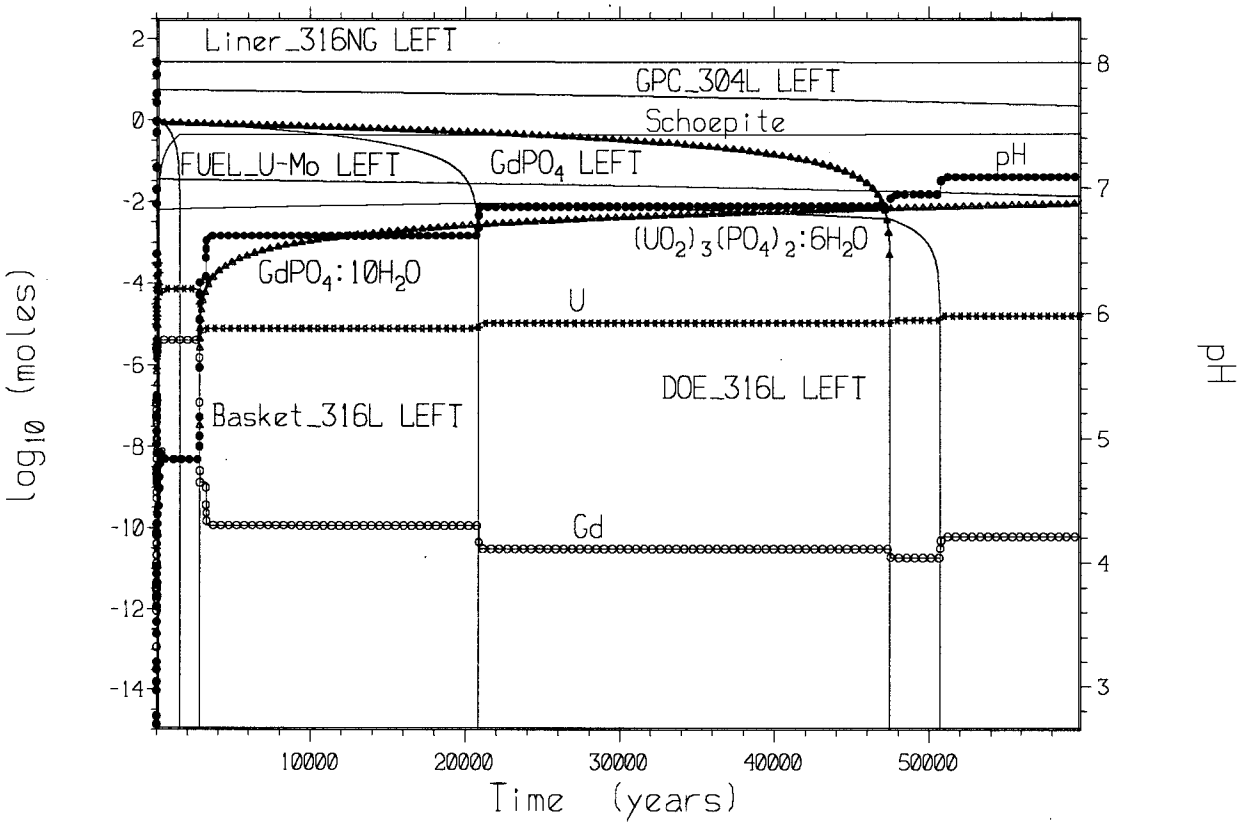

Figure 11. Case 14 (1st Stage: nm1x1033): WP Materials, Minerals, and Aqueous U

Table 35. Case 14 (1st Stage: nm1x1033): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years				
	2795	3434	21294	47864	59897
O	5.76E+02	5.83E+02	6.99E+02	8.38E+02	8.94E+02
Al	2.02E+01	2.02E+01	2.02E+01	2.02E+01	2.02E+01
B	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca	1.04E+00	1.18E+00	1.79E+00	4.71E+00	6.10E+00
Cl	3.84E-18	6.05E-14	0.00E+00	0.00E+00	0.00E+00
Cr	1.34E-15	9.56E-10	0.00E+00	0.00E+00	1.13E-17
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	2.32E-18	4.53E-13	1.41E-03	1.01E-01	1.53E-01
Fe	1.14E+03	1.14E+03	1.34E+03	1.55E+03	1.63E+03
Gd	9.34E-04	1.58E-02	4.30E-01	1.05E+00	1.33E+00
H	3.86E+00	4.16E+00	4.40E+00	4.72E+00	4.86E+00
C	4.74E-13	6.02E-12	5.58E-13	0.00E+00	2.95E-13
P	4.21E-01	4.29E-01	6.40E-01	8.99E-01	1.01E+00
K	0.00E+00	1.39E-13	0.00E+00	0.00E+00	1.06E-18
Mg	8.09E-04	2.50E-12	0.00E+00	0.00E+00	0.00E+00
Mn	1.27E+01	1.29E+01	1.88E+01	2.51E+01	2.76E+01
Mo	2.50E+00	1.71E+00	0.00E+00	0.00E+00	2.60E-18
N	7.59E-19	9.37E-14	0.00E+00	0.00E+00	7.59E-19
Na	0.00E+00	7.61E-13	0.00E+00	0.00E+00	0.00E+00
Ni	0.00E+00	2.35E-01	1.93E+01	4.74E+01	5.95E+01
S	3.48E-18	9.34E-12	0.00E+00	0.00E+00	1.74E-18
Si	6.59E+00	7.32E+00	2.77E+01	5.69E+01	6.99E+01
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.08E+02	1.08E+02	1.07E+02	1.04E+02	1.03E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**456**	**459**	**545**	**647**	**687**
Density (g/cm^3)	**5.02**	**5.00**	**4.94**	**4.88**	**4.85**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 36. Case 14 (1st Stage: nm1x1033): Solution Composition in Molality

Element	Years				
	2795	3434	21294	47864	59897
Al	1.80E-07	1.88E-08	9.37E-09	8.76E-09	1.05E-08
B	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ba	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ca	1.03E-04	3.21E-04	2.51E-04	1.68E-04	2.70E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.53E-03	1.53E-03	1.13E-03	9.71E-04	9.71E-04
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.15E-04	1.15E-04	1.10E-04	9.29E-05	1.13E-04
Fe	2.66E-12	1.75E-12	1.47E-12	1.39E-12	1.31E-12
Gd	1.31E-09	1.14E-10	3.02E-11	1.81E-11	6.14E-11
C	6.46E-05	1.06E-04	1.56E-04	1.86E-04	2.43E-04
P	4.66E-08	1.04E-07	1.85E-07	2.42E-07	6.19E-08
K	1.29E-04	1.29E-04	1.29E-04	1.29E-04	1.29E-04
Mg	5.14E-05	1.48E-04	8.27E-05	8.27E-05	8.27E-05
Mn	2.85E-12	4.98E-13	1.67E-13	1.05E-13	5.61E-14
Mo	5.68E-04	1.89E-04	4.55E-05	3.26E-05	3.26E-05
N	1.72E-04	1.72E-04	1.63E-04	1.60E-04	1.60E-04
Na	1.99E-03	1.99E-03	1.99E-03	1.99E-03	1.99E-03
Ni	8.66E-04	3.72E-04	1.25E-04	7.82E-05	4.18E-05
S	1.96E-04	1.96E-04	1.95E-04	1.94E-04	1.94E-04
Si	5.68E-05	5.01E-05	4.82E-05	4.81E-05	4.58E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	6.15E-06	7.88E-06	1.05E-05	1.23E-05	1.55E-05
Zn	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**6.25**	**6.62**	**6.85**	**6.95**	**7.09**

Figure 12 and Table 37 and Table 38 show the results of the second stage of Case 14 (nm2{xy}1303). The pH decreases slightly for the first 20,000 years of the run until all of the 304L stainless steel of the GPCs is completely degraded. From this point it raises rapidly to around 7.85 and continues to increase to above 8.1 over the coarse of the run. Uranium in solution increases by an order of magnitude during this first initial rise in pH, only to decrease to previous levels when the system stabilizes. After the pH reaches 8.0, $CaUO_4$ is the only U-bearing mineral to exist in the WP. The slightly elevated levels of U in solution during the second stage allow for the loss of another 28% of the total U.

Since the pH remains high for the rest of the case, and stable Gd minerals are able to exist within the WP, Gd loss over the entire run of the case is held to only slighly more than 4%, with most of this having been lost in the first stage during the initial period of very low pH.

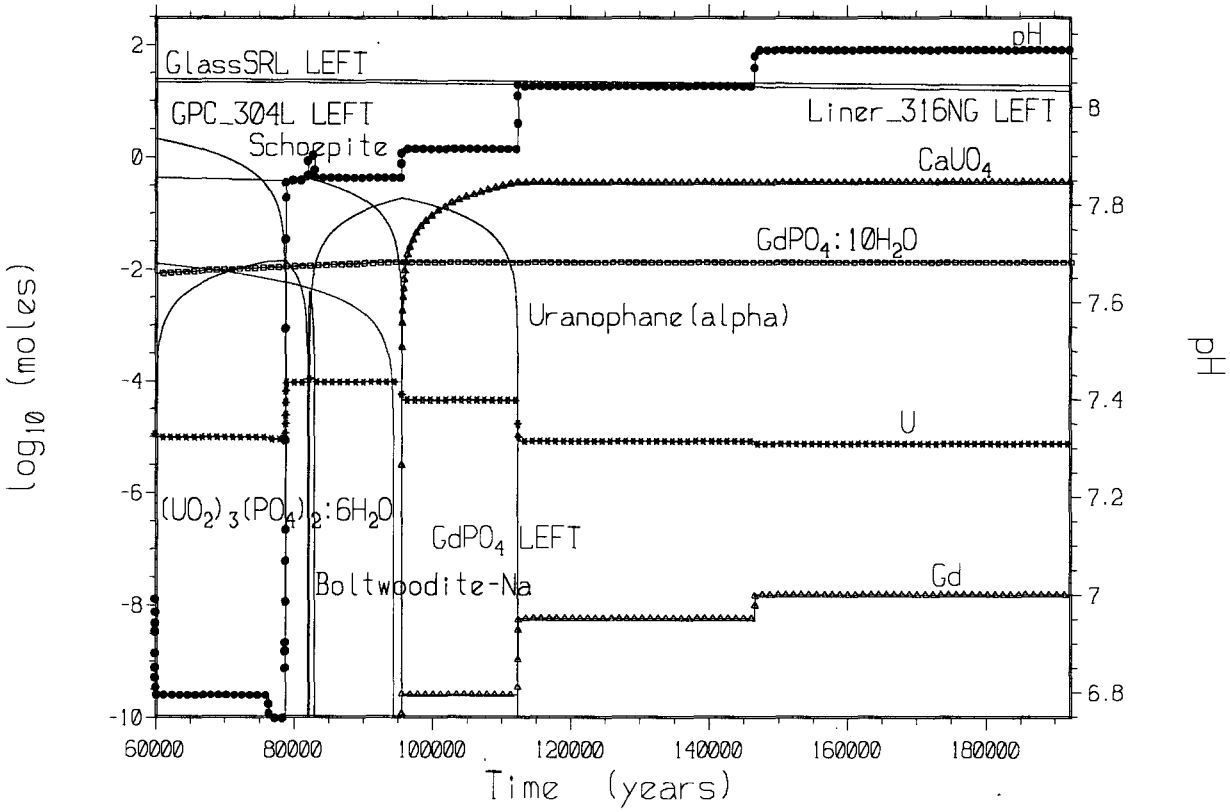

Figure 12. Case 14 (2nd Stage: nm2{xy}1303): WP Materials, Minerals, and Aqueous U

Table 37. Case 14 (2nd Stage: nm2{xy}1303): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years					
	59922	78908	272040	431980	531750	633780
O	8.95E+02	1.03E+03	1.96E+03	2.74E+03	3.00E+03	3.20E+03
Al	2.02E+01	2.11E+01	4.73E+01	6.97E+01	7.10E+01	7.10E+01
B	1.47E-19	5.56E-15	0.00E+00	2.93E-18	0.00E+00	0.00E+00
Ba	0.00E+00	7.04E-04	1.70E+00	3.14E+00	3.22E+00	3.21E+00
Ca	6.10E+00	6.45E+00	4.60E+01	6.44E+01	6.18E+01	6.59E+01
Cl	0.00E+00	0.00E+00	2.85E-16	0.00E+00	0.00E+00	9.61E-19
Cr	0.00E+00	0.00E+00	3.48E-13	2.82E-18	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	1.53E-01	6.81E-03	2.93E-01	3.91E-01	4.35E-01	4.64E-01
Fe	1.63E+03	1.84E+03	2.52E+03	3.09E+03	3.40E+03	3.61E+03
Gd	1.33E+00	1.77E+00	2.11E+00	2.10E+00	2.10E+00	2.09E+00
H	4.86E+00	5.30E+00	1.10E+01	1.89E+01	1.89E+01	1.88E+01
C	0.00E+00	6.16E-05	1.48E-01	2.75E-01	2.82E-01	2.81E-01
P	1.01E+00	1.23E+00	1.85E+00	2.33E+00	2.54E+00	2.68E+00
K	0.00E+00	0.00E+00	1.22E-15	0.00E+00	0.00E+00	1.06E-18
Mg	0.00E+00	1.33E-02	4.59E+00	1.02E+01	2.41E+00	0.00E+00
Mn	2.76E+01	3.36E+01	5.12E+01	6.59E+01	7.50E+01	8.14E+01
Mo	0.00E+00	0.00E+00	5.27E-17	1.95E-18	0.00E+00	0.00E+00
N	1.14E-18	0.00E+00	1.81E-16	0.00E+00	0.00E+00	0.00E+00
Na	0.00E+00	0.00E+00	1.50E-14	0.00E+00	0.00E+00	0.00E+00
Ni	5.95E+01	8.42E+01	1.90E+02	2.78E+02	3.32E+02	3.70E+02
S	2.61E-18	0.00E+00	4.09E-14	0.00E+00	0.00E+00	0.00E+00
Si	7.00E+01	9.98E+01	5.48E+02	9.01E+02	1.00E+03	1.09E+03
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.03E+02	1.02E+02	9.13E+01	1.02E+02	1.00E+02	9.80E+01
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**688**	**786**	**1336**	**1792**	**1967**	**2100**
Density (g/cm^3)	**4.85**	**4.79**	**4.20**	**3.98**	**3.99**	**3.99**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 38. Case 14 (2nd Stage: nm2{xy}1303): Solution Composition in Molality

Element	Years					
	59922	78908	272040	431980	531750	633780
Al	1.06E-15	1.18E-15	3.51E-14	1.18E-15	1.18E-15	9.89E-16
B	5.79E-05	1.00E-16	4.86E-04	4.77E-04	1.00E-16	1.00E-16
Ba	1.08E-08	1.66E-08	5.46E-09	5.76E-09	1.66E-08	5.64E-09
Ca	3.30E-04	2.66E-04	2.50E-04	2.72E-04	2.66E-04	3.26E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	4.09E-04	4.09E-04	4.09E-04	4.09E-04	4.09E-04	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.14E-04	1.14E-04	1.17E-04	1.17E-04	1.14E-04	1.15E-04
Fe	1.14E-12	1.15E-12	1.15E-12	1.15E-12	1.15E-12	1.14E-12
Gd	7.22E-09	2.68E-09	1.38E-08	1.45E-08	2.69E-09	2.40E-08
C	1.54E-03	1.24E-03	2.21E-03	2.14E-03	1.24E-03	2.10E-03
P	2.48E-09	4.28E-09	2.74E-09	2.42E-09	4.27E-09	1.41E-09
K	1.44E-04	1.29E-04	2.54E-04	2.52E-04	1.29E-04	1.29E-04
Mg	1.72E-04	1.39E-04	1.30E-04	9.16E-05	1.39E-04	8.27E-05
Mn	1.16E-15	1.70E-15	6.89E-16	7.13E-16	1.69E-15	7.00E-16
Mo	3.28E-05	3.28E-05	3.26E-05	3.26E-05	3.26E-05	1.00E-16
N	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.42E-04
Na	2.11E-03	1.99E-03	2.98E-03	2.94E-03	1.99E-03	1.99E-03
Ni	7.73E-07	1.19E-06	3.87E-07	4.09E-07	1.19E-06	4.02E-07
S	1.94E-04	1.93E-04	1.99E-04	1.99E-04	1.93E-04	1.92E-04
Si	1.92E-04	1.91E-04	1.44E-04	1.95E-04	1.91E-04	1.94E-04
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	2.53E-06	2.12E-06	7.69E-06	5.06E-06	2.13E-06	3.81E-06
Zn	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**7.96**	**7.86**	**8.11**	**8.10**	**7.86**	**8.09**

Figure 13 and Table 39 and Table 40 show the results of the first stage of Case 15 (nm1x1032). Case 15 has the same exact parameter constraints as those set for Case 14, except a lower drip rate was applied. The lower drip rate allows the acid released from steel degradation to remain in the WP longer. This has the effect of lowering the pH at the beginning of the run to below 5 for almost 30,000 years. Once again, since the pH is so low, GdPO4·10H2O is only able to form in small amounts and the level of Gd in solution remains high for this entire period. While the flush rate is slower, the lengthy amount of time at the lower pH allows for 12.9% Gd loss from the WP. This makes up the majority of the 13.01% that was lost during the entire case.

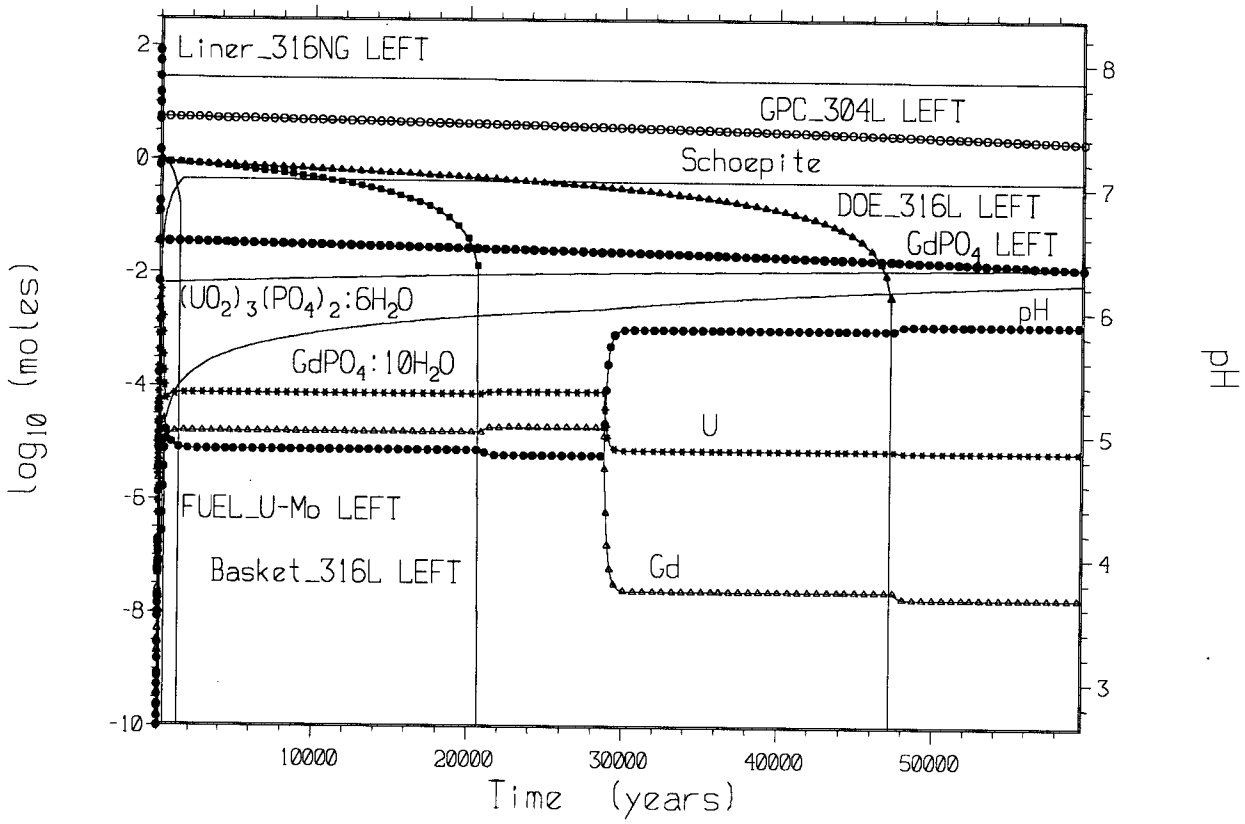

Figure 13. Case 15 (1st Stage: nm1x1032): WP Materials, Minerals, and Aqueous U

The high acidity of the system over the entire length of the first stage allows nearly all (98.11%) of the U to remain within the WP.

Table 39. Case 15 (1st Stage: nm1x1032): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years		
	32128	**48012**	**59928**
O	7.09E+02	7.69E+02	8.08E+02
Al	2.02E+01	2.02E+01	2.02E+01
B	0.00E+00	0.00E+00	0.00E+00
Ba	0.00E+00	0.00E+00	0.00E+00
Ca	1.10E+00	1.21E+00	1.21E+00
Cl	9.47E-15	1.10E-15	0.00E+00
Cr	1.40E-09	1.47E-10	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00
F	8.12E-13	8.67E-14	0.00E+00
Fe	1.42E+03	1.55E+03	1.63E+03
Gd	4.62E-01	8.30E-01	1.11E+00
H	3.75E+00	3.68E+00	3.63E+00
C	8.82E-13	0.00E+00	0.00E+00
P	7.56E-01	9.13E-01	1.02E+00
K	1.20E-14	1.48E-15	0.00E+00
Mg	8.78E-14	1.11E-14	0.00E+00
Mn	2.14E+01	2.52E+01	2.76E+01
Mo	2.64E+00	2.90E+00	2.90E+00
N	1.05E-13	1.06E-14	7.59E-19
Na	6.17E-14	7.61E-15	0.00E+00
Ni	1.05E-12	1.10E-13	1.53E-16
S	4.78E-13	6.53E-14	2.61E-18
Si	1.09E+01	1.41E+01	1.64E+01
Ti	3.15E-02	3.15E-02	3.15E-02
U	1.07E+02	1.07E+02	1.07E+02
Zn	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**561**	**609**	**639**
Density (g/cm^3)	**5.05**	**5.06**	**5.06**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 40. Case 15 (1st Stage: nm1x1032): Solution Composition in Molality

Element	Years		
	32128	48012	59928
Al	1.84E-06	1.56E-06	1.52E-06
B	1.00E-16	1.00E-16	1.00E-16
Ba	1.00E-16	1.00E-16	1.00E-16
Ca	2.77E-04	3.18E-04	3.24E-04
Cl	2.01E-04	2.01E-04	2.01E-04
Cr	1.13E-02	9.89E-03	9.71E-03
Cu	1.00E-16	1.00E-16	1.00E-16
F	1.15E-04	1.15E-04	1.15E-04
Fe	5.26E-12	4.93E-12	4.89E-12
Gd	2.50E-08	1.95E-08	1.88E-08
C	4.72E-05	4.81E-05	4.82E-05
P	2.66E-08	2.76E-08	2.78E-08
K	1.29E-04	1.29E-04	1.29E-04
Mg	8.27E-05	8.27E-05	8.27E-05
Mn	2.22E-11	1.87E-11	1.82E-11
Mo	4.07E-04	3.34E-04	3.25E-04
N	3.58E-04	3.27E-04	3.23E-04
Na	1.99E-03	1.99E-03	1.99E-03
Ni	6.19E-03	5.29E-03	5.18E-03
S	2.22E-04	2.18E-04	2.18E-04
Si	5.68E-05	5.68E-05	5.68E-05
Ti	0.00E+00	0.00E+00	0.00E+00
U	7.75E-06	7.43E-06	7.39E-06
Zn	1.00E-16	1.00E-16	1.00E-16
pH	**5.86**	**5.89**	**5.89**

Figure 14 and Figure 15 and Table 41 and Table 42 show the results of the second stage of Case 15 (nm2{xy}1302). In the second stage of Case 15, the pH remains around 6.4 for most of the run. At 600,000 years, when the 316NG liner is completely degraded, the pH increases to above 8 over a period of 15,000 years. Uranium in solution increases by an order of magnitude and over the last 33,000 years of the second stage, almost 5% more U is lost from the WP. Since the pH remained low for most of Case 15, most of the U (93.30%) was retained, however, 6.7 % was lost during periods of high pH or times when there was a dramatic change in the pH of the system, allowing U to be lost while the system attempted to equilibrate itself at the new pH.

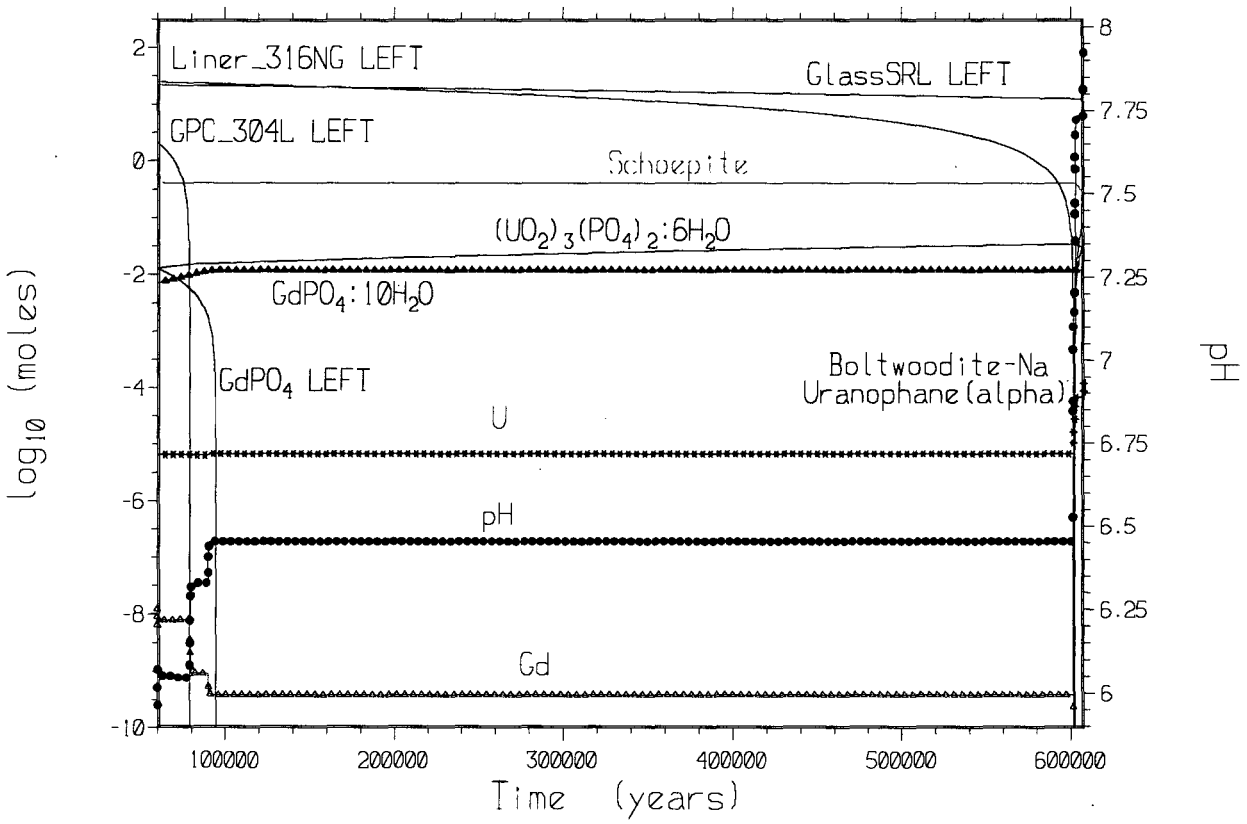

Figure 14. Case 15 (2nd Stage: nm2x1302): WP Materials, Minerals, and Aqueous U

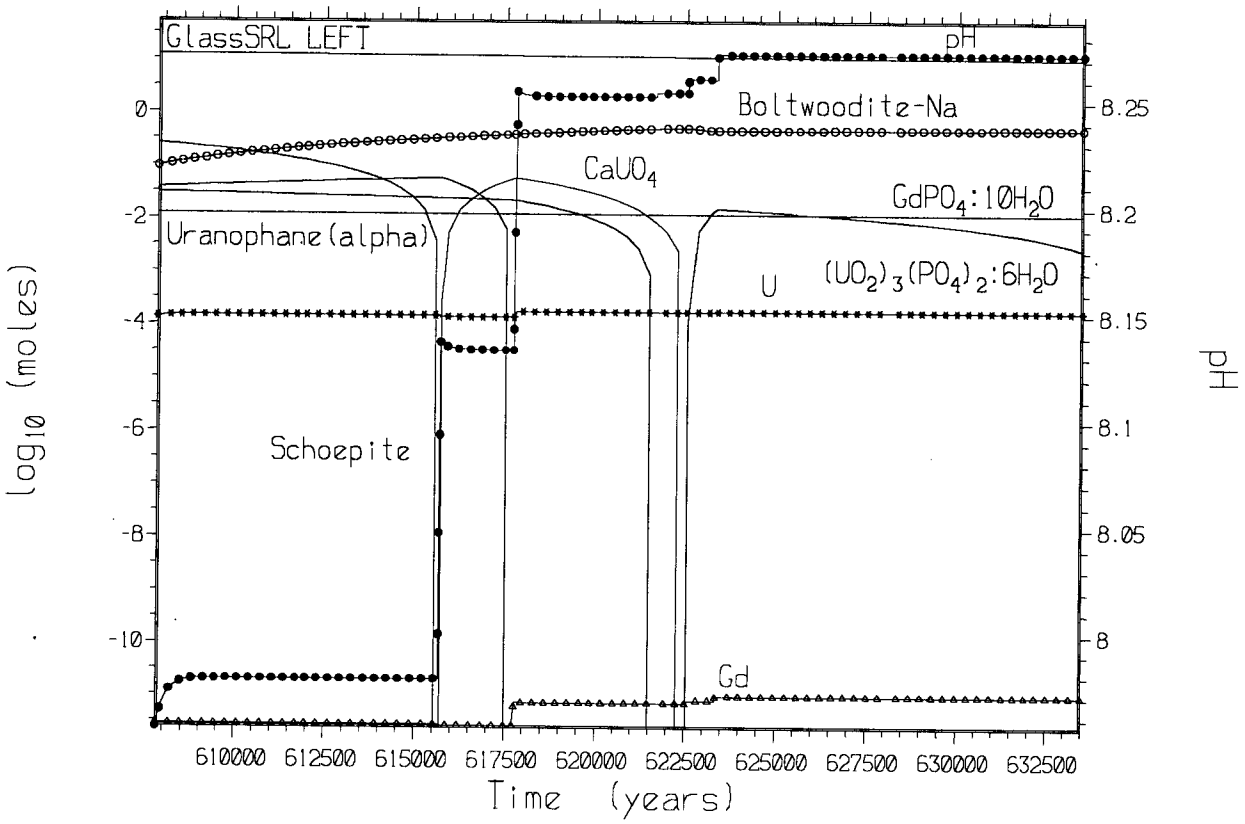

Figure 15. Case 15 (2nd Stage: nm2y1302): WP Materials, Minerals, and Aqueous U

Table 41. Case 15 (2nd Stage: nm2{xy}1302): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years				
	60119	91669	607830	617790	633780
O	8.09E+02	9.49E+02	2.10E+03	2.12E+03	2.16E+03
Al	2.02E+01	2.14E+01	4.25E+01	4.38E+01	4.64E+01
B	9.65E-16	0.00E+00	5.15E-12	9.38E-17	1.88E-17
Ba	3.39E-04	6.89E-02	1.28E+00	1.37E+00	1.53E+00
Ca	1.21E+00	1.74E+00	1.07E+01	1.15E+01	1.30E+01
Cl	0.00E+00	8.80E-15	0.00E+00	0.00E+00	0.00E+00
Cr	1.28E-04	2.61E-02	0.00E+00	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	8.08E-14	6.07E-02	1.58E-01	3.22E-01
Fe	1.63E+03	1.88E+03	3.49E+03	3.49E+03	3.50E+03
Gd	1.11E+00	1.84E+00	1.91E+00	1.91E+00	1.91E+00
H	3.63E+00	4.80E+00	1.02E+01	1.00E+01	1.03E+01
C	0.00E+00	2.10E-13	1.12E-01	1.19E-01	1.34E-01
P	1.02E+00	1.34E+00	2.53E+00	2.51E+00	2.09E+00
K	0.00E+00	5.20E-14	2.67E-01	1.47E+00	3.88E+00
Mg	1.61E-04	3.41E-01	6.41E+00	6.92E+00	7.93E+00
Mn	2.77E+01	3.47E+01	8.14E+01	8.14E+01	8.14E+01
Mo	2.90E+00	2.98E-01	0.00E+00	0.00E+00	0.00E+00
N	0.00E+00	1.49E-14	0.00E+00	3.80E-19	0.00E+00
Na	0.00E+00	1.75E-13	2.13E+00	8.88E+00	1.95E+01
Ni	0.00E+00	4.05E+00	1.84E+02	1.84E+02	1.84E+02
S	0.00E+00	8.21E-13	0.00E+00	0.00E+00	0.00E+00
Si	1.65E+01	3.39E+01	3.06E+02	3.19E+02	3.45E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	1.07E+02	1.08E+02	1.21E+02	1.21E+02	1.21E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**640**	**741**	**1550**	**1562**	**1586**
Density (g/cm^3)	**5.06**	**5.00**	**4.63**	**4.62**	**4.55**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 42. Case 15 (2nd Stage: nm2{xy}1302): Solution Composition in Molality

Element	Years				
	60119	91669	607830	617790	633780
Al	5.14E-07	5.39E-08	5.81E-08	1.16E-07	1.21E-07
B	6.68E-04	1.37E-03	4.01E-03	4.99E-03	5.60E-03
Ba	5.81E-07	6.02E-07	1.06E-08	2.97E-09	2.78E-09
Ca	3.87E-04	2.86E-04	1.05E-05	2.14E-05	1.77E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.26E-02	4.09E-03	8.08E-13	1.00E-16	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.19E-04	1.23E-04	3.42E-08	2.36E-14	2.81E-14
Fe	3.68E-12	2.09E-12	1.14E-12	1.16E-12	1.16E-12
Gd	6.37E-09	3.93E-10	2.76E-12	7.20E-12	9.68E-12
C	5.56E-05	8.42E-05	1.68E-03	3.52E-03	3.68E-03
P	3.64E-08	7.21E-08	8.64E-06	1.97E-04	2.64E-04
K	3.01E-04	4.83E-04	4.14E-04	5.52E-04	4.93E-04
Mg	1.52E-04	1.11E-04	6.11E-06	1.23E-05	1.02E-05
Mn	8.73E-12	1.22E-12	1.14E-15	5.16E-16	5.07E-16
Mo	3.51E-04	3.11E-04	1.50E-04	1.00E-16	1.00E-16
N	3.79E-04	2.13E-04	1.42E-04	1.42E-04	1.42E-04
Na	3.32E-03	4.71E-03	2.58E-03	4.77E-03	5.24E-03
Ni	6.52E-03	9.13E-04	7.56E-07	2.07E-07	1.93E-07
S	2.34E-04	2.22E-04	2.47E-04	2.60E-04	2.68E-04
Si	5.68E-05	5.28E-05	4.50E-05	4.28E-05	4.32E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	6.46E-06	6.84E-06	1.34E-04	1.73E-04	1.77E-04
Zn	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**6.07**	**6.45**	**7.96**	**8.26**	**8.27**

6.2 SOURCE TERM: EFFLUENT CONCENTRATION OF FISSILE U

Cases 20 through 23 (Table 43) are focused on maximizing the soluble concentration of fissile U (^{235}U) from fuel flowing out of the WP, referred to as the source term. Since the U in the glass is composed primarily of ^{238}U (Table 44), it is important to run cases where most of the U in solution is from the fuel. From the source term cases, enrichment fractions can be derived which show the fraction of fissile U to total U in the system. It is necessary to calculate ^{235}U enrichment of effluent waters outside of EQ6 since EQ6 does not differentiate between isotopes of an element but takes the total of all isotopes as a total elemental inventory. The enrichment calculations in this section will be included in the external accumulation calculation.

Table 43. Summary of Cases Run for Source Term Calculations

Case	Case ID	Scenario	Log fCO_2
16	nm1x3432	One-stage	-3
17	nt1x1331	One-stage - (Total surface area of liner exposed)	-3
18	nt1x1432	One-stage - (Total surface area of liner exposed)	-3
19	nm1x1031 / nm2x1402	Scenario II - Two-stage	-3
20	nc1x1031 / nc2x1402	Scenario II - Two-stage	-2

This part of the calculation focuses on the source term runs and uses input parameters designed to maximize U enrichment in solution. These cases (Sections 6.2.1 through 6.2.3) concentrate on circumstances where the fraction of ^{235}U in solution should be higher than the cases presented in Section 6.1 of this calculation. This includes assuming that the fuel is fully exposed to the solution in the WP, and it is degrading at the fast degradation rate. Since source term calculations are concerned with effluent (aqueous) composition, only tables for aqueous compositions are given for this section.

Table 44. Isotopic Mole Fractions of HLW Glass and Fermi Fuel

Isotope	Mole Fraction of Total U in HLW Glass[a]	Mole Fraction of Total U in Fermi Fuel[b]
U^{234}	0.002915	---
U^{235}	0.008860	0.2593
U^{236}	0.001748	---
U^{238}	0.986477	0.7407

Sources: [a] Ref. 16, Attachment I, p. I-7 (recalculated for mole fraction of total U in "Unenrich Fermi.xls", Attachment III)
[b] Ref. 9, Section 3.1 7 (recalculated for mole fraction of total U in "Unenrich Fermi.xls", Attachment III).

6.2.1 Influence of Degradation Rates on Source Term

Several cases (16 through 18) were run varying the degradation rates of the reactants to see the impact on U enrichment in solution. This was performed using single stage scenarios where the glass, fuel, and steels are all exposed to degradation simultaneously. All values presented in subsequent tables for Sections 6.2.1 through 6.2.3 are pulled directly from the "*.elem_aqu.txt" files (Attachment III) for each case. The times used in all cases are indicative of periods of interest due to low or high pH or significant changes in aqueous U concentration.

It is generally assumed, that during degradation of the WP, only the inside of the 316NG liner will be significantly exposed to degradation. However, there is a small gap between the 316NG liner and the Alloy 22 outer shell that may flood along with the rest of the WP. For this reason, two cases were run exposing the total surface area of the 316NG liner to degradation instead of exposing only the inner surface area. This has the general effect of increasing the degradation rate of the 316NG liner since EQ6 calculates degradation rate by multiplying the degradation rate constant (moles/cm^2·sec) with the surface area of the component (cm^2) to arrive at a reaction rate in moles/second. Reference 55 (Section 6.1.3) has also shown that increasing the exposed area of the liner increases U in solution and U loss.

For all source term cases, low and average drip rates are used. Not only are these more probable, but they allow better accumulation through dilution. If the drip rate is too high, the waters within the subsurface will not be able to dilute the effluent from the waste package significantly enough to cause precipitation of U minerals from the effluent until it is a great distance from the source. Therefore, it is not conservative for criticality to use a high drip rate. These results will also be input into PHREEQC (Ref. 60), and the lower rates allow PHREEQC to converge more easily.

Table 45 sums the results of the one stage source term cases. The cases are explained individually in more detail later in this section.

Table 45. Results of One Stage Source Term Cases

Case	Case ID	Peak U (moles/Kg)	Year	Enrichment Fraction	pH
16	nm1x3432	1.17E-02	144	0.2498	3.90
		5.33E-02	37,241	0.2181	8.82
17	nt1x1331	1.48E-03	136	0.2563	4.29
		4.34E-02	368,664	0.2167	8.81
18	nt1x1432	3.82E-02	44,673	0.2032	8.80

Figure 16 and Figure 17 and Table 46 show the results of Case 16 (nm1x3432). The high steel degradation rate is used to exhaust the acid producing steel components quickly. After the steels are completely depleted, at 28,000 years, glass degradation raises the pH of the system so that all of the U-bearing minerals dissolve by 38,000 years to create a high concentration of U in solution. Since the minerals were formed during the period when most of the U in the system was from the degradation of the Fermi fuel, the enrichment is expected to be high.

The results from ASPRIN show that when the peak U concentration (1.17E-02 and 5.33E-02 moles/Kg) occurs, the enrichment fraction of U235/total U is 0.2498 and 0.2181 respectively. The fuel contains a mole fraction of 0.2593 U235/total U so these enrichments are close to the maximum enrichment possible.

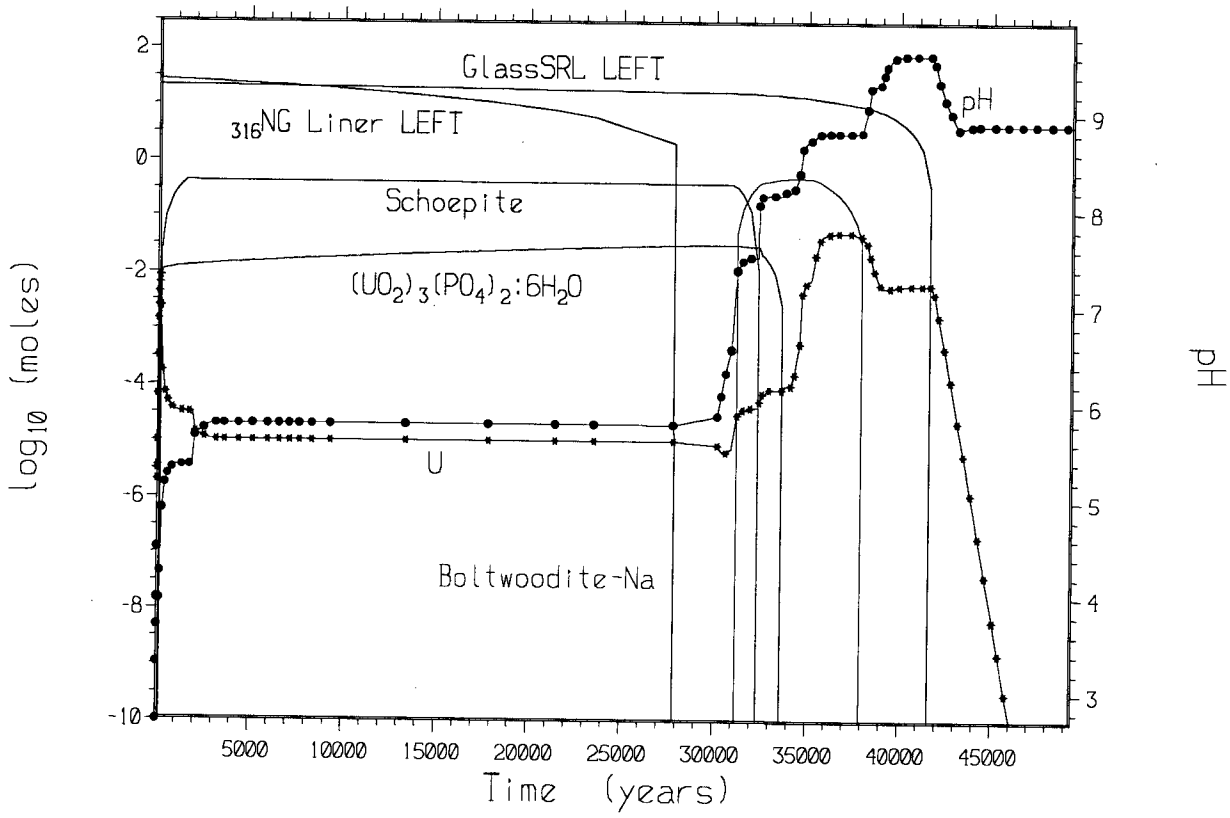

Figure 16. Case 16 (nm1x3432): WP Materials, Minerals, and Aqueous U

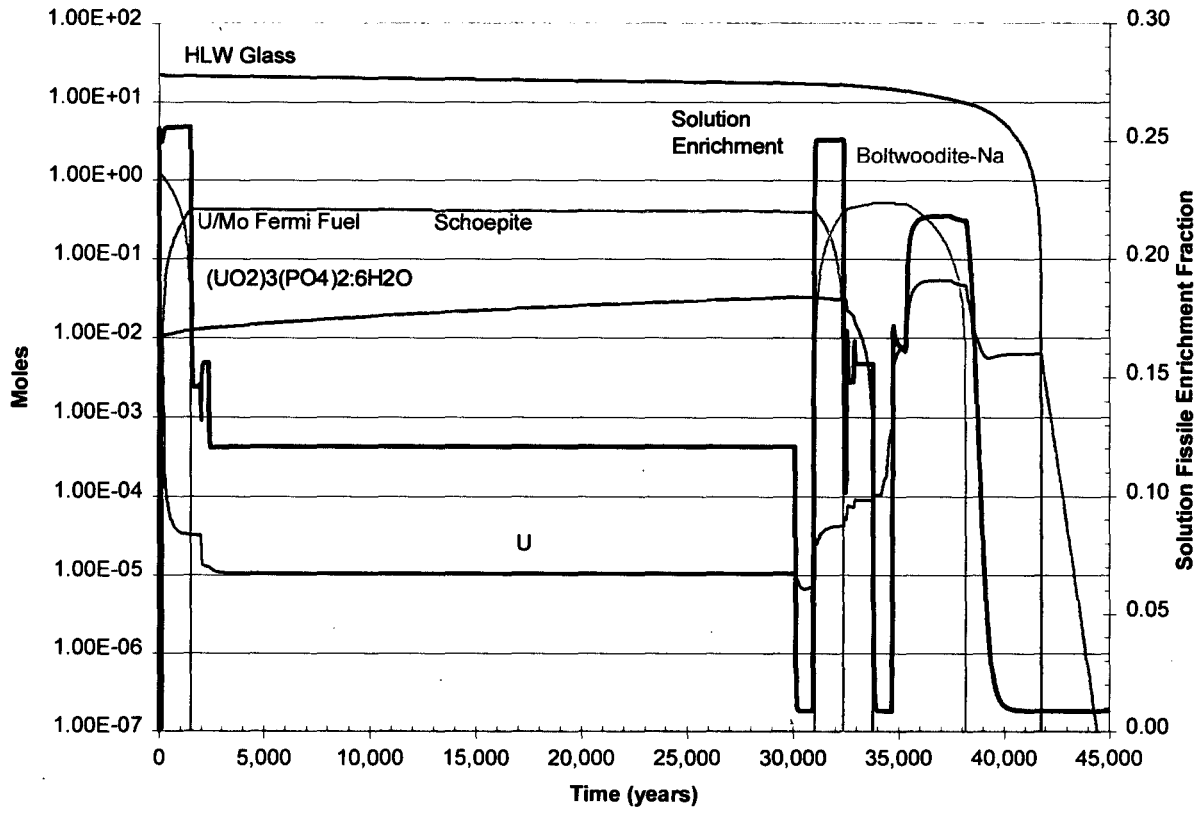

Figure 17. Case 16 (nm1x3432): Enrichment and U-bearing solids in the WP

Table 46. Case 16 (nm1x3432): Solution Composition in Molality

Element	Years			
	144	37246	41764	49725
Al	4.24E-04	1.56E-07	1.12E-07	1.29E-07
B	3.80E-02	1.12E-01	1.79E-01	1.06E-14
Ba	1.05E-05	9.89E-10	5.36E-11	2.12E-10
Ca	2.44E-03	8.82E-06	6.70E-06	1.38E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.64E+00	6.65E-14	1.00E-16	1.00E-16
Cu	2.16E-04	1.00E-16	1.00E-16	1.00E-16
F	3.37E-04	7.04E-04	1.36E-03	1.15E-04
Fe	1.03E-09	1.34E-12	2.68E-12	1.33E-12
Gd	1.67E-05	4.04E-09	3.66E-07	4.50E-08
C	1.71E-05	1.78E-01	2.00E-01	1.48E-02
P	1.67E-08	3.93E-06	1.08E-05	1.48E-07
K	3.40E-03	4.12E-03	5.42E-03	1.39E-03
Mg	6.49E-03	7.30E-05	6.53E-06	1.44E-05
Mn	3.62E-07	1.24E-15	7.93E-15	1.11E-15
Mo	1.23E-04	2.17E-07	2.55E-15	1.00E-16
N	3.21E-02	1.42E-04	1.42E-04	1.42E-04
Na	7.73E-02	2.78E-01	4.27E-01	1.49E-02
Ni	7.75E-01	4.86E-08	1.17E-09	1.28E-08
S	7.03E-04	1.73E-03	3.43E-03	1.92E-04
Si	7.82E-05	9.44E-05	5.83E-04	5.19E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.17E-02	5.33E-02	6.32E-03	1.18E-16
Zn	1.91E-04	1.00E-16	0.00E+00	1.30E-19
pH	**3.92**	**8.82**	**9.63**	**8.90**

Figure 18 and Figure 19 and Table 47 show the results of Case 17. Like Case 16, A peak U concentration (1.48E-03 moles/Kg) in solution corresponds to a high enrichment fraction (0.2563). For the first 285,000 years, the pH remains around 6 until all of the steel from the 316NG liner is completely degraded. After this point, the pH slowly rises over the next 100,000 years as glass degrades and adds to the alkalinity of the system. When the pH reaches a level of 8.81 at 370,000 years, all of the U minerals remaining in the WP dissolve, creating a peak aqueous U concentration of 4.34E-02 moles/Kg having an enrichment fraction of 0.2167.

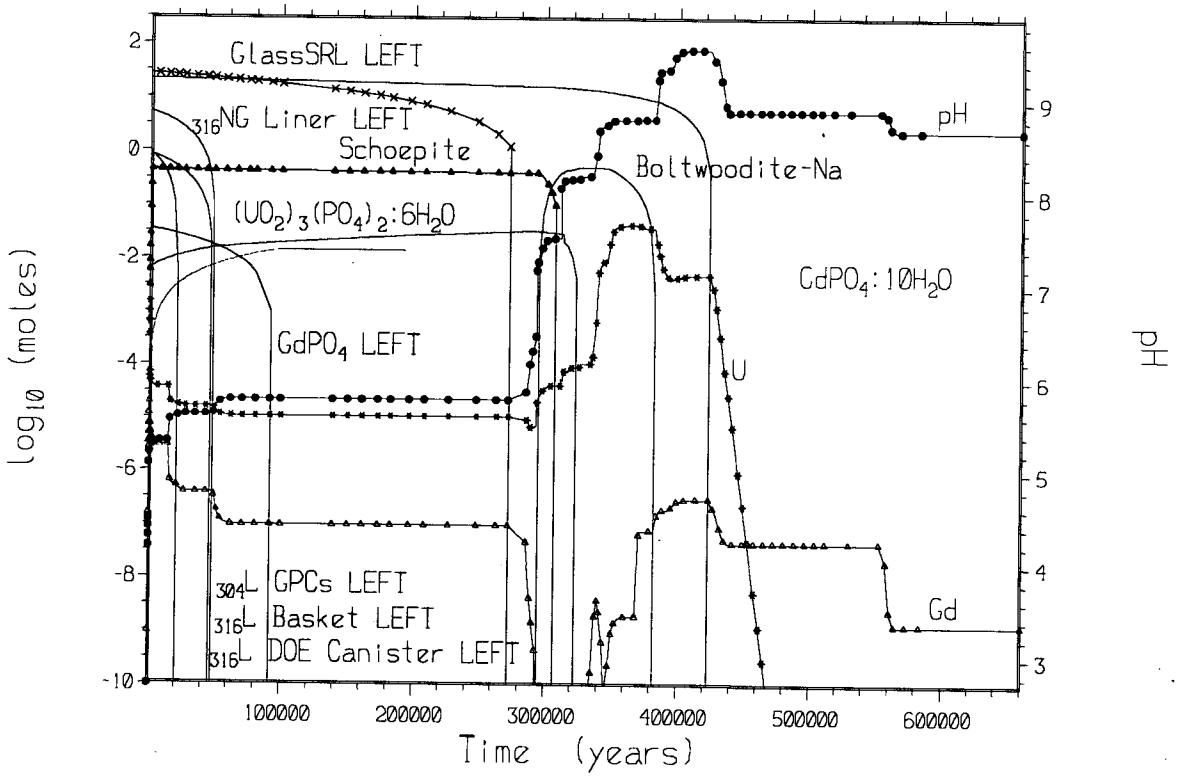

Figure 18. Case 17 (nt1x1331): WP Materials, Minerals, and Aqueous U

The results of ASPRIN (Figure 19) show that at the peak aqueous U content, the enrichment of the solution is 0.2167, very close to that for Case 16. This shows that Cases 16 and 17 produce very similar results, however, the parameters set in Case 16 allow for the enriched U concentration to peak much earlier after initial breach of the WP than in Case 17.

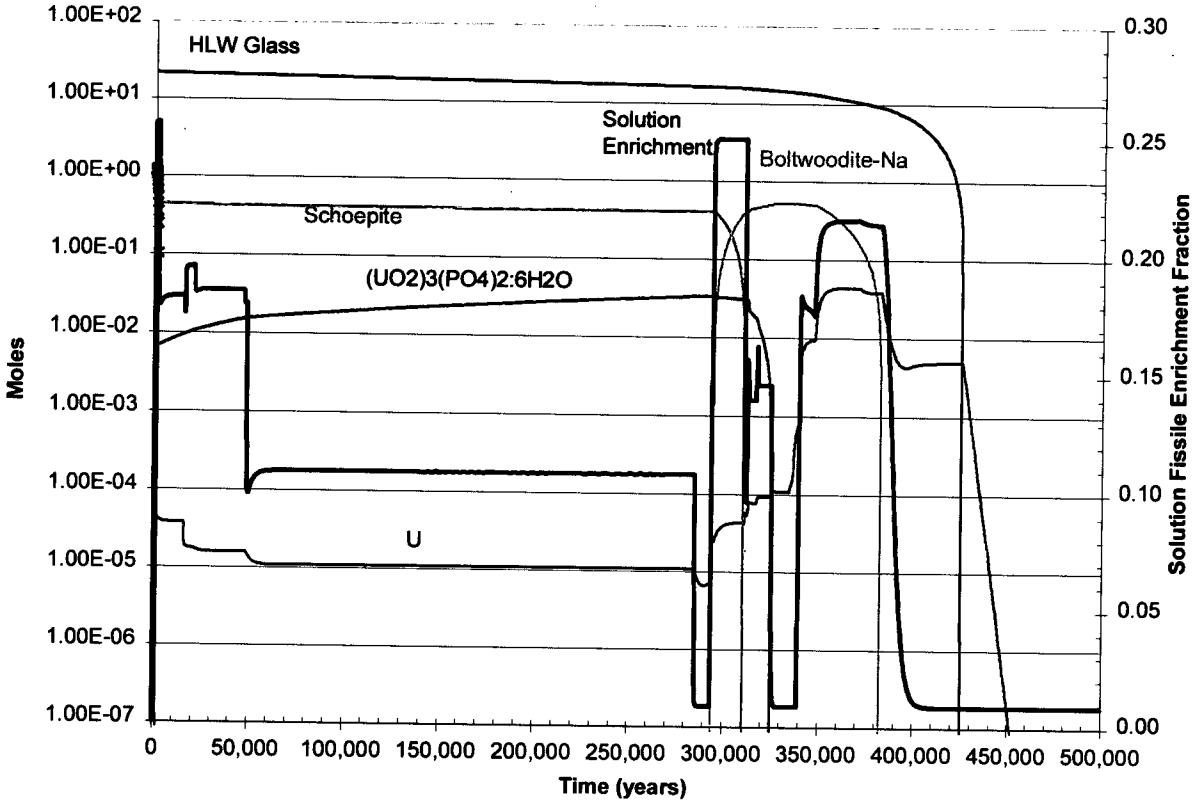

Figure 19. Case 17 (nt1x1331): Enrichment Fraction and U-bearing Solids in the WP.

Table 47. Case 17 (nt1x1331): Solution Composition in Molality

Element	Years			
	136	313280	370620	660410
Al	8.26E-05	1.01E-07	1.84E-07	2.06E-07
B	3.55E-03	3.96E-02	9.16E-02	1.00E-16
Ba	6.42E-08	6.33E-09	9.36E-10	4.61E-10
Ca	5.22E-04	1.91E-05	5.60E-06	3.72E-06
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.26E-02	3.45E-06	3.44E-16	1.00E-16
Cu	2.56E-04	1.00E-16	1.00E-16	1.00E-16
F	1.35E-04	2.07E-14	5.99E-04	1.15E-04
Fe	2.04E-10	1.15E-12	1.34E-12	1.24E-12
Gd	1.96E-05	3.46E-11	1.96E-09	1.30E-09
C	3.39E-05	2.96E-03	1.48E-01	8.68E-03
P	1.42E-08	9.13E-04	7.06E-06	1.10E-06
K	3.48E-06	1.94E-03	3.38E-03	8.31E-04
Mg	2.92E-03	2.00E-04	6.76E-05	2.93E-05
Mn	4.04E-08	7.76E-16	1.20E-15	6.96E-16
Mo	1.88E-04	6.34E-03	1.38E-08	1.00E-16
N	3.81E-04	1.42E-04	1.42E-04	1.42E-04
Na	9.02E-03	2.05E-02	2.28E-01	8.87E-03
Ni	6.86E-03	4.20E-07	4.75E-08	3.02E-08
S	1.00E-02	7.36E-04	1.45E-03	1.92E-04
Si	5.72E-05	4.01E-05	8.40E-05	4.45E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.48E-03	7.92E-05	4.34E-02	1.00E-16
Zn	2.26E-04	1.00E-16	1.00E-16	1.00E-16
pH	**4.29**	**8.17**	**8.81**	**8.69**

Figure 20 and Figure 21 and Table 48 show the results of Case 18. In Case 18, even though the surface area of the 316NG liner was doubled, the slow steel degradation rate combined with a fast HLW glass degradation rate is not enough to keep the pH of the system as low as the previous cases. At the beginning of Case 18, the pH remains below 6.8 for the first 37,000 years. After this point, it rises to a level of 8.8 as the steel from the 316L basket and DOE canister as well as the 304L GPCs are nearing exhaustion. When the pH reaches 8.8 at around 42,000 years, all of the minerals dissolve and aqueous U rises to a high of 3.82E-02 moles/Kg. When the aqueous U reaches this high plateau, most of the glass is also degraded so the enrichment for Case 18 is not expected to be as high as that for Cases 16 and 17. This is confirmed by ASPRIN (Figure 21) which shows an enrichment fraction of 0.2032 at this point.

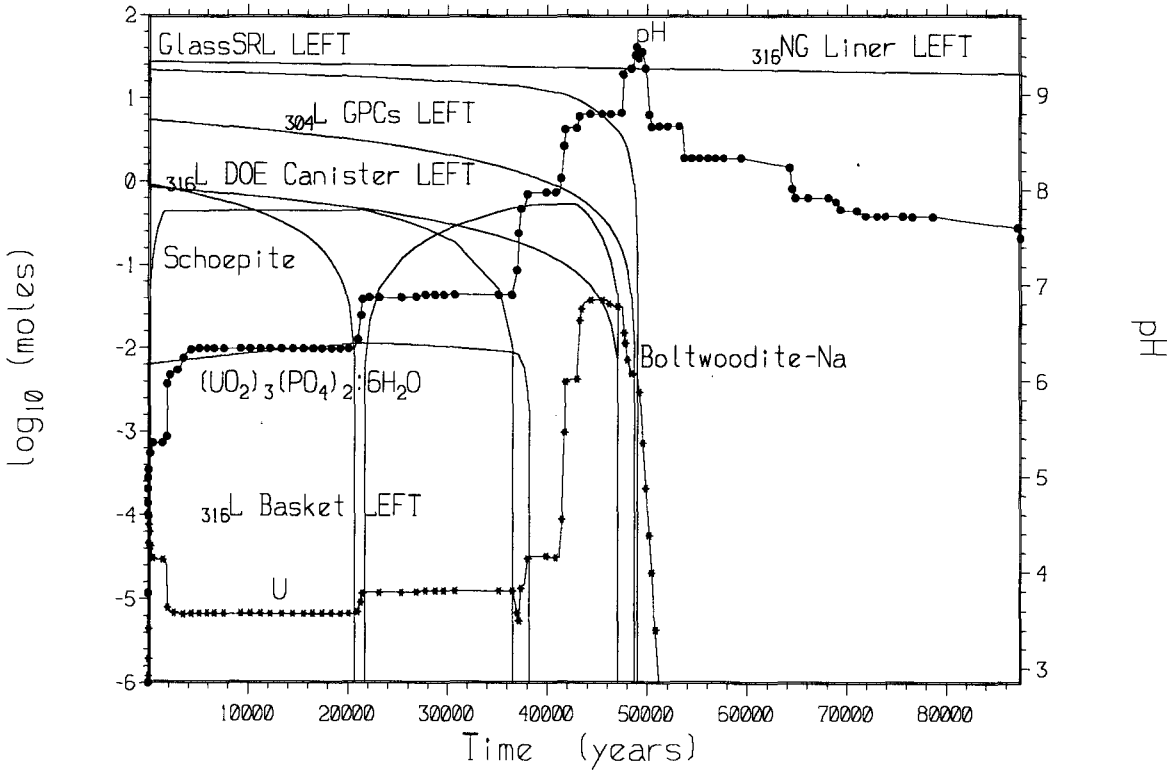

Figure 20. Case 18 (nt1x1432): WP Materials, Minerals, and Aqueous U

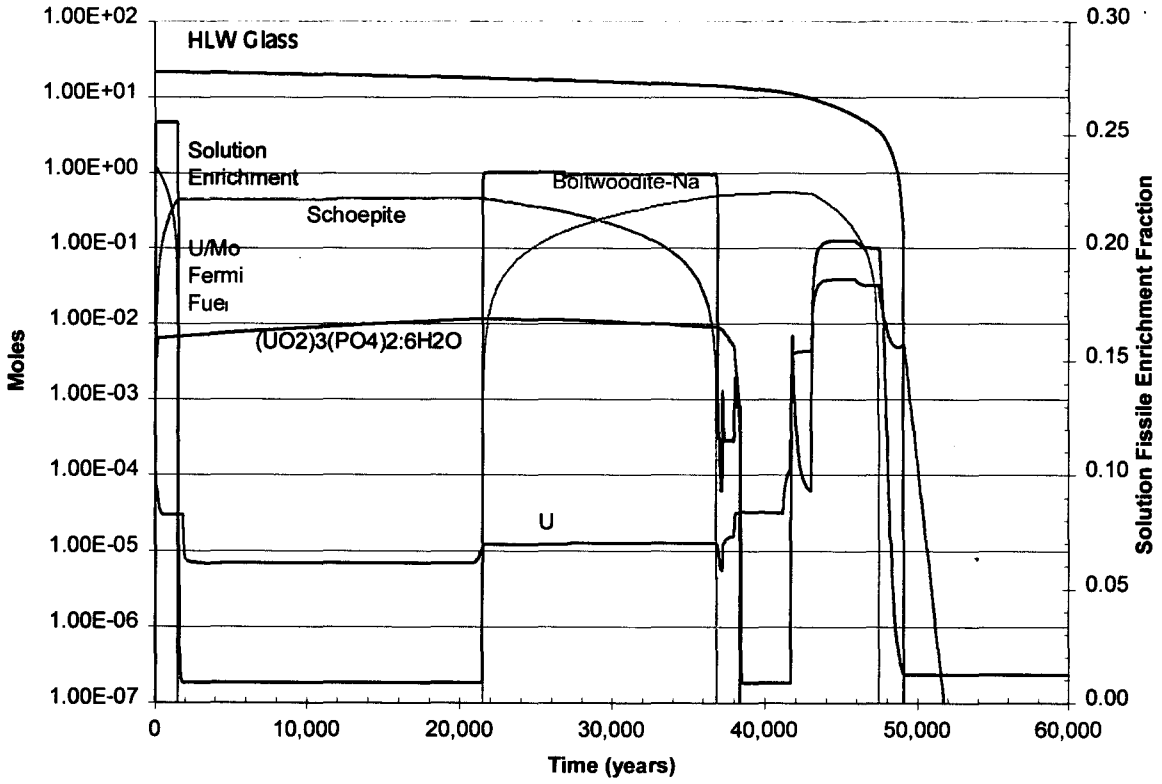

Figure 21. Case 18 (nt1x1432): Enrichment Fraction and U-bearing solids in the WP.

Table 48. Case 18 (nt1x1432): Solution Composition in Molality

Element	Years			
	18	29642	45890	87672
Al	4.00E-05	1.12E-08	1.64E-07	1.56E-08
B	2.62E-03	2.03E-02	1.10E-01	1.00E-16
Ba	9.07E-08	1.68E-07	1.02E-09	2.95E-07
Ca	9.04E-05	7.23E-04	9.96E-06	3.17E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.65E-03	2.14E-02	2.15E-02	6.02E-03
Cu	3.35E-05	1.00E-16	1.00E-16	1.00E-16
F	1.30E-04	1.53E-04	6.65E-04	1.02E-04
Fe	5.03E-11	1.48E-12	1.33E-12	1.24E-12
Gd	2.62E-06	4.16E-11	2.71E-09	5.14E-11
C	3.52E-05	1.94E-04	1.32E-01	3.89E-04
P	1.40E-08	2.84E-07	4.85E-06	1.06E-07
K	8.09E-04	4.36E-03	3.82E-03	7.07E-03
Mg	1.95E-04	7.51E-04	7.64E-05	1.88E-03
Mn	2.87E-09	2.19E-13	1.18E-15	2.81E-14
Mo	1.09E-03	4.89E-04	8.16E-04	4.81E-04
N	1.73E-04	5.47E-04	5.47E-04	2.92E-04
Na	7.18E-03	3.32E-02	2.59E-01	2.26E-03
Ni	8.99E-04	1.64E-04	5.07E-08	2.10E-05
S	3.37E-03	5.29E-04	1.76E-03	2.16E-04
Si	7.51E-05	4.49E-05	8.86E-05	3.94E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.30E-04	1.27E-05	3.82E-02	1.00E-16
Zn	2.96E-05	1.00E-16	1.00E-16	1.00E-16
pH	**4.80**	**6.91**	**8.80**	**7.30**

6.2.1 Influence of Degradation Order on Source Term

In an attempt to increase the enrichment fraction, the U input from HLW glass must be minimized as much as possible. For this reason, Case 19 (nm1x1031/nm2x1402) is a Scenario II two-stage run. By using this type of case, the fuel is allowed to degrade without U input from the HLW glass. The second stage then adds the glass to raise the pH and force the U into solution with minimal influence on total U in solution by the HLW glass. Figure 22 through Figure 24 and Table 49 show the effects of keeping the HLW glass from interacting with the solution in the WP until the second stage.

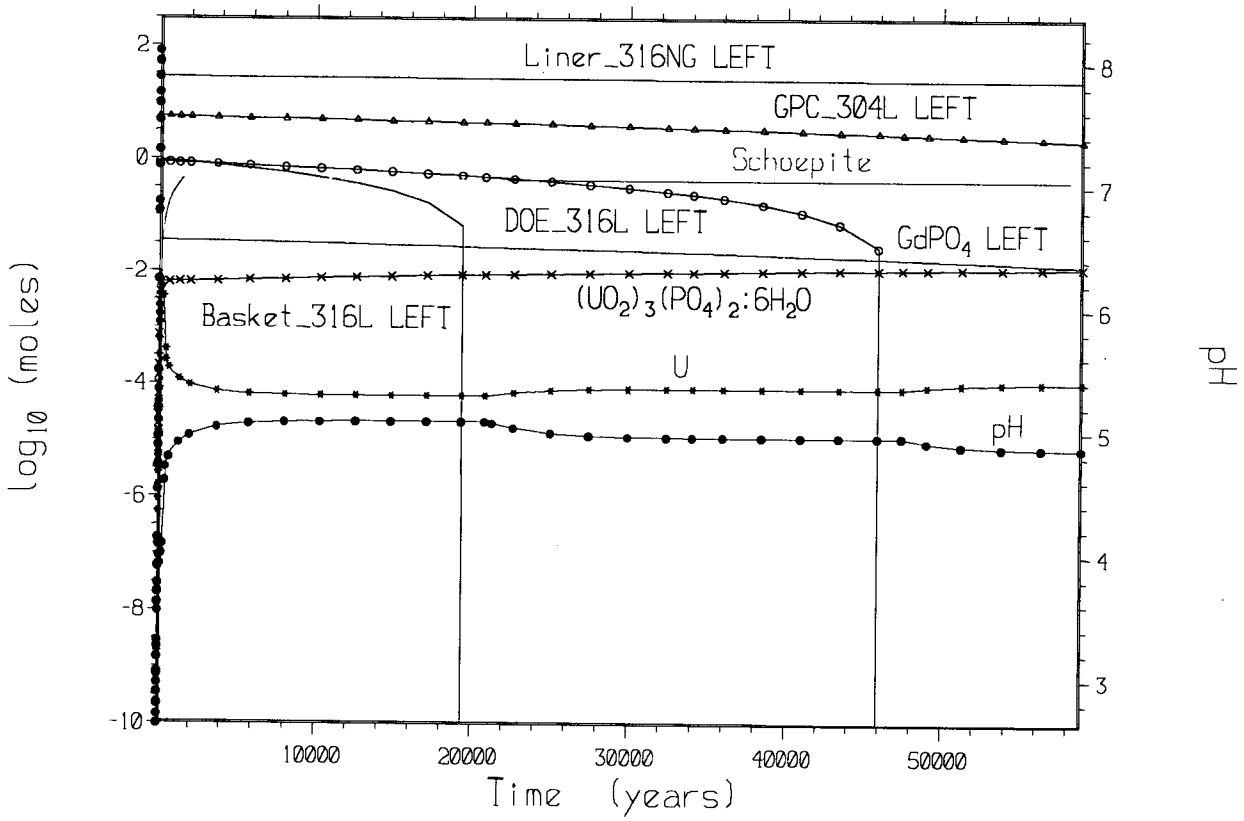

Figure 22. Case 19 (1st Stage: nm1x1031): WP Materials, Minerals, and Aqueous U

In the first stage of Case 19 (nm1x1031), the pH hovers around 5 for most of the run retaining most of the U in the package as $(UO_2)_3(PO_4)_2 \cdot 6H_2O$ and schoepite. After the second stage (nm2x1402) begins, the pH remains low until the steel from the 304L GPCs is gone just before 79,000 years. At this point, the pH begins to rise causing a like rise in aqueous U. The first U peak (1.96E-01 moles/Kg) is seen at 85,000 years when the pH is at 8.85. Four thousand years

later, the pH peaks at 10.00 at which point $Na_4UO_2(CO_3)_3$ forms causing a slight dip in aqueous U. When the pH decreases to 9.38, the U carbonate dissolves and another U peak (1.86E-01 moles/Kg) is seen at 94,000 years. Glass depletion occurs between these two U peaks. Therefore, the second peak of aqueous U should have a lower enrichment than the first, which occurs before complete degradation of the HLW glass.

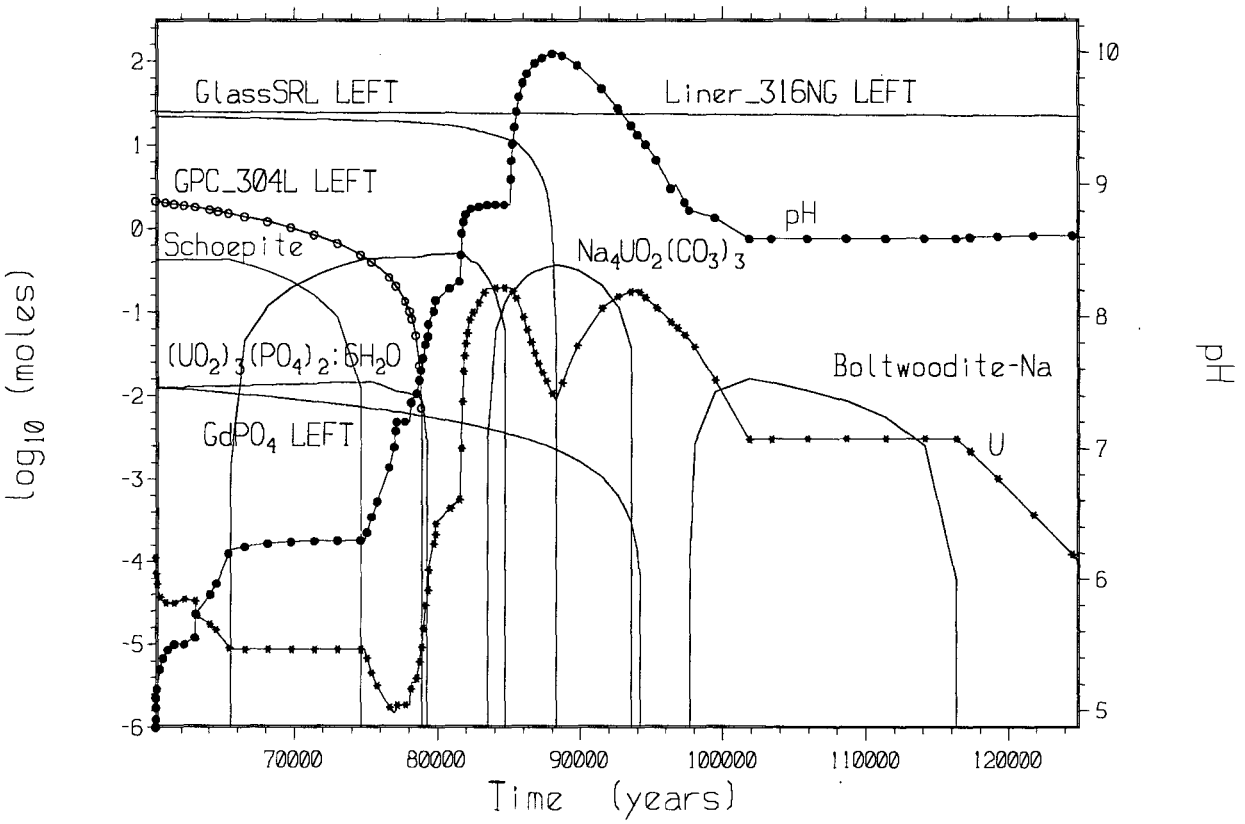

Figure 23. Case 19 (2nd Stage: nm2x1402): WP Materials, Minerals, and Aqueous U

Results from ASPRIN show that the first peak corresponds to an enrichment of 0.2200 and the second to an enrichment of 0.1802 agreeing with the above stated observations. Even though this case results in approximately the same enrichment as in Cases 16 and 17, the amount of U in solution is much higher in Case 19, over half an order of magnitude. Therefore Case 19, depending on the probability of the scenario, is a better case for source term since it is more conservative for external criticality.

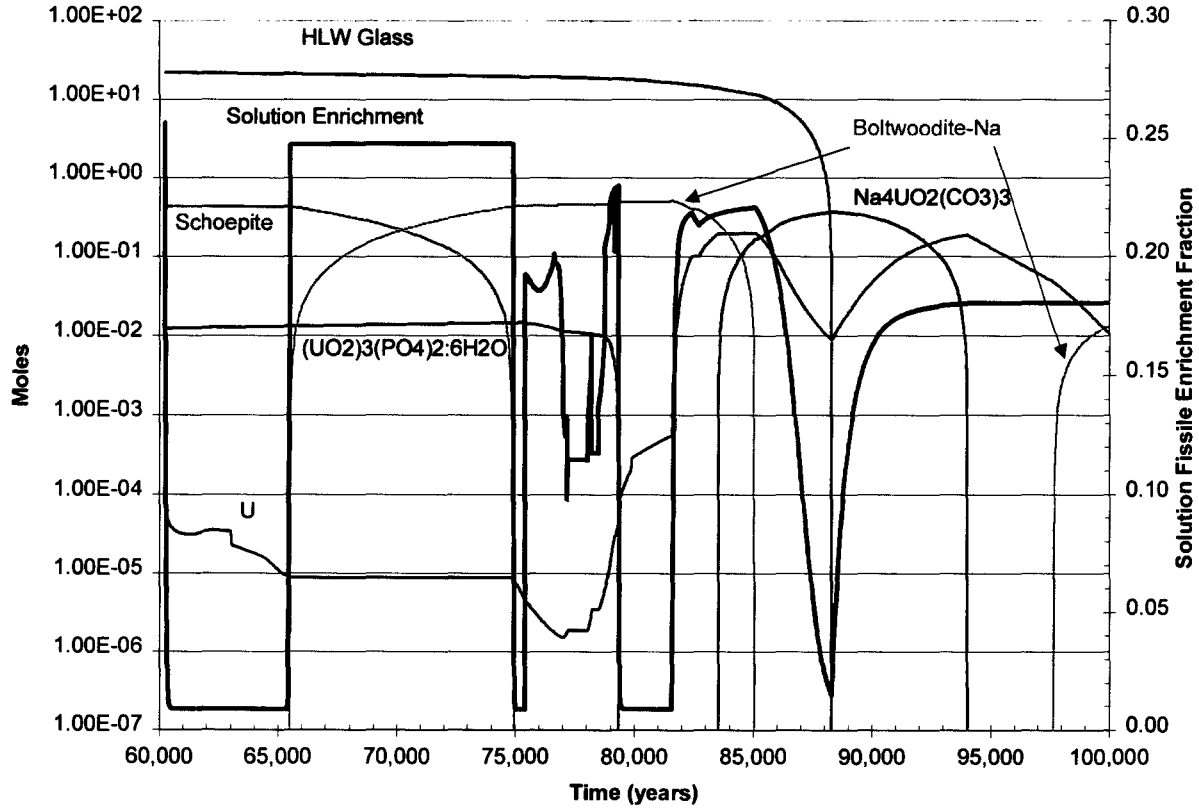

Figure 24. Case 19 (2nd Stage: nm2x1402): Enrichment Fraction and U bearing solids in the WP.

Table 49. Case 19 (2nd Stage: nm2x1402): Solution Composition in Molality

Element	Years			
	60233	**85077**	**94389**	**317180**
Al	3.61E-05	3.93E-08	4.64E-08	1.60E-06
B	1.00E-16	9.74E-02	1.23E-01	1.00E-16
Ba	1.00E-16	8.64E-10	1.32E-10	6.93E-07
Ca	1.19E-04	6.15E-05	1.18E-05	7.25E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	9.72E-02	5.29E-02	4.13E-02	4.09E-02
Cu	5.15E-14	1.04E-16	1.00E-16	1.00E-16
F	1.15E-04	4.10E-03	1.24E-03	1.23E-04
Fe	5.46E-11	1.32E-12	1.94E-12	5.98E-12
Gd	3.77E-05	1.90E-07	2.61E-07	2.31E-11
C	3.42E-05	6.20E-01	5.97E-01	4.66E-05
P	1.45E-08	2.24E-07	4.30E-06	2.22E-05
K	1.29E-04	1.55E-02	1.41E-02	8.20E-04
Mg	8.27E-05	5.12E-05	1.07E-05	2.66E-05
Mn	3.75E-09	1.40E-15	4.36E-15	3.48E-11
Mo	2.69E-03	7.90E-03	3.40E-03	3.52E-03
N	1.96E-03	1.08E-03	8.63E-04	8.56E-04
Na	1.99E-03	1.01E+00	9.72E-01	1.99E-03
Ni	5.18E-02	4.18E-08	4.91E-09	2.61E-02
S	4.53E-04	1.34E-02	3.47E-03	3.09E-04
Si	5.69E-05	2.86E-04	7.24E-04	6.60E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.10E-04	1.96E-01	1.62E-01	1.00E-16
Zn	4.55E-14	0.00E+00	0.00E+00	1.00E-16
pH	**4.87**	**8.85**	**9.33**	**5.84**

6.2.3 Influence of Higher CO_2 Partial Pressure on Source Term

There is a possibility that the partial pressure of carbon dioxide (CO_2) could increase at Yucca Mountain if there is renewed volcanic activity in the area. The higher CO_2 levels would have a profound effect on the pH of any solutions within the mountain. As shown numerous times previously in this calculation, the pH of the solution within the WP controls the solubility of U-bearing minerals. Case 20 investigates the effects of raising the partial pressure of CO_2 on the release and enrichment of U from the WP. The worst case (Case 19 – more conservative) was taken as the base case to which these results are compared.

Figure 25 and Figure 26 and Table 50 show the results of Case 20. The first stage of Cases 19 and 20 are extremely similar so the first stage of Case 20 (nc1x1031) is not presented here.

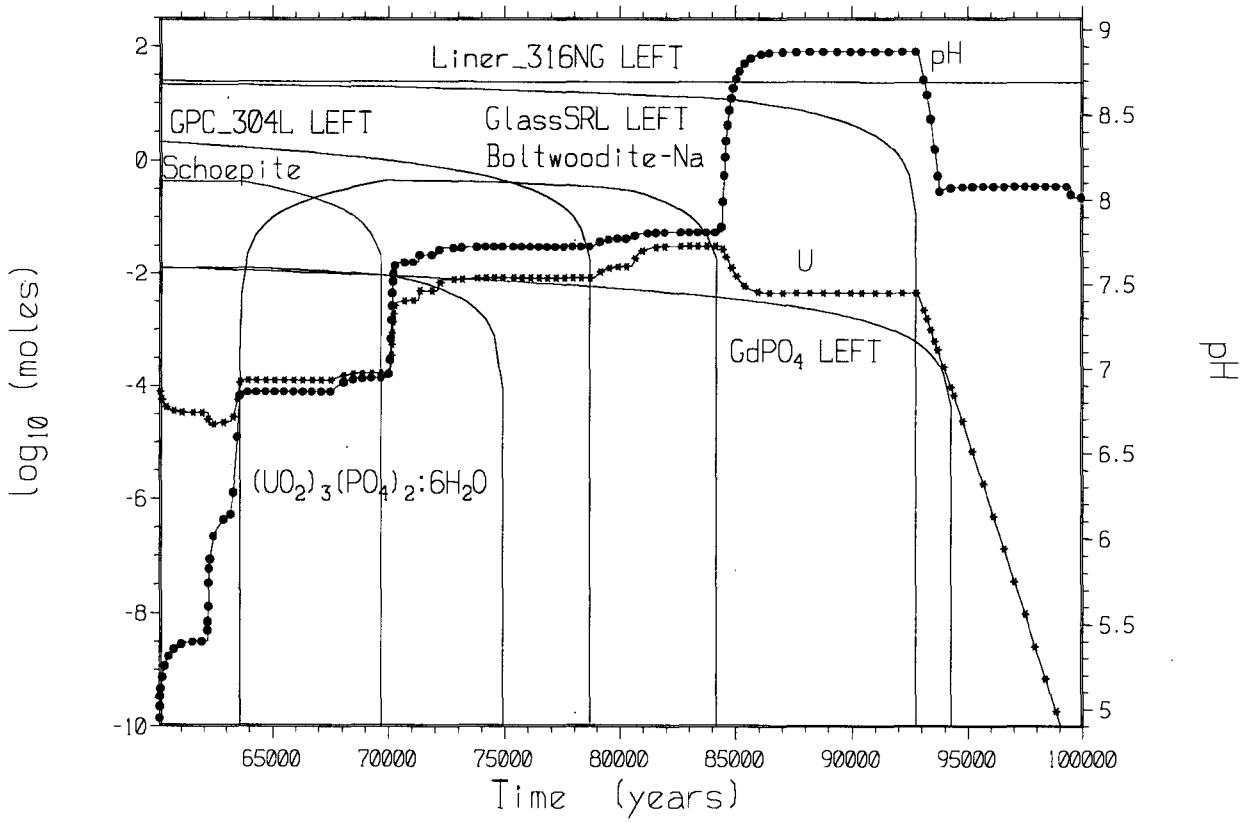

Figure 25. Case 20 (2nd Stage: nc2x1402): WP Materials, Minerals, and Aqueous U

At the start of the second stage (nc2x1402), the pH is still below 7 for the first 10,000 years as the rest of the 304L GPCs degrade. After the steel is completely exhausted, the pH rises above 7.5 and the aqueous U increases to 1.87E-3 moles/Kg. Uranium concentration in solution

continues to increase until it peaks at 3.08E-02 moles/Kg at a pH of 7.81 at 84,400 years. The pH levels at which the U-bearing minerals dissolve is much lower in Case 20 than that in Case 19. The reason for this is that U minerals are 25 times more soluble at log f_{CO_2} = -2 than at log f_{CO_2} = -3 (Ref. 56, Section 6.3.3). The point of highest concentration of U in solution corresponds to the dissolution of Na-boltwoodite, which contains primarily fissile U from the degradation of the fuel in the first stage. Therefore the enrichment fraction is the highest at this point, peaking at 0.2346. Although the enrichment is the highest here than seen for the other cases, due the significant increase in solubility of U-bearing minerals at higher CO_2 levels, Case 19 probably represents the more conservative source term.

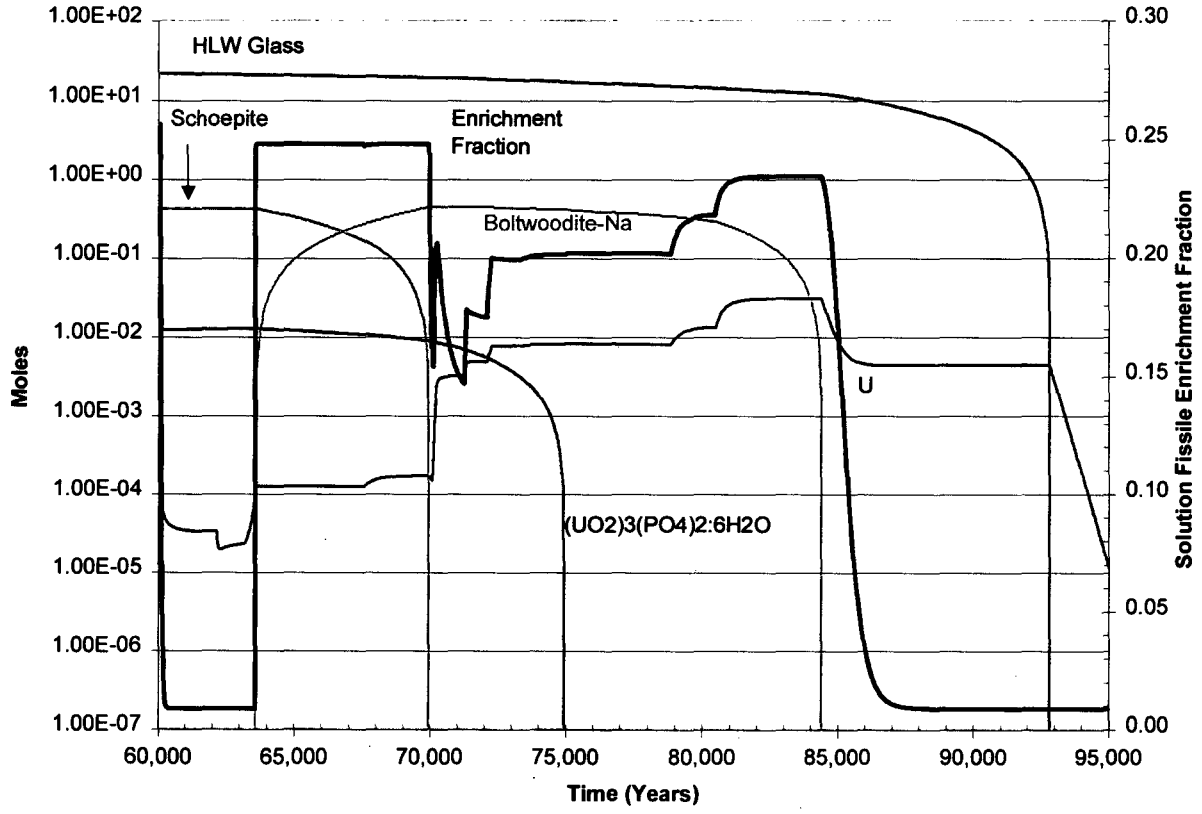

Figure 26. Case 20 (2nd Stage: nc2x1402): Enrichment Fraction and U-bearing Solids in the WP.

Table 50. Case 20 (2nd Stage: nc2x1402): Solution Composition in Molality

Element	Years				
	136	1496	5436	20844	60069
Al	2.43E-04	3.41E-05	2.60E-05	2.33E-05	3.51E-05
B	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ba	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Ca	3.24E-04	9.73E-05	5.68E-05	4.96E-05	1.17E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	7.70E-03	7.04E-02	1.66E-01	2.16E-01	1.38E-01
Cu	2.58E-04	6.56E-04	2.25E-04	3.24E-06	6.27E-11
F	1.15E-04	1.15E-04	1.15E-04	1.15E-04	1.15E-04
Fe	6.23E-10	4.65E-11	3.49E-11	3.24E-11	5.33E-11
Gd	1.98E-05	5.01E-05	1.45E-05	1.01E-05	3.68E-05
C	3.38E-04	3.35E-04	3.36E-04	3.36E-04	3.37E-04
P	1.58E-08	1.43E-08	1.54E-08	1.59E-08	1.47E-08
K	3.10E-07	1.43E-04	1.34E-04	1.29E-04	1.29E-04
Mg	2.53E-03	6.32E-03	2.22E-03	1.13E-04	8.27E-05
Mn	2.22E-07	2.99E-09	1.72E-09	1.49E-09	3.68E-09
Mo	4.90E-05	3.17E-03	8.25E-03	1.09E-02	3.39E-03
N	2.90E-04	1.53E-03	3.43E-03	4.42E-03	2.72E-03
Na	1.99E-03	1.99E-03	1.99E-03	1.99E-03	1.99E-03
Ni	4.24E-03	3.96E-02	9.41E-02	1.22E-01	7.38E-02
S	1.19E-02	8.87E-03	3.56E-03	8.27E-04	5.63E-04
Si	5.83E-05	5.53E-05	5.63E-05	5.68E-05	5.69E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	7.54E-03	1.20E-04	7.01E-05	6.13E-05	1.12E-04
Zn	2.28E-04	5.79E-04	1.99E-04	2.86E-06	5.54E-11
pH	**3.91**	**4.92**	**5.08**	**5.12**	**4.90**

6.3 SENSITIVITY ANALYSES

6.3.1 $GdPO_4$ Degradation Rate and Mass

Due to the uncertainty in the degradation rate of the $GdPO_4$ shot within the basket of the DOE canister and the results of the Enrico-Fermi criticality analysis (Ref. 7, Section 8.5), additional calculations have been made to determine the effects of faster degradation rates and greater masses of $GdPO_4$ on the retention of Gd in the WP. Because an increase of Gd loss was indicated using faster rates (Section 6.3.1.1), these higher degradation rates are also combined with larger masses of $GdPO_4$ to examine the effect of higher Gd concentrations on the losses from the WP (Section 6.3.1.2).

6.3.1.1 Effects of Increasing $GdPO_4$ Degradation Rate on Gd Loss

This section examines the effect of faster $GdPO_4$ degradation rates. Since there is no reference for the degradation rate of $GdPO_4$ in an aqueous environment, the cases presented earlier in the calculation used a rate equal to the dissolution of quartz (See Assumption 3-22). The cases presented in Section 6.3.1 use degradation rates equal to those of 304L stainless steel and A516 carbon steel. Although these rates may also not be representative of how $GdPO_4$ truly degrades in a fully saturated environment, it explores the effects of increased degradation rates on the retention of the Gd in the WP. The runs chosen as the base cases to which to compare these results are those one-stage runs which lost the most Gd, Cases 7 and 8. Table 51 presents the results of the sensitivity runs.

Table 51. Gd and U Retention: Sensitivity of Faster $GdPO_4$ Degradation Rates

Case[a]	File Name[a]	Length of Run (Years)[a]	Gd Retention[a]	U Retention[a]
21	nA1{xyz}3323	633,780	95.53%	70.01%
22	nL1{xyz}3323	633,780	95.53%	70.01%
23	nA1x3333	245,930	38.16%	60.74%
24	nL1x3333	228,640	63.13%	61.89%
Case[b]	**File Name[b]**	**Length of Run (Years)[b]**	**Gd Retention[b]**	**U Retention[b]**
7	nm1{xyz}3323	633,780	95.53%	70.01%
8	nm1{xyz}3333	622,460	94.64%	46.97%

Source: [a] Calculated in "fermi-losses.xls" (Attachment III)
[b] From Section 6.1.1
NOTE: Percent retention values presented for Gd and U represent percent of total initial moles of those elements.

The losses of Gd and U between Cases 21, 22, and 7 are exactly the same indicating that at the lower fuel degradation rate, the effect of differing the $GdPO_4$ degradation rate is inconsequential to the overall losses from the WP. This may be due to the virtual absence of U in the system because of the slowly degrading fuel. Without the U taking up the P in the system, even at low pH values $GdPO_4 \cdot 10H_2O$ can successfully form.

Cases 23 and 24, however, differ greatly from the base case, Case 8. For Cases 8, 23, and 24 it can be seen that as the $GdPO_4$ degradation rate increases, Gd retention decreases. Looking at Cases 23 and 24, most of the Gd loss occurs before the first 1000 years. Figure 27 shows that for Cases 8, 23, and 24 (all of which have a 3333 extension), the pH dips below 4 for a period of over 200 years. During this extreme period of low pH, Gd in solution for the two sensitivity cases is very high. It is during this period that most of the Gd is lost from the WP. For Case 23, all of the $GdPO_4$ is degraded during the pH low. Case 24 only has about half of the $GdPO_4$ degraded during this low pH period. Case 8 on the other hand has almost all of the $GdPO_4$ intact during this period. Therefore, with cases that have a period of very low pH at the beginning of the run, Gd retention will decrease with increasing degradation rate. Since Case 23 gives the most conservative losses of Gd, only tables for Case 23 are presented in this section.

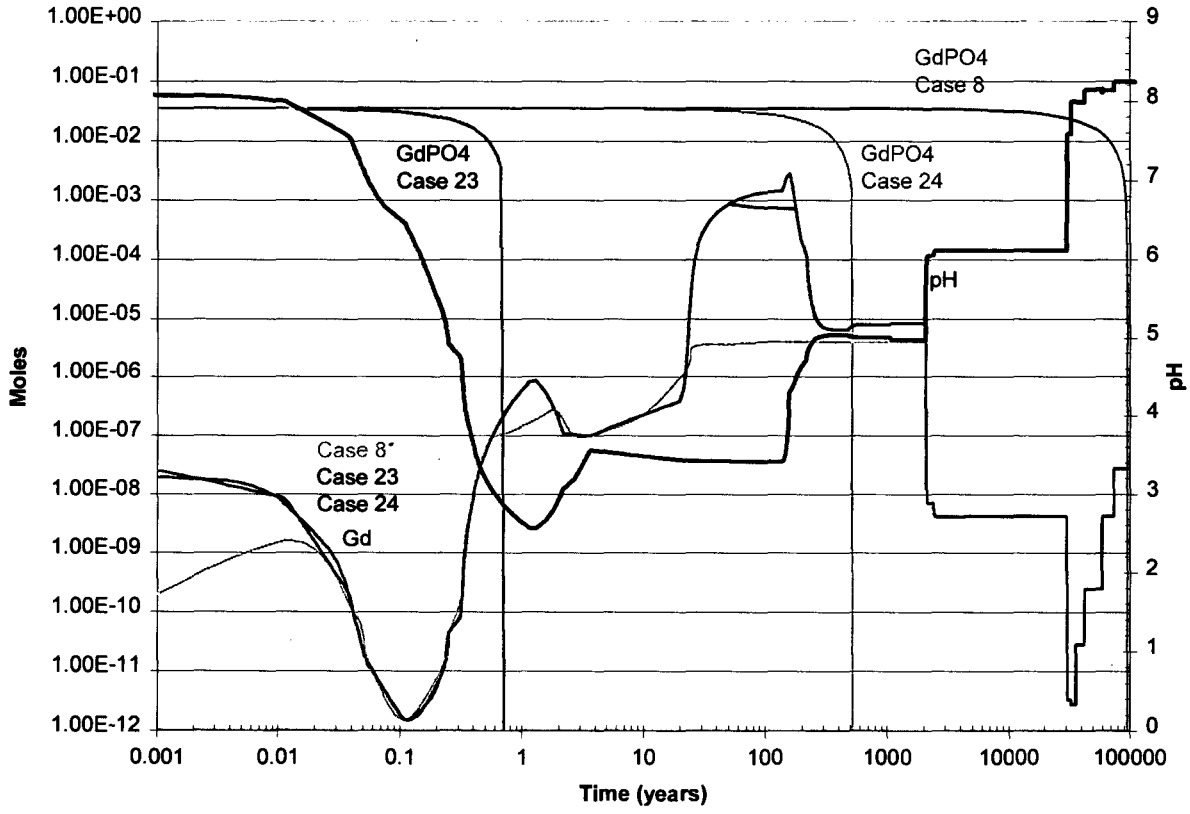

Figure 27. Cases 8, 23, and 24: $GdPO_4$ Degradation, Aqueous Gd, and pH

Table 52. Case 23 (nA1x3333): Composition of Corrosion Products (g), Total Mass, and Density

Element	Years			
	1043	2114	33132	245930
O	7.92E+02	8.45E+02	1.70E+03	2.49E+03
Al	1.97E+01	1.97E+01	2.10E+01	5.41E+01
B	0.00E+00	3.81E-18	0.00E+00	2.34E-18
Ba	1.24E-03	0.00E+00	1.54E-02	2.16E+00
Ca	3.77E-01	8.35E-01	7.93E+00	7.09E+01
Cl	0.00E+00	0.00E+00	0.00E+00	9.61E-19
Cr	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	0.00E+00	0.00E+00	2.15E-01	4.90E-01
Fe	1.63E+03	1.72E+03	3.40E+03	3.54E+03
Gd	9.11E-01	8.64E-01	8.63E-01	8.36E-01
H	3.15E+00	3.59E+00	5.25E+00	1.21E+01
C	1.03E-12	8.35E-13	1.34E-03	9.63E+00
P	1.16E+00	1.23E+00	2.38E+00	2.56E+00
K	0.00E+00	0.00E+00	0.00E+00	4.24E-18
Mg	0.00E+00	0.00E+00	7.67E-01	1.14E+01
Mn	2.73E+01	3.00E+01	8.14E+01	8.14E+01
Mo	3.95E+00	2.00E+00	0.00E+00	0.00E+00
N	0.00E+00	0.00E+00	0.00E+00	1.14E-18
Na	0.00E+00	0.00E+00	1.38E-01	5.52E-01
Ni	0.00E+00	3.46E-04	1.06E+01	1.05E+01
S	2.89E-04	0.00E+00	7.82E-18	0.00E+00
Si	1.24E+01	1.57E+01	8.42E+01	6.07E+02
Ti	3.15E-02	3.15E-02	3.15E-02	3.15E-02
U	7.55E+01	1.08E+02	1.07E+02	7.88E+01
Zn	0.00E+00	0.00E+00	0.00E+00	3.38E-11
Total (Kg)	**625**	**670**	**1321**	**1699**
Density (g/cm^3)	**5.07**	**5.07**	**5.00**	**4.28**

NOTE: Mass (g) of each element is based on 1 liter aqueous fluid. To obtain total grams of each element in the WP, multiply by WP void volume of 4102 liters.

Table 53. Case 23 (nA1x3333): Solution Composition in Molality

Element	Years			
	1043	2114	33132	245930
Al	3.12E-05	5.42E-07	6.30E-08	6.82E-08
B	2.71E-04	1.49E-04	4.35E-04	5.44E-04
Ba	2.05E-06	5.63E-07	8.70E-09	2.96E-09
Ca	4.07E-05	1.46E-04	8.53E-06	1.78E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.93E-02	1.14E-02	1.00E-16	1.00E-16
Cu	6.15E-15	1.00E-16	1.00E-16	1.00E-16
F	1.16E-04	1.16E-04	3.72E-08	1.18E-04
Fe	3.33E-11	3.79E-12	1.14E-12	1.15E-12
Gd	7.86E-06	7.14E-09	2.80E-12	2.68E-08
C	3.57E-05	5.46E-05	1.84E-03	2.99E-03
P	1.48E-08	3.52E-08	9.98E-06	2.86E-09
K	1.99E-04	1.67E-04	2.41E-04	2.69E-04
Mg	1.14E-04	9.97E-05	4.97E-06	1.02E-04
Mn	1.29E-09	9.51E-12	9.63E-16	5.07E-16
Mo	3.34E-03	8.99E-04	5.06E-10	1.00E-16
N	5.28E-04	3.55E-04	1.42E-04	1.42E-04
Na	2.53E-03	2.29E-03	2.35E-03	3.09E-03
Ni	1.21E-02	7.13E-03	6.21E-07	2.09E-07
S	2.52E-04	2.26E-04	1.98E-04	1.99E-04
Si	5.69E-05	5.68E-05	4.51E-05	4.02E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	5.46E-05	6.50E-06	1.52E-04	1.33E-05
Zn	5.44E-15	1.00E-16	1.00E-16	1.78E-17
pH	**5.01**	**6.05**	**7.99**	**8.24**

6.3.1.2 Effects of Increased $GdPO_4$ Mass on Gd Loss

Due to the highly reactive nature of the Enrico Fermi-Fuel and losses seen in Section 6.3.1.1, the mass of $GdPO_4$ in the WP was doubled in an attempt to keep more (mass) of Gd in the WP. Table 54 presents the results of the cases where the mass of $GdPO_4$ was doubled.

Table 54. Gd and U Retention[f]: Cases with an Increase in $GdPO_4$ Mass

Case	File Name	Gd Retention[a]	U Retention[a]	Length of Run (Years)	Mass Retained (Kg)[b,c]	Case	File Name	Mass Retained (Kg)[d,e]
25	nA1d3333	68.85%	61.53%	245,970	12.37	23	nA1x3333	3.43
26	nL1d3333	69.51%	62.15%	228,780	12.49	24	nL1x3333	5.66

NOTES: [a] Calculated in "moresense.xls" (Attachment III)
[b] Calculated in "S+A sensitivity.xls" (Attachment III)
[c] Out of a maximum of 17.9708 Kg
[d] Calculated in "S+A.xls" (Attachment III)
[e] Out of a maximum of 8.9854 Kg
[f] Gd and U Retention presented as percentage of total initial moles within the WP.

Figure 28 shows a comparison between Cases 23, 24, 25, and 26. The number in parentheses indicates the case number.

Comparing Cases 24 and 26, which both simulate $GdPO_4$ degradation at the 304L stainless steel degradation rate, the results between the case with 3% Gd (Case 24) and the case with 6% Gd (Case 26) are very similar. The $GdPO_4$ is fully degraded around 500 and 600 years. $GdPO_4 \cdot 10H_2O$ quickly forms in the first few hours of degradation. When the pH reaches a plateau at 3.4, the Gd in solution rises significantly. For Case 24, all of the $GdPO_4 \cdot 10H_2O$ dissolves at this pH. For Case 26, this also occurs but not until slightly over a hundred years later as the extra Gd released by the larger amount of $GdPO_4$ succumbs to the lower pH. At 155 years into the run $GdPO_4 \cdot 10H_2O$ is able to form again when the pH increases.

Comparing Cases 23 and 25, which both simulate $GdPO_4$ degradation at the A516 steel degradation rate, there is a significant increase in the retention of Gd in Case 25. Similar to Cases 24 and 26, $GdPO_4 \cdot 10H_2O$ forms for Cases 23 and 25, with more of it forming for Case 25 due to the doubled mass of Gd. As the pH low is approached, the $GdPO_4 \cdot 10H_2O$ content in the WP for Case 23 is cut in half while that for Case 25 remains stable. This is possibly due to the significant reserve of Gd in the system from the doubled mass and fast degradation rate. Since the Gd reservoir is so high, even at very low pH levels, $GdPO_4 \cdot 10H_2O$ levels are affected very little. Because of this, a larger percentage of Gd is lost from the WP for Case 23.

Since only Case 25 is significantly different from the previous section, only tables for this case are presented here.

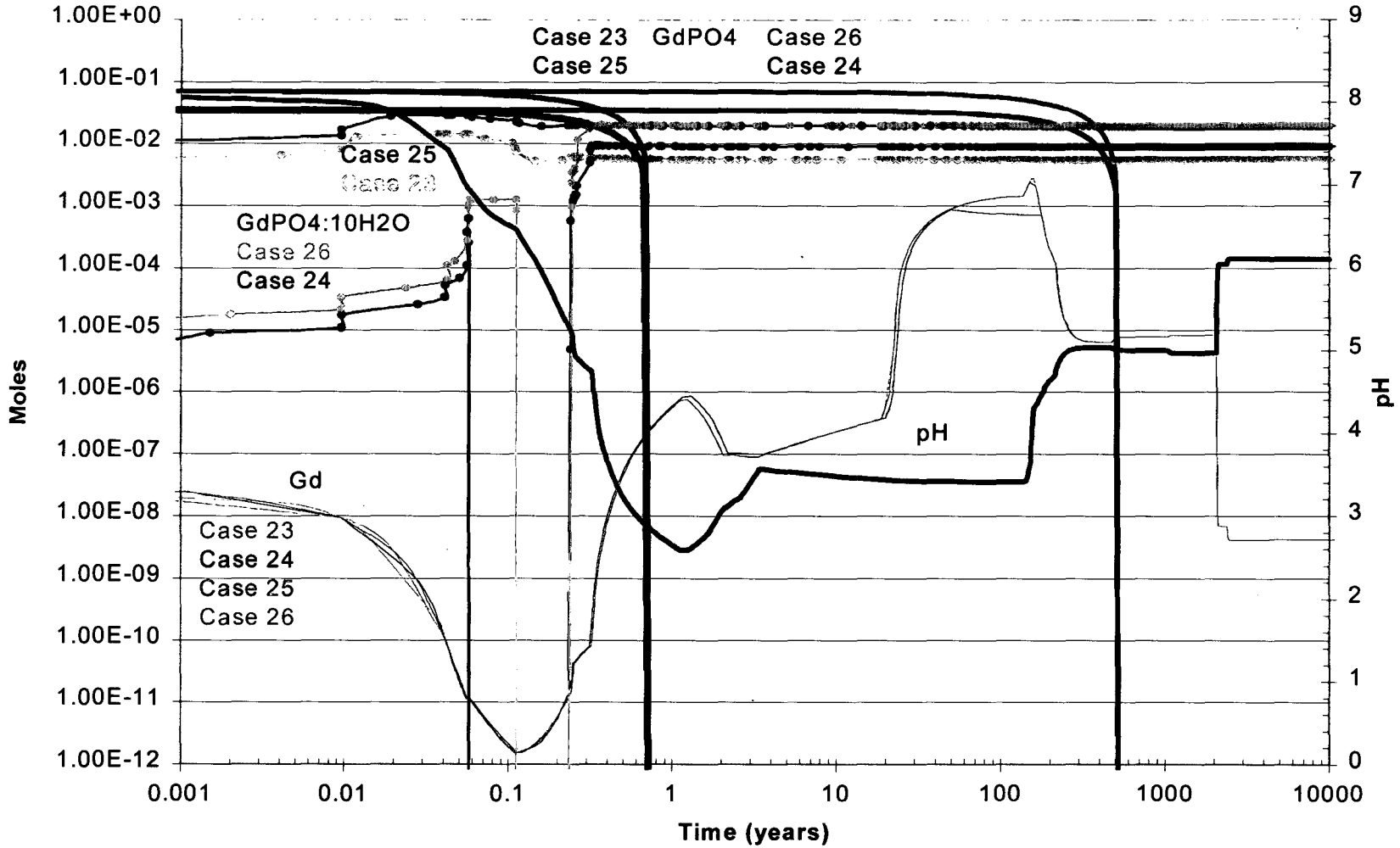

Figure 28. Cases 23-26: Gd Solids, Aqueous Gd, and pH

Table 55. Case 25 (nA1d3333): Composition of Corrosion Products (Kg), Total Mass, and Density

Element	Years				
	15064	40096	65071	100280	245970
O	5.06E+03	7.05E+03	7.33E+03	7.88E+03	1.02E+04
Al	8.29E+01	8.99E+01	1.05E+02	1.27E+02	2.22E+02
B	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba	0.00E+00	2.96E-01	1.25E+00	2.70E+00	8.86E+00
Ca	1.43E+01	4.67E+01	9.44E+01	1.36E+02	2.91E+02
Cl	0.00E+00	0.00E+00	1.58E-17	3.94E-18	3.94E-18
Cr	2.96E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	2.11E-18	1.83E+00	1.84E+00	1.88E+00	2.01E+00
Fe	1.02E+04	1.39E+04	1.40E+04	1.41E+04	1.45E+04
Gd	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.24E+01
H	1.67E+01	2.36E+01	1.91E+01	2.44E+01	5.09E+01
C	0.00E+00	2.59E-02	1.09E-01	6.19E+00	3.95E+01
P	9.00E+00	1.14E+01	1.15E+01	1.16E+01	1.23E+01
K	0.00E+00	0.00E+00	1.74E-17	0.00E+00	1.74E-17
Mg	9.04E-01	6.37E+00	1.72E+01	2.39E+01	4.66E+01
Mn	2.21E+02	3.33E+02	3.33E+02	3.33E+02	3.33E+02
Mo	2.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
N	9.34E-18	1.56E-18	1.56E-18	3.11E-18	4.67E-18
Na	0.00E+00	1.18E+01	6.22E+00	1.35E+01	2.27E+00
Ni	2.20E+01	4.33E+01	4.33E+01	4.32E+01	4.29E+01
S	0.00E+00	7.13E-18	0.00E+00	0.00E+00	0.00E+00
Si	1.84E+02	4.08E+02	6.48E+02	1.00E+03	2.49E+03
Ti	1.29E-01	1.29E-01	1.29E-01	1.29E-01	1.29E-01
U	4.43E+02	4.03E+02	3.17E+02	3.17E+02	3.23E+02
Zn	0.00E+00	0.00E+00	0.00E+00	2.98E-11	1.94E-10
Total (Kg)	**1.63E+04**	**2.24E+04**	**2.29E+04**	**2.40E+04**	**2.86E+04**
Density (g/cm^3)	**5.05**	**4.97**	**4.90**	**4.73**	**4.28**

Table 56. Case 25 (nA1d3333): Solution Composition in Molality

Element	Years				
	15064	40096	65071	100280	245970
Al	3.69E-07	6.17E-08	8.60E-08	6.82E-08	6.82E-08
B	1.29E-04	4.31E-04	4.93E-04	5.44E-04	5.44E-04
Ba	4.88E-07	9.10E-09	4.74E-09	2.96E-09	2.96E-09
Ca	1.89E-04	8.89E-06	9.56E-05	1.78E-04	1.78E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	8.17E-03	1.00E-16	1.00E-16	1.00E-16	1.00E-16
Cu	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	1.16E-04	1.17E-04	1.17E-04	1.18E-04	1.18E-04
Fe	3.37E-12	1.14E-12	1.15E-12	1.15E-12	1.15E-12
Gd	4.23E-09	2.83E-11	4.17E-09	2.68E-08	2.68E-08
C	5.76E-05	1.80E-03	2.32E-03	2.99E-03	2.99E-03
P	3.86E-08	6.50E-07	9.17E-09	2.86E-09	2.86E-09
K	1.62E-04	2.40E-04	2.56E-04	2.69E-04	2.69E-04
Mg	7.45E-05	5.19E-06	5.54E-05	1.02E-04	1.02E-04
Mn	6.59E-12	1.00E-15	6.28E-16	5.07E-16	5.07E-16
Mo	5.92E-04	1.00E-16	1.00E-16	1.00E-16	1.00E-16
N	2.84E-04	1.42E-04	1.42E-04	1.42E-04	1.42E-04
Na	2.25E-03	2.40E-03	2.66E-03	3.09E-03	3.09E-03
Ni	4.93E-03	6.51E-07	3.37E-07	2.09E-07	2.09E-07
S	2.17E-04	1.97E-04	1.98E-04	1.99E-04	1.99E-04
Si	5.80E-05	4.51E-05	3.99E-05	4.02E-05	4.02E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	6.30E-06	1.47E-04	1.73E-05	1.33E-05	1.33E-05
Zn	1.00E-16	1.00E-16	1.00E-16	1.78E-17	1.78E-17
pH	**6.11**	**7.98**	**8.13**	**8.24**	**8.24**

6.3.2 New Glass Degradation Rate

Section 6.2.3.3 of Reference 46 presents an updated model for the degradation of HLW glass. Specific changes to the model involve changes to the K_{eff} of the low pH leg. K_{eff} is a term which combines the intrinsic dissolution rate (k_0, dependent only on glass composition) and the reaction affinity (Q/K) into a single term. The K_{eff} for the low pH leg of the model was changed from 9.2 to 14.0 due to uncertainties at lower pH values and unavailability of test results. This has the net effect of increasing the glass dissolution rate at pH values below 7. The cases presented previously in this calculation were run at the old glass rate from Reference 28. This section investigates the consequences of using the new glass rate proposed in Reference 46. The new glass rates can be found in Table 4 of this calculation.

6.3.2.1 Effects on Internal Accumulation

To study the effects of the new glass dissolution rate on the retention of U in the WP, via formation of U-bearing minerals, one case was rerun with the new glass rate. Case 27 is Case 2 run with the new glass rate. Case 2 was chosen because it is the only case that has a fast fuel degradation rate and retains half of the glass by the end of 634,000 years. The results are presented below in Table 57 through Table 59 and Figure 29 as well as in "moresense.xls" (Attachment III).

Table 57 Gd and U Retention for Different HLW Glass Degradation Rates

Case	File Name	Gd Retention	U Retention	Length of Run (Years)
27	nm1n1331	100%	99.75%	634,730
2	nm1x1331	99.77%	99.60%	634,370

NOTE: Gd and U retention expressed in percentage of total initial moles in the WP

The end results of Cases 27 and 2 are similar but the cases themselves are very different. Where Case 2 retains a pH of around 6 for most of the run, the pH in Case 27 rises above 7 around 80,000 years when the basket, DOE canister, and GPCs are fully degraded. The pH then decreases to around 6 after the glass is completely degraded at about 380,000 years. The pH remains near 6 until the 316NG liner is completely exhausted at around 580,000 years. At 634,000 years it has only risen to 6.60. This differs from Case 2 where half the glass still remains intact within the WP at 634,000 years. The slightly higher U loss in Case 2 is due to the pH rise at the very end of the run. In other cases, it is expected that more U would be lost from the WP using the new HLW glass rate, which might cause a higher pH earlier in the case, allowing more U loss from the package. Therefore, the older glass rate is more conservative for internal criticality.

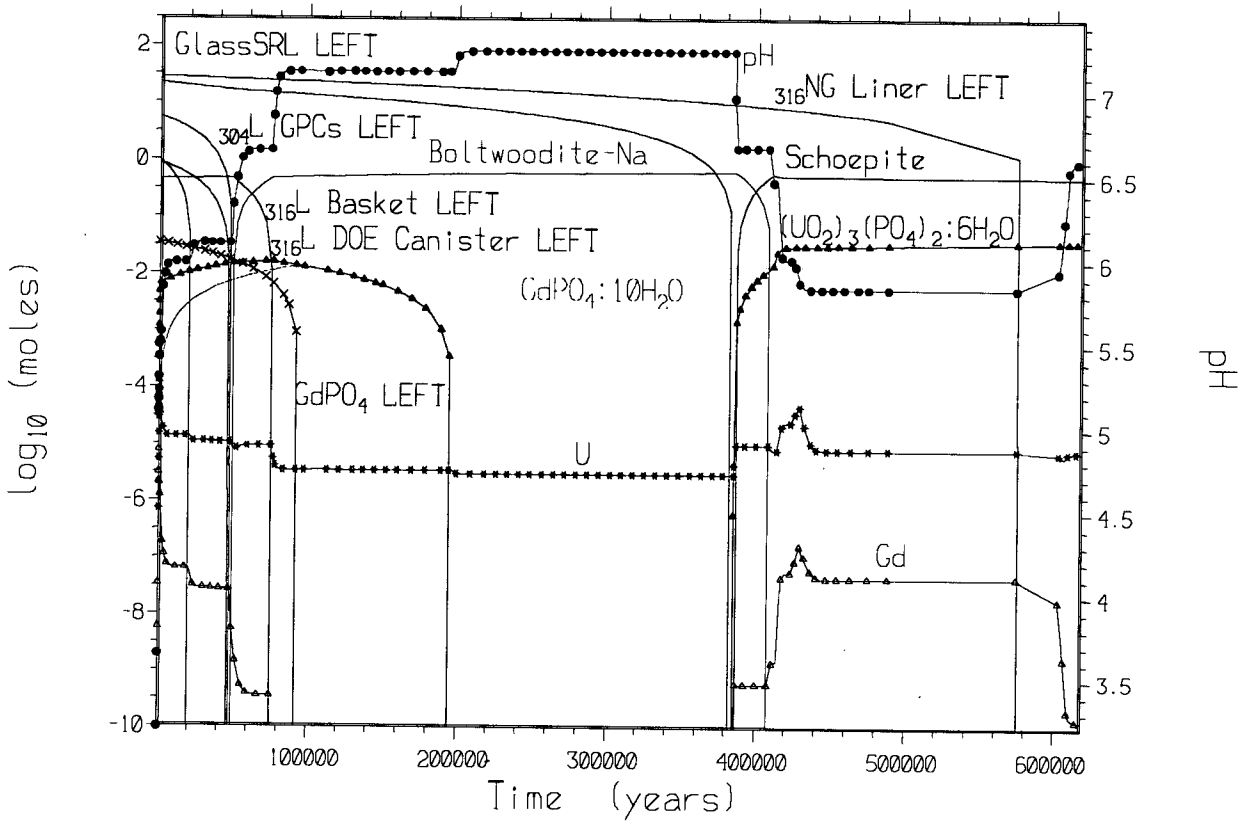

Figure 29. Case 27 (nm1n1331): WP Materials, Minerals, and Aqueous U

Table 58. Case 27 (nm1n1331): Composition of Corrosion Products (Kg), Total Mass, and Density

Element	Years						
	76156	143380	307030	407530	427840	553340	634730
O	4.92E+03	5.83E+03	8.03E+03	9.22E+03	9.30E+03	9.99E+03	1.03E+04
Al	1.53E+02	1.84E+02	2.57E+02	2.92E+02	2.91E+02	2.91E+02	2.91E+02
B	0.00E+00	0.00E+00	5.83E-13	2.84E-15	0.00E+00	0.00E+00	0.00E+00
Ba	4.54E+00	6.51E+00	1.13E+01	1.35E+01	1.35E+01	1.35E+01	1.34E+01
Ca	1.80E+01	2.68E+01	4.68E+01	5.42E+01	5.28E+01	5.49E+01	5.63E+01
Cl	3.00E-15	2.28E-14	0.00E+00	0.00E+00	2.61E-12	0.00E+00	0.00E+00
Cr	1.72E+00	2.47E+00	4.26E+00	5.11E+00	5.11E+00	5.11E+00	4.56E+00
Cu	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F	1.51E-14	6.21E-01	1.37E+00	1.03E+00	3.73E-08	0.00E+00	0.00E+00
Fe	7.78E+03	8.73E+03	1.10E+04	1.24E+04	1.27E+04	1.42E+04	1.48E+04
Gd	7.25E+00	8.98E+00	8.98E+00	8.98E+00	8.98E+00	8.98E+00	8.98E+00
H	3.32E+01	4.01E+01	5.64E+01	6.48E+01	5.91E+01	5.95E+01	6.12E+01
C	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-11	8.22E-13	5.09E-02
P	5.50E+00	6.60E+00	8.45E+00	9.53E+00	9.70E+00	1.08E+01	1.12E+01
K	3.19E+01	4.31E+01	6.94E+01	7.50E+01	7.16E+01	6.78E+01	6.54E+01
Mg	5.30E+00	1.12E+01	2.52E+01	3.10E+01	3.08E+01	3.11E+01	3.13E+01
Mn	1.37E+02	1.62E+02	2.23E+02	2.61E+02	2.69E+02	3.16E+02	3.34E+02
Mo	4.30E+01	4.84E+01	7.74E+01	1.05E+02	1.13E+02	6.77E+01	3.58E+01
N	1.18E-15	1.59E-15	0.00E+00	0.00E+00	4.47E-11	0.00E+00	0.00E+00
Na	6.40E+01	7.29E+01	9.11E+01	5.82E+01	3.78E+01	1.75E+01	5.03E+00
Ni	4.14E+02	5.65E+02	9.32E+02	1.16E+03	1.19E+03	1.18E+03	1.18E+03
S	5.32E-13	3.36E-12	0.00E+00	0.00E+00	9.20E-11	0.00E+00	1.89E-01
Si	7.12E+02	1.01E+03	1.73E+03	2.08E+03	2.09E+03	2.12E+03	2.13E+03
Ti	1.29E-01	1.29E-01	1.29E-01	1.29E-01	1.29E-01	1.29E-01	1.29E-01
U	5.07E+02	5.31E+02	5.90E+02	6.17E+02	6.17E+02	6.17E+02	6.16E+02
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (Kg)	**1.48E+04**	**1.73E+04**	**2.32E+04**	**2.65E+04**	**2.68E+04**	**2.90E+04**	**2.99E+04**
Density (g/cm^3)	**4.55**	**4.46**	**4.32**	**4.28**	**4.30**	**4.36**	**4.38**

Table 59. Case 27 (nm1n1331): Solution Composition in Molality

Element	Years						
	76156	110680	307030	407530	427840	553340	634730
Al	1.93E-07	1.24E-08	1.65E-08	1.70E-06	1.17E-03	1.25E-06	2.02E-08
B	4.72E-02	3.76E-02	3.71E-02	3.63E-06	9.09E-10	1.00E-16	1.00E-16
Ba	1.62E-07	1.27E-07	1.21E-07	1.57E-07	5.49E-07	7.11E-07	6.35E-06
Ca	5.72E-04	2.55E-04	4.18E-04	1.60E-03	2.55E-04	4.54E-05	1.96E-05
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	4.07E-02	4.08E-02	4.08E-02	4.09E-02	4.09E-02	4.09E-02	3.00E-04
Cu	1.52E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
F	3.90E-04	1.45E-05	2.50E-04	8.69E-04	5.22E-03	1.15E-04	1.15E-04
Fe	1.81E-12	1.34E-12	1.28E-12	1.78E-12	5.11E-12	5.97E-12	1.80E-12
Gd	3.51E-10	3.22E-12	2.49E-11	5.91E-10	1.76E-07	4.51E-08	1.39E-10
C	1.30E-04	3.19E-04	4.11E-04	1.34E-04	5.02E-05	4.74E-05	1.05E-04
P	1.51E-07	3.65E-06	4.50E-07	1.59E-07	3.06E-08	2.77E-08	1.00E-07
K	5.69E-03	7.03E-03	7.01E-03	5.44E-03	1.49E-03	6.50E-04	5.48E-04
Mg	1.30E-03	1.99E-03	2.00E-03	1.18E-03	8.84E-05	1.67E-05	1.08E-05
Mn	7.83E-13	9.71E-14	5.55E-14	7.11E-13	2.32E-11	3.48E-11	6.07E-13
Mo	8.80E-04	2.70E-03	1.70E-03	3.14E-04	9.93E-04	5.81E-03	3.12E-03
N	8.56E-04	8.56E-04	8.56E-04	8.56E-04	8.56E-04	8.56E-04	1.42E-04
Na	5.91E-02	7.27E-02	7.25E-02	5.65E-02	1.55E-02	6.73E-03	5.79E-03
Ni	5.84E-04	7.26E-05	4.15E-05	5.34E-04	1.75E-02	2.62E-02	4.57E-04
S	9.57E-04	8.25E-04	8.18E-04	3.09E-04	3.09E-04	3.09E-04	4.05E-05
Si	4.63E-05	4.18E-05	4.10E-05	4.64E-05	6.12E-05	6.76E-05	5.68E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	9.32E-06	3.45E-06	3.00E-06	1.01E-05	6.55E-05	8.18E-06	7.81E-06
Zn	1.46E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16	1.00E-16
pH	**6.66**	**7.13**	**7.25**	**6.68**	**5.92**	**5.84**	**6.60**

6.3.2.2 Effects on Source Term

Case 28 (nm2n1402) demonstrates the effects that using the new glass degradation rate has on the effluent concentration of fissile U. The results of Case 28 are presented in Figure 30 and Figure 31 and Table 60. Case 19 and Case 28 are very similar and show similar results. The major difference between the two cases is the timing in which everything occurs. In Case 28, the first U peak of 1.57E-01 moles/Kg occurs 67,600 years when the pH is 8.83. The second peak occurs nearly 12,000 years later with an intensity of 1.71E-01 moles/Kg at a pH of 8.84. The peak U in Case 19 (Figure 23) is slightly higher and occurs later in the case than do the peaks for Case 28 (Figure 30).

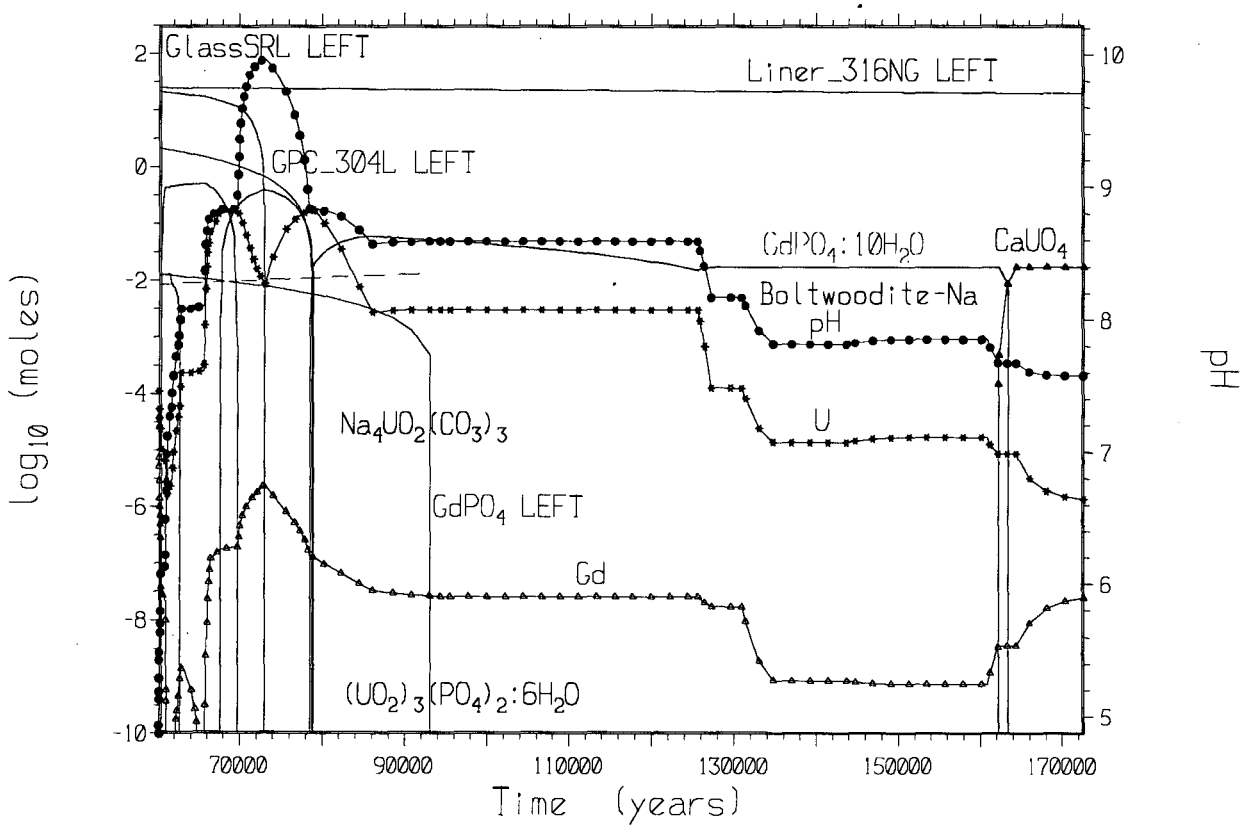

Figure 30. Case 28 (nm2n1402): WP Materials, Minerals, and Aqueous U

The enrichment fraction of the U peaks in Case 28 are very close to those seen in Case 19. The first peak corresponds to an enrichment of 0.2168 and the second to 0.1820. This is comparable to the 0.2200 and 0.1802 in Case 19. Since Case 19 (Figure 24) has the larger peaks in U, more fissile U is able to leave the WP for this case than for Case 28 (Figure 31). Therefore, the older glass rate from Reference 28 is more conservative for source term.

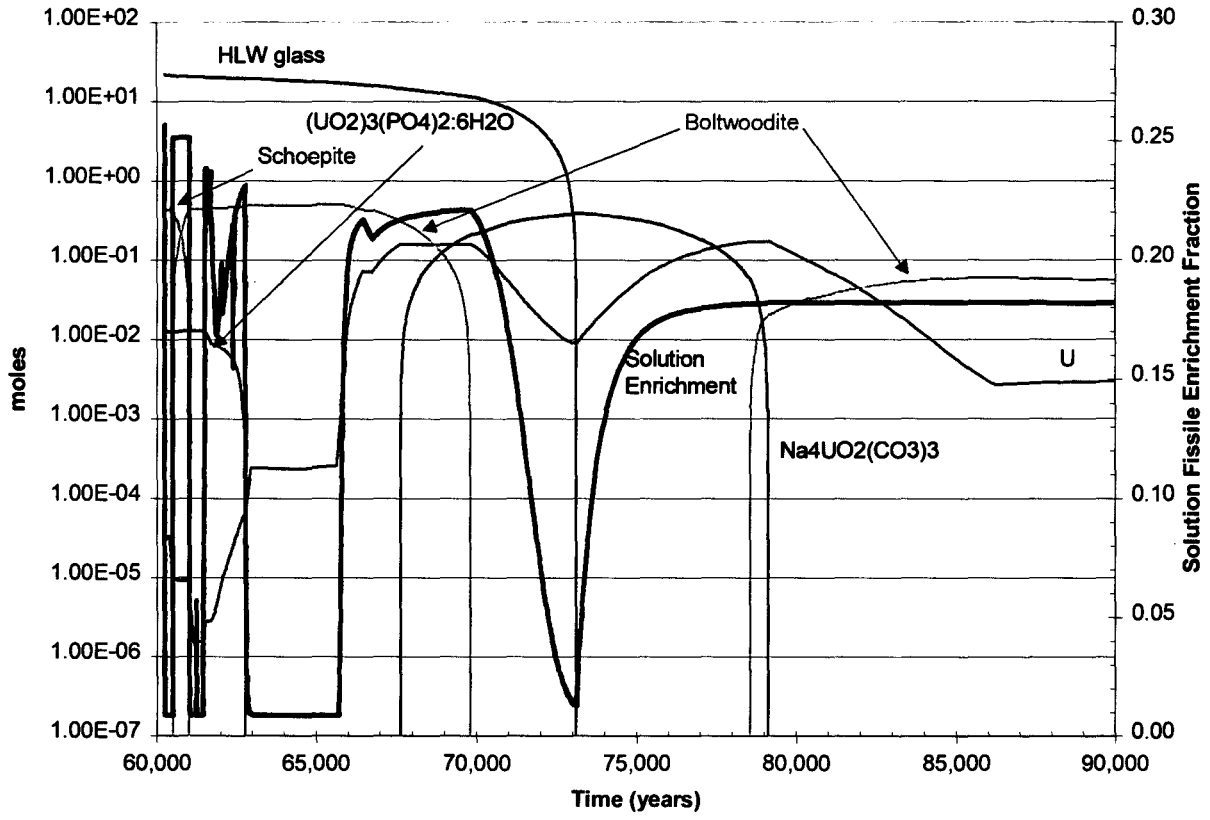

Figure 31. Case 28 (nm2n1402): Enrichment and U-bearing Solids in the WP

Table 60. Case 28 (nm2n1402): Solution Composition in Molality

Element	Years						
	60487	62033	64606	67634	73116	78608	94389
Al	9.28E-06	3.34E-08	1.02E-07	3.79E-08	3.67E-09	3.91E-08	5.52E-08
B	1.63E-01	3.63E-01	2.04E-01	9.67E-02	2.03E-01	9.90E-02	2.17E-01
Ba	6.00E-07	1.19E-07	2.55E-08	9.37E-10	2.43E-11	9.42E-10	2.27E-09
Ca	6.82E-06	3.33E-05	5.80E-05	1.06E-04	4.67E-06	1.06E-04	2.76E-04
Cl	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Cr	1.02E-01	1.23E-01	1.43E-01	1.50E-01	1.53E-01	1.53E-01	4.12E-02
Cu	4.69E-14	2.66E-14	1.03E-14	3.45E-15	5.43E-16	1.56E-16	1.00E-16
F	5.05E-04	4.21E-08	1.58E-11	3.19E-03	1.21E-02	1.43E-03	5.72E-05
Fe	4.38E-12	1.18E-12	1.14E-12	1.31E-12	4.23E-12	1.34E-12	1.24E-12
Gd	3.76E-08	4.01E-11	2.74E-10	1.73E-07	2.49E-06	1.35E-07	2.62E-08
C	6.18E-05	1.07E-03	4.05E-03	5.00E-01	1.43E+00	5.34E-01	1.84E-02
P	4.81E-08	1.28E-03	1.90E-03	2.19E-07	6.68E-05	3.02E-07	8.68E-08
K	2.69E-02	1.42E-02	6.23E-03	1.62E-02	8.36E-02	1.63E-02	6.68E-03
Mg	1.86E-02	1.38E-02	1.63E-03	5.47E-05	3.10E-06	5.41E-05	2.03E-04
Mn	1.95E-11	2.00E-14	2.13E-15	1.36E-15	2.14E-14	1.40E-15	7.86E-16
Mo	1.15E-01	6.49E-02	4.38E-02	1.70E-02	5.07E-03	3.49E-03	3.26E-03
N	2.05E-03	2.49E-03	2.83E-03	2.98E-03	3.04E-03	3.05E-03	8.62E-04
Na	2.67E-01	3.63E-01	4.12E-01	1.06E+00	2.89E+00	1.07E+00	1.60E-01
Ni	1.46E-02	1.48E-05	1.41E-06	4.56E-08	2.76E-10	4.56E-08	1.06E-07
S	2.71E-03	5.51E-03	7.58E-03	1.19E-02	3.27E-02	4.62E-03	3.18E-04
Si	4.59E-05	3.80E-05	4.61E-05	2.85E-04	8.22E-03	2.92E-04	6.26E-05
Ti	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U	1.02E-05	9.24E-06	2.33E-04	1.57E-01	8.75E-03	1.68E-01	3.03E-03
Zn	4.15E-14	2.35E-14	9.12E-15	3.15E-19	0.00E+00	0.00E+00	2.47E-19
pH	**6.07**	**7.57**	**8.08**	**8.83**	**9.97**	**8.84**	**8.59**

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8. ATTACHMENTS

Attachment I. Listing of Files on Compact Disks (11 pages)

Attachment II. Sketch SK-0200 REV 04 (2 pages)

Attachment III. Two Compact Discs

ATTACHMENT I. LISTING OF FILES ON COMPACT DISKS

This attachment contains the MS-DOS directory for files placed on the electronic media (Attachment I). The files are of various types:

1. Excel files (extensions = xls).
2. EQ3/6 input files (extension = 3i or 6i).

   ASCII text file: provides input parameters for EQ3/6.
3. EQ3/6 output files (extension = 3o or 6o).

   ASCII text file: provides detailed information about the system at each print point, which is specified by the user in the input file.
4. EQ3/6 pickup files (extension = 3p or 6p).

   ASCII text file: provides a description of the system at the end of that run to be used as an input file for a continuation run.
5. EQ6 Tab-delimited text files (extension = txt).

   *.elem_aqu: total aqueous moles of elements.

   *.elem_min: total moles of elements in minerals.

   *.elem_tot: total moles of elements (aqueous + mineral).

   *.min_info: moles of each mineral.
6. EQ6 binary output file (extension = bin).

   Binary file: provides detailed information about the system at the full numerical precision for *every* time step.
7. EQ3/6 text data files used for the calculations, "data0.ymd".
8. Batch files (extension = bat) used to start EQ6 runs.
9. Winzip files (extension = zip).

Below are listed the contents of the DOS directories within the electronic attachment:

The first column is the DOS file name.

The second column lists <DIR> if it is a directory
or gives the files size (bytes) if it is a file.

The third and fourth columns are the date and time of the last update.

The fifth column is the filename.

Directory of Fermi-IA1

```
DATA0    NUC      2,302,224  09-15-99 11:40a DATA0.NUC
DATA0    YMD      2,657,459  03-16-01  1:22p data0.ymd
DATA0    YMP      2,649,470  09-11-00  5:23p data0.ymp
ENRIC~34 XLS      1,075,200  11-14-01  3:24p enrich-fermi1.xls
ENRIC~38 XLS      1,047,552  11-14-01  3:49p enrich-fermi2.xls
ENRIC~44 XLS        535,040  11-15-01 10:15a enrich-sens-Fermi.xls
FERMI~48 XLS         39,424  09-20-01  8:28a Fermi-IA-2001.xls
FERMI~50 XLS        256,512  09-13-01 10:24a fermi-losses.xls
HLWGL~52 XLS         57,856  08-01-01 10:17a HLWglass-2001.xls
J13NOM20 3I          13,734  10-23-00 12:44p j13nom20.3i
J13NOM20 3O         114,582  10-23-00 12:45p j13nom20.3o
J13NOM20 3P          11,786  10-23-00 12:45p j13nom20.3p
J13NOM30 3I          13,660  10-10-00  1:31p j13nom30.3i
J13NOM30 3O         115,224  10-10-00  1:32p j13nom30.3o
J13NOM30 3P          11,712  10-10-00  1:32p j13nom30.3p
LOSSE~66 XLS         18,944  08-20-01  3:59p losses-oldtime.xls
MORES~68 XLS         18,944  09-17-01  7:22a moresense.xls
OLDFE~72 XLS         16,896  09-13-01  8:19a oldfermi-recalc.xls
ONE-ST~5        <DIR>        11-15-01  8:50a One-Stage
S_ASE~76 XLS        108,544  08-23-01  7:32a S+A sensitivity.xls
S_A~78   XLS        790,016  09-19-01  9:02a S+A.xls
SENSI~82 XLS      9,253,888  11-15-01  9:27a Sensitivity.xls
SOURCE~7        <DIR>        11-15-01 10:37a Source Term
UENR~112 XLS         19,968  11-13-01  3:01p Uenrich Fermi.xls
        22 file(s)     21,128,635 bytes

Directory of D:\One-Stage

.               <DIR>        11-13-01  3:01p .
..              <DIR>        11-13-01  3:01p ..
NG1X3323 6I          45,736  07-16-01  5:11p ng1x3323.6i
NG1X3323 6O      31,486,614  07-16-01  9:01p ng1x3323.6o
NG1X3323 6P          43,166  07-16-01  9:01p ng1x3323.6p
NG1X~104 TXT        232,706  07-16-01  9:00p ng1x3323.elem_aqu.txt
NG1X~106 TXT        218,217  07-16-01  9:00p ng1x3323.elem_min.txt
NG1X~108 TXT        218,230  07-16-01  9:00p ng1x3323.elem_tot.txt
NG1X~112 TXT        465,870  07-16-01  9:00p ng1x3323.min_info.txt
NM1X1321 6I          46,466  07-11-01  1:16p nm1x1321.6i
NM1X1321 6O       2,802,843  07-11-01  1:25p nm1x1321.6o
NM1X1321 6P          43,554  07-11-01  1:25p nm1x1321.6p
NM1X~128 TXT         28,656  07-11-01  1:25p nm1x1321.elem_aqu.txt
NM1X~130 TXT         26,887  07-11-01  1:25p nm1x1321.elem_min.txt
NM1X~132 TXT         26,900  07-11-01  1:25p nm1x1321.elem_tot.txt
NM1X~134 TXT         58,272  07-11-01  1:25p nm1x1321.min_info.txt
NM1X1331 6I          46,466  07-11-01  1:16p nm1x1331.6i
NM1X1331 6O       2,784,787  07-11-01  1:31p nm1x1331.6o
NM1X1331 6P          43,226  07-11-01  1:31p nm1x1331.6p
NM1X~150 TXT         27,886  07-11-01  1:31p nm1x1331.elem_aqu.txt
NM1X~152 TXT         26,165  07-11-01  1:31p nm1x1331.elem_min.txt
NM1X~154 TXT         26,178  07-11-01  1:31p nm1x1331.elem_tot.txt
NM1X~156 TXT         53,551  07-11-01  1:31p nm1x1331.min_info.txt
NM1X1333 6I          46,466  07-25-01  1:34p nm1x1333.6i
NM1X1333 6O      17,695,889  07-25-01  2:05p nm1x1333.6o
NM1X1333 6P          42,816  07-25-01  2:05p nm1x1333.6p
```

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NM1X~216 TXT       183,811  07-25-01  2:05p nm1x1333.elem_aqu.txt
NM1X~218 TXT       172,370  07-25-01  2:05p nm1x1333.elem_min.txt
NM1X~222 TXT       172,383  07-25-01  2:05p nm1x1333.elem_tot.txt
NM1X~224 TXT       364,691  07-25-01  2:05p nm1x1333.min_info.txt
NM1X2331 6I         46,466  07-11-01  1:17p nm1x2331.6i
NM1X2331 6O      3,499,254  07-11-01  2:32p nm1x2331.6o
NM1X2331 6P         43,636  07-11-01  2:32p nm1x2331.6p
NM1X~244 TXT        35,201  07-11-01  2:32p nm1x2331.elem_aqu.txt
NM1X~246 TXT        33,024  07-11-01  2:32p nm1x2331.elem_min.txt
NM1X~248 TXT        33,037  07-11-01  2:32p nm1x2331.elem_tot.txt
NM1X~250 TXT        77,821  07-11-01  2:32p nm1x2331.min_info.txt
NM1X2422 6I         45,652  07-12-01  1:53p nm1x2422.6i
NM1X2422 6O     12,646,847  07-12-01  2:28p nm1x2422.6o
NM1X2422 6P         42,668  07-12-01  2:28p nm1x2422.6p
NM1X~296 TXT       102,961  07-12-01  2:28p nm1x2422.elem_aqu.txt
NM1X~298 TXT        96,560  07-12-01  2:28p nm1x2422.elem_min.txt
NM1X~300 TXT        96,573  07-12-01  2:28p nm1x2422.elem_tot.txt
NM1X~302 TXT       254,139  07-12-01  2:28p nm1x2422.min_info.txt
NM1X2432 6I         45,651  07-12-01  1:53p nm1x2432.6i
NM1X2432 6O     12,914,822  07-12-01  3:00p nm1x2432.6o
NM1X2432 6P         42,586  07-12-01  3:00p nm1x2432.6p
NM1X~348 TXT       107,581  07-12-01  3:00p nm1x2432.elem_aqu.txt
NM1X~350 TXT       100,892  07-12-01  3:00p nm1x2432.elem_min.txt
NM1X~352 TXT       100,905  07-12-01  3:00p nm1x2432.elem_tot.txt
NM1X~354 TXT       274,469  07-12-01  3:00p nm1x2432.min_info.txt
NM1X3323 6I         45,655  07-12-01  1:53p nm1x3323.6i
NM1X3323 6O     31,856,704  07-12-01  4:39p nm1x3323.6o
NM1X3323 6P         43,078  07-12-01  4:39p nm1x3323.6p
NM1X~456 TXT       235,786  07-12-01  4:39p nm1x3323.elem_aqu.txt
NM1X~458 TXT       221,105  07-12-01  4:39p nm1x3323.elem_min.txt
NM1X~462 TXT       221,118  07-12-01  4:39p nm1x3323.elem_tot.txt
NM1X~464 TXT       504,572  07-12-01  4:39p nm1x3323.min_info.txt
NM1X3333 6I         45,655  07-12-01  9:09a nm1x3333.6i
NM1X3333 6O     30,373,686  07-12-01 10:53a nm1x3333.6o
NM1X3333 6P         43,078  07-12-01 10:53a nm1x3333.6p
NM1X~562 TXT       219,231  07-12-01 10:53a nm1x3333.elem_aqu.txt
NM1X~566 TXT       205,582  07-12-01 10:53a nm1x3333.elem_min.txt
NM1X~568 TXT       205,595  07-12-01 10:53a nm1x3333.elem_tot.txt
NM1X~570 TXT       444,410  07-12-01 10:53a nm1x3333.min_info.txt
NM1X3433 6I         45,655  07-12-01 11:51a nm1x3433.6i
NM1X3433 6O     30,750,097  07-12-01  1:17p nm1x3433.6o
NM1X3433 6P         42,996  07-12-01  1:17p nm1x3433.6p
NM1X~670 TXT       229,626  07-12-01  1:17p nm1x3433.elem_aqu.txt
NM1X~674 TXT       215,329  07-12-01  1:17p nm1x3433.elem_min.txt
NM1X~676 TXT       215,342  07-12-01  1:17p nm1x3433.elem_tot.txt
NM1X~678 TXT       572,539  07-12-01  1:17p nm1x3433.min_info.txt
SECOND~5       <DIR>        11-15-01  9:30a second part
THIRDP~7       <DIR>        11-15-01 10:00a third part
        70 file(s)    184,808,386 bytes

Directory of D:\One-Stage\second part

.              <DIR>        11-15-01 10:46a .
..             <DIR>        11-15-01 10:46a ..
NG1Y3323 6I         30,372  07-17-01  6:53a ng1y3323.6i
NG1Y3323 6O     27,899,955  07-17-01  8:41a ng1y3323.6o
NG1Y3323 6P         30,367  07-17-01  8:41a ng1y3323.6p
```

```
NG1Y3~94 TXT       219,616  07-17-01  8:40a ng1y3323.elem_aqu.txt
NG1Y3~96 TXT       205,943  07-17-01  8:40a ng1y3323.elem_min.txt
NG1Y~100 TXT       205,956  07-17-01  8:40a ng1y3323.elem_tot.txt
NG1Y~102 TXT       343,174  07-17-01  8:40a ng1y3323.min_info.txt
NM1Y1333 6I         30,577  07-25-01  3:02p nm1y1333.6i
NM1Y1333 6O     20,670,995  07-25-01  3:54p nm1y1333.6o
NM1Y1333 6P         30,585  07-25-01  3:54p nm1y1333.6p
NM1Y~172 TXT       228,471  07-25-01  3:54p nm1y1333.elem_aqu.txt
NM1Y~174 TXT       214,246  07-25-01  3:54p nm1y1333.elem_min.txt
NM1Y~176 TXT       214,259  07-25-01  3:54p nm1y1333.elem_tot.txt
NM1Y~180 TXT       315,064  07-25-01  3:54p nm1y1333.min_info.txt
NM1Y3323 6I         30,289  07-12-01  5:36p nm1y3323.6i
NM1Y3323 6O     28,171,181  07-12-01 10:25p nm1y3323.6o
NM1Y3323 6P         30,289  07-12-01 10:25p nm1y3323.6p
NM1Y~270 TXT       219,616  07-12-01 10:25p nm1y3323.elem_aqu.txt
NM1Y~274 TXT       205,943  07-12-01 10:25p nm1y3323.elem_min.txt
NM1Y~276 TXT       205,956  07-12-01 10:25p nm1y3323.elem_tot.txt
NM1Y~278 TXT       340,774  07-12-01 10:25p nm1y3323.min_info.txt
NM1Y3333 6I         29,310  07-12-01  2:02p nm1y3333.6i
NM1Y3333 6O     28,916,112  07-12-01 11:58p nm1y3333.6o
NM1Y3333 6P         29,310  07-12-01 11:58p nm1y3333.6p
NM1Y~372 TXT       222,696  07-12-01 11:57p nm1y3333.elem_aqu.txt
NM1Y~374 TXT       208,831  07-12-01 11:57p nm1y3333.elem_min.txt
NM1Y~378 TXT       208,844  07-12-01 11:57p nm1y3333.elem_tot.txt
NM1Y~380 TXT       324,558  07-12-01 11:57p nm1y3333.min_info.txt
NM1Y3433 6I         28,027  07-12-01  2:04p nm1y3433.6i
NM1Y3433 6O     26,458,687  07-13-01 12:58a nm1y3433.6o
NM1Y3433 6P         27,618  07-13-01 12:58a nm1y3433.6p
NM1Y~466 TXT       221,156  07-13-01 12:58a nm1y3433.elem_aqu.txt
NM1Y~470 TXT       207,387  07-13-01 12:58a nm1y3433.elem_min.txt
NM1Y~472 TXT       207,400  07-13-01 12:58a nm1y3433.elem_tot.txt
NM1Y~474 TXT       304,930  07-13-01 12:58a nm1y3433.min_info.txt
        35 file(s)    137,238,494 bytes

Directory of D:\One-Stage\third part

.              <DIR>        07-13-01 12:58a .
..             <DIR>        07-13-01 12:58a ..
NG1Z3323 6I         29,164  07-17-01 12:12p ng1z3323.6i
NG1Z3323 6O     20,531,160  07-17-01  1:39p ng1z3323.6o
NG1Z3323 6P         29,163  07-17-01  1:39p ng1z3323.6p
NG1Z3~72 TXT       170,336  07-17-01  1:39p ng1z3323.elem_aqu.txt
NG1Z3~74 TXT       159,735  07-17-01  1:39p ng1z3323.elem_min.txt
NG1Z3~76 TXT       159,748  07-17-01  1:39p ng1z3323.elem_tot.txt
NG1Z3~80 TXT       242,384  07-17-01  1:39p ng1z3323.min_info.txt
NM1Z3323 6I         29,086  07-13-01  6:58a nm1z3323.6i
NM1Z3323 6O     20,814,521  07-13-01  9:32a nm1z3323.6o
NM1Z3323 6P         29,003  07-13-01  9:32a nm1z3323.6p
NM1Z3323 6T        683,102  07-13-01  9:32a nm1z3323.6t
NM1Z3323 6TX       690,396  07-13-01  9:32a nm1z3323.6tx
NM1Z~156 TXT       171,491  07-13-01  9:31a nm1z3323.elem_aqu.txt
NM1Z~160 TXT       160,818  07-13-01  9:31a nm1z3323.elem_min.txt
NM1Z~162 TXT       160,831  07-13-01  9:31a nm1z3323.elem_tot.txt
NM1Z~164 TXT       244,016  07-13-01  9:32a nm1z3323.min_info.txt
NM1Z3333 6I         28,107  07-13-01  6:57a nm1z3333.6i
NM1Z3333 6O     28,944,873  07-13-01 11:17a nm1z3333.6o
NM1Z3333 6P         28,106  07-13-01 11:17a nm1z3333.6p
```

```
NM1Z3333 6T         929,403  07-13-01 11:17a nm1z3333.6t
NM1Z3333 6TX      1,022,828  07-13-01 11:17a nm1z3333.6tx
NM1Z~268 TXT        258,116  07-13-01 11:16a nm1z3333.elem_aqu.txt
NM1Z~270 TXT        242,043  07-13-01 11:16a nm1z3333.elem_min.txt
NM1Z~274 TXT        242,056  07-13-01 11:16a nm1z3333.elem_tot.txt
NM1Z~276 TXT        366,416  07-13-01 11:17a nm1z3333.min_info.txt
NM1Z3433 6I          27,617  07-13-01  6:56a nm1z3433.6i
NM1Z3433 6O      27,644,398  07-13-01 12:18p nm1z3433.6o
NM1Z3433 6P          27,616  07-13-01 12:18p nm1z3433.6p
NM1Z3433 6T         842,656  07-13-01 12:18p nm1z3433.6t
NM1Z3433 6TX        851,516  07-13-01 12:18p nm1z3433.6tx
NM1Z~376 TXT        257,731  07-13-01 12:18p nm1z3433.elem_aqu.txt
NM1Z~378 TXT        241,682  07-13-01 12:18p nm1z3433.elem_min.txt
NM1Z~380 TXT        241,695  07-13-01 12:18p nm1z3433.elem_tot.txt
NM1Z~384 TXT        293,503  07-13-01 12:18p nm1z3433.min_info.txt
        34 file(s)    106,795,316 bytes

Directory of D:\Source Term

.              <DIR>         11-15-01 10:00a .
..             <DIR>         11-15-01 10:00a ..
ASPRIN   EXE       299,130  07-03-01  9:07a asprin.exe
DEFLTS~8 TXT           187  07-26-01  9:25a defltsolids.txt
DEFLT~10 TXT           858  07-10-01  2:35p defltsolids_longlist.txt
ONESTA~5       <DIR>         11-15-01 10:37a one stage
TWOSTA~7       <DIR>         11-15-01 10:46a two stage
         3 file(s)        300,175 bytes

Directory of D:\Source Term\one stage

.              <DIR>         07-13-01 12:18p .
..             <DIR>         07-13-01 12:18p ..
NM1X3432 6I          46,471  07-26-01  8:58a nm1x3432.6i
NM1X3432 6O       3,236,897  07-26-01  9:03a nm1x3432.6o
NM1X3432 6P          43,636  07-26-01  9:03a nm1x3432.6p
NM1X3432 BIN      6,049,296  07-26-01  9:03a nm1x3432.bin
NM1X3~42 TXT         32,121  07-26-01  9:03a nm1x3432.elem_aqu.txt
NM1X3~44 TXT         30,136  07-26-01  9:03a nm1x3432.elem_min.txt
NM1X3~46 TXT         30,149  07-26-01  9:03a nm1x3432.elem_tot.txt
NM1X3~48 TXT         65,619  07-26-01  9:03a nm1x3432.min_info.txt
NM1X3432 TXT      1,455,396  11-14-01  9:44a nm1x3432.txt
NT1X1331 6I          46,478  07-18-01 10:21a nt1x1331.6i
NT1X1331 6O       3,464,822  07-18-01 10:26a nt1x1331.6o
NT1X1331 6P          43,324  07-18-01 10:26a nt1x1331.6p
NT1X1331 BIN      7,102,184  07-18-01 10:26a nt1x1331.bin
NT1X1~96 TXT         34,816  07-18-01 10:26a nt1x1331.elem_aqu.txt
NT1X1~98 TXT         32,663  07-18-01 10:26a nt1x1331.elem_min.txt
NT1X~100 TXT         32,676  07-18-01 10:26a nt1x1331.elem_tot.txt
NT1X~102 TXT         76,137  07-18-01 10:26a nt1x1331.min_info.txt
NT1X1331 TXT      1,703,332  11-14-01  9:46a nt1x1331.txt
NT1X1432 6I          46,467  07-25-01  7:10p nt1x1432.6i
NT1X1432 6O       3,765,523  07-25-01  7:16p nt1x1432.6o
NT1X1432 6P          42,898  07-25-01  7:16p nt1x1432.6p
NT1X1432 BIN      7,965,424  07-25-01  7:16p nt1x1432.bin
NT1X~154 TXT         37,511  07-25-01  7:16p nt1x1432.elem_aqu.txt
NT1X~156 TXT         35,190  07-25-01  7:16p nt1x1432.elem_min.txt
NT1X~158 TXT         35,203  07-25-01  7:16p nt1x1432.elem_tot.txt
```

```
NT1X~160 TXT        88,573  07-25-01   7:16p nt1x1432.min_info.txt
NT1X1432 TXT     1,908,654  11-14-01   9:48a nt1x1432.txt
        27 file(s)     37,451,596 bytes

Directory of D:\Source Term\two stage

.              <DIR>        11-14-01   9:48a .
..             <DIR>        11-14-01   9:48a ..
NC1X1031 6I         44,775  07-18-01   1:18p nc1x1031.6i
NC1X1031 6O      1,326,343  07-18-01   1:21p nc1x1031.6o
NC1X1031 6P         41,236  07-18-01   1:21p nc1x1031.6p
NC1X1031 BIN     6,003,824  07-25-01   8:21a nc1x1031.bin
NC1X1~36 TXT        14,026  07-18-01   1:21p nc1x1031.elem_aqu.txt
NC1X1~38 TXT        13,169  07-18-01   1:21p nc1x1031.elem_min.txt
NC1X1~40 TXT        13,182  07-18-01   1:21p nc1x1031.elem_tot.txt
NC1X1~42 TXT        20,145  07-18-01   1:21p nc1x1031.min_info.txt
NC1X1031 TXT     1,043,308  11-14-01  10:00a nc1x1031.txt
NC2X1402 6I         32,777  07-18-01   1:58p nc2x1402.6i
NC2X1402 6O      5,117,352  07-18-01   2:17p nc2x1402.6o
NC2X1402 6P         32,855  07-18-01   2:17p nc2x1402.6p
NC2X1402 BIN    51,507,080  07-25-01   8:34a nc2x1402.bin
NC2X~222 TXT        44,441  07-18-01   2:17p nc2x1402.elem_aqu.txt
NC2X~224 TXT        41,688  07-18-01   2:17p nc2x1402.elem_min.txt
NC2X~226 TXT        41,701  07-18-01   2:17p nc2x1402.elem_tot.txt
NC2X~228 TXT        92,412  07-18-01   2:17p nc2x1402.min_info.txt
NC2X1402 TXT    10,667,092  11-14-01   9:51a nc2x1402.txt
NM1X1031 6I         44,527  07-18-01   8:53a nm1x1031.6i
NM1X1031 6O      1,726,189  07-18-01   1:24p nm1x1031.6o
NM1X1031 6P         41,384  07-18-01   1:24p nm1x1031.6p
NM1X1031 BIN     7,452,600  07-25-01   8:37a nm1x1031.bin
NM1X~300 TXT        18,646  07-18-01   1:24p nm1x1031.elem_aqu.txt
NM1X~302 TXT        17,501  07-18-01   1:24p nm1x1031.elem_min.txt
NM1X~304 TXT        17,514  07-18-01   1:24p nm1x1031.elem_tot.txt
NM1X~306 TXT        29,947  07-18-01   1:24p nm1x1031.min_info.txt
NM1X1031 TXT     1,813,835  11-14-01   9:57a nm1x1031.txt
NM2X1402 6I         32,923  07-19-01   9:07a nm2x1402.6i
NM2X1402 6O      2,886,235  07-19-01   9:17a nm2x1402.6o
NM2X1402 6P         33,167  07-19-01   9:17a nm2x1402.6p
NM2X1402 BIN    15,910,448  07-25-01   8:44a nm2x1402.bin
NM2X~378 TXT        27,501  07-19-01   9:17a nm2x1402.elem_aqu.txt
NM2X~380 TXT        25,804  07-19-01   9:17a nm2x1402.elem_min.txt
NM2X~382 TXT        25,817  07-19-01   9:17a nm2x1402.elem_tot.txt
NM2X~384 TXT        63,787  07-19-01   9:17a nm2x1402.min_info.txt
NM2X1402 TXT     3,836,115  11-14-01  12:48p nm2x1402.txt
        36 file(s)    110,101,346 bytes

Total files listed:
       227 file(s)    597,823,948 bytes
```

Directory of Fermi-IA2

```
SENSIT~5       <DIR>        11-15-01  11:23a Sensitivity
TWO-ST~7       <DIR>        11-15-01  12:31p Two-Stage
         0 file(s)              0 bytes

Directory of D:\Sensitivity
```

```
.              <DIR>        11-15-01 12:31p .
..             <DIR>        11-15-01 12:31p ..
GDPO4M~5       <DIR>        11-15-01 11:23a GdPO4 mass
GDPO4R~7       <DIR>        11-15-01 11:37a GdPO4 rate
GLASSR~9       <DIR>        11-15-01 12:29p glass rate
         0 file(s)              0 bytes

Directory of D:\Sensitivity\GdPO4 mass

.              <DIR>        11-15-01 12:35p .
..             <DIR>        11-15-01 12:35p ..
NA1D3333 6I         45,731  08-20-01  1:39p nA1d3333.6i
NA1D3333 6O     33,509,003  08-20-01  4:08p na1d3333.6o
NA1D3333 6P         43,226  08-20-01  4:08p na1d3333.6p
NA1D~110 TXT       255,806  08-20-01  4:08p nA1d3333.elem_aqu.txt
NA1D~112 TXT       239,877  08-20-01  4:08p nA1d3333.elem_min.txt
NA1D~114 TXT       239,890  08-20-01  4:08p nA1d3333.elem_tot.txt
NA1D~118 TXT       530,449  08-20-01  4:08p nA1d3333.min_info.txt
NL1D3333 6I         45,733  08-20-01  1:41p nL1d3333.6i
NL1D3333 6O     32,192,728  08-20-01  5:46p nl1d3333.6o
NL1D3333 6P         43,230  08-20-01  5:46p nl1d3333.6p
NL1D~222 TXT       240,406  08-20-01  5:45p nL1d3333.elem_aqu.txt
NL1D~224 TXT       225,437  08-20-01  5:45p nL1d3333.elem_min.txt
NL1D~226 TXT       225,450  08-20-01  5:45p nL1d3333.elem_tot.txt
NL1D~230 TXT       495,897  08-20-01  5:45p nL1d3333.min_info.txt
        14 file(s)     68,332,863 bytes

Directory of D:\Sensitivity\GdPO4 rate

.              <DIR>        08-20-01  5:45p .
..             <DIR>        08-20-01  5:45p ..
NA1X3323 6I         45,731  07-16-01  7:10p nA1x3323.6i
NA1X3323 6O     33,581,652  07-16-01 10:41p na1x3323.6o
NA1X3323 6P         43,226  07-16-01 10:41p na1x3323.6p
NA1X~112 TXT       255,806  07-16-01 10:40p nA1x3323.elem_aqu.txt
NA1X~114 TXT       239,877  07-16-01 10:40p nA1x3323.elem_min.txt
NA1X~116 TXT       239,890  07-16-01 10:40p nA1x3323.elem_tot.txt
NA1X~120 TXT       550,810  07-16-01 10:40p nA1x3323.min_info.txt
NA1X3333 6I         45,731  07-24-01  9:13a nA1x3333.6i
NA1X3333 6O     33,507,357  07-24-01 12:34p na1x3333.6o
NA1X3333 6P         43,226  07-24-01 12:34p na1x3333.6p
NA1X~228 TXT       255,806  07-24-01 12:34p nA1x3333.elem_aqu.txt
NA1X~230 TXT       239,877  07-24-01 12:34p nA1x3333.elem_min.txt
NA1X~232 TXT       239,890  07-24-01 12:34p nA1x3333.elem_tot.txt
NA1X~236 TXT       530,456  07-24-01 12:34p nA1x3333.min_info.txt
NA1Y3323 6I         30,437  07-17-01  6:52a nA1y3323.6i
NA1Y3323 6O     29,606,682  07-17-01 10:26a na1y3323.6o
NA1Y3323 6P         30,437  07-17-01 10:26a na1y3323.6p
NA1Y~332 TXT       241,176  07-17-01 10:25a nA1y3323.elem_aqu.txt
NA1Y~334 TXT       226,159  07-17-01 10:25a nA1y3323.elem_min.txt
NA1Y~338 TXT       226,172  07-17-01 10:25a nA1y3323.elem_tot.txt
NA1Y~340 TXT       379,240  07-17-01 10:25a nA1y3323.min_info.txt
NA1Z3323 6I         29,235  07-17-01 12:12p na1z3323.6i
NA1Z3323 6O     15,049,863  07-17-01  2:39p na1z3323.6o
NA1Z3323 6P         29,153  07-17-01  2:39p na1z3323.6p
NA1Z~394 TXT       129,141  07-17-01  2:39p nA1z3323.elem_aqu.txt
```

```
NA1Z~396 TXT       121,108  07-17-01  2:39p nA1z3323.elem_min.txt
NA1Z~398 TXT       121,121  07-17-01  2:39p nA1z3323.elem_tot.txt
NA1Z~400 TXT       184,258  07-17-01  2:39p nA1z3323.min_info.txt
NL1X3323 6I         45,732  07-17-01  6:54a nL1x3323.6i
NL1X3323 6O     32,225,921  07-17-01 12:09p nl1x3323.6o
NL1X3323 6P         43,228  07-17-01 12:09p nl1x3323.6p
NL1X~504 TXT       240,021  07-17-01 12:09p nL1x3323.elem_aqu.txt
NL1X~506 TXT       225,076  07-17-01 12:09p nL1x3323.elem_min.txt
NL1X~508 TXT       225,089  07-17-01 12:09p nL1x3323.elem_tot.txt
NL1X~512 TXT       514,946  07-17-01 12:09p nL1x3323.min_info.txt
NL1X3333 6I         45,732  07-24-01  9:13a nL1x3333.6i
NL1X3333 6O     32,263,697  07-25-01  9:32p nl1x3333.6o
NL1X3333 6P         43,228  07-25-01  9:32p nl1x3333.6p
NL1X~616 TXT       241,176  07-25-01  9:31p nL1x3333.elem_aqu.txt
NL1X~618 TXT       226,159  07-25-01  9:31p nL1x3333.elem_min.txt
NL1X~620 TXT       226,172  07-25-01  9:31p nL1x3333.elem_tot.txt
NL1X~624 TXT       497,364  07-25-01  9:31p nL1x3333.min_info.txt
NL1Y3323 6I         30,439  07-17-01 12:14p nl1y3323.6i
NL1Y3323 6O     28,503,399  07-17-01  4:25p nl1y3323.6o
NL1Y3323 6P         30,439  07-17-01  4:25p nl1y3323.6p
NL1Y~716 TXT       224,621  07-17-01  4:25p nL1y3323.elem_aqu.txt
NL1Y~720 TXT       210,636  07-17-01  4:25p nL1y3323.elem_min.txt
NL1Y~722 TXT       210,649  07-17-01  4:25p nL1y3323.elem_tot.txt
NL1Y~724 TXT       349,800  07-17-01  4:25p nL1y3323.min_info.txt
NL1Z3323 6I         29,236  07-18-01  6:48a nl1z3323.6i
NL1Z3323 6O     19,410,445  07-18-01  8:06a nl1z3323.6o
NL1Z3323 6P         29,153  07-18-01  8:06a nl1z3323.6p
NL1Z~790 TXT       161,481  07-18-01  8:05a nL1z3323.elem_aqu.txt
NL1Z~794 TXT       151,432  07-18-01  8:05a nL1z3323.elem_min.txt
NL1Z~796 TXT       151,445  07-18-01  8:05a nL1z3323.elem_tot.txt
NL1Z~798 TXT       229,954  07-18-01  8:05a nL1z3323.min_info.txt
        56 file(s)    233,010,187 bytes

Directory of D:\Sensitivity\glass rate

.              <DIR>        07-18-01  8:05a .
..             <DIR>        07-18-01  8:05a ..
NM1N1331 6I         46,392  08-20-01  1:30p nm1n1331.6i
NM1N1331 6O      3,124,338  08-20-01  5:51p nm1n1331.6o
NM1N1331 6P         43,160  08-20-01  5:51p nm1n1331.6p
NM1N1~22 TXT        29,811  08-20-01  5:51p nm1n1331.elem_aqu.txt
NM1N1~24 TXT        27,970  08-20-01  5:51p nm1n1331.elem_min.txt
NM1N1~26 TXT        27,983  08-20-01  5:51p nm1n1331.elem_tot.txt
NM1N1~28 TXT        58,660  08-20-01  5:51p nm1n1331.min_info.txt
NM2N1402 6I         32,923  08-21-01  3:58p nm2n1402.6i
NM2N1402 6O      2,544,605  08-21-01  4:04p nm2n1402.6o
NM2N1402 6P         33,659  08-21-01  4:04p nm2n1402.6p
NM2N1~44 TXT        24,036  08-21-01  4:04p nm2n1402.elem_aqu.txt
NM2N1~46 TXT        22,555  08-21-01  4:04p nm2n1402.elem_min.txt
NM2N1~48 TXT        22,568  08-21-01  4:04p nm2n1402.elem_tot.txt
NM2N1~50 TXT        52,712  08-21-01  4:04p nm2n1402.min_info.txt
NM2N1402 TXT     3,332,738  11-15-01  8:31a nm2n1402.txt
        15 file(s)      9,424,110 bytes

Directory of D:\Two-Stage

.              <DIR>        11-15-01 12:29p .
```

```
..              <DIR>          11-15-01 12:29p ..
SCENAR~5        <DIR>          11-15-01 12:31p Scenario I
SCENAR~7        <DIR>          11-15-01 12:35p Scenario II
         0 file(s)              0 bytes

Directory of D:\Two-Stage\Scenario I

.               <DIR>          11-15-01  8:31a .
..              <DIR>          11-15-01  8:31a ..
NM1X1303 6I          38,545    07-16-01  7:35a nm1x1303.6i
NM1X1303 6O       3,664,654    07-16-01  7:41a nm1x1303.6o
NM1X1303 6P          34,824    07-16-01  7:41a nm1x1303.6p
NM1X1~24 TXT         43,671    07-16-01  7:41a nm1x1303.elem_aqu.txt
NM1X1~26 TXT         40,966    07-16-01  7:41a nm1x1303.elem_min.txt
NM1X1~28 TXT         40,979    07-16-01  7:41a nm1x1303.elem_tot.txt
NM1X1~30 TXT         67,345    07-16-01  7:41a nm1x1303.min_info.txt
NM1X1403 6I          38,544    07-16-01  7:30a nm1x1403.6i
NM1X1403 6O       4,224,287    07-16-01  7:48a nm1x1403.6o
NM1X1403 6P          34,988    07-16-01  7:48a nm1x1403.6p
NM1X1~50 TXT         46,751    07-16-01  7:48a nm1x1403.elem_aqu.txt
NM1X1~52 TXT         43,854    07-16-01  7:48a nm1x1403.elem_min.txt
NM1X1~54 TXT         43,867    07-16-01  7:48a nm1x1403.elem_tot.txt
NM1X1~56 TXT         88,503    07-16-01  7:48a nm1x1403.min_info.txt
SECOND~5        <DIR>          11-15-01 12:33p second stage
        14 file(s)      8,451,778 bytes

Directory of D:\Two-Stage\Scenario I\second stage

.               <DIR>          11-15-01 12:40p .
..              <DIR>          11-15-01 12:40p ..
NM2X1031 6I          40,418    07-16-01 12:38p nm2x1031.6i
NM2X1031 6O       1,183,740    07-16-01 12:39p nm2x1031.6o
NM2X1031 6P          40,405    07-16-01 12:39p nm2x1031.6p
NM2X1~14 TXT         12,871    07-16-01 12:39p nm2x1031.elem_aqu.txt
NM2X1~16 TXT         12,086    07-16-01 12:39p nm2x1031.elem_min.txt
NM2X1~18 TXT         12,099    07-16-01 12:39p nm2x1031.elem_tot.txt
NM2X1~20 TXT         22,629    07-16-01 12:39p nm2x1031.min_info.txt
NM2X1332 6I          41,457    07-16-01  4:51p nm2x1332.6i
NM2X1332 6O       7,506,988    07-16-01  5:07p nm2x1332.6o
NM2X1332 6P          41,771    07-16-01  5:07p nm2x1332.6p
NM2X1~52 TXT         75,626    07-16-01  5:07p nm2x1332.elem_aqu.txt
NM2X1~54 TXT         70,929    07-16-01  5:07p nm2x1332.elem_min.txt
NM2X1~56 TXT         70,942    07-16-01  5:07p nm2x1332.elem_tot.txt
NM2X1~58 TXT        144,331    07-16-01  5:07p nm2x1332.min_info.txt
NM2Y1031 6I          29,531    07-16-01 12:41p nm2y1031.6i
NM2Y1031 6O         357,876    07-16-01 12:41p nm2y1031.6o
NM2Y1031 6P          29,695    07-16-01 12:41p nm2y1031.6p
NM2Y1~68 TXT          4,401    07-16-01 12:41p nm2y1031.elem_aqu.txt
NM2Y1~70 TXT          4,144    07-16-01 12:41p nm2y1031.elem_min.txt
NM2Y1~72 TXT          4,157    07-16-01 12:41p nm2y1031.elem_tot.txt
NM2Y1~74 TXT          7,627    07-16-01 12:41p nm2y1031.min_info.txt
        21 file(s)      9,713,723 bytes

Directory of D:\Two-Stage\Scenario II

.               <DIR>          11-15-01 12:33p .
..              <DIR>          11-15-01 12:33p ..
```

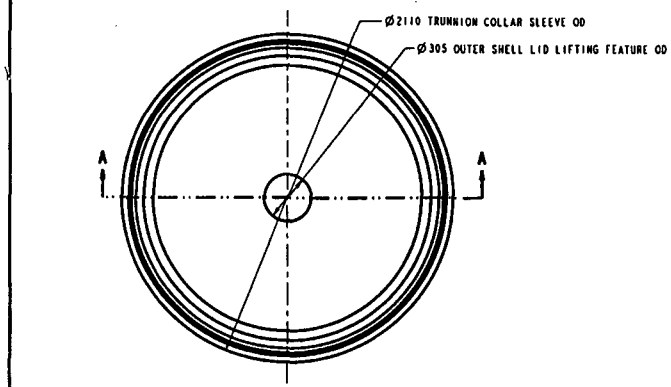
```
NM1X1023 6I          44,527  07-12-01  5:32p nm1x1023.6i
NM1X1023 6O      10,068,668  07-12-01  5:55p nm1x1023.6o
NM1X1023 6P          41,220  07-12-01  5:55p nm1x1023.6p
NM1X1~42 TXT         85,636  07-12-01  5:55p nm1x1023.elem_aqu.txt
NM1X1~44 TXT         80,315  07-12-01  5:55p nm1x1023.elem_min.txt
NM1X1~46 TXT         80,328  07-12-01  5:55p nm1x1023.elem_tot.txt
NM1X1~48 TXT        149,609  07-12-01  5:55p nm1x1023.min_info.txt
NM1X1032 6I          44,527  07-16-01 11:40a nm1x1032.6i
NM1X1032 6O       2,591,200  07-16-01 11:48a nm1x1032.6o
NM1X1032 6P          41,302  07-16-01 11:48a nm1x1032.6p
NM1X1032 6T         116,736  07-16-01 11:48a nm1x1032.6t
NM1X1032 6TX        118,331  07-16-01 11:48a nm1x1032.6tx
NM1X1~68 TXT         25,191  07-16-01 11:48a nm1x1032.elem_aqu.txt
NM1X1~70 TXT         23,638  07-16-01 11:48a nm1x1032.elem_min.txt
NM1X1~72 TXT         23,651  07-16-01 11:48a nm1x1032.elem_tot.txt
NM1X1~74 TXT         42,255  07-16-01 11:48a nm1x1032.min_info.txt
NM1X1033 6I          44,527  07-12-01  5:32p nm1x1033.6i
NM1X1033 6O      10,139,044  07-12-01  6:17p nm1x1033.6o
NM1X1033 6P          41,302  07-12-01  6:17p nm1x1033.6p
NM1X~112 TXT         84,866  07-12-01  6:16p nm1x1033.elem_aqu.txt
NM1X~114 TXT         79,593  07-12-01  6:16p nm1x1033.elem_min.txt
NM1X~116 TXT         79,606  07-12-01  6:16p nm1x1033.elem_tot.txt
NM1X~118 TXT        154,499  07-12-01  6:16p nm1x1033.min_info.txt
SECOND~5       <DIR>         11-15-01 12:40p second stage
        23 file(s)     24,200,571 bytes

Directory of D:\Two-Stage\Scenario II\second stage

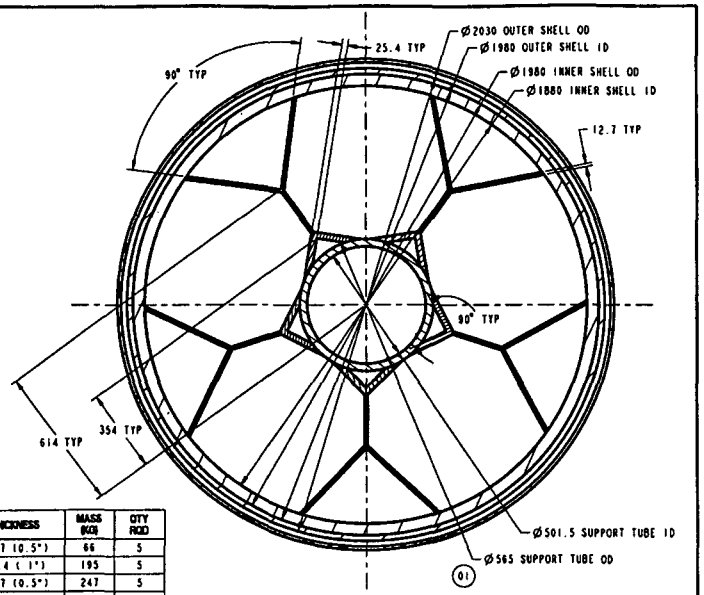
.              <DIR>         07-16-01 12:41p .
..             <DIR>         07-16-01 12:41p ..
NM2X1302 6I          32,920  07-16-01  2:47p nm2x1302.6i
NM2X1302 6O       8,420,000  07-16-01  3:05p nm2x1302.6o
NM2X1302 6P          33,413  07-16-01  3:05p nm2x1302.6p
NM2X1~38 TXT         66,386  07-16-01  3:05p nm2x1302.elem_aqu.txt
NM2X1~40 TXT         62,265  07-16-01  3:05p nm2x1302.elem_min.txt
NM2X1~42 TXT         62,278  07-16-01  3:05p nm2x1302.elem_tot.txt
NM2X1~44 TXT         90,003  07-16-01  3:05p nm2x1302.min_info.txt
NM2X1303 6I          32,920  07-12-01  6:29p nm2x1303.6i
NM2X1303 6O      27,393,171  07-13-01  2:58a nm2x1303.6o
NM2X1303 6P          33,085  07-13-01  2:58a nm2x1303.6p
NM2X~132 TXT        194,206  07-13-01  2:58a nm2x1303.elem_aqu.txt
NM2X~136 TXT        182,117  07-13-01  2:58a nm2x1303.elem_min.txt
NM2X~138 TXT        182,130  07-13-01  2:58a nm2x1303.elem_tot.txt
NM2X~140 TXT        288,249  07-13-01  2:58a nm2x1303.min_info.txt
NM2X1323 6I          33,817  07-12-01  6:24p nm2x1323.6i
NM2X1323 6O      27,310,618  07-13-01  1:58a nm2x1323.6o
NM2X1323 6P          34,064  07-13-01  1:58a nm2x1323.6p
NM2X~230 TXT        191,896  07-13-01  1:57a nm2x1323.elem_aqu.txt
NM2X~232 TXT        179,951  07-13-01  1:57a nm2x1323.elem_min.txt
NM2X~234 TXT        179,964  07-13-01  1:57a nm2x1323.elem_tot.txt
NM2X~236 TXT        267,941  07-13-01  1:57a nm2x1323.min_info.txt
NM2Y1302 6I          29,228  07-16-01  3:24p nm2y1302.6i
NM2Y1302 6O         826,333  07-16-01  3:26p nm2y1302.6o
NM2Y1302 6P          29,228  07-16-01  3:26p nm2y1302.6p
NM2Y~248 TXT          7,866  07-16-01  3:26p nm2y1302.elem_aqu.txt
NM2Y~250 TXT          7,393  07-16-01  3:26p nm2y1302.elem_min.txt
NM2Y~252 TXT          7,406  07-16-01  3:26p nm2y1302.elem_tot.txt
```

```
NM2Y~254 TXT        14,349  07-16-01  3:26p nm2y1302.min_info.txt
NM2Y1303 6I         30,503  07-13-01  6:55a nm2y1303.6i
NM2Y1303 6O     30,205,779  07-13-01  2:23p nm2y1303.6o
NM2Y1303 6P         30,503  07-13-01  2:23p nm2y1303.6p
NM2Y~350 TXT       243,871  07-13-01  2:23p nm2y1303.elem_aqu.txt
NM2Y~354 TXT       228,686  07-13-01  2:23p nm2y1303.elem_min.txt
NM2Y~356 TXT       228,699  07-13-01  2:23p nm2y1303.elem_tot.txt
NM2Y~360 TXT       347,794  07-13-01  2:23p nm2y1303.min_info.txt
NM2Y1323 6I         31,482  07-13-01  6:54a nm2y1323.6i
NM2Y1323 6O     30,293,869  07-13-01  1:20p nm2y1323.6o
NM2Y1323 6P         31,482  07-13-01  1:20p nm2y1323.6p
NM2Y~456 TXT       243,101  07-13-01  1:20p nm2y1323.elem_aqu.txt
NM2Y~460 TXT       227,964  07-13-01  1:20p nm2y1323.elem_min.txt
NM2Y~462 TXT       227,977  07-13-01  1:20p nm2y1323.elem_tot.txt
NM2Y~464 TXT       319,735  07-13-01  1:20p nm2y1323.min_info.txt
NM2Z1303 6I         30,503  07-16-01  6:47a nm2z1303.6i
NM2Z1303 6O     22,538,351  07-16-01 10:43a nm2z1303.6o
NM2Z1303 6P         30,421  07-16-01 10:43a nm2z1303.6p
NM2Z~540 TXT       192,666  07-16-01 10:43a nm2z1303.elem_aqu.txt
NM2Z~542 TXT       180,673  07-16-01 10:43a nm2z1303.elem_min.txt
NM2Z~546 TXT       180,686  07-16-01 10:43a nm2z1303.elem_tot.txt
NM2Z~548 TXT       243,295  07-16-01 10:43a nm2z1303.min_info.txt
NM2Z1323 6I         31,480  07-16-01 12:46p nm2z1323.6i
NM2Z1323 6O     23,506,589  07-16-01  1:57p nm2z1323.6o
NM2Z1323 6P         31,400  07-16-01  1:57p nm2z1323.6p
NM2Z~626 TXT       194,206  07-16-01  1:57p nm2z1323.elem_aqu.txt
NM2Z~628 TXT       182,117  07-16-01  1:57p nm2z1323.elem_min.txt
NM2Z~630 TXT       182,130  07-16-01  1:57p nm2z1323.elem_tot.txt
NM2Z~634 TXT       245,423  07-16-01  1:57p nm2z1323.min_info.txt
        56 file(s)    176,654,582 bytes

Total files listed:
       199 file(s)    529,787,814 bytes
```



SECTION A-A



SECTION B-B

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY REQ
DIVIDER PLATE	SA-516 K02700	12.7 (0.5")	66	5
INNER BRACKET	SA-516 K02700	25.4 (1")	195	5
OUTER BRACKET	SA-516 K02700	12.7 (0.5")	247	5
SUPPORT TUBE	SA-516 K02700	31.75 (1.25")	1265	1
INNER SHELL	SA-240 S31600	50	7621	1
INNER SHELL LID	SA-240 S31600	80	1765	2
INNER LID LIFTING FEATURE	SA-240 S31600	27	12	1
OUTER SHELL	SB-575 N06022	25	4692	1
EXTENDED OUTER SHELL LID	SB-575 N06022	25	172	1
EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25	629	1
EXTENDED OUTER LID REINFORCING RING	SB-575 N06022	50	129	1
OUTER LID LIFTING FEATURE	SB-575 N06022	27	13	2
OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	10	268	1
OUTER SHELL FLAT BOTTOM LID	SB-575 N06022	25	669	1
UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	655	1
LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	642	1
INNER SHELL SUPPORT RING	SB-575 N06022	20	53	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	325	***
TOTAL 316 WELDS	SFA-5.9 S31680	-	133	***
WASTE PACKAGE ASSEMBLY	-	-	23360	1
HLW GLASS ASSEMBLY	-	-	2500*	5
18" CANISTER SHORT	-	-	2270**	1
WP ASSEMBLY WITH SNF	-	-	38130	-

(03) * WASTE ACCEPTANCE SYSTEM REQUIREMENTS DOCUMENT. E00000000-00811-1708-00001 REV 03, DOE/RW-0351. ACC: WOO.19990226.0001, PAGE 18, SECTION 4.2.3.1.A.4.

** UNITED STATES DEPARTMENT OF ENERGY 1998. DESIGN SPECIFICATION FOR DEPARTMENT OF ENERGY STANDARDIZED SPENT NUCLEAR FUEL CANISTERS, VOLUME I, DESIGN SPECIFICATION, REV 01. WASHINGTON D.C.: UNITED STATES DEPARTMENT OF ENERGY. TIC: 241528

*** SEE SK-0197 FOR WELD CONFIGURATION AND MASSES

UNITS: mm

DO NOT SCALE FROM SKETCH

REVISIONS			
REV	DESCRIPTION	DRW BY	DATE
00	ISSUED APPROVED	DGM	1/26/00
01	IN SECTION B-B Ø 565 SUPPORT TUBE OD "WAS" ID	DGM	4/21/00
02	"MODIFIED" REVISION TABLE, "ADDED" DIMENSION 4 TO DETAIL A, "MODIFIED" CROSS HATCHING ON DETAIL A	BH	4/25/00
03	IN NOTE **, DOE/RW-0351 "WAS" DOE/RW-315P, IN REVISION BLOCK REV 00, 1/26/00 "WAS" 1/25/00, "ADDED" REVISION BALLOONS TO SECTION B-B AND DETAIL "A"	EJC	6/5/00

"FOR INFORMATION ONLY"

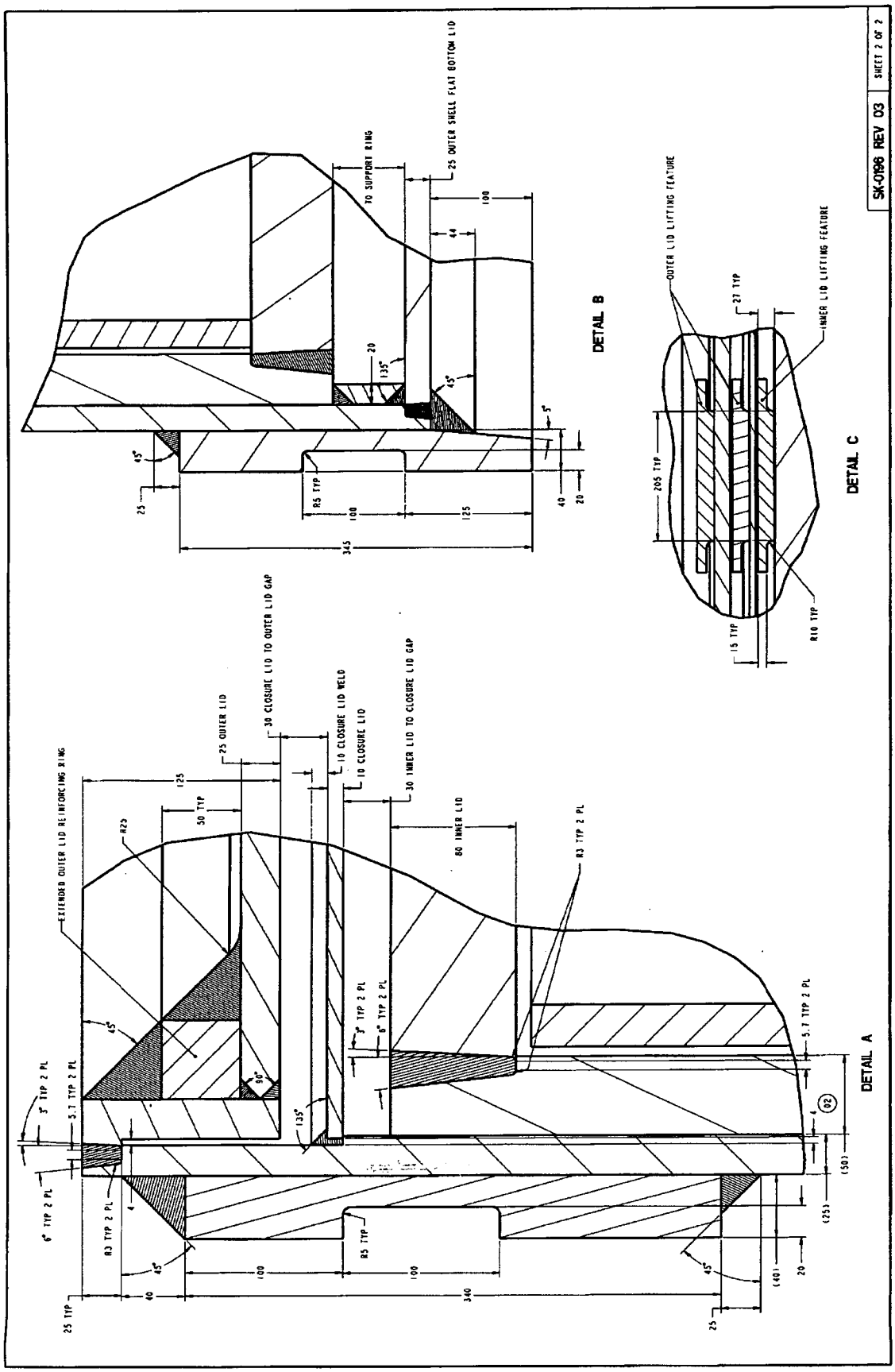
5 DHLW/DOE SNF - SHORT WP ASSSEMBLY CONFIGURATION FOR SITE RECOMENDATION

SKETCH NUMBER: SK-0196 REV 03 SHEET 1 OF 2

SKETCHED BY: EUGENE CONNELL EJC 06/06/00 SmB 06/06/00 SmB for MJA 06/06/00

DATE: 06/05/00

FILE: /home/pro_library/checkout/sketches/5dhlw_short/sk-0196_rev03.dwg


SK-0196 REV 03
SHEET 2 OF 2
DETAIL A
DETAIL B
DETAIL C
EXTENDED OUTER LID REINFORCING RING
25 OUTER LID
30 CLOSURE LID TO OUTER LID GAP
10 CLOSURE LID WELD
10 CLOSURE LID
30 INNER LID TO CLOSURE LID GAP
80 INNER LID
R3 TYP 2 PL
R3 TYP
R23
25 OUTER SHELL FLAT BOTTOM LID
TO SUPPORT RING
OUTER LID LIFTING FEATURE
INNER LID LIFTING FEATURE
27 TYP
205 TYP
15 TYP
R10 TYP
R5 TYP
5.7 TYP 2 PL
3" TYP 2 PL
6" TYP 2 PL
25 TYP
340
345

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Complete Only Applicable Items

This is a placeholder page for records that cannot be scanned.

2. Record Date	3. Accession Number
12/04/2001	ATT-TO MOL.20020102.0190
4. Author Name(s)	**5. Author Organization**
PATRICIA BERNOT EMMA PARKER	N/A

6. Title/Description
EQ6 CALCULATION FOR CHEMICAL DEGRADATION OF ENRICO CODISPOSAL WASTE PACKAGE: EFFECTS OF UPDATED DESIGN AND RATES

7. Document Number(s)	8. Version Designator
CAL-EDC-MD-000015	REV. 00

9. Document Type	10. Medium
REPORT	~~OPTIC/PAPER~~ DISK * 1-CRV

11. Access Control Code
PUB

12. Traceability Designator
DC# 28752

13. Comments
THIS IS A SPECIAL PROCESS CD-ROM AS PART OF ATTACHMENT III 1 OF 2 ~~AND CAN BE LOCATED THROUGH THE RPC.~~ (AB) 01-04-02

THIS DATA SUBMITTAL TO THE RECORDS PROCESSING CENTER IS FOR ARCHIVE PURPOSES ONLY, AND IS NOT AVAILABLE FOR VIEWING OR REPRODUCTION

1813

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

ELECTRONIC FILE CERTIFICATION

QA: N/A

1. DOCUMENT TITLE:

EQ6 Calculation for Chemical Degradation of Enrico Fermi Codisposal Waste Packages: Effects of Updated Design and Rates

2. IDENTIFIER (e.g., DI OR PI):	3. REVISION DESIGNATOR:
CAL-EDC-MD-000015	Rev. 00

ATTACHED SOFTWARE FILE INFORMATION

4. PDF FILE SUBMITTED: ☐ YES ☑ NO

5. FILE NAMES(S) WITH FILE EXTENSION(S) PROVIDED BY THE SOFTWARE:

See Attached

6. DATE LAST MODIFIED:	7. NATIVE APPLICATION: (i.e., EXCEL, WORD, CORELDRAW)	8. FILE SIZE IN KILOBYTES:
See Attached	Word	See Attached

9. FILE LINKAGE INSTRUCTIONS/INFORMATION:

Standard

10. PRINTER SPECIFICATION (I.E., HP4SI) INCLUDING POSTSCRIPT INFORMATION (i.e., PRINTER DRIVER) AND PRINTING PAGE SETUP: (i.e., LANDSCAPE, 11 X 17 PAPER)

T1024AHP5Si 8 1/ 2 x 11 Color- 8 1/2 X 11 T1005HP5MC

11. COMPUTING PLATFORM USED: (i.e., PC, SUN, WIN 95, NT, HP)	12. OPERATING SYSTEM AND VERSION: (i.e., WINDOWS UNIX, SOLARIS)
PC#117728	Windows 95

13. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S):	14. ACCESS RESTRICTIONS: (COPYRIGHT OR LICENSE ISSUES)
None	None

COMMENTS/SPECIAL INSTRUCTIONS

15. IS SOFTWARE AVAILABLE FROM SOFTWARE CONFIGURATION MANAGEMENT? ☑ YES ☐ NO
SOFTWARE MEDIA TRACKING NUMBER N/A .

Note: The software product(s) to develop this document are Commercail-Off-The-Shelf (COTS) software products which require no Software Media Number (SMN). The COTS software products are under Software Configuration Management (SCM).

Originator: Patricia Bernot & Emma Parker

CERTIFICATION

16. DOCUMENT OWNER (Print and Sign):			17. DATE:
Dan Thomas D C Thomas			12/14/2001
18. ORGANIZATION:	19. DEPARTMENT:	20. LOCATION/MAIL STOP:	21. PHONE:
BSC	Waste Package Criticality	MS423/1006	295-4507
22. SUBMITTED BY (Print and Sign):			23. DATE:
Daynett D. Vosicky Daynett D. Vosicky			12-14-2001

DC USE ONLY

24. DATE RECEIVED:	25. DATE FILES TRANSFERRED:	26. DC NO.:
12-14-01	NA	28752
27. NAME (Print and Sign):		28. DATE:
NA		NA

8. ATTACHMENTS

Attachment I. Listing of Files on Compact Disks (11 pages)

Attachment II. Sketch SK-0200 REV 04 (2 pages)

Attachment III. Two Compact Discs

ATTACHMENT I. LISTING OF FILES ON COMPACT DISKS

This attachment contains the MS-DOS directory for files placed on the electronic media (Attachment I). The files are of various types:

1. Excel files (extensions = xls).
2. EQ3/6 input files (extension = 3i or 6i).

   ASCII text file: provides input parameters for EQ3/6.
3. EQ3/6 output files (extension = 3o or 6o).

   ASCII text file: provides detailed information about the system at each print point, which is specified by the user in the input file.
4. EQ3/6 pickup files (extension = 3p or 6p).

   ASCII text file: provides a description of the system at the end of that run to be used as an input file for a continuation run.
5. EQ6 Tab-delimited text files (extension = txt).

   *.elem_aqu: total aqueous moles of elements.

   *.elem_min: total moles of elements in minerals.

   *.elem_tot: total moles of elements (aqueous + mineral).

   *.min_info: moles of each mineral.
6. EQ6 binary output file (extension = bin).

   Binary file: provides detailed information about the system at the full numerical precision for *every* time step.
7. EQ3/6 text data files used for the calculations, "data0.ymd".
8. Batch files (extension = bat) used to start EQ6 runs.
9. Winzip files (extension = zip).

Below are listed the contents of the DOS directories within the electronic attachment:

The first column is the DOS file name.

The second column lists <DIR> if it is a directory
or gives the files size (bytes) if it is a file.

The third and fourth columns are the date and time of the last update.

The fifth column is the filename.

Directory of Fermi-IA1

```
DATA0     NUC      2,302,224  09-15-99 11:40a DATA0.NUC
DATA0     YMD      2,657,459  03-16-01  1:22p data0.ymd
DATA0     YMP      2,649,470  09-11-00  5:23p data0.ymp
ENRIC~34  XLS      1,075,200  11-14-01  3:24p enrich-fermi1.xls
ENRIC~38  XLS      1,047,552  11-14-01  3:49p enrich-fermi2.xls
ENRIC~44  XLS        535,040  11-15-01 10:15a enrich-sens-Fermi.xls
FERMI~48  XLS         39,424  09-20-01  8:28a Fermi-IA-2001.xls
FERMI~50  XLS        256,512  09-13-01 10:24a fermi-losses.xls
HLWGL~52  XLS         57,856  08-01-01 10:17a HLWglass-2001.xls
J13NOM20  3I          13,734  10-23-00 12:44p j13nom20.3i
J13NOM20  3O         114,582  10-23-00 12:45p j13nom20.3o
J13NOM20  3P          11,786  10-23-00 12:45p j13nom20.3p
J13NOM30  3I          13,660  10-10-00  1:31p j13nom30.3i
J13NOM30  3O         115,224  10-10-00  1:32p j13nom30.3o
J13NOM30  3P          11,712  10-10-00  1:32p j13nom30.3p
LOSSE~66  XLS         18,944  08-20-01  3:59p losses-oldtime.xls
MORES~68  XLS         18,944  09-17-01  7:22a moresense.xls
OLDFE~72  XLS         16,896  09-13-01  8:19a oldfermi-recalc.xls
ONE-ST~5        <DIR>         11-15-01  8:50a One-Stage
S_ASE~76  XLS        108,544  08-23-01  7:32a S+A sensitivity.xls
S_A~78    XLS        790,016  09-19-01  9:02a S+A.xls
SENSI~82  XLS      9,253,888  11-15-01  9:27a Sensitivity.xls
SOURCE~7        <DIR>         11-15-01 10:37a Source Term
UENR~112  XLS         19,968  11-13-01  3:01p Uenrich Fermi.xls
        22 file(s)     21,128,635 bytes

Directory of D:\One-Stage

.               <DIR>         11-13-01  3:01p .
..              <DIR>         11-13-01  3:01p ..
NG1X3323  6I          45,736  07-16-01  5:11p ng1x3323.6i
NG1X3323  6O      31,486,614  07-16-01  9:01p ng1x3323.6o
NG1X3323  6P          43,166  07-16-01  9:01p ng1x3323.6p
NG1X~104  TXT        232,706  07-16-01  9:00p ng1x3323.elem_aqu.txt
NG1X~106  TXT        218,217  07-16-01  9:00p ng1x3323.elem_min.txt
NG1X~108  TXT        218,230  07-16-01  9:00p ng1x3323.elem_tot.txt
NG1X~112  TXT        465,870  07-16-01  9:00p ng1x3323.min_info.txt
NM1X1321  6I          46,466  07-11-01  1:16p nm1x1321.6i
NM1X1321  6O       2,802,843  07-11-01  1:25p nm1x1321.6o
NM1X1321  6P          43,554  07-11-01  1:25p nm1x1321.6p
NM1X~128  TXT         28,656  07-11-01  1:25p nm1x1321.elem_aqu.txt
NM1X~130  TXT         26,887  07-11-01  1:25p nm1x1321.elem_min.txt
NM1X~132  TXT         26,900  07-11-01  1:25p nm1x1321.elem_tot.txt
NM1X~134  TXT         58,272  07-11-01  1:25p nm1x1321.min_info.txt
NM1X1331  6I          46,466  07-11-01  1:16p nm1x1331.6i
NM1X1331  6O       2,784,787  07-11-01  1:31p nm1x1331.6o
NM1X1331  6P          43,226  07-11-01  1:31p nm1x1331.6p
NM1X~150  TXT         27,886  07-11-01  1:31p nm1x1331.elem_aqu.txt
NM1X~152  TXT         26,165  07-11-01  1:31p nm1x1331.elem_min.txt
NM1X~154  TXT         26,178  07-11-01  1:31p nm1x1331.elem_tot.txt
NM1X~156  TXT         53,551  07-11-01  1:31p nm1x1331.min_info.txt
NM1X1333  6I          46,466  07-25-01  1:34p nm1x1333.6i
NM1X1333  6O      17,695,889  07-25-01  2:05p nm1x1333.6o
NM1X1333  6P          42,816  07-25-01  2:05p nm1x1333.6p
```

```
NM1X~216 TXT       183,811  07-25-01   2:05p nm1x1333.elem_aqu.txt
NM1X~218 TXT       172,370  07-25-01   2:05p nm1x1333.elem_min.txt
NM1X~222 TXT       172,383  07-25-01   2:05p nm1x1333.elem_tot.txt
NM1X~224 TXT       364,691  07-25-01   2:05p nm1x1333.min_info.txt
NM1X2331 6I         46,466  07-11-01   1:17p nm1x2331.6i
NM1X2331 6O      3,499,254  07-11-01   2:32p nm1x2331.6o
NM1X2331 6P         43,636  07-11-01   2:32p nm1x2331.6p
NM1X~244 TXT        35,201  07-11-01   2:32p nm1x2331.elem_aqu.txt
NM1X~246 TXT        33,024  07-11-01   2:32p nm1x2331.elem_min.txt
NM1X~248 TXT        33,037  07-11-01   2:32p nm1x2331.elem_tot.txt
NM1X~250 TXT        77,821  07-11-01   2:32p nm1x2331.min_info.txt
NM1X2422 6I         45,652  07-12-01   1:53p nm1x2422.6i
NM1X2422 6O     12,646,847  07-12-01   2:28p nm1x2422.6o
NM1X2422 6P         42,668  07-12-01   2:28p nm1x2422.6p
NM1X~296 TXT       102,961  07-12-01   2:28p nm1x2422.elem_aqu.txt
NM1X~298 TXT        96,560  07-12-01   2:28p nm1x2422.elem_min.txt
NM1X~300 TXT        96,573  07-12-01   2:28p nm1x2422.elem_tot.txt
NM1X~302 TXT       254,139  07-12-01   2:28p nm1x2422.min_info.txt
NM1X2432 6I         45,651  07-12-01   1:53p nm1x2432.6i
NM1X2432 6O     12,914,822  07-12-01   3:00p nm1x2432.6o
NM1X2432 6P         42,586  07-12-01   3:00p nm1x2432.6p
NM1X~348 TXT       107,581  07-12-01   3:00p nm1x2432.elem_aqu.txt
NM1X~350 TXT       100,892  07-12-01   3:00p nm1x2432.elem_min.txt
NM1X~352 TXT       100,905  07-12-01   3:00p nm1x2432.elem_tot.txt
NM1X~354 TXT       274,469  07-12-01   3:00p nm1x2432.min_info.txt
NM1X3323 6I         45,655  07-12-01   1:53p nm1x3323.6i
NM1X3323 6O     31,856,704  07-12-01   4:39p nm1x3323.6o
NM1X3323 6P         43,078  07-12-01   4:39p nm1x3323.6p
NM1X~456 TXT       235,786  07-12-01   4:39p nm1x3323.elem_aqu.txt
NM1X~458 TXT       221,105  07-12-01   4:39p nm1x3323.elem_min.txt
NM1X~462 TXT       221,118  07-12-01   4:39p nm1x3323.elem_tot.txt
NM1X~464 TXT       504,572  07-12-01   4:39p nm1x3323.min_info.txt
NM1X3333 6I         45,655  07-12-01   9:09a nm1x3333.6i
NM1X3333 6O     30,373,686  07-12-01  10:53a nm1x3333.6o
NM1X3333 6P         43,078  07-12-01  10:53a nm1x3333.6p
NM1X~562 TXT       219,231  07-12-01  10:53a nm1x3333.elem_aqu.txt
NM1X~566 TXT       205,582  07-12-01  10:53a nm1x3333.elem_min.txt
NM1X~568 TXT       205,595  07-12-01  10:53a nm1x3333.elem_tot.txt
NM1X~570 TXT       444,410  07-12-01  10:53a nm1x3333.min_info.txt
NM1X3433 6I         45,655  07-12-01  11:51a nm1x3433.6i
NM1X3433 6O     30,750,097  07-12-01   1:17p nm1x3433.6o
NM1X3433 6P         42,996  07-12-01   1:17p nm1x3433.6p
NM1X~670 TXT       229,626  07-12-01   1:17p nm1x3433.elem_aqu.txt
NM1X~674 TXT       215,329  07-12-01   1:17p nm1x3433.elem_min.txt
NM1X~676 TXT       215,342  07-12-01   1:17p nm1x3433.elem_tot.txt
NM1X~678 TXT       572,539  07-12-01   1:17p nm1x3433.min_info.txt
SECOND~5       <DIR>        11-15-01   9:30a second part
THIRDP~7       <DIR>        11-15-01  10:00a third part
        70 file(s)    184,808,385 bytes

Directory of D:\One-Stage\second part

.              <DIR>        11-15-01  10:46a .
..             <DIR>        11-15-01  10:46a ..
NG1Y3323 6I         30,372  07-17-01   6:53a ng1y3323.6i
NG1Y3323 6O     27,899,955  07-17-01   8:41a ng1y3323.6o
NG1Y3323 6P         30,367  07-17-01   8:41a ng1y3323.6p
```

```
NG1Y3~94 TXT       219,616  07-17-01  8:40a ng1y3323.elem_aqu.txt
NG1Y3~96 TXT       205,943  07-17-01  8:40a ng1y3323.elem_min.txt
NG1Y~100 TXT       205,956  07-17-01  8:40a ng1y3323.elem_tot.txt
NG1Y~102 TXT       343,174  07-17-01  8:40a ng1y3323.min_info.txt
NM1Y1333 6I         30,577  07-25-01  3:02p nm1y1333.6i
NM1Y1333 6O     20,670,995  07-25-01  3:54p nm1y1333.6o
NM1Y1333 6P         30,585  07-25-01  3:54p nm1y1333.6p
NM1Y~172 TXT       228,471  07-25-01  3:54p nm1y1333.elem_aqu.txt
NM1Y~174 TXT       214,246  07-25-01  3:54p nm1y1333.elem_min.txt
NM1Y~176 TXT       214,259  07-25-01  3:54p nm1y1333.elem_tot.txt
NM1Y~180 TXT       315,064  07-25-01  3:54p nm1y1333.min_info.txt
NM1Y3323 6I         30,289  07-12-01  5:36p nm1y3323.6i
NM1Y3323 6O     28,171,181  07-12-01 10:25p nm1y3323.6o
NM1Y3323 6P         30,289  07-12-01 10:25p nm1y3323.6p
NM1Y~270 TXT       219,616  07-12-01 10:25p nm1y3323.elem_aqu.txt
NM1Y~274 TXT       205,943  07-12-01 10:25p nm1y3323.elem_min.txt
NM1Y~276 TXT       205,956  07-12-01 10:25p nm1y3323.elem_tot.txt
NM1Y~278 TXT       340,774  07-12-01 10:25p nm1y3323.min_info.txt
NM1Y3333 6I         29,310  07-12-01  2:02p nm1y3333.6i
NM1Y3333 6O     28,916,112  07-12-01 11:58p nm1y3333.6o
NM1Y3333 6P         29,310  07-12-01 11:58p nm1y3333.6p
NM1Y~372 TXT       222,696  07-12-01 11:57p nm1y3333.elem_aqu.txt
NM1Y~374 TXT       208,831  07-12-01 11:57p nm1y3333.elem_min.txt
NM1Y~378 TXT       208,844  07-12-01 11:57p nm1y3333.elem_tot.txt
NM1Y~380 TXT       324,558  07-12-01 11:57p nm1y3333.min_info.txt
NM1Y3433 6I         28,027  07-12-01  2:04p nm1y3433.6i
NM1Y3433 6O     26,458,687  07-13-01 12:58a nm1y3433.6o
NM1Y3433 6P         27,618  07-13-01 12:58a nm1y3433.6p
NM1Y~466 TXT       221,156  07-13-01 12:58a nm1y3433.elem_aqu.txt
NM1Y~470 TXT       207,387  07-13-01 12:58a nm1y3433.elem_min.txt
NM1Y~472 TXT       207,400  07-13-01 12:58a nm1y3433.elem_tot.txt
NM1Y~474 TXT       304,930  07-13-01 12:58a nm1y3433.min_info.txt
        35 file(s)    137,238,494 bytes

Directory of D:\One-Stage\third part

.              <DIR>          07-13-01 12:58a .
..             <DIR>          07-13-01 12:58a ..
NG1Z3323 6I         29,164  07-17-01 12:12p ng1z3323.6i
NG1Z3323 6O     20,531,160  07-17-01  1:39p ng1z3323.6o
NG1Z3323 6P         29,163  07-17-01  1:39p ng1z3323.6p
NG1Z3~72 TXT       170,336  07-17-01  1:39p ng1z3323.elem_aqu.txt
NG1Z3~74 TXT       159,735  07-17-01  1:39p ng1z3323.elem_min.txt
NG1Z3~76 TXT       159,748  07-17-01  1:39p ng1z3323.elem_tot.txt
NG1Z3~80 TXT       242,384  07-17-01  1:39p ng1z3323.min_info.txt
NM1Z3323 6I         29,086  07-13-01  6:58a nm1z3323.6i
NM1Z3323 6O     20,814,521  07-13-01  9:32a nm1z3323.6o
NM1Z3323 6P         29,003  07-13-01  9:32a nm1z3323.6p
NM1Z3323 6T        683,102  07-13-01  9:32a nm1z3323.6t
NM1Z3323 6TX       690,396  07-13-01  9:32a nm1z3323.6tx
NM1Z~156 TXT       171,491  07-13-01  9:31a nm1z3323.elem_aqu.txt
NM1Z~160 TXT       160,818  07-13-01  9:31a nm1z3323.elem_min.txt
NM1Z~162 TXT       160,831  07-13-01  9:31a nm1z3323.elem_tot.txt
NM1Z~164 TXT       244,016  07-13-01  9:32a nm1z3323.min_info.txt
NM1Z3333 6I         28,107  07-13-01  6:57a nm1z3333.6i
NM1Z3333 6O     28,944,873  07-13-01 11:17a nm1z3333.6o
NM1Z3333 6P         28,106  07-13-01 11:17a nm1z3333.6p
```

```
NM1Z3333 6T         929,403  07-13-01 11:17a nm1z3333.6t
NM1Z3333 6TX      1,022,828  07-13-01 11:17a nm1z3333.6tx
NM1Z~268 TXT        258,116  07-13-01 11:16a nm1z3333.elem_aqu.txt
NM1Z~270 TXT        242,043  07-13-01 11:16a nm1z3333.elem_min.txt
NM1Z~274 TXT        242,056  07-13-01 11:16a nm1z3333.elem_tot.txt
NM1Z~276 TXT        366,416  07-13-01 11:17a nm1z3333.min_info.txt
NM1Z3433 6I          27,617  07-13-01  6:56a nm1z3433.6i
NM1Z3433 6O      27,644,398  07-13-01 12:18p nm1z3433.6o
NM1Z3433 6P          27,616  07-13-01 12:18p nm1z3433.6p
NM1Z3433 6T         842,656  07-13-01 12:18p nm1z3433.6t
NM1Z3433 6TX        851,516  07-13-01 12:18p nm1z3433.6tx
NM1Z~376 TXT        257,731  07-13-01 12:18p nm1z3433.elem_aqu.txt
NM1Z~378 TXT        241,682  07-13-01 12:18p nm1z3433.elem_min.txt
NM1Z~380 TXT        241,695  07-13-01 12:18p nm1z3433.elem_tot.txt
NM1Z~384 TXT        293,503  07-13-01 12:18p nm1z3433.min_info.txt
        34 file(s)    106,795,316 bytes

Directory of D:\Source Term

.              <DIR>         11-15-01 10:00a .
..             <DIR>         11-15-01 10:00a ..
ASPRIN   EXE       299,130  07-03-01  9:07a asprin.exe
DEFLTS~8 TXT           187  07-26-01  9:25a defltsolids.txt
DEFLT~10 TXT           858  07-10-01  2:35p defltsolids_longlist.txt
ONESTA~5       <DIR>         11-15-01 10:37a one stage
TWOSTA~7       <DIR>         11-15-01 10:46a two stage
         3 file(s)        300,175 bytes

Directory of D:\Source Term\one stage

.              <DIR>         07-13-01 12:18p .
..             <DIR>         07-13-01 12:18p ..
NM1X3432 6I          46,471  07-26-01  8:58a nm1x3432.6i
NM1X3432 6O       3,236,897  07-26-01  9:03a nm1x3432.6o
NM1X3432 6P          43,636  07-26-01  9:03a nm1x3432.6p
NM1X3432 BIN      6,049,296  07-26-01  9:03a nm1x3432.bin
NM1X3~42 TXT         32,121  07-26-01  9:03a nm1x3432.elem_aqu.txt
NM1X3~44 TXT         30,136  07-26-01  9:03a nm1x3432.elem_min.txt
NM1X3~46 TXT         30,149  07-26-01  9:03a nm1x3432.elem_tot.txt
NM1X3~48 TXT         65,619  07-26-01  9:03a nm1x3432.min_info.txt
NM1X3432 TXT      1,455,396  11-14-01  9:44a nm1x3432.txt
NT1X1331 6I          46,478  07-18-01 10:21a nt1x1331.6i
NT1X1331 6O       3,464,822  07-18-01 10:26a nt1x1331.6o
NT1X1331 6P          43,324  07-18-01 10:26a nt1x1331.6p
NT1X1331 BIN      7,102,184  07-18-01 10:26a nt1x1331.bin
NT1X1~96 TXT         34,816  07-18-01 10:26a nt1x1331.elem_aqu.txt
NT1X1~98 TXT         32,663  07-18-01 10:26a nt1x1331.elem_min.txt
NT1X~100 TXT         32,676  07-18-01 10:26a nt1x1331.elem_tot.txt
NT1X~102 TXT         76,137  07-18-01 10:26a nt1x1331.min_info.txt
NT1X1331 TXT      1,703,332  11-14-01  9:46a nt1x1331.txt
NT1X1432 6I          46,467  07-25-01  7:10p nt1x1432.6i
NT1X1432 6O       3,765,523  07-25-01  7:16p nt1x1432.6o
NT1X1432 6P          42,898  07-25-01  7:16p nt1x1432.6p
NT1X1432 BIN      7,965,424  07-25-01  7:16p nt1x1432.bin
NT1X~154 TXT         37,511  07-25-01  7:16p nt1x1432.elem_aqu.txt
NT1X~156 TXT         35,190  07-25-01  7:16p nt1x1432.elem_min.txt
NT1X~158 TXT         35,203  07-25-01  7:16p nt1x1432.elem_tot.txt
```

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```
NT1X~160 TXT        88,573  07-25-01  7:16p nt1x1432.min_info.txt
NT1X1432 TXT     1,908,654  11-14-01  9:48a nt1x1432.txt
        27 file(s)     37,451,596 bytes

Directory of D:\Source Term\two stage

.              <DIR>        11-14-01  9:48a .
..             <DIR>        11-14-01  9:48a ..
NC1X1031 6I         44,775  07-18-01  1:18p nc1x1031.6i
NC1X1031 6O      1,326,343  07-18-01  1:21p nc1x1031.6o
NC1X1031 6P         41,236  07-18-01  1:21p nc1x1031.6p
NC1X1031 BIN     6,003,824  07-25-01  8:21a nc1x1031.bin
NC1X1~36 TXT        14,026  07-18-01  1:21p nc1x1031.elem_aqu.txt
NC1X1~38 TXT        13,169  07-18-01  1:21p nc1x1031.elem_min.txt
NC1X1~40 TXT        13,182  07-18-01  1:21p nc1x1031.elem_tot.txt
NC1X1~42 TXT        20,145  07-18-01  1:21p nc1x1031.min_info.txt
NC1X1031 TXT     1,043,308  11-14-01 10:00a nc1x1031.txt
NC2X1402 6I         32,777  07-18-01  1:58p nc2x1402.6i
NC2X1402 6O      5,117,352  07-18-01  2:17p nc2x1402.6o
NC2X1402 6P         32,855  07-18-01  2:17p nc2x1402.6p
NC2X1402 BIN    51,507,080  07-25-01  8:34a nc2x1402.bin
NC2X~222 TXT        44,441  07-18-01  2:17p nc2x1402.elem_aqu.txt
NC2X~224 TXT        41,688  07-18-01  2:17p nc2x1402.elem_min.txt
NC2X~226 TXT        41,701  07-18-01  2:17p nc2x1402.elem_tot.txt
NC2X~228 TXT        92,412  07-18-01  2:17p nc2x1402.min_info.txt
NC2X1402 TXT    10,667,092  11-14-01  9:51a nc2x1402.txt
NM1X1031 6I         44,527  07-18-01  8:53a nm1x1031.6i
NM1X1031 6O      1,726,189  07-18-01  1:24p nm1x1031.6o
NM1X1031 6P         41,384  07-18-01  1:24p nm1x1031.6p
NM1X1031 BIN     7,452,600  07-25-01  8:37a nm1x1031.bin
NM1X~300 TXT        18,646  07-18-01  1:24p nm1x1031.elem_aqu.txt
NM1X~302 TXT        17,501  07-18-01  1:24p nm1x1031.elem_min.txt
NM1X~304 TXT        17,514  07-18-01  1:24p nm1x1031.elem_tot.txt
NM1X~306 TXT        29,947  07-18-01  1:24p nm1x1031.min_info.txt
NM1X1031 TXT     1,813,835  11-14-01  9:57a nm1x1031.txt
NM2X1402 6I         32,923  07-19-01  9:07a nm2x1402.6i
NM2X1402 6O      2,886,235  07-19-01  9:17a nm2x1402.6o
NM2X1402 6P         33,167  07-19-01  9:17a nm2x1402.6p
NM2X1402 BIN    15,910,448  07-25-01  8:44a nm2x1402.bin
NM2X~378 TXT        27,501  07-19-01  9:17a nm2x1402.elem_aqu.txt
NM2X~380 TXT        25,804  07-19-01  9:17a nm2x1402.elem_min.txt
NM2X~382 TXT        25,817  07-19-01  9:17a nm2x1402.elem_tot.txt
NM2X~384 TXT        63,787  07-19-01  9:17a nm2x1402.min_info.txt
NM2X1402 TXT     3,836,115  11-14-01 12:48p nm2x1402.txt
        36 file(s)    110,101,346 bytes

Total files listed:
       227 file(s)    597,823,948 bytes
```

Directory of Fermi-IA2

```
SENSIT~5       <DIR>        11-15-01 11:23a Sensitivity
TWO-ST~7       <DIR>        11-15-01 12:31p Two-Stage
         0 file(s)              0 bytes

Directory of D:\Sensitivity
```

```
.               <DIR>          11-15-01 12:31p .
..              <DIR>          11-15-01 12:31p ..
GDPO4M~5        <DIR>          11-15-01 11:23a GdPO4 mass
GDPO4R~7        <DIR>          11-15-01 11:37a GdPO4 rate
GLASSR~9        <DIR>          11-15-01 12:29p glass rate
          0 file(s)              0 bytes

Directory of D:\Sensitivity\GdPO4 mass

.               <DIR>          11-15-01 12:35p .
..              <DIR>          11-15-01 12:35p ..
NA1D3333 6I          45,731    08-20-01  1:39p nA1d3333.6i
NA1D3333 6O      33,509,003    08-20-01  4:08p na1d3333.6o
NA1D3333 6P          43,226    08-20-01  4:08p na1d3333.6p
NA1D~110 TXT        255,806    08-20-01  4:08p nA1d3333.elem_aqu.txt
NA1D~112 TXT        239,877    08-20-01  4:08p nA1d3333.elem_min.txt
NA1D~114 TXT        239,890    08-20-01  4:08p nA1d3333.elem_tot.txt
NA1D~118 TXT        530,449    08-20-01  4:08p nA1d3333.min_info.txt
NL1D3333 6I          45,733    08-20-01  1:41p nL1d3333.6i
NL1D3333 6O      32,192,728    08-20-01  5:46p nl1d3333.6o
NL1D3333 6P          43,230    08-20-01  5:46p nl1d3333.6p
NL1D~222 TXT        240,406    08-20-01  5:45p nL1d3333.elem_aqu.txt
NL1D~224 TXT        225,437    08-20-01  5:45p nL1d3333.elem_min.txt
NL1D~226 TXT        225,450    08-20-01  5:45p nL1d3333.elem_tot.txt
NL1D~230 TXT        495,897    08-20-01  5:45p nL1d3333.min_info.txt
        14 file(s)     68,332,863 bytes

Directory of D:\Sensitivity\GdPO4 rate

.               <DIR>          08-20-01  5:45p .
..              <DIR>          08-20-01  5:45p ..
NA1X3323 6I          45,731    07-16-01  7:10p nA1x3323.6i
NA1X3323 6O      33,581,652    07-16-01 10:41p na1x3323.6o
NA1X3323 6P          43,226    07-16-01 10:41p na1x3323.6p
NA1X~112 TXT        255,806    07-16-01 10:40p nA1x3323.elem_aqu.txt
NA1X~114 TXT        239,877    07-16-01 10:40p nA1x3323.elem_min.txt
NA1X~116 TXT        239,890    07-16-01 10:40p nA1x3323.elem_tot.txt
NA1X~120 TXT        550,810    07-16-01 10:40p nA1x3323.min_info.txt
NA1X3333 6I          45,731    07-24-01  9:13a nA1x3333.6i
NA1X3333 6O      33,507,357    07-24-01 12:34p na1x3333.6o
NA1X3333 6P          43,226    07-24-01 12:34p na1x3333.6p
NA1X~228 TXT        255,806    07-24-01 12:34p nA1x3333.elem_aqu.txt
NA1X~230 TXT        239,877    07-24-01 12:34p nA1x3333.elem_min.txt
NA1X~232 TXT        239,890    07-24-01 12:34p nA1x3333.elem_tot.txt
NA1X~236 TXT        530,456    07-24-01 12:34p nA1x3333.min_info.txt
NA1Y3323 6I          30,437    07-17-01  6:52a nA1y3323.6i
NA1Y3323 6O      29,606,682    07-17-01 10:26a na1y3323.6o
NA1Y3323 6P          30,437    07-17-01 10:26a na1y3323.6p
NA1Y~332 TXT        241,176    07-17-01 10:25a nA1y3323.elem_aqu.txt
NA1Y~334 TXT        226,159    07-17-01 10:25a nA1y3323.elem_min.txt
NA1Y~338 TXT        226,172    07-17-01 10:25a nA1y3323.elem_tot.txt
NA1Y~340 TXT        379,240    07-17-01 10:25a nA1y3323.min_info.txt
NA1Z3323 6I          29,235    07-17-01 12:12p na1z3323.6i
NA1Z3323 6O      15,049,863    07-17-01  2:39p na1z3323.6o
NA1Z3323 6P          29,153    07-17-01  2:39p na1z3323.6p
NA1Z~394 TXT        129,141    07-17-01  2:39p nA1z3323.elem_aqu.txt
```

```
NA1Z~396 TXT       121,108  07-17-01  2:39p nA1z3323.elem_min.txt
NA1Z~398 TXT       121,121  07-17-01  2:39p nA1z3323.elem_tot.txt
NA1Z~400 TXT       184,258  07-17-01  2:39p nA1z3323.min_info.txt
NL1X3323 6I         45,732  07-17-01  6:54a nL1x3323.6i
NL1X3323 6O     32,225,921  07-17-01 12:09p nl1x3323.6o
NL1X3323 6P         43,228  07-17-01 12:09p nl1x3323.6p
NL1X~504 TXT       240,021  07-17-01 12:09p nL1x3323.elem_aqu.txt
NL1X~506 TXT       225,076  07-17-01 12:09p nL1x3323.elem_min.txt
NL1X~508 TXT       225,089  07-17-01 12:09p nL1x3323.elem_tot.txt
NL1X~512 TXT       514,946  07-17-01 12:09p nL1x3323.min_info.txt
NL1X3333 6I         45,732  07-24-01  9:13a nL1x3333.6i
NL1X3333 6O     32,263,697  07-25-01  9:32p nl1x3333.6o
NL1X3333 6P         43,228  07-25-01  9:32p nl1x3333.6p
NL1X~616 TXT       241,176  07-25-01  9:31p nL1x3333.elem_aqu.txt
NL1X~618 TXT       226,159  07-25-01  9:31p nL1x3333.elem_min.txt
NL1X~620 TXT       226,172  07-25-01  9:31p nL1x3333.elem_tot.txt
NL1X~624 TXT       497,364  07-25-01  9:31p nL1x3333.min_info.txt
NL1Y3323 6I         30,439  07-17-01 12:14p nl1y3323.6i
NL1Y3323 6O     28,503,399  07-17-01  4:25p nl1y3323.6o
NL1Y3323 6P         30,439  07-17-01  4:25p nl1y3323.6p
NL1Y~716 TXT       224,621  07-17-01  4:25p nL1y3323.elem_aqu.txt
NL1Y~720 TXT       210,636  07-17-01  4:25p nL1y3323.elem_min.txt
NL1Y~722 TXT       210,649  07-17-01  4:25p nL1y3323.elem_tot.txt
NL1Y~724 TXT       349,800  07-17-01  4:25p nL1y3323.min_info.txt
NL1Z3323 6I         29,236  07-18-01  6:48a nl1z3323.6i
NL1Z3323 6O     19,410,445  07-18-01  8:06a nl1z3323.6o
NL1Z3323 6P         29,153  07-18-01  8:06a nl1z3323.6p
NL1Z~790 TXT       161,481  07-18-01  8:05a nL1z3323.elem_aqu.txt
NL1Z~794 TXT       151,432  07-18-01  8:05a nL1z3323.elem_min.txt
NL1Z~796 TXT       151,445  07-18-01  8:05a nL1z3323.elem_tot.txt
NL1Z~798 TXT       229,954  07-18-01  8:05a nL1z3323.min_info.txt
        56 file(s)    233,010,187 bytes

Directory of D:\Sensitivity\glass rate

.              <DIR>        07-18-01  8:05a .
..             <DIR>        07-18-01  8:05a ..
NM1N1331 6I         46,392  08-20-01  1:30p nm1n1331.6i
NM1N1331 6O      3,124,338  08-20-01  5:51p nm1n1331.6o
NM1N1331 6P         43,160  08-20-01  5:51p nm1n1331.6p
NM1N1~22 TXT        29,811  08-20-01  5:51p nm1n1331.elem_aqu.txt
NM1N1~24 TXT        27,970  08-20-01  5:51p nm1n1331.elem_min.txt
NM1N1~26 TXT        27,983  08-20-01  5:51p nm1n1331.elem_tot.txt
NM1N1~28 TXT        58,660  08-20-01  5:51p nm1n1331.min_info.txt
NM2N1402 6I         32,923  08-21-01  3:58p nm2n1402.6i
NM2N1402 6O      2,544,605  08-21-01  4:04p nm2n1402.6o
NM2N1402 6P         33,659  08-21-01  4:04p nm2n1402.6p
NM2N1~44 TXT        24,036  08-21-01  4:04p nm2n1402.elem_aqu.txt
NM2N1~46 TXT        22,555  08-21-01  4:04p nm2n1402.elem_min.txt
NM2N1~48 TXT        22,568  08-21-01  4:04p nm2n1402.elem_tot.txt
NM2N1~50 TXT        52,712  08-21-01  4:04p nm2n1402.min_info.txt
NM2N1402 TXT     3,332,738  11-15-01  8:31a nm2n1402.txt
        15 file(s)      9,424,110 bytes

Directory of D:\Two-Stage

.              <DIR>        11-15-01 12:29p .
```

```
..              <DIR>          11-15-01 12:29p ..
SCENAR~5        <DIR>          11-15-01 12:31p Scenario I
SCENAR~7        <DIR>          11-15-01 12:35p Scenario II
         0 file(s)              0 bytes

Directory of D:\Two-Stage\Scenario I

.               <DIR>          11-15-01  8:31a .
..              <DIR>          11-15-01  8:31a ..
NM1X1303 6I          38,545    07-16-01  7:35a nm1x1303.6i
NM1X1303 6O       3,664,654    07-16-01  7:41a nm1x1303.6o
NM1X1303 6P          34,824    07-16-01  7:41a nm1x1303.6p
NM1X1~24 TXT         43,671    07-16-01  7:41a nm1x1303.elem_aqu.txt
NM1X1~26 TXT         40,966    07-16-01  7:41a nm1x1303.elem_min.txt
NM1X1~28 TXT         40,979    07-16-01  7:41a nm1x1303.elem_tot.txt
NM1X1~30 TXT         67,345    07-16-01  7:41a nm1x1303.min_info.txt
NM1X1403 6I          38,544    07-16-01  7:30a nm1x1403.6i
NM1X1403 6O       4,224,287    07-16-01  7:48a nm1x1403.6o
NM1X1403 6P          34,988    07-16-01  7:48a nm1x1403.6p
NM1X1~50 TXT         46,751    07-16-01  7:48a nm1x1403.elem_aqu.txt
NM1X1~52 TXT         43,854    07-16-01  7:48a nm1x1403.elem_min.txt
NM1X1~54 TXT         43,867    07-16-01  7:48a nm1x1403.elem_tot.txt
NM1X1~56 TXT         88,503    07-16-01  7:48a nm1x1403.min_info.txt
SECOND~5        <DIR>          11-15-01 12:33p second stage
        14 file(s)      8,451,778 bytes

Directory of D:\Two-Stage\Scenario I\second stage

.               <DIR>          11-15-01 12:40p .
..              <DIR>          11-15-01 12:40p ..
NM2X1031 6I          40,418    07-16-01 12:38p nm2x1031.6i
NM2X1031 6O       1,183,740    07-16-01 12:39p nm2x1031.6o
NM2X1031 6P          40,405    07-16-01 12:39p nm2x1031.6p
NM2X1~14 TXT         12,871    07-16-01 12:39p nm2x1031.elem_aqu.txt
NM2X1~16 TXT         12,086    07-16-01 12:39p nm2x1031.elem_min.txt
NM2X1~18 TXT         12,099    07-16-01 12:39p nm2x1031.elem_tot.txt
NM2X1~20 TXT         22,629    07-16-01 12:39p nm2x1031.min_info.txt
NM2X1332 6I          41,457    07-16-01  4:51p nm2x1332.6i
NM2X1332 6O       7,506,988    07-16-01  5:07p nm2x1332.6o
NM2X1332 6P          41,771    07-16-01  5:07p nm2x1332.6p
NM2X1~52 TXT         75,626    07-16-01  5:07p nm2x1332.elem_aqu.txt
NM2X1~54 TXT         70,929    07-16-01  5:07p nm2x1332.elem_min.txt
NM2X1~56 TXT         70,942    07-16-01  5:07p nm2x1332.elem_tot.txt
NM2X1~58 TXT        144,331    07-16-01  5:07p nm2x1332.min_info.txt
NM2Y1031 6I          29,531    07-16-01 12:41p nm2y1031.6i
NM2Y1031 6O         357,876    07-16-01 12:41p nm2y1031.6o
NM2Y1031 6P          29,695    07-16-01 12:41p nm2y1031.6p
NM2Y1~68 TXT          4,401    07-16-01 12:41p nm2y1031.elem_aqu.txt
NM2Y1~70 TXT          4,144    07-16-01 12:41p nm2y1031.elem_min.txt
NM2Y1~72 TXT          4,157    07-16-01 12:41p nm2y1031.elem_tot.txt
NM2Y1~74 TXT          7,627    07-16-01 12:41p nm2y1031.min_info.txt
        21 file(s)      9,713,723 bytes

Directory of D:\Two-Stage\Scenario II

.               <DIR>          11-15-01 12:33p .
..              <DIR>          11-15-01 12:33p ..
```

```
NM1X1023 6I          44,527  07-12-01  5:32p nm1x1023.6i
NM1X1023 6O      10,068,668  07-12-01  5:55p nm1x1023.6o
NM1X1023 6P          41,220  07-12-01  5:55p nm1x1023.6p
NM1X1~42 TXT         85,636  07-12-01  5:55p nm1x1023.elem_aqu.txt
NM1X1~44 TXT         80,315  07-12-01  5:55p nm1x1023.elem_min.txt
NM1X1~46 TXT         80,328  07-12-01  5:55p nm1x1023.elem_tot.txt
NM1X1~48 TXT        149,609  07-12-01  5:55p nm1x1023.min_info.txt
NM1X1032 6I          44,527  07-16-01 11:40a nm1x1032.6i
NM1X1032 6O       2,591,200  07-16-01 11:48a nm1x1032.6o
NM1X1032 6P          41,302  07-16-01 11:48a nm1x1032.6p
NM1X1032 6T         116,736  07-16-01 11:48a nm1x1032.6t
NM1X1032 6TX        118,331  07-16-01 11:48a nm1x1032.6tx
NM1X1~68 TXT         25,191  07-16-01 11:48a nm1x1032.elem_aqu.txt
NM1X1~70 TXT         23,638  07-16-01 11:48a nm1x1032.elem_min.txt
NM1X1~72 TXT         23,651  07-16-01 11:48a nm1x1032.elem_tot:txt
NM1X1~74 TXT         42,255  07-16-01 11:48a nm1x1032.min_info.txt
NM1X1033 6I          44,527  07-12-01  5:32p nm1x1033.6i
NM1X1033 6O      10,139,044  07-12-01  6:17p nm1x1033.6o
NM1X1033 6P          41,302  07-12-01  6:17p nm1x1033.6p
NM1X~112 TXT         84,866  07-12-01  6:16p nm1x1033.elem_aqu.txt
NM1X~114 TXT         79,593  07-12-01  6:16p nm1x1033.elem_min.txt
NM1X~116 TXT         79,606  07-12-01  6:16p nm1x1033.elem_tot.txt
NM1X~118 TXT        154,499  07-12-01  6:16p nm1x1033.min_info.txt
SECOND~5       <DIR>         11-15-01 12:40p second stage
        23 file(s)     24,200,571 bytes

Directory of D:\Two-Stage\Scenario II\second stage

.              <DIR>         07-16-01 12:41p .
..             <DIR>         07-16-01 12:41p ..
NM2X1302 6I          32,920  07-16-01  2:47p nm2x1302.6i
NM2X1302 6O       8,420,000  07-16-01  3:05p nm2x1302.6o
NM2X1302 6P          33,413  07-16-01  3:05p nm2x1302.6p
NM2X1~38 TXT         66,386  07-16-01  3:05p nm2x1302.elem_aqu.txt
NM2X1~40 TXT         62,265  07-16-01  3:05p nm2x1302.elem_min.txt
NM2X1~42 TXT         62,278  07-16-01  3:05p nm2x1302.elem_tot.txt
NM2X1~44 TXT         90,003  07-16-01  3:05p nm2x1302.min_info.txt
NM2X1303 6I          32,920  07-12-01  6:29p nm2x1303.6i
NM2X1303 6O      27,393,171  07-13-01  2:58a nm2x1303.6o
NM2X1303 6P          33,085  07-13-01  2:58a nm2x1303.6p
NM2X~132 TXT        194,206  07-13-01  2:58a nm2x1303.elem_aqu.txt
NM2X~136 TXT        182,117  07-13-01  2:58a nm2x1303.elem_min.txt
NM2X~138 TXT        182,130  07-13-01  2:58a nm2x1303.elem_tot.txt
NM2X~140 TXT        288,249  07-13-01  2:58a nm2x1303.min_info.txt
NM2X1323 6I          33,817  07-12-01  6:24p nm2x1323.6i
NM2X1323 6O      27,310,618  07-13-01  1:58a nm2x1323.6o
NM2X1323 6P          34,064  07-13-01  1:58a nm2x1323.6p
NM2X~230 TXT        191,896  07-13-01  1:57a nm2x1323.elem_aqu.txt
NM2X~232 TXT        179,951  07-13-01  1:57a nm2x1323.elem_min.txt
NM2X~234 TXT        179,964  07-13-01  1:57a nm2x1323.elem_tot.txt
NM2X~236 TXT        267,941  07-13-01  1:57a nm2x1323.min_info.txt
NM2Y1302 6I          29,228  07-16-01  3:24p nm2y1302.6i
NM2Y1302 6O         826,333  07-16-01  3:26p nm2y1302.6o
NM2Y1302 6P          29,228  07-16-01  3:26p nm2y1302.6p
NM2Y~248 TXT          7,866  07-16-01  3:26p nm2y1302.elem_aqu.txt
NM2Y~250 TXT          7,393  07-16-01  3:26p nm2y1302.elem_min.txt
NM2Y~252 TXT          7,406  07-16-01  3:26p nm2y1302.elem_tot.txt
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```
NM2Y~254 TXT          14,349  07-16-01   3:26p nm2y1302.min_info.txt
NM2Y1303 6I           30,503  07-13-01   6:55a nm2y1303.6i
NM2Y1303 6O       30,205,779  07-13-01   2:23p nm2y1303.6o
NM2Y1303 6P           30,503  07-13-01   2:23p nm2y1303.6p
NM2Y~350 TXT         243,871  07-13-01   2:23p nm2y1303.elem_aqu.txt
NM2Y~354 TXT         228,686  07-13-01   2:23p nm2y1303.elem_min.txt
NM2Y~356 TXT         228,699  07-13-01   2:23p nm2y1303.elem_tot.txt
NM2Y~360 TXT         347,794  07-13-01   2:23p nm2y1303.min_info.txt
NM2Y1323 6I           31,482  07-13-01   6:54a nm2y1323.6i
NM2Y1323 6O       30,293,869  07-13-01   1:20p nm2y1323.6o
NM2Y1323 6P           31,482  07-13-01   1:20p nm2y1323.6p
NM2Y~456 TXT         243,101  07-13-01   1:20p nm2y1323.elem_aqu.txt
NM2Y~460 TXT         227,964  07-13-01   1:20p nm2y1323.elem_min.txt
NM2Y~462 TXT         227,977  07-13-01   1:20p nm2y1323.elem_tot.txt
NM2Y~464 TXT         319,735  07-13-01   1:20p nm2y1323.min_info.txt
NM2Z1303 6I           30,503  07-16-01   6:47a nm2z1303.6i
NM2Z1303 6O       22,538,351  07-16-01  10:43a nm2z1303.6o
NM2Z1303 6P           30,421  07-16-01  10:43a nm2z1303.6p
NM2Z~540 TXT         192,666  07-16-01  10:43a nm2z1303.elem_aqu.txt
NM2Z~542 TXT         180,673  07-16-01  10:43a nm2z1303.elem_min.txt
NM2Z~546 TXT         180,686  07-16-01  10:43a nm2z1303.elem_tot.txt
NM2Z~548 TXT         243,295  07-16-01  10:43a nm2z1303.min_info.txt
NM2Z1323 6I           31,480  07-16-01  12:46p nm2z1323.6i
NM2Z1323 6O       23,506,589  07-16-01   1:57p nm2z1323.6o
NM2Z1323 6P           31,400  07-16-01   1:57p nm2z1323.6p
NM2Z~626 TXT         194,206  07-16-01   1:57p nm2z1323.elem_aqu.txt
NM2Z~628 TXT         182,117  07-16-01   1:57p nm2z1323.elem_min.txt
NM2Z~630 TXT         182,130  07-16-01   1:57p nm2z1323.elem_tot.txt
NM2Z~634 TXT         245,423  07-16-01   1:57p nm2z1323.min_info.txt
        56 file(s)    176,654,582 bytes

Total files listed:
       199 file(s)    529,787,814 bytes
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