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Engineering Physics and Mathematics Division

A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE WITH AUTOMATED SENSITIVITY-CALCULATION CAPABILITY

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ABSTRACT

WAPPA-C is a waste package performance assessment code that predicts the temporal and spatial extent of the loss of containment capability of a given waste package design. This code was enhanced by the addition of the capability to calculate the sensitivity of model results to any parameter. The GRESS automated procedure was used to add this capability in only two man-months of effort. The verification analysis of the enhanced code, WAPPAG, showed that the sensitivities calculated using GRESS were accurate to within the precision of perturbation results against which the sensitivities were compared. Sensitivities of all summary table values to eight diverse data values were verified.

I. INTRODUCTION

WAPPA[1] is a waste package performance assessment code that predicts the temporal and spatial extent of the loss of containment capability of a given waste package design. The code models the problem in a one-dimension radial geometry on timescales up to one million years after isolation. WAPPA has five distinct barrier degredation process models that are driven internally by waste decay and externally be repository stress and fluids. The five process models treat the effects due to radiation, thermal heat removal, mechanical stress, corrosion and leaching. The modelling approach is barrier-integrated and process-sequential. These process models are coupled at the system level by state variables such as source inventory, decay power, temperatures and radionuclide distributions, material property degredations and barrier integrity parameters. The WAPPA code will be used in conjunction with UCBNE10.2,[2] modified to include integrated decay chains, and with BRINETEMP[3] in the overall repository performance assessment. BRINETEMP will be used to calculate brine flow rates and waste package surface temperatures as input to WAPPA. The radionuclide fluxes out of the waste package as calculated in WAPPA will be used as input to UCBNE10.2 to calculate the migration of the radionuclides through the groundwater. The purpose of this paper is to report on the testing and verification of a version of WAPPA that will calculate, at the user's option, the derivative of all responses with respect to any variable used in the code.

II. BACKGROUND

The Office of Nuclear Waste Isolation (ONWI) is responsible for the characterization and performance assessment of candidate high-level waste salt repository sites. Because of the large uncertainties generally associated with the data characterizing geological media and waste behavior and because of the predictive nature of the simulations supporting the assessment, sensitivity and uncertainty analysis are necessary components of the overall performance assessment. To date both statistical and deterministic methods have been used to calculate uncertainties associated with the geological disposal of high-level waste.[4]

Generally, statistical methods are preferred for codes with a moderate number of parameters; direct deterministic methods when there are many performance measures of interest and a moderate number of parameters; and adjoint deterministic methods when there are a limited number of performance measures and a large number of parameters. For large codes with an extensive data base, such as the computer models used by ONWI for performance assessment, the deterministic approaches are more cost efficient for producing a comprehensive ranking of sensitivities of results to data. Both the direct and adjoint perturbation methods, which have been widely used in analyses of nuclear systems,[5] rely on model reruns for calculating first derivatives. The cost of the reruns can be prohibitively expensive depending upon the scope of the analysis and the number of variables of interest. To circumvent this problem, a procedure[6] was developed to make use of computer calculus and the chain rule of differentiation to calculate first derivatives of any model variable with respect to any other model variable. In addition, to avoid the costly programming effort of implementing this capability in the various codes of interest to ONWI, a Gradient-Enhanced Software System (GRESS)[7] was developed that automatically adds the necessary lines of coding to any FORTRAN source program. GRESS has already been successfully applied to the SWENT, UCBNE10.2, ORIGEN2 and TEMP computer codes.[8,9,10,11] The following sections summarize the application of GRESS to WAPPA and the testing and verification of WAPPAG, the gradient-enhanced version of WAPPA.

III. APPLICATION OF GRESS TO WAPPA

The translation of WAPPA through the GRESS precompiler required about two man-months effort and resulted in the version of WAPPA that has an automated derivative-taking capability, WAPPAG. Most of the effort in translating WAPPA was expended in changing the three-dimensional arrays to two-dimensional arrays and eliminating all doubly argumented variables. These changes were necessary because of the limitations of the current version of GRESS. These limitations will not be present in the next version of GRESS. The testing and verification of the derivative-taking capability of WAPPAG required about one man-month of effort.

WAPPAG has the capability to calculate the first derivative of any variable with respect to any other variable in the code. For most applications, the variables with respect to which the derivatives will be calculated are chosen to be data values of interest. These variables will be referred to as parameters. The variables for which derivatives are calculated with respect to the parameters of interest will be referred to as the responses. In WAPPAG the user has full control over the choice of parameters and responses. In addition to the derivatives, first order sensitivities are also calculated in WAPPAG. The sensitivities, s, are defined by $s = (a/R)/(dR/da)$, where R and a are the reference values of the response and parameter of interest. Defined in this manner, the values of s are normalized sensitivities in the sense that s is equal to the percent change in response R per percent change in a.

IV. SENSITIVITY COMPARISONS WITH RERUNS

The sample problem used in this initial verification is one that accompanied the WAPPA source tape that ORNL had received from ONWI. The problem models the performance of a Commercial High Level Waste (CHLW) borehole concept for the proposed Deaf Smith County repository. The waste canister has a cast steel overpack and is modeled with one glassy waste-form, two metal barriers, two air gaps, two corrosion/oxide layers and one high-MG brine crushed salt backfill.

The responses chosen for comparing sensitivities for this verification study are the masses out of the waste package of the 24 nuclides considered in the sample problem (Summary Table 10 in the WAPPA output). The nuclide distributions are calculated at 260 time steps after initial placement of the wasteform into the repository, but the results are printed for only 52 time steps of interest. The nuclide masses listed in Summary Table 10 of the WAPPA output are the total masses out of the waste package integrated over all the years up to each of the 52 time periods. Sensitivities and gradients for the 10,000 year time period were calculated both by reruns and by WAPPAG for selected data from the various input files. The reference calculated responses are listed in Table 1, which is a copy of Summary Table 10 of the WAPPA output. Comparisons between rerun-calculated sensitivities and GRESS-calculated sensitivities are shown in Tables 2-7.

The first parameter with respect to which sensitivities were calculated was the thermal power source term at the time of burial. This variable, RHEAT(1), is used in the Thermal Model to calculate temperature within the various problem annuli. The temperatures are then used in the Mechanical, Corrosion and Leach models. Thus the sensitivity of the responses of interest with respect to RHEAT(1) provides a good test for WAPPAG since all but one of the process models are involved. The reference thermal power source at time of burial is 984.3 watts per metric ton of initial heavy metal. The sensitivities of the nuclide masses escaping the waste package boundary 10,000 years after isolation of the waste to the value of RHEAT(1) are listed in Table 2. The sensitivities calculated using WAPPAG are within the calculated precision of the first-order sensitivities estimated from reruns.

The ^{14}C, ^{129}I, ^{135}Cs and ^{137}Cs masses are the most sensitive to the initial decay heat. Note that if the value of RHEAT(1) is changed, in reality the subsequent tabular values of RHEAT input to WAPPA would be changed proportionally. If the sensitivity to initial decay heat is important, the sensitivities to all twenty values of RHEAT would be calculated; but for the purpose of verifying WAPPAG only the sensitivities to RHEAT(1) were calculated.

The second parameter chosen for verification purposes was the height of the wasteform, SHTWP. Although this parameter would not be of real interest in most sensitivity studies, the height directly affects the volume and density of the wasteform and dose rate densities and thus provides a good verification test. The WAPPAG and rerun-calculated sensitivities of the element masses to SHTWP are compared in Table 3 and show excellent agreement. The sensitivities to SHTWP are generally greater than those to RHEAT(1). The ^{99}Tc, ^{126}Sn, Pu and Am nuclides are the most sensitive to the wasteform height.

The third parameter with respect to which sensitivities were calculated was the outside radius of the wasteform. The sensitivities shown in Table 4 verify that WAPPAG correctly calculated the sensitivities of the nuclide masses to this parameter. All of the sensitivities of the nuclide masses to this radius are greater than the corresponding values with respect to height. This result was anticipated because the problem modelling is one dimensional in the radial direction. Thus the radius affects not only the dose and property densities to a higher order than does the height, but a change in radius affects the analytical solution of the temperature profile.

The gas gap thickness between the metal canister and the overpack for this sample problem is 1.5 cm. The outer radius of the gap, SRTEMP(4), was the fourth parameter examined. The sensitivities of the responses of interest, the nuclide masses escaping the waste package during the first 10,000 years, to a change in the outer radius of this gap were calculated by WAPPAG and reruns. The sensitivities, shown in Table 5, are in good agreement. Except for ^{230}Th, all the mass sensitivities to SRTEMP(4) are opposite in sign compared to the sensitivities to SRTEMP(1). For the heavy elements, an increase in gap thickness decreases their escape from the waste package by about 2 percent for each percent increase in the gap thickness. The ^{14}C, ^{129}I, ^{135}Cs, ^{137}Cs and ^{230}Th are the only nuclides whose sensitivity indicates an increase in mass out of the waste package for an increase in gap thickness. However, at 10,000 years the decrease in the escape of the heavy actinides is more important since the I and Cs radioactivity are very low at that time.

The fifth parameter with respect to which sensitivities were calculated was the ^{233}U mass at 5,000 years. This value, RADTOX(11,13), is datum taken from ORIGEN2 output and input into WAPPA as a member of the tabulated mass inventories at each of twenty ORIGEN2 time steps. The WAPPAG sensitivities of masses to RADTOX(11,13) are zero, and the rerun-calculated sensitivities for a -1.0% perturbation are also zero as shown in Table 6.

Sensitivities were calculated with respect to a sixth parameter, RGAMA(1), the gamma ray source in photons/sec/MTIHM at time of isolation of the waste. Because the cumulative gamma dose rate does not affect property degradation and radiolysis enhancement factors in the model until a critical dose level is reached, RGAMA(1) had no effect upon the masses out of the waste package. The zero sensitivities in Table 7 confirm this effect and verify that for this test case the arithmetically calculated WAPPAG sensitivities are correct for this parameter.

V. WAPPAG SENSITIVITIES FOR TWO LEACHING PARAMETERS

WAPPA prints fourteen Summary Tables providing various types of information based upon the nuclide concentrations throughout the time period being modelled. For this sample problem there are 24 nuclides and 52 printed time steps, resulting in a total of 17,472 printed values. Sensitivities of these responses to the leach rate coefficient for diffusion of the matrix component, WLRHLF, and to the diffusion coefficient of the representative matrix component in water, WDBULM, were calculated using WAPPAG. Results of directly calculated sensitivities were obtained from perturbations of WLRHLF and WDBULM. Comparison of these sensitivities to the WAPPAG-calculated sensitivities verified that the WAPPAG sensitivities were accurate to within the precision of the directly calculated sensitivities.

VI. CONCLUSIONS

The WAPPA-C waste package performance assessment code was enhanced by the addition of the capability to calculate the sensitivity of model results to any parameter. The GRESS automated procedure was used to add this capability in only two man-months of effort. Another month was expended for testing and verification analysis. The verification analysis showed that the sensitivities calculated using GRESS were accurate to within the precision of the perturbation results against which these sensitivities were compared. The sensitivities for all summary table values were verified.

VII. FUTURE WORK

The GRESS precompiler is presently being updated to handle most all FORTRAN 77 statements and to handle up to seven-dimensional arrays. In addition, work is now underway that will couple the derivatives between the GRESS versions of UCBNE10.2, BRINETEMP and WAPPA. This coupling will provide sensitivities of the responses of interest in an overall performance assessment study to the basic data. A software system is being developed that will automate most of the actual coupling of gradients between the various computer codes.[12]

Another activity that might prove beneficial would be to calculate sensitivities of selected intermediate variables in any of the codes of interest. By careful selection of the intermediate variables for which sensitivities to other variables could be calculated, the effect of different physical process upon the responses of interest could be isolated. For example, consider that the degradation of a material affects the calculation of a variable y that in turn is used in the determination of a response R. The effect of the degradation process can be quantitatively determined by calculating the sensitivity of R with respect to y. Furthermore, if a sensitivity of R with respect to a data value a is calculated, the portion of the sensitivity due to the degradation process can be determined by also calculating the sensitivity of y to a. Even if the physical process is intertwined into the calculation of the response of interest, dummy variables can often be introduced into the equations in such a manner that they multiply any variables effected by the physical process. By then taking out the process of interest and calculating the sensitivity of R with respect to the dummy variable, a quantitative value of the sensitivity of the entire process upon R can be determined.

At some point the sensitivities will be used in conjunction with response surface techniques and/or statistical methods to quantify the overall uncertainties in the performance assessment that arise from use of the computer models. Presently work is being carried out to identify the best way to use the sensitivity data in an uncertainty analysis.

Table 1. Reference Values of Summary Table 10 for Sample Problem

DATE: [illegible]   [illegible]PA   PAGE NO. 380

TIME: [illegible]   A [illegible] PERFORMANCE ASSESSMENT CODE

[illegible] CONCEPT: 0 YEAR [illegible]ETTING TIME. 4.000

[illegible] WITH CA[illegible]T STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS

[illegible] COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

[illegible]RY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

[illegible] SINCE EMPLACEMENT (YEARS)

ELEMENT	5.0	10.0	15.0	20.0	25.0	30.0	35.0	45.0
C	[illegible]	[illegible]	[illegible]	0.17493E+03	0.18513E+03	0.19117E+03	0.19507E+03	0.19950E+03
Se	[illegible]	[illegible]	[illegible]	0.20163E-01	0.23514E-01	0.27313E-01	0.30718E-01	0.37360E-01
Sr	[illegible]	[illegible]	[illegible]	0.15731E+02	0.18632E+02	0.20897E+02	0.23143E+02	0.26949E+02
Tc	[illegible]	[illegible]	[illegible]	[illegible]	0.23825E-01	0.27330E-01	0.30743E-01	0.37414E-01
Sn	[illegible]	[illegible]	[illegible]	0.20171E-02	0.23825E-02	0.27330E-02	0.30743E-02	0.37414E-02
[illegible]	[illegible]	[illegible]	[illegible]	0.24939E+03	0.26356E+03	0.27212E+03	0.27755E+03	0.28373E+03
Cs	[illegible]	[illegible]	[illegible]	0.23592E+04	0.24806E+04	0.25504E+04	0.25942E+04	0.26419E+04
Cs	[illegible]	[illegible]	[illegible]	0.23592E+04	0.24806E+04	0.25504E+04	0.25942E+04	0.26419E+04
RA	[illegible]	[illegible]	[illegible]	0.91560E-06	0.10168E-05	0.10847E-05	0.11343E-05	0.12029E-05
[illegible]	[illegible]	[illegible]	[illegible]	0.58525E-02	0.62858E-02	0.65547E-02	0.67330E-02	0.69409E-02
[illegible]	[illegible]	[illegible]	[illegible]	0.20171E-01	0.23825E-01	0.27331E-01	0.30746E-01	0.37417E-01
[illegible]	[illegible]	[illegible]	[illegible]	0.20171E-01	0.23825E-01	0.27331E-01	0.30744E-01	0.37417E-01
U	[illegible]	0.11914E-01	[illegible]	0.20171E-01	0.23825E-01	0.27331E-01	0.30744E-01	0.37417E-01
NP	[illegible]	0.11914E-01	[illegible]	0.20170E-01	0.23824E-01	0.27329E-01	0.30741E-01	0.37411E-01
PU	[illegible]	[illegible]	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
PU	[illegible]	0.11910E-01	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
PU	[illegible]	[illegible]	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
[illegible]	[illegible]	[illegible]	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
PU	[illegible]	0.11910E-01	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
PU	[illegible]	[illegible]	[illegible]	0.20162E-01	0.23812E-01	0.27310E-01	0.30714E-01	0.37355E-01
AM	[illegible]	[illegible]	[illegible]	0.20171E-02	0.23825E-02	0.27331E-02	0.30744E-02	0.37417E-02
AM	[illegible]	0.11914E-02	[illegible]	0.20171E-02	0.23825E-02	0.27331E-02	0.30744E-02	0.37417E-02
CM	[illegible]	[illegible]	[illegible]	0.20132E-01	0.23757E-01	0.27210E-01	0.30536E-01	0.36829E-01
C[illegible]	[illegible]	[illegible]	[illegible]	0.20132E-01	0.23757E-01	0.27210E-01	0.30536E-01	0.36829E-01
MATRIX	[illegible]	[illegible]	[illegible]	0.15722E+07	0.16582E+07	0.17254E+07	0.17626E+07	0.18049E+07

```
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STNUCMM(IT-1)=[illegible]*DELTAT          [illegible]=STNUCMM(ITM1-1)
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Table 1 (Continued)

DATE: 23-JAN-86　　　　WAPPA　　　　PAGE NO. 381
TIME: 08:24:38　　　　A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 4.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	55.0	65.0	75.0	95.0	125.0	150.0	175.0	200.0
C	0.20192E+03	0.20341E+03	0.20440E+03	0.20552E+03	0.20644E+03	0.20699E+03	0.20742E+03	0.20776E+03
Se	0.43852E-01	0.50239E-01	0.56540E-01	0.68877E-01	0.86800E-01	0.10135E+00	0.11554E+00	0.12935E+00
Sr	0.29905E+02	0.32173E+02	0.33861E+02	0.36038E+02	0.37882E+02	0.39006E+02	0.39874E+02	0.40560E+02
Tc	0.43955E-01	0.50420E-01	0.56835E-01	0.69572E-01	0.88529E-01	0.10423E+00	0.11985E+00	0.13541E+00
Sn	0.43956E-02	0.50422E-02	0.56839E-02	0.69580E-02	0.88549E-02	0.10426E-01	0.11990E-01	0.13548E-01
I	0.28710E+03	0.28918E+03	0.29055E+03	0.29211E+03	0.29339E+03	0.29416E+03	0.29476E+03	0.29523E+03
Cs	0.26667E+04	0.26816E+04	0.26911E+04	0.27016E+04	0.27098E+04	0.27147E+04	0.27184E+04	0.27214E+04
Cs	0.26667E+04	0.26816E+04	0.26911E+04	0.27016E+04	0.27098E+04	0.27147E+04	0.27184E+04	0.27214E+04
Ra	0.12502E-05	0.12838E-05	0.13089E-05	0.13438E-05	0.13809E-05	0.14076E-05	0.14320E-05	0.14551E-05
Th	0.70563E-02	0.71284E-02	0.71764E-02	0.72318E-02	0.72777E-02	0.73059E-02	0.73280E-02	0.73458E-02
U	0.43962E-01	0.50432E-01	0.56855E-01	0.69619E-01	0.88649E-01	0.10443E+00	0.12016E+00	0.13585E+00
U	0.43962E-01	0.50432E-01	0.56855E-01	0.69619E-01	0.88649E-01	0.10443E+00	0.12016E+00	0.13585E+00
U	0.43962E-01	0.50432E-01	0.56855E-01	0.69619E-01	0.88649E-01	0.10443E+00	0.12016E+00	0.13585E+00
Np	0.43950E-01	0.50411E-01	0.56822E-01	0.69542E-01	0.88458E-01	0.10412E+00	0.11969E+00	0.13520E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Pu	0.43844E-01	0.50228E-01	0.56524E-01	0.68852E-01	0.86762E-01	0.10130E+00	0.11548E+00	0.12928E+00
Am	0.43962E-02	0.50432E-02	0.56855E-02	0.69620E-02	0.88650E-02	0.10443E-01	0.12016E-01	0.13585E-01
Am	0.43962E-02	0.50432E-02	0.56855E-02	0.69620E-02	0.88650E-02	0.10443E-01	0.12016E-01	0.13585E-01
Cm	0.42560E-01	0.47635E-01	0.51921E-01	0.57772E-01	0.62702E-01	0.65678E-01	0.67914E-01	0.69617E-01
Cm	0.42560E-01	0.47635E-01	0.51921E-01	0.57772E-01	0.62702E-01	0.65678E-01	0.67914E-01	0.69617E-01
MATRIX	0.18281E+07	0.18424E+07	0.18513E+07	0.18626E+07	0.18714E+07	0.18767E+07	0.18809E+07	0.18841E+07

STNUCW(I,ITM1)=SNUCWT(I)　　SNUCWT(I)=SALCWT(I)　　+SNUCWP(I)*DELTAT
STNUCWM(ITM1)=PRSTNUCWM-WLFLXM*DELTAT　　PRSTNUCWM=STNUCWM(ITM1-1)

Table 1 (Continued)

DATE: 23-JAN-86 WAPPA PAGE NO. 382
TIME: 03:24:39 A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 6.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	225.0	250.0	275.0	300.0	350.0	400.0	450.0	500.0
C	0.20805E+03	0.20830E+03	0.20852E+03	0.20871E+03	0.20904E+03	0.20931E+03	0.20954E+03	0.20973E+03
Se	0.14293E+00	0.15601E+00	0.16899E+00	0.18148E+00	0.20575E+00	0.22890E+00	0.25097E+00	0.27200E+00
Sr	0.41135E+02	0.41637E+02	0.42080E+02	0.42475E+02	0.43143E+02	0.43696E+02	0.44163E+02	0.44563E+02
Tc	0.15091E+00	0.16636E+00	0.18175E+00	0.19710E+00	0.22765E+00	0.25802E+00	0.28820E+00	0.31820E+00
Sn	0.15101E-01	0.16649E-01	0.18192E-01	0.19730E-01	0.22794E-01	0.25841E-01	0.28872E-01	0.31886E-01
I	0.29563E+03	0.29598E+03	0.29628E+03	0.29655E+03	0.29701E+03	0.29738E+03	0.29770E+03	0.29797E+03
Cs	0.27239E+04	0.27259E+04	0.27278E+04	0.27294E+04	0.27322E+04	0.27345E+04	0.27364E+04	0.27381E+04
Cs	0.27236E+04	0.27259E+04	0.27278E+04	0.27294E+04	0.27322E+04	0.27345E+04	0.27364E+04	0.27381E+04
Ra	0.14768E-05	0.14971E-05	0.15165E-05	0.15350E-05	0.15705E-05	0.16047E-05	0.16384E-05	0.16721E-05
Th	0.73611E-02	0.73745E-02	0.73865E-02	0.73973E-02	0.74160E-02	0.74320E-02	0.74458E-02	0.74581E-02
U	0.15151E+00	0.16713E+00	0.18273E+00	0.19830E+00	0.22939E+00	0.26039E+00	0.29133E+00	0.32220E+00
U	0.15151E+00	0.16713E+00	0.18273E+00	0.19830E+00	0.22939E+00	0.26039E+00	0.29133E+00	0.32220E+00
U	0.15151E+00	0.16713E+00	0.18273E+00	0.19830E+00	0.22939E+00	0.26039E+00	0.29133E+00	0.32220E+00
Np	0.15064E+00	0.16602E+00	0.18136E+00	0.19664E+00	0.22706E+00	0.25730E+00	0.28736E+00	0.31727E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Pu	0.14276E+00	0.15593E+00	0.16882E+00	0.18142E+00	0.20571E+00	0.22891E+00	0.25105E+00	0.27217E+00
Am	0.15150E-01	0.16712E-01	0.18271E-01	0.19828E-01	0.22933E-01	0.26029E-01	0.29116E-01	0.32194E-01
Am	0.15150E-01	0.16712E-01	0.18271E-01	0.19828E-01	0.22933E-01	0.26029E-01	0.29116E-01	0.32194E-01
Cm	0.71023E-01	0.72254E-01	0.73343E-01	0.74315E-01	0.75963E-01	0.77327E-01	0.78477E-01	0.79461E-01
Cm	0.71023E-01	0.72254E-01	0.73343E-01	0.74315E-01	0.75963E-01	0.77327E-01	0.78477E-01	0.79461E-01
MATRIX	0.18869E+07	0.18893E+07	0.18914E+07	0.18932E+07	0.18964E+07	0.18990E+07	0.19012E+07	0.19030E+07

```
STNUCW(I,ITM1)=SNUCWT(I)        SNUCWT(I)=SNUCWT(I)        +SNUCWP(I)*DELTAT
STNUCWM(ITM1)=PRSTNUCWM+WLFLXM*DELTAT              PRSTNUCWM=STNUCWM(ITM1-1)
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Table 1 (Continued)

DATE: 23-JAN-86 WAPPA PAGE NO. 383
TIME: 06:24:38 A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 4.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	575.0	650.0	725.0	800.0	850.0	900.0	950.0	1000.0
C	0.20997E+03	0.21017E+03	0.21033E+03	0.21046E+03	0.21054E+03	0.21061E+03	0.21068E+03	0.21074E+03
Se	0.30145E+00	0.32853E+00	0.35345E+00	0.37638E+00	0.39069E+00	0.40425E+00	0.41711E+00	0.42931E+00
Sr	0.45057E+02	0.45457E+02	0.45790E+02	0.46971E+02	0.46236E+02	0.46386E+02	0.46522E+02	0.46647E+02
Tc	0.36281E+00	0.40695E+00	0.45059E+00	0.49371E+00	0.52218E+00	0.55041E+00	0.57839E+00	0.60612E+00
Sn	0.36373E-01	0.40816E-01	0.45218E-01	0.49574E-01	0.52452E-01	0.55309E-01	0.58145E-01	0.60958E-01
I	0.29830E+03	0.29858E+03	0.29880E+03	0.29899E+03	0.29910E+03	0.29920E+03	0.29929E+03	0.29935E+03
Cs	0.27401E+04	0.27418E+04	0.27431E+04	0.27443E+04	0.27449E+04	0.27456E+04	0.27461E+04	0.27466E+04
Cs	0.27401E+04	0.27418E+04	0.27431E+04	0.27443E+04	0.27449E+04	0.27456E+04	0.27461E+04	0.27466E+04
Ra	0.17194E-05	0.17623E-05	0.18022E-05	0.18399E-05	0.18642E-05	0.18880E-05	0.19114E-05	0.19345E-05
Th	0.74737E-02	0.74870E-02	0.74984E-02	0.75085E-02	0.75146E-02	0.75203E-02	0.75257E-02	0.75307E-02
U	0.36840E+00	0.41446E+00	0.46039E+00	0.50619E+00	0.53666E+00	0.56707E+00	0.59743E+00	0.62773E+00
U	0.36840E+00	0.41446E+00	0.46039E+00	0.50619E+00	0.53666E+00	0.56707E+00	0.59743E+00	0.62773E+00
U	0.36840E+00	0.41446E+00	0.46039E+00	0.50619E+00	0.53666E+00	0.56707E+00	0.59743E+00	0.62773E+00
Np	0.36177E+00	0.40532E+00	0.44943E+00	0.49258E+00	0.52112E+00	0.54945E+00	0.57759E+00	0.60553E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Pu	0.30181E+00	0.32915E+00	0.35437E+00	0.37767E+00	0.39226E+00	0.40611E+00	0.41928E+00	0.43181E+00
Am	0.36792E-01	0.41367E-01	0.45916E-01	0.50436E-01	0.53432E-01	0.56411E-01	0.59373E-01	0.62316E-01
Am	0.36792E-01	0.41367E-01	0.45916E-01	0.50436E-01	0.53432E-01	0.56411E-01	0.59373E-01	0.62316E-01
Cm	0.80573E-01	0.81653E-01	0.82461E-01	0.83140E-01	0.83538E-01	0.83897E-01	0.84223E-01	0.84521E-01
Cm	0.80573E-01	0.81653E-01	0.82461E-01	0.83140E-01	0.83538E-01	0.83897E-01	0.84223E-01	0.84521E-01
MATRIX	0.19053E+07	0.19072E+07	0.190[illegible]E+07	0.19101E+07	0.19108E+07	0.19115E+07	0.19122E+07	0.19127E+07

STNUCW(I,ITM1)=SNUCWT(I) SNUCWT(I)=SNUCWT(I) +SNUCWP(I)*DELTAT
STNUCWM(ITM1)=PRSTNUCWR*WLFLXM*DELTAT F[illegible]CWM=STNUCWM(ITM1-1)

Table 1 (Continued)

DATE: 2[illegible]-JAN-[illegible]
TIME: 0[illegible]:24:3[illegible]

WAPPA
A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

PAGE NO. 384

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 4.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	1050.0	1100.0	1150.0	1200.0	1400.0	1600.0	1800.0	2000.0
C	0.21060E+03	0.21085E+03	0.21090E+03	0.21095E+03	0.21111E+03	0.21126E+03	0.21138E+03	0.21148E+03
Se	0.44099E+00	0.45227E+00	0.46316E+00	0.47369E+00	0.51213E+00	0.54611E+00	0.57642E+00	0.60365E+00
Sr	0.46764E+02	0.46874E+02	0.46979E+02	0.47078E+02	0.47425E+02	0.47717E+02	0.47967E+02	0.48185E+02
Tc	0.63365E+00	0.66100E+00	0.68817E+00	0.71516E+00	0.82115E+00	0.92433E+00	0.10247E+01	0.11224E+01
Sn	0.63753E-01	0.66533E-01	0.69296E-01	0.72043E-01	0.82855E-01	0.93414E-01	0.10372E+00	0.11378E+00
I	0.29945E+03	0.29953E+03	0.29960E+03	0.29966E+03	0.29990E+03	0.30009E+03	0.30026E+03	0.30041E+03
Cs	0.27471E+04	0.27475E+04	0.27480E+04	0.27484E+04	0.27498E+04	0.27510E+04	0.27520E+04	0.27529E+04
Cs	0.27471E+04	0.27475E+04	0.27480E+04	0.27484E+04	0.27498E+04	0.27510E+04	0.27520E+04	0.27529E+04
Ra	0.19573E-05	0.19797E-05	0.20018E-05	0.20237E-05	0.21095E-05	0.21945E-05	0.22803E-05	0.23682E-05
Th	0.75356E-02	0.75402E-02	0.75449E-02	0.75491E-02	0.75655E-02	0.75805E-02	0.75945E-02	0.76079E-02
U	0.65799E+00	0.68819E+00	0.71835E+00	0.74848E+00	0.86852E+00	0.98788E+00	0.11066E+01	0.12246E+01
U	0.65799E+00	0.68819E+00	0.71835E+00	0.74848E+00	0.86852E+00	0.98788E+00	0.11066E+01	0.12246E+01
U	0.65799E+00	0.68819E+00	0.71835E+00	0.74848E+00	0.86852E+00	0.98788E+00	0.11066E+01	0.12246E+01
Np	0.63330E+00	0.66092E+00	0.68436E+00	0.71570E+00	0.82329E+00	0.92855E+00	0.10316E+01	0.11324E+01
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Pu	0.44365E+00	0.45549E+00	0.46676E+00	0.47767E+00	0.51781E+00	0.55365E+00	0.58595E+00	0.61527E+00
Am	0.65243E-01	0.68154E-01	0.71050E-01	0.73930E-01	0.85248E-01	0.96236E-01	0.10684E+00	0.11699E+00
Am	0.65243E-01	0.68154E-01	0.71050E-01	0.73930E-01	0.85248E-01	0.96236E-01	0.10684E+00	0.11699E+00
Cm	0.84797E-01	0.85058E-01	0.85304E-01	0.85536E-01	0.86340E-01	0.87004E-01	0.87563E-01	0.88042E-01
Cm	0.84797E-01	0.85058E-01	0.85304E-01	0.85536E-01	0.86340E-01	0.87004E-01	0.87563E-01	0.88042E-01
MATRIX	0.19133E+07	0.19138E+07	0.1914[illegible]E+07	0.19147E+07	0.19163E+07	0.19177E+07	0.19188E+07	0.19198E+07

STNUCW(I,ITM1)=SNUCWT(I) [illegible]NUCWT(I)=SNUCWT(I) +SNUCWP(I)*DELTAT
STNUCWM(ITM1)=PRSTNUCWM*[illegible] [illegible]TAT [illegible] STNUC [illegible](ITM1-1)

Table 1 (Continued)

DATE: 23-JAN-86 WAPPA PAGE NO. 385
TIME: [illegible]
A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 4.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	2250.0	2500.0	2750.0	3000.0	3500.0	4000.0	4500.0	5000.0
C	0.21160E+03	0.21170E+03	0.21179E+03	0.21188E+03	0.21203E+03	0.21216E+03	0.21227E+03	0.21237E+03
Se	0.63451E+00	0.66274E+00	0.68673E+00	0.71280E+00	0.75582E+00	0.79367E+00	0.82739E+00	0.85774E+00
Sr	0.48425E+02	0.42641E+02	0.46636E+02	0.49013E+02	0.49326E+02	0.49595E+02	0.49832E+02	0.50042E+02
Tc	0.12412E+01	0.13568E+01	0.14695E+01	0.15793E+01	0.17904E+01	0.19913E+01	0.21829E+01	0.23658E+01
Sn	0.12605E+00	0.13804E+00	0.14975E+00	0.16120E+00	0.18328E+00	0.20442E+00	0.22467E+00	0.24410E+00
I	0.30057E+03	0.30071E+03	0.30084E+03	0.30096E+03	0.30117E+03	0.30135E+03	0.30151E+03	0.30165E+03
Ca	0.27539E+04	0.27547E+04	0.27555E+04	0.27562E+04	0.2757[illegible]+04	0.27586E+04	0.27596E+04	0.27604E+04
Cs	0.27539E+04	0.27547E+04	0.27555E+04	0.27562E+04	0.27575E+04	0.27586E+04	0.27596E+04	0.27604E+04
Ra	0.24779E-05	0.25856E-05	0.26929E-05	0.28003E-05	0.30187E-05	0.32459E-05	0.34864E-05	0.37441E-05
Th	0.76239E-02	0.76393E-02	0.76543E-02	0.76689E-02	0.76977E-02	0.77263E-02	0.77553E-02	0.77851E-02
U	0.13712E+01	0.15170E+01	0.16620E+01	0.18061E+01	0.20919E+01	0.23745E+01	0.26539E+01	0.29303E+01
U	0.13712E+01	0.15170E+01	0.16620E+01	0.18061E+01	0.20919E+01	0.23745E+01	0.26539E+01	0.29303E+01
U	0.13712E+01	0.15170E+01	0.16620E+01	0.18061E+01	0.20919E+01	0.23745E+01	0.26539E+01	0.29303E+01
Np	0.12557E+01	0.13763E+01	0.14962E+01	0.16095E+01	0.18324E+01	0.20463E+01	0.22517E+01	0.24493E+01
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Pu	0.64883E+00	0.67981E+00	0.70859E+00	0.73548E+00	0.78424E+00	0.82793E+00	0.86756E+00	0.90388E+00
Am	0.12919E+00	0.14099E+00	0.15238E+00	0.16335E+00	0.18396E+00	0.20292E+00	0.22026E+00	0.23603E+00
Am	0.12919E+00	0.14099E+00	0.15238E+00	0.16335E+00	0.18396E+00	0.20292E+00	0.22026E+00	0.23603E+00
Cm	0.88560E-01	0.89015E-01	0.89417E-01	0.89777E-01	0.90386E-01	0.90890E-01	0.91314E-01	0.91675E-01
Cm	0.88560E-01	0.89015E-01	0.89417E-01	0.89777E-01	0.90386E-01	0.90890E-01	0.91314E-01	0.91675E-01
MATRIX	0.19210E+07	0.19219E+07	0.19228E+07	0.19237E+07	0.19251E+07	0.19263E+07	0.19274E+07	0.19284E+07

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STNUCW(I,ITM1)=SNUCWT(I)      SNUCAT(I)=SNUCAT(I)        +SNUCMP(I)*DELTAT
STNUCWM(ITM1)=PRSTNUCW*WNLFLA[illegible]LTAT          PRSTN[illegible]STNUCW(ITM1-1)
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Table 1 (Continued)

DATE: 23-JAN-86 WAPPA PAGE NO. 386
TIME: [illegible]
A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE

CHLW BOREHOLE CONCEPT: 0 YEAR WETTING TIME. 4.000
CANISTER WITH CAST STEEL OVERPACK, 2 METALS, 24 NUCLIDES, 2 AIR GAPS
DEAF SMITH COUNTY CHLW HIGH-MG BRINE CRUSHED SALT BACKFILL 6.000

SUMMARY TABLE # 10

TOTAL ELEMENT MASS OUT AT WASTE PACKAGE BOUNDARY (GRAMS)

TIME SINCE EMPLACEMENT (YEARS)

ELEMENT	6250.0	7500.0	8750.0	10000.0
C	0.21260E+03	0.21282E+03	0.21302E+03	0.21321E+03
Se	0.92730E+00	0.99237E+00	0.10540E+01	0.11128E+01
Sr	0.50521E+02	0.50967E+02	0.51387E+02	0.51787E+02
Tc	0.26048E+01	0.32293E+01	0.36419E+01	0.40439E+01
Sn	0.29090E+00	0.33632E+00	0.38059E+00	0.42384E+00
I	0.30197E+03	0.30227E+03	0.30255E+03	0.30281E+03
Cs	0.27624E+04	0.27642E+04	0.27659E+04	0.27675E+04
Cs	0.27624E+04	0.27642E+04	0.27659E+04	0.27675E+04
Ra	0.44560E-05	0.52647E-05	0.61964E-05	0.72772E-05
Th	0.76659E-02	0.79580E-02	0.80644E-02	0.81881E-02
U	0.36142E+01	0.42921E+01	0.49650E+01	0.56331E+01
U	0.36142E+01	0.42921E+01	0.49650E+01	0.56331E+01
U	0.36142E+01	0.42921E+01	0.49650E+01	0.56331E+01
Np	0.29204E+01	0.33901E+01	0.38429E+01	0.42860E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Pu	0.98658E+00	0.10691E+01	0.11467E+01	0.12218E+01
Am	0.27161E+00	0.30361E+00	0.33239E+00	0.35820E+00
Am	0.27161E+00	0.30361E+00	0.33239E+00	0.35820E+00
Cm	0.92432E-01	0.93064E-01	0.93601E-01	0.94059E-01
Cm	0.92432E-01	0.93064E-01	0.93601E-01	0.94059E-01
MATRIX	0.19306E+07	0.19327E+07	0.19346E+07	0.19365E+07

STNUCW(I,ITM1)=SNUCWT(I) SNUCWT(I)=SNUCWT(I) +SNUCWP(I)*DELTAT
STNUCW(I,ITM1)=[illegible] [illegible]*STNUCWP(ITM1-1)

Table 2. Comparison of WAPPAG and Directly Calculated Sensitivities to Thermal Power at Time of Burial

Rerun perturbation, %	-0.944833E+00
Parameter value, W/MTIHM	0.984300E+03
Parameter name	RHEAT(1)

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	-0.139775E+01	-0.141480E+01	0.213209E+03
Se 79	-0.126189E+00	-0.122580E+00	0.111276E+01
Sr 90	-0.245947E-01	-0.210575E-01	0.517873E+02
Tc 99	0.158648E+00	0.163489E+00	0.404388E+01
Sn 126	0.182543E-00	0.187391E+00	0.423839E+00
I 129	-0.144410E+01	-0.146271E+01	0.302813E+03
Cs 135	-0.149290E+01	-0.151266E+01	0.276751E+04
Cs 137	-0.149290E+01	-0.151266E+01	0.276751E+04
Ra 226	-0.601444E+00	-0.602368E+00	0.727716E-05
Th 230	-0.845911E+00	-0.849164E+00	0.818810E-02
U 233	0.369588E+00	0.374087E+00	0.563315E+01
U 234	0.369588E+00	0.374087E+00	0.563315E+01
U 238	0.369588E+00	0.374087E+00	0.563315E+01
Np 237	0.187171E+00	0.192005E+00	0.428599E+01
Pu 238	-0.134674E+00	-0.131020E+00	0.122183E+01
Pu 239	-0.134674E+00	-0.131020E+00	0.122183E+01
Pu 240	-0.134674E+00	-0.131020E+00	0.122183E+01
Pu 241	-0.134674E+00	-0.131020E+00	0.122183E+01
Pu 242	-0.134674E+00	-0.131020E+00	0.122183E+01
Pu 244	-0.134674E+00	-0.131020E+00	0.122183E+01
Am 241	0.136951E+00	0.141553E+00	0.358202E+00
Am 243	0.136951E+00	0.141553E+00	0.358202E+00
Cm 244	0.125190E-01	0.160715E-01	0.940592E-01
Cm 245	0.125190E-01	0.160715E-01	0.940592E-01

Table 3. Comparison of WAPPAG and Directly Calculated Sensitivities to the Wasteform Height

Rerun perturbation	0.999998E+00
Parameter value, m	0.370000E+01
Parameter name	SHTWP

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	-0.374480E+00	-0.370955E+00	0.213209E+03
Se 79	0.845037E+00	0.842392E+00	0.111276E+01
Sr 90	0.955058E+00	0.951906E+00	0.517873E+02
Tc 99	0.113061E+01	0.112917E+01	0.404388E+01
Sn 126	0.115462E+01	0.115326E+01	0.423839E+00
I 129	-0.420103E+00	-0.415598E+00	0.302813E+03
Cs 135	-0.467530E+00	-0.462265E+00	0.276751E+04
Cs 137	-0.467530E+00	-0.462265E+00	0.276751E+04
Ra 226	0.376438E+00	0.376176E+00	0.727716E-05
Th 230	0.163473E+00	0.159067E+00	0.818810E-02
U 233	0.134260E+01	0.134239E+01	0.563315E+01
U 234	0.134260E+01	0.134239E+01	0.563315E+01
U 238	0.134260E+01	0.134239E+01	0.563315E+01
Np 237	0.115927E+01	0.115795E+01	0.428599E+01
Pu 238	0.836422E+00	0.833868E+00	0.122183E+01
Pu 239	0.836422E+00	0.833868E+00	0.122183E+01
Pu 240	0.836422E+00	0.833868E+00	0.122183E+01
Pu 241	0.836422E+00	0.833868E+00	0.122183E+01
Pu 242	0.836422E+00	0.833868E+00	0.122183E+01
Pu 244	0.836422E+00	0.833868E+00	0.122183E+01
Am 241	0.110881E+01	0.110754E+01	0.358202E+00
Am 243	0.110881E+01	0.110754E+01	0.358202E+00
Cm 244	0.989706E+00	0.986804E+00	0.940592E-01
Cm 245	0.989706E+00	0.986804E+00	0.940592E-01

Table 4. Comparison of WAPPAG and Directly Calculated Sensitivities to the Outside Radius of the Wasteform

Rerun perturbation	0.998985E-02
Parameter value, m	0.267300E+00
Parameter name	SRTEMP(1)

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	-0.193548E+01	-0.192568E+01	0.213209E+03
Se 79	0.197116E+01	0.214798E+01	0.111276E+01
Sr 90	0.247692E+01	0.250775E+01	0.517673E+02
Tc 99	0.236960E+01	0.252596E+01	0.404388E+01
Sn 126	0.240556E+01	0.255010E+01	0.423839E+00
I 129	-0.214671E+01	-0.214173W+01	0.302813E+03
Cs 135	-0.247961E+01	-0.246728E+01	0.276751E+04
Cs 137	-0.247961E+01	-0.246728E+01	0.276751E+04
Ra 226	0.111017E+01	0.151566E+01	0.727716E-05
Th 230	0.234794E+00	0.272117E+00	0.818810E-02
U 233	0.268899E+01	0.273269E+01	0.563315E+01
U 234	0.268899E+01	0.273269E+01	0.563315E+01
U 238	0.268899E+01	0.273269E+01	0.563315E+01
Np 237	0.241280E+01	0.255367E+01	0.428599E+01
Pu 238	0.195461E+01	0.215058E+01	0.122183E+01
Pu 239	0.195461E+01	0.215058E+01	0.122183E+01
Pu 240	0.195461E+01	0.215058E+01	0.122183E+01
Pu 241	0.195461E+01	0.215058E+01	0.122183E+01
Pu 242	0.195461E+01	0.215058E+01	0.122183E+01
Pu 244	0.195461E+01	0.215058E+01	0.122183E+01
Am 241	0.233614E+01	0.250435E+01	0.358202E+00
Am 243	0.233614E+01	0.250435E+01	0.358202E+00
Cm 244	0.243261E+01	0.245171E+01	0.940592E-01
Cm 245	0.243261E+01	0.245171E+01	0.940592E-01

Table 5. Comparison of WAPPAG and Directly Calculated Sensitivities to the Outer Radius of the Outermost Gap

Rerun perturbation, %	0.338989E+00
Parameter value, m	0.295000E+00
Parameter name	SRTEMP(4)

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	0.165940E+01	0.165378E+01	0.213209E+03
Se 79	-0.197326E+01	-0.196764E+01	0.111276E+01
Sr 90	-0.171478E+01	-0.171188E+01	0.517873E+02
Tc 99	-0.186445E+01	-0.185777E+01	0.404388E+01
Sn 126	-0.185474E+01	-0.184792E+01	0.423839E+00
I 129	0.176379E+01	0.175958E+01	0.302813E+03
Cs 135	0.198282E+01	0.197950E+01	0.276751E+04
Cs 137	0.198282E+01	0.197950E+01	0.276751E+04
Ra 226	-0.162479E+01	-0.162254E+01	0.727716E-05
Th 230	0.285323E+00	0.273961E+00	0.818810E-02
U 233	-0.177831E+01	-0.177088E+01	0.563315E+01
U 234	-0.177831E+01	-0.177088E+01	0.563315E+01
U 238	-0.177831E+01	-0.177088E+01	0.563315E+01
Np 237	-0.185288E+01	-0.184614E+01	0.428599E+01
Pu 238	-0.197794E+01	-0.197265E+01	0.122183E+01
Pu 239	-0.197794E+01	-0.197265E+01	0.122183E+01
Pu 240	-0.197794E+01	-0.197265E+01	0.122183E+01
Pu 241	-0.197794E+01	-0.197265E+01	0.122183E+01
Pu 242	-0.197794E+01	-0.197265E+01	0.122183E+01
Pu 244	-0.197794E+01	-0.197265E+01	0.122183E+01
Am 241	-0.187275E+01	-0.186621E+01	0.358202E+00
Am 243	-0.187275E+01	-0.186621E+01	0.358202E+00
Cm 244	-0.178447E+01	-0.178047E+01	0.940592E-01
Cm 245	-0.178447E+01	-0.178047E+01	0.940592E-01

Table 6. Comparison of WAPPAG and Directly Calculated Sensitivities to U-233 Mass at 5,000 Years

Rerun perturbation, %	-0.100000E+01
Parameter value, g/MTIHM	0.480000E+03
Parameter name	RADTOX(11,13)

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	0.000000E+00	0.000000E+00	0.213209E+03
Se 79	0.000000E+00	0.000000E+00	0.111276E+01
Sr 90	0.000000E+00	0.000000E+00	0.517873E+02
Tc 99	0.000000E+00	0.000000E+00	0.404388E+01
Sn 126	0.000000E+00	0.000000E+00	0.423839E+00
I 129	0.000000E+00	0.000000E+00	0.302813E+03
Cs 135	0.000000E+00	0.000000E+00	0.276751E+04
Cs 137	0.000000E+00	0.000000E+00	0.276751E+04
Ra 226	0.000000E+00	0.000000E+00	0.727716E-05
Th 230	0.000000E+00	0.000000E+00	0.818810E-02
U 233	0.000000E+00	0.000000E+00	0.563315E+01
U 234	0.000000E+00	0.000000E+00	0.563315E+01
U 238	0.000000E+00	0.000000E+00	0.563315E+01
Np 237	0.000000E+00	0.000000E+00	0.428599E+01
Pu 238	0.000000E+00	0.000000E+00	0.122183E+01
Pu 239	0.000000E+00	0.000000E+00	0.122183E+01
Pu 240	0.000000E+00	0.000000E+00	0.122183E+01
Pu 241	0.000000E+00	0.000000E+00	0.122183E+01
Pu 242	0.000000E+00	0.000000E+00	0.122183E+01
Pu 244	0.000000E+00	0.000000E+00	0.122183E+01
Am 241	0.000000E+00	0.000000E+00	0.358202E+00
Am 243	0.000000E+00	0.000000E+00	0.358202E+00
Cm 244	0.000000E+00	0.000000E+00	0.940592E-01
Cm 245	0.000000E+00	0.000000E+00	0.940592E-01

Table 7. Comparison of WAPPAG and Directly Calculated Sensitivities to the Gamma Ray Source at Burial

Rerun perturbation, %	-0.990000E+02
Parameter value, p/s/MTIHM	0.743600E+16
Parameter name	RGAMA(1)

NUCLIDE	SENSITIVITY (WAPPAG)	SENSITIVITY (RERUN)	MASS OUT AFTER 10,000 YEARS
C 14	0.000000E+00	0.000000E+00	0.213209E+03
Se 79	0.000000E+00	0.000000E+00	0.111276E+01
Sr 90	0.000000E+00	0.000000E+00	0.517873E+02
Tc 99	0.000000E+00	0.000000E+00	0.404388E+01
Sn 126	0.000000E+00	0.000000E+00	0.423839E+00
I 129	0.000000E+00	0.000000E+00	0.302813E+03
Cs 135	0.000000E+00	0.000000E+00	0.276751E+04
Cs 137	0.000000E+00	0.000000E+00	0.276751E+04
Ra 226	0.000000E+00	0.000000E+00	0.727716E-05
Th 230	0.000000E+00	0.000000E+00	0.818810E-02
U 233	0.000000E+00	0.000000E+00	0.563315E+01
U 234	0.000000E+00	0.000000E+00	0.563315E+01
U 238	0.000000E+00	0.000000E+00	0.563315E+01
Np 237	0.000000E+00	0.000000E+00	0.428599E+01
Pu 238	0.000000E+00	0.000000E+00	0.122183E+01
Pu 239	0.000000E+00	0.000000E+00	0.122183E+01
Pu 240	0.000000E+00	0.000000E+00	0.122183E+01
Pu 241	0.000000E+00	0.000000E+00	0.122183E+01
Pu 242	0.000000E+00	0.000000E+00	0.122183E+01
Pu 244	0.000000E+00	0.000000E+00	0.122183E+01
Am 241	0.000000E+00	0.000000E+00	0.358202E+00
Am 243	0.000000E+00	0.000000E+00	0.358202E+00
Cm 244	0.000000E+00	0.000000E+00	0.940592E-01
Cm 245	0.000000E+00	0.000000E+00	0.940592E-01

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