OCT 23 2001 (20) Sta. 15

ENGINEERING DATA TRANSMITTAL

1. EDT 632701

2. To: (Receiving Organization)	3. From: (Originating Organization)	4. Related EDT No.:
Spent Nuclear Fuel	FH	N/A
J. Proj./Prog./Dept./Div.:	**6. Design Authority/ Design Agent/Cog.Engr.:**	**7. Purchase Order No.:**
Sludge Treatment/Disposal	C. A. Petersen	N/A
		9. Equip./Component No.: N/A
		10. System/Bldg./Facility:

USQ categorical exclusion D applies

11. Receiver Remarks: **11A. Design Baseline Document?** [X] Yes [] No

12. Major Asm. Dwg. No.: N/A

13. Permit/Permit Application No.: N/A

14. Required Response Date: N/A

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title a Description of Data Transmitted	Desig-	for Trans-mittal	Origi- Dispo-sition	Receiv- Dispo-sition
1	HNF-8760		0	Design and Safety Basis Sludge Characterization from Exposure-Adjusted Radioisotopic Source Terms for N Reactor Fuel Stored at K-East and K-West Basins	NA	1		

16. KEY

Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)
E, S, Q, D or N/A (see WHC-CM-3-5, Sec. 12.7)	1. Approval 4. Review 2. Release J. Past-Review 3. Information 6. Dicl (Receipt Acknow. Required)	1. Approved 4. Reviewed no/comment 2. Approved w/comment 5. Reviewed w/comment 3. Disapproved w/comment 6. Receipt acknowledged

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		Env.			

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Authorized Representative for Receiving Organization Date

20. C. A. Petersen 10/10/01
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21. DOE APPROVAL (if required)
Ctrl. No. _____
[] Approved
[] Approved w/comments
[] Disapproved w/comments

BD-7400-172-2 (10/97)

BD-7400-172-1

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DISTRIBUTION	Fluor Hanford	Date October 10, 2001
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A-6000-135 (10/97)

HNF-8760
Revision *0*

Design and Safety Basis Sludge Characterization from Exposure-Adjusted Radioisotopic Source Terms for N Reactor Fuel Stored at K-East and K-West Basins

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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HNF-8760
Revision 0
EDT 632701

Design and Safety Basis Sludge Characterization from Exposure-Adjusted Radioisotopic Source Terms for N Reactor Fuel Stored at K-East and K-West Basins

Project No: SNF Dowment Type: CN Division: SNF

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Date Published
October 2001

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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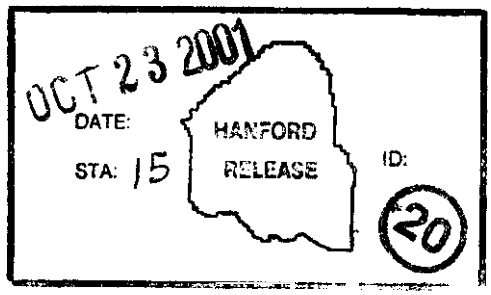

Release Approval — Date — Release Stamp

Total Pages: 94

Design and Safety Basis Sludge Characterization from Exposure-Adjusted Radioisotopic Source Terms for N Reactor Fuel Stored at K-East and K-West Basins

September 30,2001

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1.0 Purpose

This calculation note documents both the refined methodology (technical approacn and supporting basis) and the results for adjusting the currently available average exposure and consequential radioisotopic source term for K-East and K-West Basin uranium-bearing sludge. This refinement more accurately accounts for local peaking factors known to occur in the fuel elements during irradiation in N Reactor, at the locations that have subsequently been observed to be the primary sources of fuel related sludge in the K Basins. The heavy metal and fission product material originated almost entirely from spent nuclear fuel from the Hanford N Reactor.

This calculation note documents the methods used to characterize radionuclides in KE and KW Basins. The objectives of this calculation are the following:

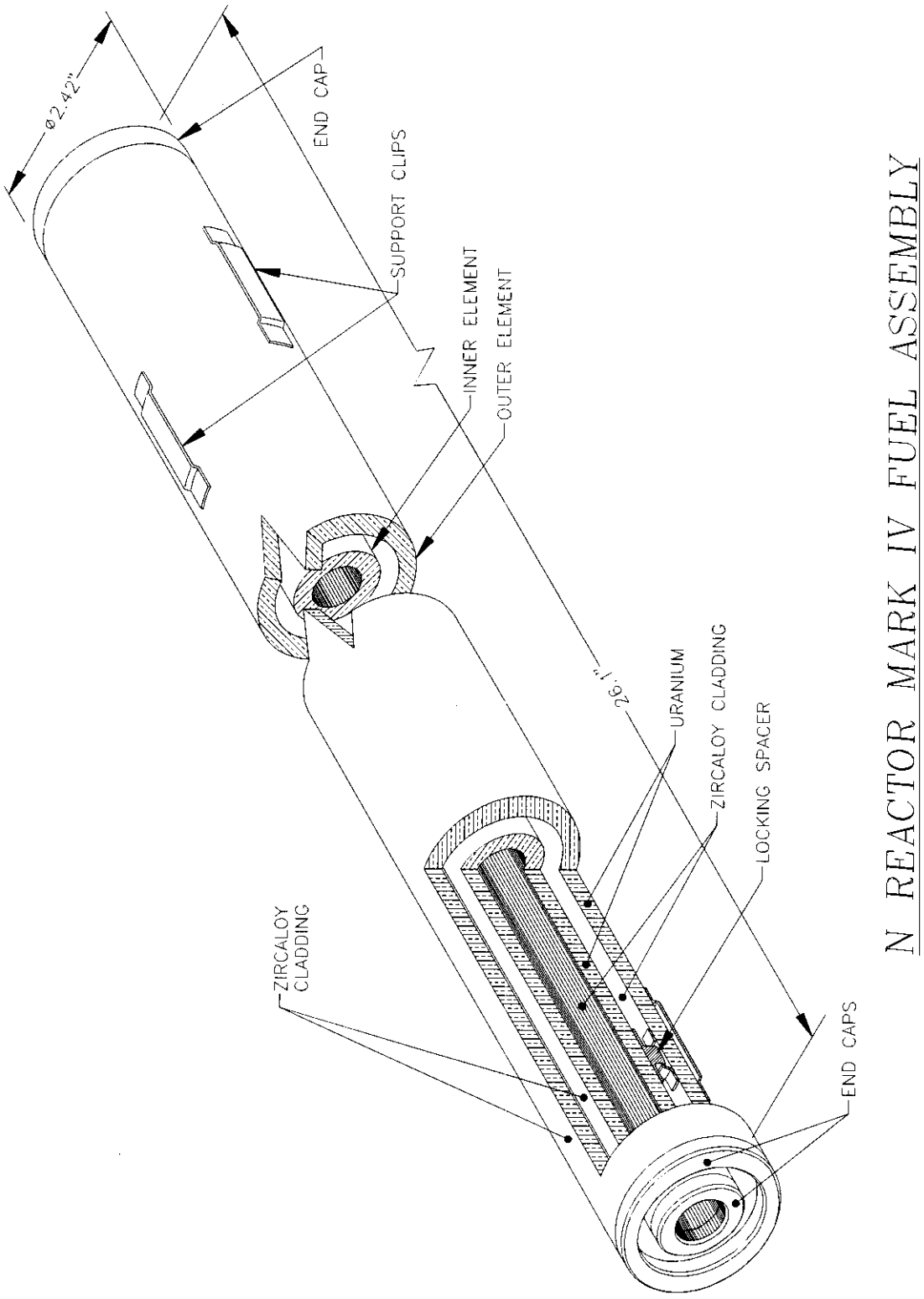
- Provide a comparison of the sludge measurement characterization (floor, canister, and internal sludge) to predictive models and reactor data.
- Determine if the average fuel radionuclide values in Packer (1999) provide reasonable estimates for developing the design basis radionuclide values for the fuel piece slurry component of the wash sludge.
- Determine best estimates for the source term and decay heat generation safety basis values for use in engineering calculations. Safety basis values are to be determined for the fuel piece slurry component of the wash sludge.

2.0 Introduction

The Safeguards and Accountability database was used as the primary source document for exposure data for spent N Reactor fuel stored at the K-East and K-West basins. This database is a listing of all keys (i.e., groups of fuel discharged from the reactor at the same time), and the exposure for that key, mass of uranium in the key, fuel type (whether Mark IV or Mark **IA),** and several other parameters. There are nearly five hundred records (keys) in this database. Figure 1 illustrates an N Reactor Mark **IV** fuel assembly. The axial length of the endcap is approximately 0.19 inch.

Mark IA and Mark IV fuel are low enriched zircalloy-2 clad metallic uranium tube-in-tube assemblies held together with spacers and clips. Unexposed Mark IV fuel assemblies have an enrichment of 0.947 **wt%** ^{235}U in both inner and outer tubes. Unexposed Mark IA assemblies have an enrichment of 1.25 **wt%** ^{235}U in the outer tube and 0.947 **wt%** ^{235}U in the inner tube.

Figure 1. N Reactor **Mark** IV Fuel Assembly.



Sludge currently in the K basins is due to corrosion of the spent uranium fuel pieces stored underwater in the basins. **As** the fuel was exposed to the neutron field within the reactor during operation, the buildup and depletion of fission products and higher transuranic isotopes (i.e., burnup) was not spatially uniform over the volume of the fuel. Self-shielding by the fuel resulted in a neutron flux distribution that was dependent upon the neutron energy spectrum. In other words, neutrons were born from fission within the fuel and escaped to the graphite moderator, where they slowed down to thermal energies, and then diffused back into the fuel to cause additional fission and continue the chain reaction. This resulted in a high neutron energy (fast flux) maximum in the fuel that decayed away into the graphite moderator, and **a** low neutron energy (thermal flux) distribution that maximized in the graphite moderator and decreased in the direction of the fuel. Hence, fast neutrons streamed from the fuel out into the graphite moderator, and thermal neutrons streamed from the graphite back into the fuel.

The spatial shape of the neutron distribution was therefore a strong function of energy spectrum, and various transmutation reactions are dependent on neutron energy. In general, fission product distributions are proportional to the fission distribution (fission product migration is not expected to be significant in metallic N Reactor fuel – as compared to high-burnup commercial or liquid metal reactor oxide fuel – because of the relatively low burnup and metal form of the fuel). Radial plutonium production edge effects have been reported previously (Carlsen et al 1981; Palmer et al 1982).

However, ^{239}Pu buildup arises from resonance absorption in ^{238}U, and this tends to be primarily an intermediate energy (epithermal flux) process. Therefore, the fission product distribution within the fuel tends to possess an enhanced "skin-effect" because the plutonium buildup tends to peak near the outer edges of the fuel, and thermal neutrons streaming in from the graphite will cause fission in whatever fissile isotope they encounter first. An edge-enhanced plutonium distribution will result in **an** edge-enhanced fission (and thus fission product) distribution. Figures 2 through ***5*** illustrate some of these characteristic shapes.

Corrosion initiates at the outer edges of the fuel, where exposure is highest. Exposure (and thus the radioisotopic source term) is therefore increased over the average exposure for each key documented in the Safeguards database. This adjusted exposure is based on calculational models of fission product and power distributions within the fuel elements, along with working assumptions for fuel corrosion (i.e., from where on the fuel did the corrosion originate?)

3.0 Methodology

3.1. Radial Exposure Profiles

The radial exposure peaking function is derived from WIMS-E lattice burnup calculations performed in the early 1990's. WIMS-E (Gubhins et al. 1982) is a British lattice transport code used in the past to generate macroscopic nuclear cross sections for diffusion theory analysis of N Reactor, and for performing burnup analysis (e.g., isotopic production estimates). WIMS-E has been validated for a number of low-enriched uranium (LEU) systems (including critical experiments and burnup in Mark IV fuel assemblies).

Both Mark IV and Mark IA fuel assemblies were exposed in the N Reactor graphite moderated lattice, using hot operating conditions calculated by the DCODE computer code (temperatures, densities, and thermally-expanded dimensions) (Thierer 1968). Twenty radial intervals of equal volume were assigned to each of the inner and outer elements, and separate burnable materials were assigned to each interval. This is a requirement in WIMS – in order to burn each radial mesh interval within a single tube separately according to the neutron spectrum solution in that interval, the material in each interval must be uniquely specified. This allows WIMS to evaluate the bumup equations independently for each radial interval, and thus track the radial bumup profile as driven by the local transport solution (i.e., for each mesh interval). Twenty bumup steps were evaluated. The first step was for only two days to bum in equilibrium xenon, and the next 19 steps were for 10 days each. WIMS-E tracks several dozen fission products separately (those fission products most important for reactivity effects, not necessarily dose effects), and (using the 1994 library) also tracks transuranics up through ^{245}Cm.

The bumup validation discussed in section 3.4 used the 1994 library, but the radial profile work discussed here was performed using the 1986 library; these calculations were performed before the 1994 library had been released. The isotopic results were then extracted out of the WIMS-E output files into a spreadsheet, and these archived results were used in this calculation note to characterize radial exposure. The structure of the spreadsheet is as follows. Isotopes are listed by row, the radial intervals are listed by column, and the exposure steps are listed by "tab".

These stored WIMS-E results are in the form **of** grams of isotope per cm length of the lattice specified by the user. Once in the spreadsheet, it is an easy matter to manipulate these results and create new, derived rows and columns, such as ratios of raw numbers from WIMS-E (e.g., $^{240}Pu/(^{238}Pu + ^{239}Pu + ^{240}Pu + ^{241}Pu + ^{242}Pu)$ = **wt%** ^{240}Pu, or summation of fission products divided by the summation of U and Pu isotopes). This enables the direct plotting **of** the radial profiles in Figures 2 through 5. Figure 2 shows the radial profile of ^{235}U depletion as a function of bumup for Mark IA fuel assemblies. Results for both inners and outers are plotted on the same scale. Figure **3** shows the radial buildup of ^{239}Pu in **Mark** IA assemblies, and Figure 4 shows the radial fission product to heavy metal (i.e., U + Pu) ratio as a function of bumup. Figure 5 shows the radial **wt%** ^{240}Pu in Pu as a function of bumup. Note that the radial **wt%** ^{240}Pu profile is not the same as the radial fission product to heavy metal ratio. This demonstrates that even though **wt%** ^{240}Pu is related to exposure (i.e., MWd/MTU) for the average assembly, the detailed profile shapes are not that similar, and peaking fractions derived from the **wt%** ^{240}Pu shapes would not reflect the "true" exposure profile. For this analysis, peaking fractions were derived from the actual accumulated fission radial profiles, which were assumed to evolve according to the WIMS-E fission product to heavy metal ratio profiles.

The results shown in Figures 2 through 5 were extracted from the same archived results as were previously documented (Schwinkendorf 1997 – see Appendix G, *Radial **Isotopic** Profile Evolution During Burnup*). In this reference, exposure-dependent radial profile plots similar to Figures 2 through 5 were presented for Mark IV fuel assemblies. These extensive bumup results (grams per cm of every isotope WIMS-E tracks, for each of the 40 radial mesh, and for every one of 20 bumup steps) are maintained by the author in the form **of** a 3D QuattroPro™ spreadsheet.

The (derived) WIMS-E results for "fission product to heavy metal mass ratio" were extracted from the spreadsheet archive and converted to an ASCII data file so that they could be read by the Fortran computer code Profile3 (see listing, Attachment 1). This program reads in the radial fission product profiles as a function of exposure for either Mark IV or Mark IA fuel, as selected by the user. The program then sorts the exposure profiles (for the inner and outer separately, and then for the assembly) in order of descending exposure so that it can selectively remove those outer mesh intervals where exposure is maximum. As can be observed in Figure 4, the exposure is maximized at the surface, but as the outer volumes are removed from the outer surface, at some point the inner surface may contain a higher exposure than the next radial increment in from the outer surface. By ordering the exposure profiles, basing a radial peaking factor on the first N intervals of the sorted array guarantees that the highest exposure intervals are assumed to go to the sludge. With twenty equal-volume radial intervals defined for each tube, selecting N intervals corresponds to removing 0.05N of the fuel, or 5% corrosion for each radial interval removed. Profile3 loops over both exposure and percent corrosion to create an ASCII output file of peak-to-average ratios for inners, outers, and assemblies, as well as the ratio of average inner and average outer to the average assembly. These later two parameters are useful as they represent the ratios of inner and outer exposure to assembly average exposure. Inner and outer peaking factors are later multiplied by these inner-to-assembly and outer-to-assembly factors to arrive at localized exposures, given the assembly-average exposure contained in the Safeguards and Accountability database.

Given the amount of corrosion (5%, 10%, 15%, up to 95% in the loop), the Profile3 code calculates peaking factors as the average of the corroded off volumes divided by the average for each tube (i.e., all twenty intervals). Profile3 does this for all 20 bumup steps and 19 corrosion increments. The output file from Profile3 consists of five columns (inner P/A, outer P/A, assembly P/A, average inner/assembly, and average outer/assembly), and 19 blocks of 20 rows (the exposure loop (20 rows) is written first, followed by the percent corrosion loop). Profile3 was executed once for Mark IA fuel, with the output file renamed "PAmkia.dat", and executed again for Mark IV fuel, with the output file renamed "PAmkiv.dat". The results are written to an ASCII output file that is later read by another computer program, Pradnuc2 (see listing, Attachment 2). Pradnuc2 is a program that reads the Safeguards and Accountability database, and the peaking factor output from Profile3 and outputs an exposure adjusted input file directly readable by Radnuc 2A.

Tables 1 and 2 contain core average hot operating conditions for Mark IV and Mark IA fuel, as exposed in the N Reactor lattice. These values are input to the WIMS-E bumup model.

Table 1. Hot Operating Conditions Used for N Reactor Mark IV Fuel Bum (from DCODE).

Region	Temperature (K)	Density (g/cm^3)	Mark IV radius (cm)
Coolantchannel	499.	0.838	0.614
Zr clad	534.	6.520	0.664
Inner fuel element	608.	18.329	1.559
Zr clad	536.	6.520	1.635
Coolant channel	503.	0.833	2.174
Zr clad	538.	6.519	2.225
Outer fuel element	608.	18.329	3.036
Zr clad	538.	6.519	3.101
Water	501.	0.835	3.444
Process tube	514.	6.523	4.144
void			4.242
Graphite stack	733.	1.710	8.598
void			10.206
Graphite stack	793.	1.710	12.160

Table 2. Hot Operating Conditions Used for N Reactor Mark **IA** Fuel Bum (from DCODE).

Region	Temperature (K)	Density (g/cm^3)	Mark IA radius (cm)
Coolant channel	484.	0.857	0.562
Zr clad	495.	6.526	0.625
Inner fuel element	518.	18.411	1.488
Zr clad	511.	6.523	1.589
Coolant channel	505.	0.829	2.255
Zr clad	560.	6.516	2.312
Outer fuel element	647.	18.267	3.012
Zr clad	571.	6.514	3.077
Water	521.	0.808	3.444
Process tube	533.	6.520	4.145
void			4.242
Graphite stack	733.	1.710	8.598
void			10.206
Graphite stack	793.	1.710	12.160

Figure 2. Radial ^{235}U Mass Ratio Profile, N Reactor Mark IA Fuel Assembly.

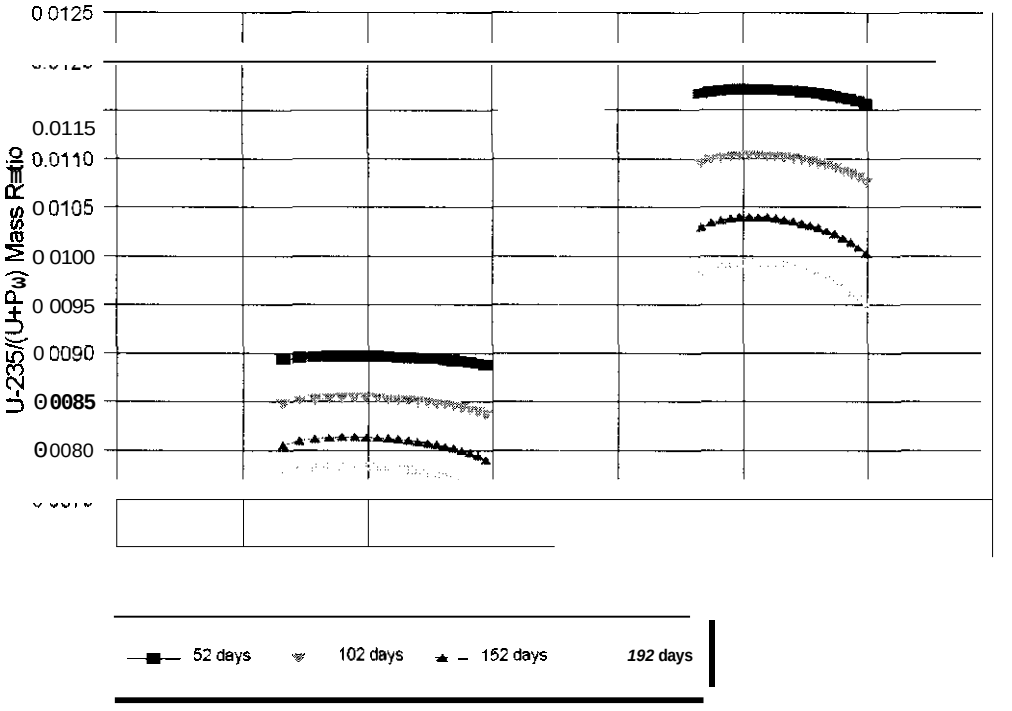


Figure 3. Radial ^{239}Pu Mass Ratio Profile, N Reactor Mark IA Fuel Assembly.

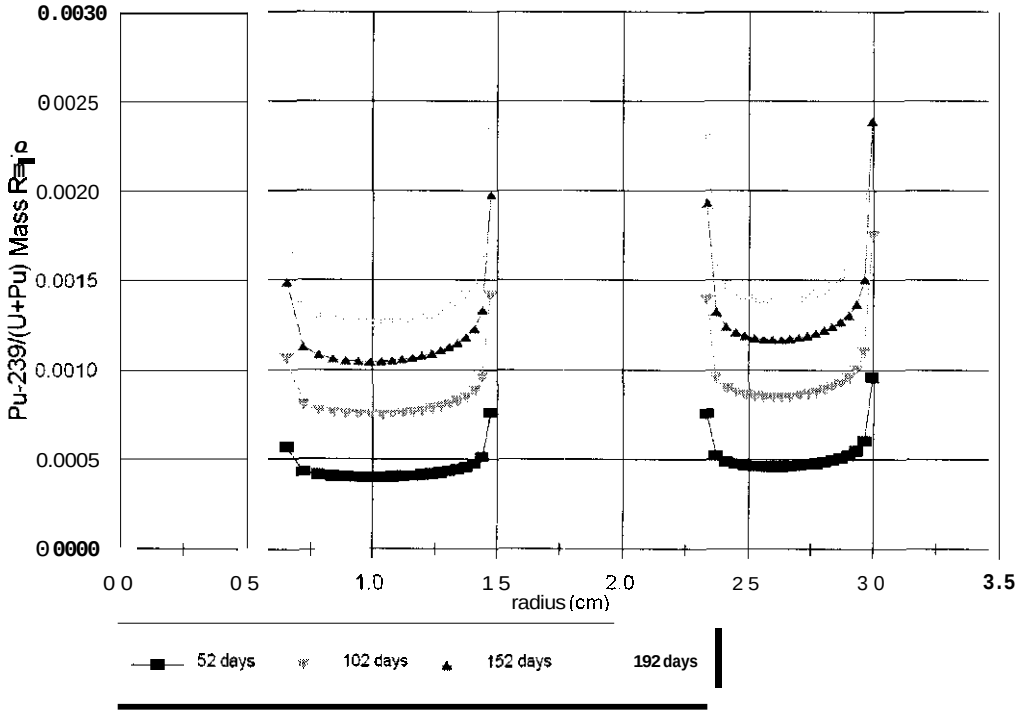


Figure **4.** Radial Fission Product/Heavy Metal Mass Ratio Profile, N Reactor Mark IA Assembly.

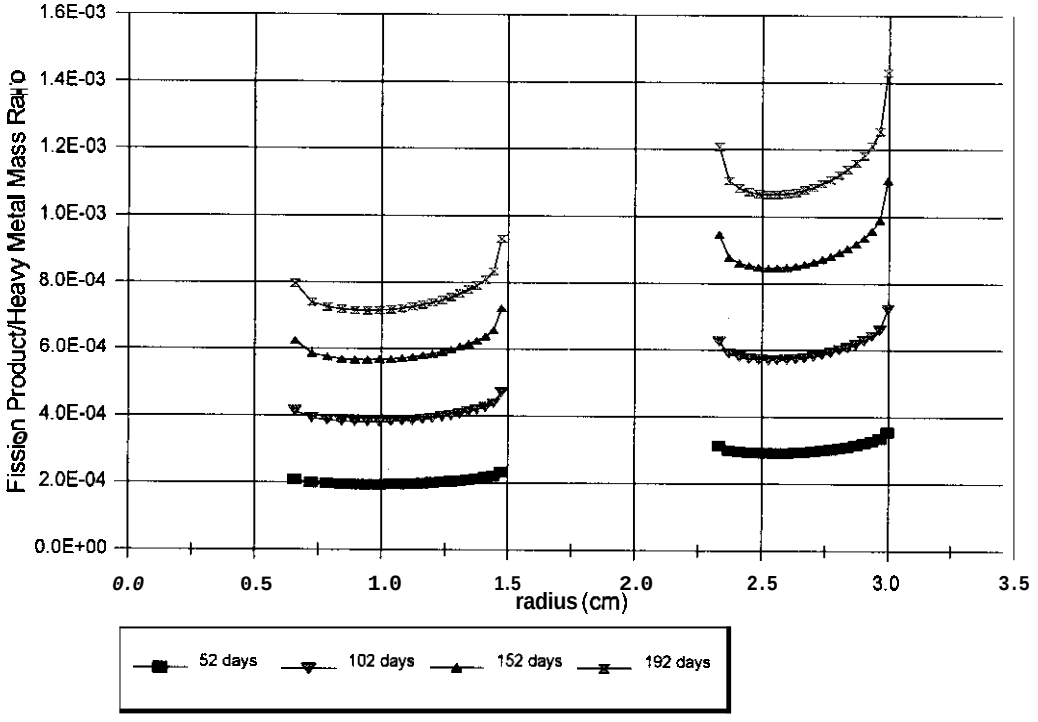
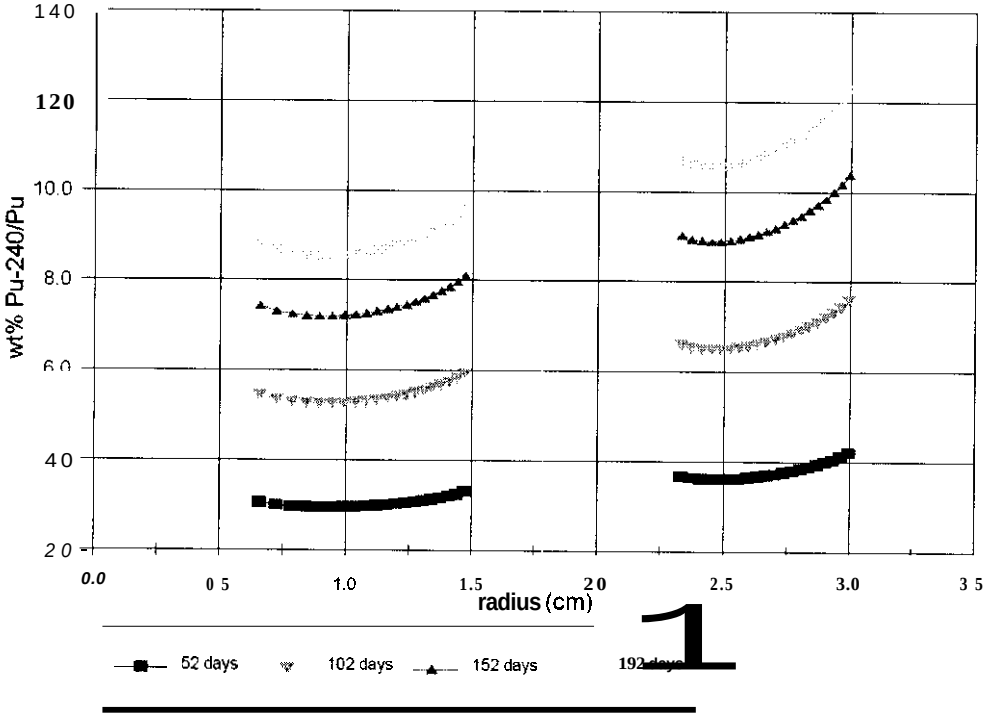


Figure *5.* Radial **wt%** ^{240}**Pu** in Total Pu, N Reactor **Mark** IA Fuel Assembly.



3.2. Axial Exposure Profiles

The axial exposure peaking functions are derived from an analytical model for power variation along the length of an N Reactor fuel assembly. Whereas the radial exposure effects within an N Reactor fuel assembly are characterized over small length scales (less than an inch), the axial variation occurs over a much larger length scale (several to many inches). It is therefore assumed that even though a detailed neutron transport bumup solution was used for the radial peaking effects (because it was archived from earlier analysis and was available), a neutron diffusion theory based model for axial peaking effects should suffice. Except for the endcaps (which explains why there is **an** axial peaking effect within the assembly), the fuel is essentially homogeneous along the length of the assembly. The axial exposure profile was assumed to be proportional to the axial power profile, which should be fairly accurately characterized by the thermal flux profile down the assembly (N Reactor was a thermal spectrum reactor). Assuming that there exists some "baseline", or asymptotic thermal flux at large distances from the endcaps, φ_t^{∞}, (arising from radial neutron transport), and given that the thermal flux rises to some peaked value at the fuel/endcap interface, $P_o\varphi_t^{\infty}$, the functional form of the axial profile should follow a decaying exponential. To see this, we note that the two-group neutron diffusion equations may be written as (taking the liberty that $\varphi_t = \varphi_2$):

$$\begin{aligned} -\nabla\cdot D_1\nabla\varphi_1 + \Sigma_{R_1}\varphi_1 &= \frac{1}{k}\left(\nu\Sigma_{f_1}\varphi_1 + \nu\Sigma_{f_2}\varphi_2\right) \\ -\nabla\cdot D_2\nabla\varphi_2 + \Sigma_{a_2}\varphi_2 &= \Sigma_{1\to 2}\varphi_1 \end{aligned} \qquad \textbf{(1)}$$

Taken by itself, the thermal diffusion equation inside the fuel region may be regarded as:

$$\nabla^2\varphi_2 - \frac{1}{L^2}\varphi_2 = 0 \qquad \textbf{(2)}$$

Within a fuel element, the fuel is homogeneous in the axial direction, and so the thermal diffusion coefficient may be taken outside the divergence operator. The equation is then divided by the diffusion coefficient, and the diffusion length L is defined in the usual way, $L = \sqrt{D_2/\Sigma_{a_2}}$.

There is no thermalization source (right-hand-side) in equation (2) because the incremental thermal neutrons (above φ_t^{∞}) can be considered as arising from a plane-source streaming in from the fuel/endcap interface, and are thus treated as a boundary condition. The classic neutron diffusion theory solution to the problem of a plane source of neutrons diffusing into a non-multiplying medium' is:

$$\varphi_t(z) = Ae^{-z/L} + Be^{+z/L} \qquad \textbf{(3)}$$

---

[1] Of course, the fuel **is** a multiplying medium, but it does not produce thermal neutrons (fission produces fast neutrons), and our model here concerns the thermal equation in a two-group model, and it assumes the thermal neutron source term to be from the endcap region.

Applying the boundary condition that the flux remain finite at large distances from the plane source (and, in fact, must decay away to the asymptotic limit φ_t^∞), B must equal zero. Applying the boundary condition that the flux is equal to $P_o\varphi_t^\infty$ at $z = 0$, yields the solution:

$$\frac{\varphi_t(z)}{\varphi_t^\infty} = 1 + (P_o - 1)e^{-z/L} \tag{4}$$

Actually, the asymptotic limiting value, φ_t^∞, may be regarded as a particular solution to the inhomogeneous differential equation:

$$\nabla^2\varphi_2 - \frac{1}{L^2}\varphi_2 = -\varphi_t^\infty/L^2 \tag{5}$$

Equation *(5)* shows that for large distances from the plane source (i.e., the Laplace term vanishes), the **flux** approaches the limiting value. Equation *(5)* describes the total thermal **flux,** while Equation *(2)* describes the incremental flux (above φ_t^∞).

Given the analytic form of the power profile (assumed proportional to the thermal flux), the peak to average formulae may be derived. If the entire volume V (over the range $0 < z < z_v$, *see* Figure *6)* is corroded off the end of the fuel, the average of equation (4) over this range is:

$$\begin{aligned}\frac{\bar{\varphi}_t(z_v)}{\varphi_t^\infty} &= \frac{1}{z_v}\int_0^{z_v}[1 + (P_o - 1)e^{-z/L}]dz \\ &= 1 + \frac{L}{z_v}(P_o - 1)(1 - e^{-z_v/L})\end{aligned} \tag{6}$$

Equation *(6)* may be evaluated at $z_v = a/2$, the half-length of the **fuel** assembly, to obtain the average over the entire length (this assumes that corrosion occurs at both ends of an element).

Thus, the "peak to average ratio", defined here as the average in the corroded off volume, divided by the average in the entire fuel assembly, is **equal** to:

$$\left(\frac{P}{A}\right)_{z_v} = \frac{\bar{\varphi}_t(z_v)}{\bar{\varphi}_t(a/2)} = \frac{1 + \frac{L}{z_v}(P_o - 1)(1 - e^{-z_v/L})}{1 + \frac{2L}{a}(P_o - 1)(1 - e^{-a/2L})} \tag{7}$$

In a similar fashion, the peak to average ratio over the range $z_v < z < z_v + \Delta z$ (see Figure ***6***) is:

$$\left(\frac{P}{A}\right)_{\Delta z} = \frac{\bar{\varphi}_t(z_v+\Delta z)}{\bar{\varphi}_t(a/2)} = \frac{1 + \frac{L}{\Delta z}(P_o-1)(e^{-z_v/L} - e^{-(z_v+\Delta z)/L})}{1 + \frac{2L}{a}(P_o-1)(1 - e^{-a/2L})} \quad \textbf{(8)}$$

Equation **(8)** is used, along with the radial peaking factors derived from section 3.1 above, to find the total peaking factor of the radial corrosion volume element, V,.

Both equations **(7)** and **(8)** have special limiting forms, and it is possible to show that, in equation (7), in the limit as z_v approaches zero, $\varphi_t(z_v) \rightarrow \varphi_t(0) = P_o\varphi_t^\infty$, and in equation (8), in the limit as Δz approaches zero, it is possible to show using series expansions that

$$\bar{\varphi}_t(z_v+\Delta z) \rightarrow \varphi_t^\infty[1 + (P_o - 1)e^{-z_v/L}] = \varphi_t(z_v) \quad \textbf{(9)}$$

These axial peak to average functions are therefore well behaved and have proper behavior in their limiting forms (i.e., no singularities exist). Equations (7) and **(8)** were incorporated into the Fortran program Pradnuc2 to serve as a phenomenologically-based model to estimate the axial peaking factors for corrosion volumes V and V_o as shown in Figure ***6***.

In Figure 6, V_o is depicted as radial pitting on both the inner and/or outer surfaces of a tubular N Reactor fuel element. The radial peaking factor tables produced by Profile3 (and input to Pradnuc2) assume that the maximum exposure uranium metal corrodes off first, which may be from either the inner or outer surfaces of the element. This is a conservative assumption, and not unrealistic. After the endcap comes off, the end of the tube is exposed, and radial penetration may take place from either inner or outer surface. Profile3 sorts the exposures so that every 5% increment of fuel that corrodes off originates from the surface with the higher exposure. Uranium that corrodes off either inner or outer elements will have adjusted exposures that depend on these radial and axial peaking functions. Volume V will have an exposure adjusted only by axial peaking, whereas volume V_o will have an exposure that is adjusted for both axial and radial peaking. Figure 7 illustrates an example axial thermal flux profile, with just the numerators of equations (7) and **(8)** plotted as constants over their respective intervals.

Figure *6*. Tubular Fuel Element, Showing Regions of Enhanced Exposure, Corroded Off.

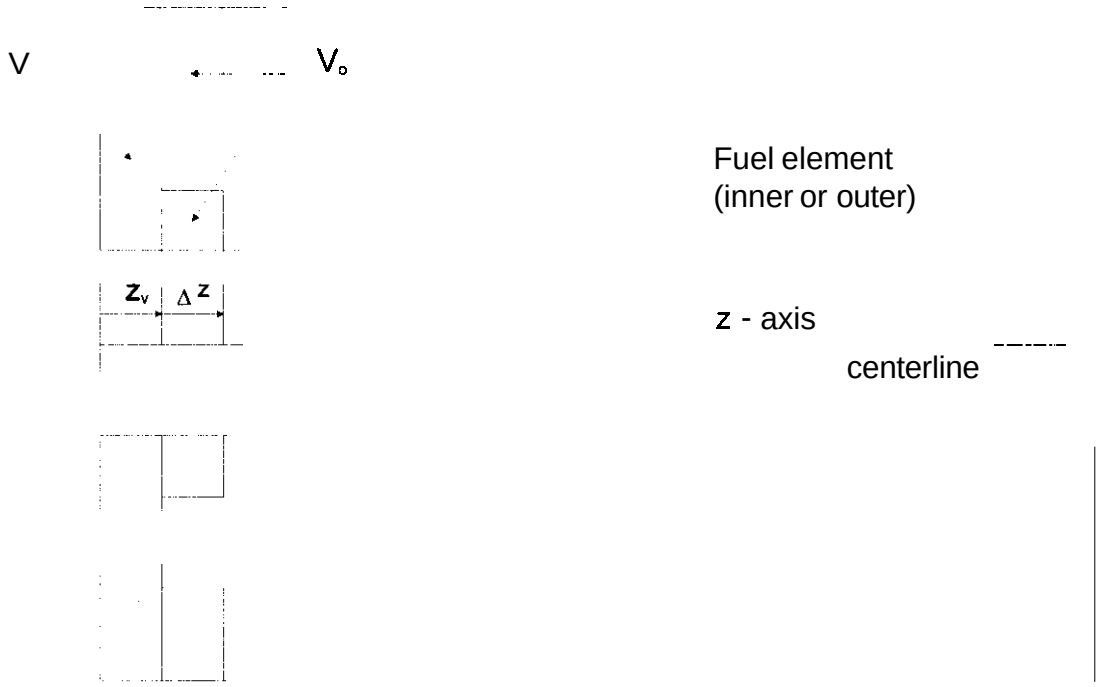
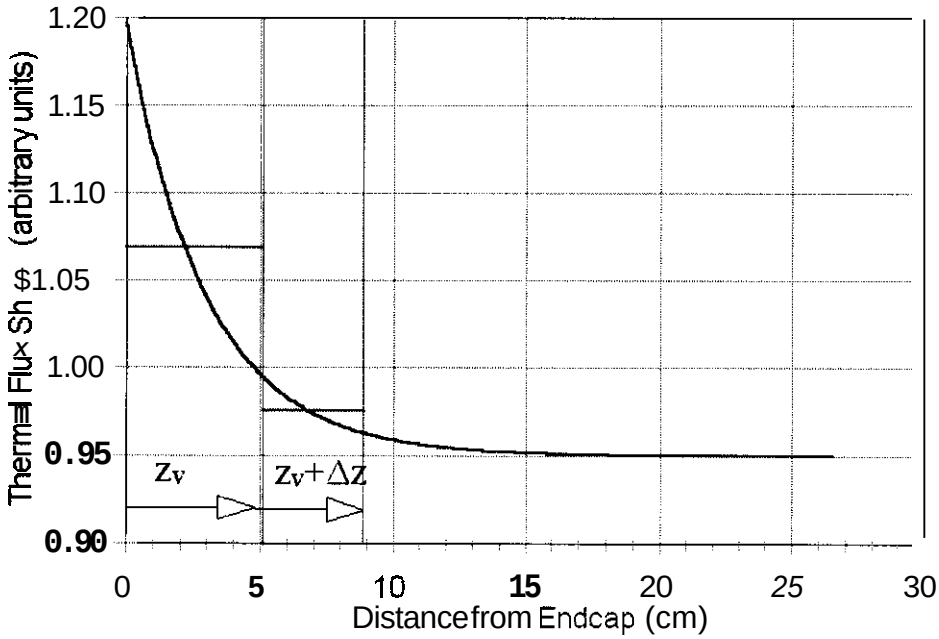


Figure 7. Typical Analytic Exposure Profile Used for Calculating Axial Peaking Functions.



For a particular inner element, the combined radial and axial exposure adjustment is:

$$E_i = \left[(P/A)_{z_v} V + (P/A)_r (P/A)_{\Delta z} V_o \right] \frac{(P/A)_{i/a}}{V+V_o} E_a \ , \qquad \textbf{(10)}$$

where: $(P/A)_{z_v}$ is evaluated using equation (7),
$(P/A)_{\Delta z}$ is evaluated using equation (8),
$(P/A)_r$ and $(P/A)_{i/a}$ are radial peaking factors from WIMS-E, and
E is the average exposure from the Safeguards and Accountability database.

More specifically, $(P/A)_r$ is the peak to average of the inner element, interpolated from the first column of file PAmkia.dat (or PAmkiv.dat), and $(P/A)_{i/a}$ is the ratio of inner element to assembly exposure, interpolated from the fourth column of file PAmkia.dat (or PAmkiv.dat), discussed in section 3.1. The exposure of the uranium metal corroding off an outer element is defined similarly, but the second and fifth columns of files PAmkia.dat or PAmkiv.dat are used. The exposure of the sludge coming from any given set of inners or outers is found from blending the values from equation (10) by the amount of inners and outers damaged, by key.

There are three categories of fuel element damage considered in this calculation note. "Breached" fuel is considered damaged, but contributes the least uranium to sludge (these fuel pieces contribute little to the sludge, but what they do contribute would be expected to have the highest exposure adjustment because only the outer edges are involved). The next category is "defected", and contributes more uranium to sludge, per assembly. The worst is "bad", which contributes even more uranium to the sludge, per assembly. Given assumptions on the fraction of each of the elements (inners or outers) in each of these three categories, the computer program Pradnuc2 combines exposure adjustments for both inners and outers [from equation (10) above] along with quantitative (i.e., parameterized) assumptions for how much of the corrosion volume arises from V versus V_o, and thus estimates the overall exposure adjustment for the key. This process is repeated for all keys in the K-East and K-West Basin database.

For example, if it is assumed that the fraction of breached inners is f_i, and the fraction of breached outers is f_o, then the adjusted exposure for the uranium in the sludge from this breached group of fuel pieces is:

$$E_{br} = \frac{E_i (V+V_o)_i f_i + E_o (V+V_o)_o f_o}{(V+V_o)_i f_i + (V+V_o)_o f_o} \qquad \textbf{(11)}$$

Finally, the three groups for each key are then combined according to the mass fraction each contributes to the total. If f_{br}, f_{df}, and f_{bd} are the mass fractions of each of the breached, defected, and bad groups of fuel that goes to sludge:

$$E_k^* = \frac{E_{br} f_{br} + E_{df} f_{df} + E_{bd} f_{bd}}{f_{br} + f_{df} + f_{bd}} \qquad \textbf{(12)}$$

This adjusted exposure, E_k^*, is used to calculate the corresponding **wt%** ^{240}Pu, according to WIMS-E (see section 3.3), and this **wt%** ^{240}Pu is written out to a Radnuc 2A input file. This entire process is repeated for all keys in the database.

After the adjusted exposure for the uranium that corrodes off into the sludge is found, the uranium mass in that key is adjusted to reflect just the uranium that went to the sludge. This is just the uranium in the combined regions V + V,. If v_i and v_o are the volume fractions of an inner element and an outer element to the total assembly volume, then the adjusted key mass (which corrodes off to the sludge) is found from the expression:

$$M_k^* = [(f_i v_i + f_o v_o)_{br} f_{br} + (f_i v_i + f_o v_o)_{df} f_{df} + (f_i v_i + f_o v_o)_{bd} f_{bd}] M_k \quad \textbf{(13)}$$

Numerical Value for Thermal Diffusion Length

The numerical values used for the thermal neutron diffusion length, ***L***, were calculated from two-group cross sections from the WIMS-E lattice model. WIMS-E solved the transport equation for the graphite moderated lattice, assuming hot operating conditions from DCODE. After the transport solution was complete, this 69-group solution was used to collapse the cross sections down to a two-group set, spatially collapsed over the fuel region out to the outer radius of the process tube, plus a second region extending from the process tube out to the cylindricized cell radius of the lattice. The motivation for this approach is that the diffusion length of interest (for characterizing the thermal flux relaxation along the fuel assembly - inside the fuel) is a more localized parameter than if the diffusion length were derived from cross sections resulting from collapsing the entire fuel-graphite lattice. By using the fuel cross sections, ***L*** should describe the axial spatial shape of the flux inside the fuel more accurately. Table **3** contains the results for Mark IV fuel, and Table 4 contains the results for Mark IA fuel. At this point, the calculation of the thermal neutron diffusion length is simple.

From Table **3,** for Mark IV fuel, the diffusion length is:

$$L = \sqrt{D_2/\Sigma_{a_2}} = \sqrt{0.54162/0.059164} = 3.02565 \quad \textbf{(14)}$$

From Table 4, for Mark IA fuel, the result is:

$$L = \sqrt{D_2/\Sigma_{a_2}} = \sqrt{0.54203/0.060352} = 2.99686 \quad \textbf{(15)}$$

These values for L are programmed into the Pradnuc2 code for Mark IV and Mark IA fuel assemblies, as are representative values for P , taken from 2DB4 calculations (Attachment 12).

Table 3. Two-group Cross Sections for Mark IV Fuel, for Calculating the Diffusion Length.

Mark IV fuel	Fuel region		Graphite moderator	
cross section	group 1	group 2	group 1	group 2
D	1.1403E+00	5.4162E-01	1.4618E+00	1.1215E+00
Σ_R	2.6423E-02	5.9164E-02	2.6345E-03	1.2459E-04
$\nu\Sigma$	7.5713E-03	7.7553E-02	0.0000E+00	0.0000E+00
$\Sigma_{g\to g'}$	4.6212E-01	1.2196E-02	2.7061E-01	2.6296E-03
	3.4596E-05	7.7118E-01	2.1018E-05	3.0922E-01
Σ_s	2.87120E-03	3.19047E-02	0.00000E+00	0.00000E+00

Table 4. Two-group Cross Sections for Mark **IA** Fuel, for Calculating the Diffusion Length.

Mark IA fuel	Fuel region		Graphite moderator	
cross section	group 1	group 2	group 1	group 2
D	1.1939E+00	5.4203E-01	1.4771E+00	1.1211E+00
Σ_R	2.7322E-02	6.0352E-02	2.6368E-03	1.2467E-04
$\nu\Sigma$	7.4955E-03	8.3871E-02	0.0000E+00	0.0000E+00
$E_{g\to g'}$	4.6794E-01	1.3750E-02	2.6988E-01	2.6319E-03
	3.4454E-05	8.1691E-01	2.0659E-05	3.0928E-01
Σ	2.85613E-03	3.45039E-02	0.00000E+00	0.00000E+00

3.3. WIMS-E **wt%** ^{240}Pu Model

A comparison was made between the assembly average **wt%** ^{240}Pu versus exposure relationships, predicted by WIMS-E versus the Safeguards and Accountability database. The Safeguards database contains both exposure (MWd/MTU) and **wt%** ^{240}Pu columns, although it is believed that the **wt%** ^{240}Pu column is a derived (i.e., calculated) result. Figure 8 contains both the Safeguards database (symbols) and the WIMS-E prediction. The WIMS-E burnup calculations were performed years ago, and are not now reproducible. The Safeguards database contains higher exposure fuel than the WIMS-E calculations include. However, the curve is smooth, and contains very little "concave down" curvature. If the WIMS-E relationship is extended quadratically, the result is shown in Figure 9. The WIMS-E relationship, extended quadratically, was incorporated into the Pradnuc2 program to predict **wt%** ^{240}Pu given exposure.

Figure 8. **wt%** ^{240}Pu as a Function of N Reactor Exposure.
Safeguards and Accountability Database versus WIMS-E Computer Code.

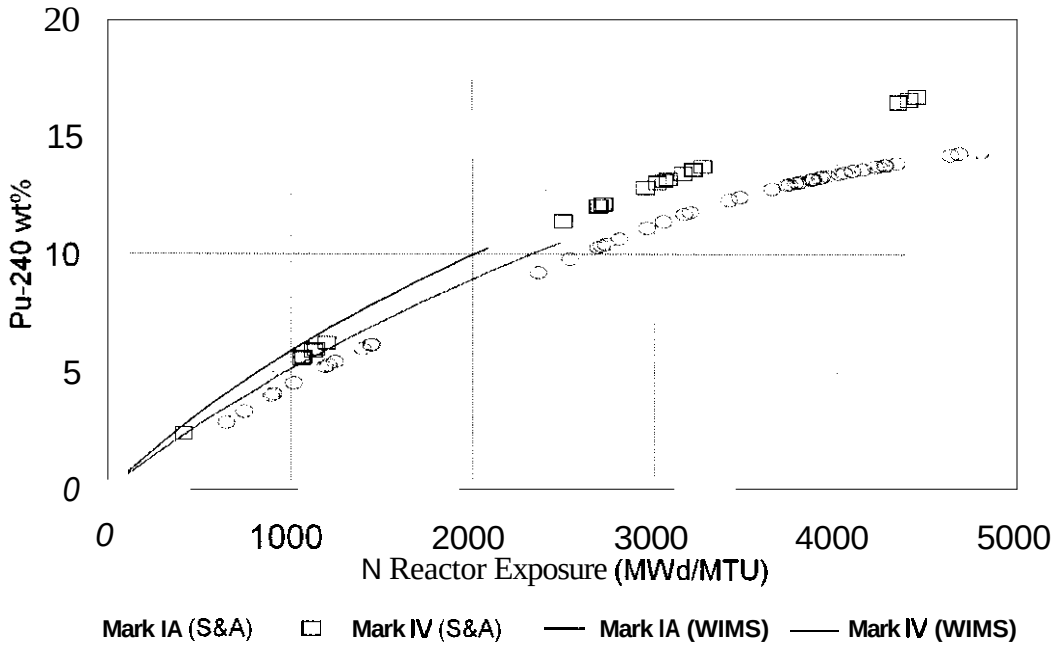
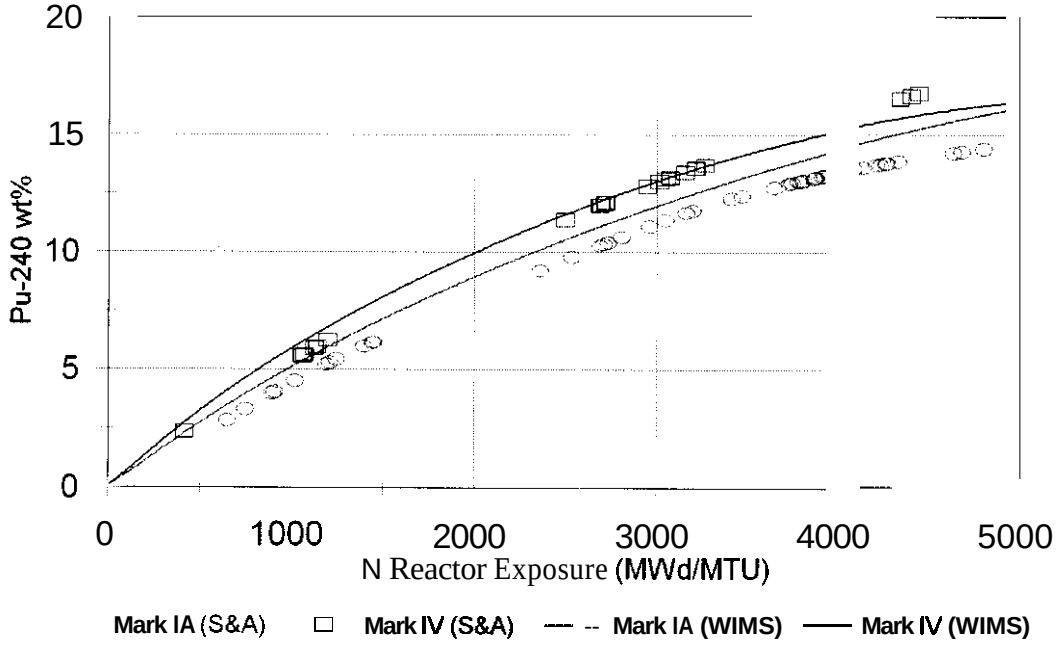


Figure 9. **wt%** ^{240}Pu as a Function of N Reactor Exposure.
Safeguards and Accountability Database versus Quadratic Extension to WIMS-E Results.



3.4. WIMS-E Validation

WIMS is a commercial lattice transport code available from AEA Technologies, Winfrith, England (Gubbins et al. 1982; Schwinkendorf 1989). The Schwinkendorf (1989) reference, while not formally released in 1989, was included as an attachment to a more recent report (Packer 2000). This code is no longer used by Fluor Federal Services. WIMS-E is a collection of modules for performing reactor physics functions such as one-dimensional transport calculations (in either cylindrical or plate geometries), two-dimensional transport calculations (using either (r,θ) or (x,y) geometries), bumup, and various other functions. WIMS-E uses the 69-group UKAEA 1986 cross section library. A later version (WIMS6a) used the 1994 UKAEA cross section library, which included transuranics up through curium. Validation calculations were performed for transuranic buildup in Mark IV fuel (Schwinkendorfet al., 1996), using this 1994 library. Agreement was shown to be excellent, even for the highest transuranic isotope considered, ^{244}Cm. This reference served as a technical justification for using WIMS-E to create a new set of improved N Reactor cross section libraries for ORIGEN2, and this was completed the following year (Schwarz 1997). The 1996 paper has been included in this calculation note as Attachment 3. ORIGEN2 was subsequently used to create the exposure data tables contained within version 2A of Radnuc.

LEU validation included critical experiment data from three sources (Schwinkendorf 1992, Appendix A). The first was the Mark IA fuel assembly critical experiments (Brown et al. 1965). The second (Hellens and Honeck 1962) was for 1.0 wt% ^{235}U-enriched rods and included measured boron poison effects. The published results were in the form of bucklings, not critical masses or k_{eff}. In order to compare WIMS-E results to the published results, WIMS-E results were output as two-group lattice-averaged cross sections for each experiment, and an analytical formula was used to calculate buckling for each case. WIMS-E results compared very well with experimental results, both as a function of water-to-uranium volume ratio and as a function of amount of poison added. The third source (Kupinski and Toffer 1970) contained data over a range of rod outside diameters (OD) and ^{235}U enrichments (0.444-cm [0.175-in.] OD to 7.62-cm [3.0-in.] OD and 3.0-wt% ^{235}U to 4.89-wt% ^{235}U). These results were in the form of critical masses in spherical and cylindrical geometry. Validations also exist for the earlier WIMS-D version in Schwinkendorf (1985a,1985b), which documents comparisons with annular uranium metal tubes over a range of enrichments from 0.947-wt% ^{235}U to 2.1-wt% ^{235}U.

4.0 Assumptions

The primary assumptions in this analysis are that radial exposure peaking factors may be characterized by WIMS-E bumup calculations, and axial exposure peaking factors may be modeled as analytic functions derived from neutron diffusion theory. The WIMS-E calculations include one-dimensional integral transport theory, using Bonalumi's method for cylindrical geometry, and accesses the 69-group "1986" UKAEA nuclear cross section library. WIMS-E performed this detailed transport calculation for the N Reactor graphite moderated lattice using hot operating conditions calculated by the DCODE fuel performance code. After a 10-day burnup step, the burnup equations were integrated in time for every mesh interval in the lattice model, followed by another transport theory calculation to obtain the flux solution for the next bum step. This cyclic process was repeated for 20 bumup steps.

In addition, sludge in the K Basins is assumed to be exclusively from the fuel now in the basins, and no contribution exists from fuel previously in the basins that was subsequently sent to the processing plants. Fuel that was sent to the processing plants did not reside in the K Basins for very long, thus this is likely a good assumption.

5.0 Input Data

The input data for this calculation note come from two sources. The first is the Safeguards and Accountability database, which is a listing of all N Reactor keys (and some single-pass reactor keys). For this analysis, the half-dozen or so single-pass reactor fuel keys have been neglected. Their contribution to the decay heat source term is negligible, because of their low mass, and considering their lengthy decay time (the last single-pass reactor was shut down by 1971). A key is a grouping of fuel assemblies that were discharged from the reactor during a particular charge/discharge operation. These keys therefore have a common discharge date. The Safeguards and Accountability database is reproduced in this calculation note as Attachment 4. The second source of input data is actually derived from transport theory bumup calculations from the WIMS-E computer code. Radial profiles of fission product to heavy metal mass ratio, consisting of twenty equal-volume mesh intervals for each fuel tube, and for each of 20 bumup steps, were reduced (by the computer code Profile3) to a set of numeric peaking factors, as described in section 3.1. The results are two data files (one for Mark IV and one for Mark IA fuel) read by the program Pradnuc2, along with the Safeguards database, to derive adjusted exposure factors for each key. The correlation between **wt%** ^{240}Pu and assembly average exposure was also derived from these WIMS-E bumup calculations, and used by Pradnuc2 to provide Radnuc 2A with the **wt%** ^{240}Pu corresponding to the adjusted exposure for the uranium that corroded off to the sludge. Radnuc 2A uses **wt%** ^{240}Pu to interpolate exposure results from ORIGEN2.

6.0 Calculations

The calculation of the design basis and safety basis sludge characterization was performed with the Radnuc 2A code on a modified Safeguards and Accountability database of fuel stored in the K Reactor basins. The Safeguards and Accountability database is a record of fuel, discharge date, and its average discharge exposure. The modified Safeguards and Accountability database took into account the increased exposure of the corroded fuel that contributed to the sludge due to the higher exposure fuel element profile that generally occurred at the corrosion site.

6.1. Description of Fuel Corrosion

An N Reactor fuel assembly is a tube-in-tube zircalloy-clad metallic uranium unit that was irradiated in a horizontal process tube, discharged to a load out pit where the cladding was often damaged due to normal handling practices, and stored in the K Reactor basins from the 1980s. A typical N Reactor fuel assembly is shown in Figure 1 as a reference. The corrosion typically initiated at the outer tube endcap region where exposures are highest. The progression of fuel corrosion is sketched in Figures 10 through 12. An intact fuel tube with its endcap and cladding is shown in Figure 10 prior to discharge.

Figure 10. End Region of Fuel Element Prior to Onset of Corrosion.

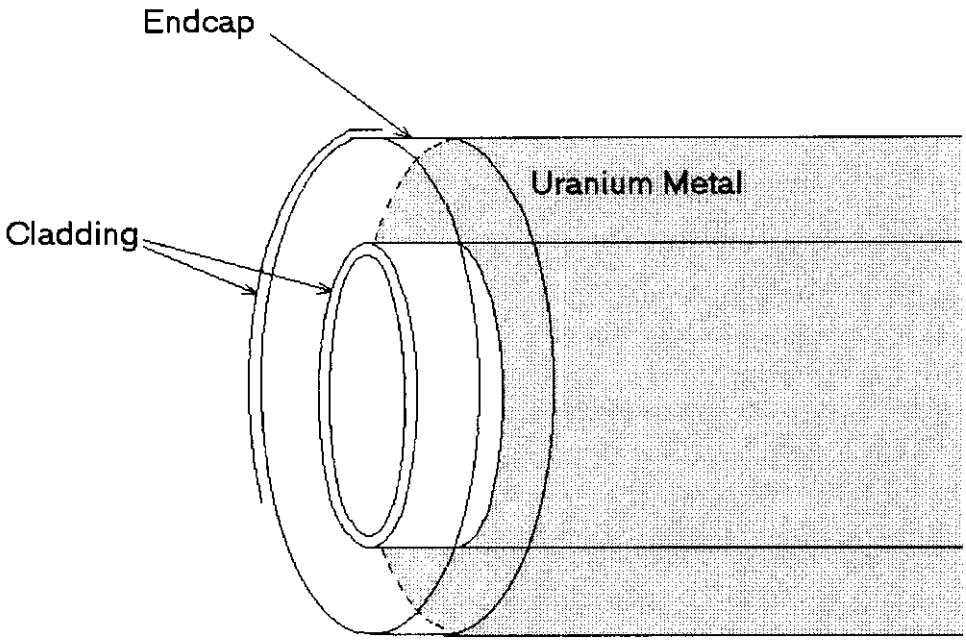


Figure 11. Onset of Corrosion at the Endcap/Fuel Element Interface.

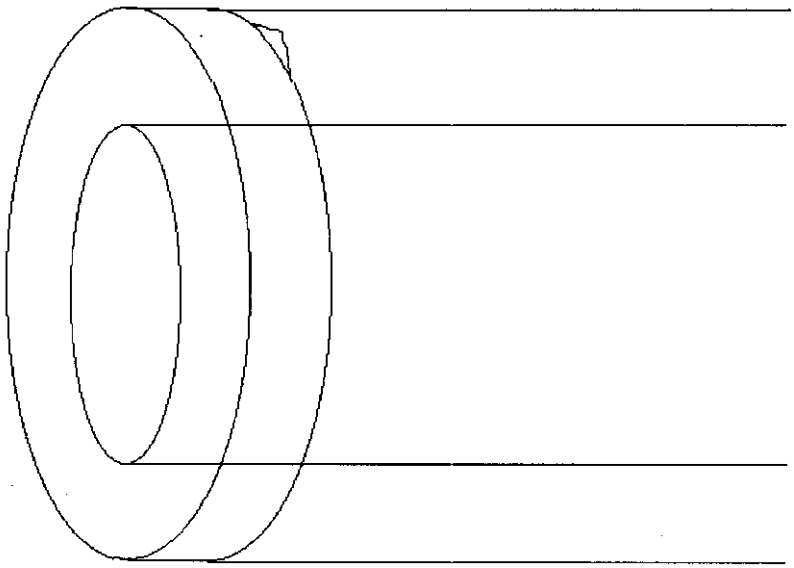


Figure 12. Corrosion Continues, Expands, and Peels Cladding Off.

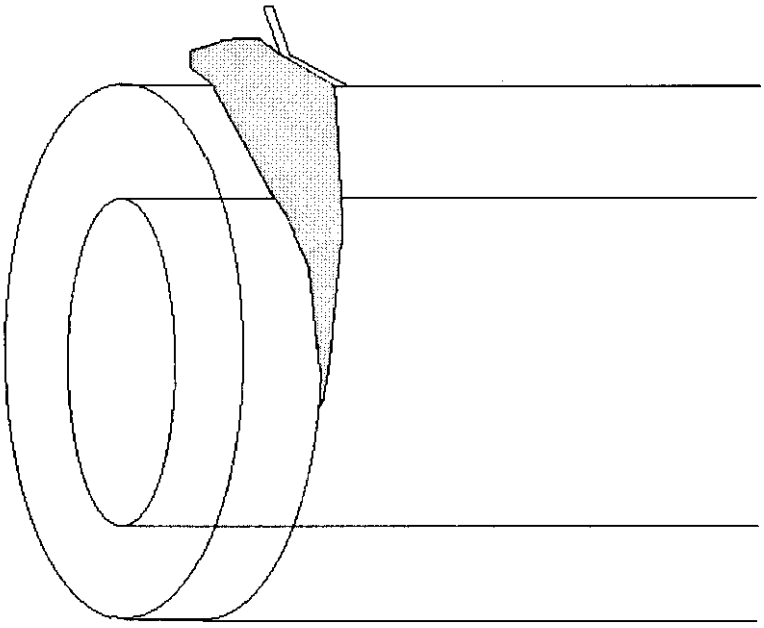
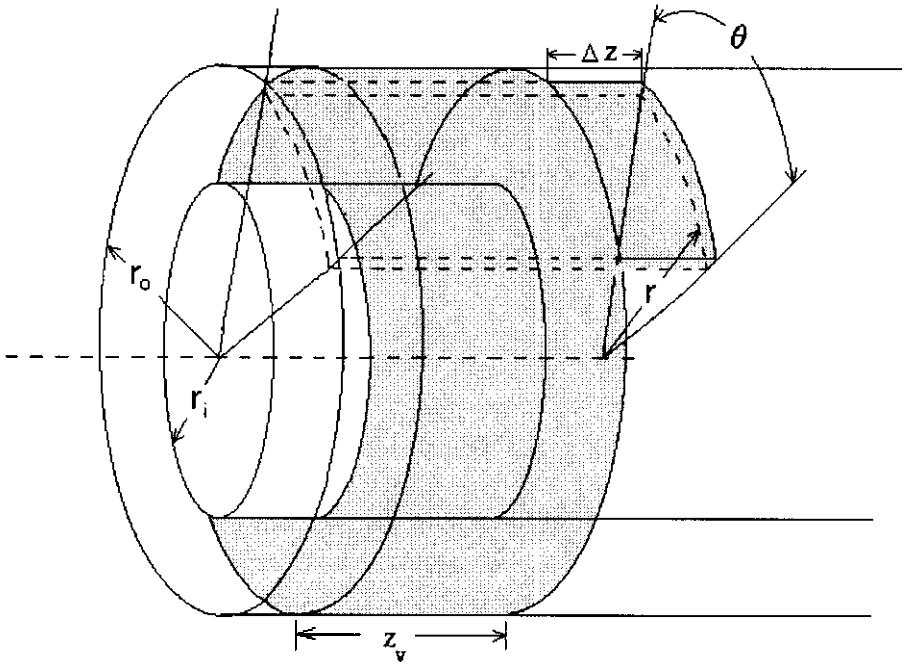


Figure 13. Three-Dimensional View of Figure 6, Showing Both Axial and Radial Corrosion.



Fuel separation from the endcap begins in Figure 11 due to fuel impact during discharge from the reactor. Corrosion opens the break at the endcap and progresses into the fuel region in Figure 12. The endcap will be forced off due to oxidation of the metal fuel (doubling its volume) and the corrosion will continue down the length of the fuel region like a burning cigar.

6.2 Fuel Corrosion Description Parameters

A survey of damaged fuel was conducted (Pitner, **1998)** to characterize the types and extent of damaged fuel. The results of this survey placed the examined fuel in four categories (intact, breached, defected, and bad). From the description and statistics of this study, the parameters listed in Table 5 were used in the fuel corrosion model to determine exposure peaking above average fuel element exposure. The peaking factors were then used to modify the Safeguards and Accountability database that was used as input to the Radnuc 2A calculations. The intact fuels have no damage. The breached, defected, and bad categories possess progressively more severe corrosion damage. The first four columns in Table 5 (inner and outer elements in each basin) are the fraction of that fuel component in each of these categories.

Table 5. Summary of Fuel Corrosion Categories and Model Parameters.

Category	K-East Basin		K-West Basin		Fuel Corrosion Parameters			
	Inners	Outers	Inners	Outers	Fuel Fraction F_f	Radial P_r	Axial P_z	Angular P_θ
Intact	0.86	0.49	0.84	0.50	0.00	0.00	0.00	0.00
Breached	0.09	0.09	0.14	0.39	0.01	0.25	0.25	0.05
Defected	0.04	**0.38**	**0.00**	*0.00*	0.05	0.25	0.25	0.25
Bad	0.01	0.04	0.02	0.11	0.15	0.25	0.25	**1.**00

These factors may be expressed mathematically using the following definitions:

$$
\begin{aligned}
(V+V_o) &= F_f\,\pi(r_o^2 - r_i^2)\frac{a}{2} \\
P_r &= \frac{(r_o - r)}{(r_o - r_i)} \\
P_z &= \frac{\Delta z}{(r_o - r_i)} \\
p_\theta &= \frac{\theta}{2x}
\end{aligned}
\qquad \textbf{(16)}
$$

In equation **(16),** r_o and r_i are the outer and inner radii of the fuel element, a is the length, r **is** the inner radius of corrosion volume V_o, Δz is the axial extent of V_o, and θ is the angle defining V_o.

From these definitions, the volume V_o is found from:

$$V_o = \pi(r_o^2 - r^2)\,\Delta z\,P_\theta \qquad \textbf{(17)}$$

Equation **(16)** gives the total corrosion volume, and *so* the end region corrosion volume V is simply the difference between the two. Given V, the axial extent of V is found from:

$$z_v = \frac{TI}{\pi(r_o^2 - r_i^2)} \qquad \textbf{(18)}$$

The parameters z_v and Δz are fed into equations (7) and **(8),** the axial peaking functions, and the radial extent of corrosion, by volume,[2] is:

$$C_r(\%) = 100\,\frac{(r_o^2 - r^2)}{(r_o^2 - r_i^2)} \qquad \textbf{(19)}$$

Thus, the corrosion model parameters completely define the geometry of V and V,, and provide the necessary input to the peaking functions.

[2] **This parameter, along with exposure** (MWd/MTU), **are used** to **interpolate the radial peaking factor** from **the** WIMS-E **result tables.**

6.3 Comparison of Model With Average K-East Basin Floor Sample

For validation, the model results were compared with the K-East Basin floor samples. This comparison was considered to be the most representative because variations in fuel exposures tended to be blended and averaged out by contributions of all canisters. For example, normalized fuel exposure within an N Reactor process tube could typically vary from a peak of 1.6 for fuel in the central positions to a lower value of 0.06 for fuel in the ends of the tube due to the axial power distribution. In addition, the ratio of process tube exposure to average exposure in a discharge would typically vary from a high of 1.5 to a low of 0.4. Extensive core analysis of N Reactor has been performed in the past (NUSAR 1988), and computed neutron flux profiles have been compared with measured flux shapes acquired using the Traveling Wire Flux Mapper (TWFM) system. Predicted peak to average values compare well with measured values for the nine zones for which TWFM data traces were obtained. Figure 4.3-47 from NUSAR (1988) is reproduced herein as Figure 14. The exposure uncertainty of individual fuel elements in a key can thus be significant and lead to incorrect comparisons to predicted data. Floor sludge measurement data in the K-East Basin were reported in WHC-SP-1182 (Makenas, 1996) and Welsh (2001). The mean values of the data and model predictions are listed in Table 6.

The measured data were converted to isotopic activities per gram of uranium so that comparisons could be made with the predictive model. The predictive model determined the decay time of the K-East Basin keys to correspond to September 1, 1995, which corresponds to the analysis date in WHC-SP-1182 (Makenas, 1996).

Considering the large standard deviations in the measured data, the comparison of model predictions with the measured data show good agreement for ^{241}Am, $^{239/240}Pu$, ^{238}Pu, ^{137}Cs, ^{134}Cs, ^{154}Eu, and ^{90}Sr. A general observation is that a retention factor of **0.7** can be safely applied to the model prediction for Cs and Sr to account for depletion by solubility from fine fuel particles and fuel oxide. However, this factor will not be applied to the predicted results in order to be conservative and to allow for retention of these elements in the sludge and fuel particles coming from the washing machine that will not have time to dissolve from the removed corrosion.

The ^{237}Np content depends on the ^{236}U content of recycled fuel. The ^{236}U content assumed in ORIGEN2 (which affects Radnuc 2A) was 500 ppm, which is reasonable. A correction factor of 2.3, as per Table 6, will be applied to the predicted results to provide a conservative basis.

Cobalt is produced by contamination activation of cladding impurities, stainless steel fuel spacer pads, and plate out of contamination on the fuel during reactor operation. No indication was found of cobalt as a fuel contaminant. No mechanism can thus be identified to explain cobalt production in sludge from fuel corrosion. Radnuc 2A contains a model to generate cobalt from cladding impurity activation, which relates to exposure and decay time. From Table 6, the model results for ^{60}Co will be multiplied by a factor of 7.2 to provide a conservative basis.

The model prediction for ^{152}Eu is lower than the measured data by a factor of 3.68. The measured results in WHC-SP-I 182 (Makenas, 1996) indicate that the ^{152}Eu data were consistently less than the reported values apparently from measurement difficulties. Thus, the model results for ^{152}Eu will be multiplied by a factor of 3.7 to provide a conservative basis.

Figure 14. Computed vs. Measured N Reactor Neutron **Flux** Distributions from NUSAR (1988).

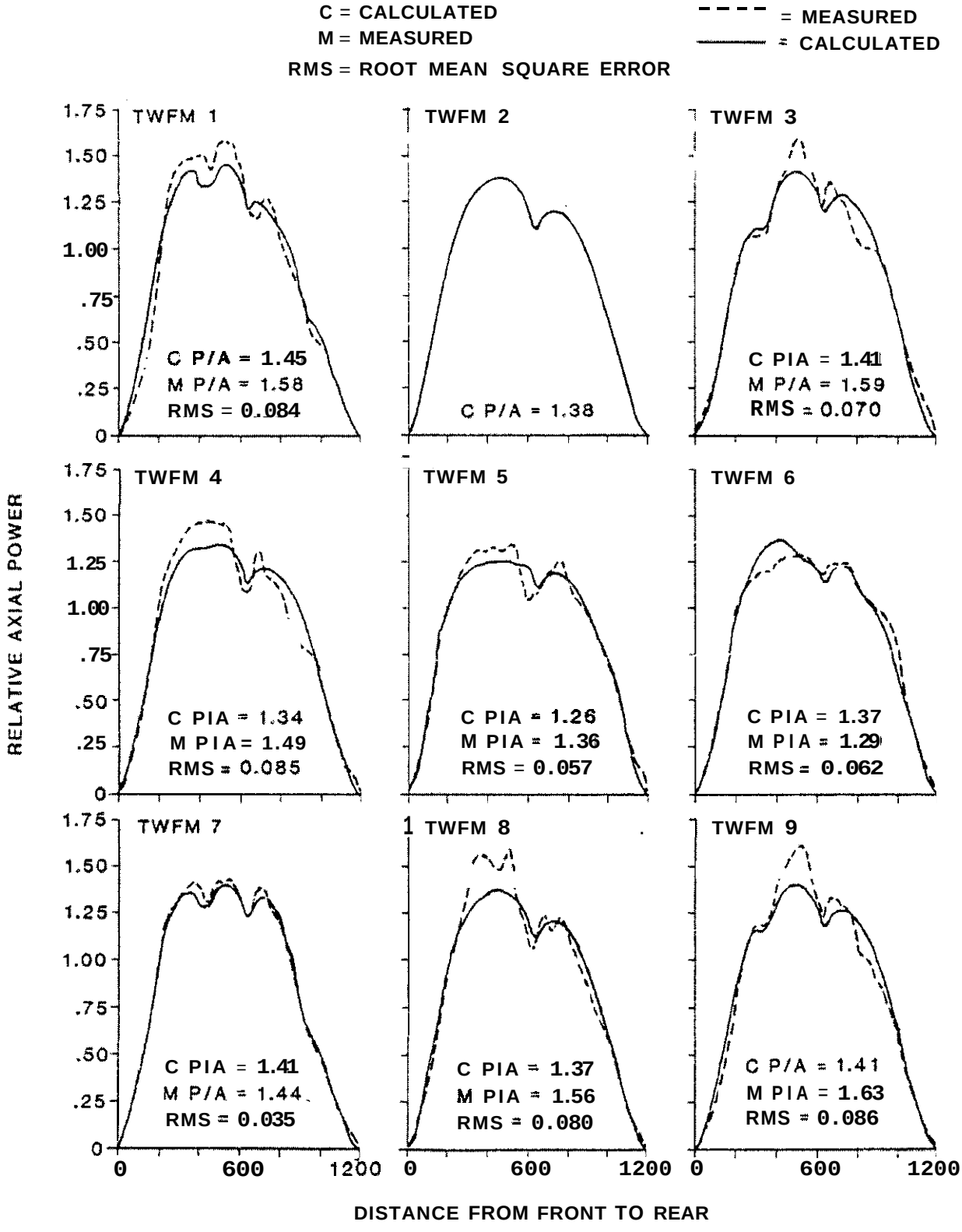


Table 6. K-East Basin Mean Floor Sludge Activity Compared with Model Predictions.

Isotope	Measured Activity (μ Ci/g)	Uranium (μ g/g)	Normalized Measured Activity (Ci/g-uranium)	Model Prediction (Ci/g-uranium)	Ratio of Measured Mean Activity to Model Prediction
^{241}Am	2.15 e+01 ± 1.94 e+01	9.64 e+04	2.23e-04 ± 2.01 e-04	1.95e-04	1.14
^{237}Np	6.43 e-03 ± 3.30 e-03	9.64 e+04	6.67e-08 ± 3.42 e-08	2.93e-08	2.28
$^{239/240}Pu$	2.25 e+01 ± 1.84 e+01	9.64 e+04	2.33e-04 ± 1.91 e-04	2.01e-04	1.16
^{238}Pu	4.30 e+00 ± 5.25 e+00	9.64 e+04	4.46e-05 ± 5.44 e-05	6.38e-05	0.70
^{60}Co	1.75 e+00 ± 1.29 e+00	9.64 e+04	1.82e-05 ± 1.34 e-05	2.54e-06	7.17
^{137}Cs	4.42 e+02 ± 5.67 e+02	9.64 e+04	4.58e-03 ± 5.88 e-03	6.76e-03	0.68
^{134}Cs	1.06 e-01 ± 1.43 e-01	9.64 e+04	1.10e-06 ± 1.49 e-06	1.79e-05	0.06
^{152}Eu	1.92 e-01 (1)	9.64 e+04	1.99e-06	5.41e-07	3.68
^{154}Eu	1.92 e-01 ± 3.29 e-01	9.64 e+04	3.49e-05 ± 3.41 e-05	6.81e-05	0.51
^{155}Eu	1.66 e+00 ± 1.70 e+00	9.64 e+04	1.72e-05 ± 1.77 e-05	1.54e-05	1.12
^{90}Sr	3.30 e+02 ± 3.78 e+02	9.64 e+04	3.43e-03 ± 3.92 e-03	5.07e-03	0.68

'''Single data point. Standard deviation does not apply

6.4 Comparison of Model with Maximum K-East Basin Floor and Canister Samples

The model was used to predict maximum activity levels of isotopes that are available in K-East Basin floor and canister samples. The key data in the basins were first calculated and sorted by isotopic activity per MTU of fuel to select **20** percent of the basin inventory with the highest activity decayed to May **31,** 1998. This reduced database will be referred to herein as the Safety Basis database, and is listed in Attachment 5.

Some of the fuel in these keys have higher than average exposure due to the reactor axial power distribution and discharge exposure factors discussed in Section **6.3.** The combined effect of these parameters is **1.6** (axial fuel power), multiplied by **1.5** (process tube exposure), which results in a factor of **2.4** times the average key exposure, expressed in MWd/MTU. The highest fuel exposure in the basins could therefore be estimated by multiplying each key exposure in Attachment 4 by a factor of **2.4.** Unfortunately, this results in exposures that exceed the region of applicability of the quadratic correlation of **wt%** ^{240}Pu to exposure in MWd/MTU as discussed in Section **3.3** (exposures this high produce incorrect **wt%** ^{240}Pu values). Radnuc **2A** uses key exposure expressed in **wt%** ^{240}Pu, and so this calculation cannot be made directly. Instead, Radnuc **2A** was executed using exposures unadjusted by the factor **2.4,** and the resulting activity and decay heatings were then adjusted by multiplying by **2.4.** This simpler approach will yield conservative results for fission products. Activities of actinides such as ^{241}Am, that build up from multiple parents, should be determined by more accurate models.

The correction factors of ^{60}Co, ^{237}Np, and ^{152}Eu, were incorporated into the predicted results. The results of the model predictions and comparisons with measured data are listed in Table 7. The agreement with the predictive model is reasonable.

Table 7. K-East Basin Floor Safety Basis Sludge Maximum Activity Compared with Model Predictions.

Isotope	Maximum Measured Activity (Ci/g-uranium)		Maximum Activity Model Prediction (Ci/g-uranium)	Ratio of Measured Maximum Activity to Model Prediction
	Basin Floor	Canister		
^{241}Am	7.39e-04	3.62e-04	7.42e-04	1.00
^{237}Np	1.27e-07	3.32e-08	2.17e-07	0.59
$^{239/240}$Pu	6.29e-04	3.00e-04	6.36e-04	0.99
^{238}Pu	2.27e-04	8.35e-05	2.32e-04	0.98
^{60}Co	5.60e-05	7.48e-05	3.90e-05	1.92

Isotope	Maximum Measured Activity (Ci/g-uranium)		Maximum Activity Model Prediction (Ci/g-uranium)	Ratio of Measured Maximum Activity to Model Prediction
	Basin Floor	Canister		
^{137}Cs	1.74e-02	5.12e-03	2.05e-02	0.85
^{134}Cs	4.08e-06	3.78e-06	2.08e-05	0.20
^{152}Eu	1.99e-06	---	6.42e-06	0.31
^{154}Eu	1.22e-04	5.66e-05	2.19e-04	0.56
^{155}Eu	5.97e-05	2.42e-05	2.85e-05	2.10
^{90}Sr	1.26e-02	5.71e-03	1.51e-02	0.84
^{99}Tc	---	2.55e-06	4.48e-06	0.57

6.5 Comparison with Average Radionuclide Inventory in HNF-SD-SNF-TI-009

A comparison was made with the average radionuclide inventory reported in Table 2.4 in the Packer (1999) reference. The average radionuclide inventory of the predicted model was determined from the total K Basin inventories decayed to May 31, 1998. The results of this calculation and activities listed in the referenced report are listed in Table 8.

Table 8. Comparison with Average Radionuclide Inventory of HNF-SD-SNF-TI-009 Table 2.4 and Predicted Results.

Nuclide	Activity (Ci/MTU)		Ratio (TI-009/Model)
	HNF-SD-SNF-TI-009	Predictive Model	
^{3}H	1.74e+01	1.93e+01	0.90
^{14}C	3.30e-01	3.75e-01	0.88
^{55}Fe	8.76e-01	9.67e-01	0.91
^{60}Co	1.89e+00	1.50e+01	0.13
^{63}Ni	2.14e+00	2.43e+00	0.88
^{85}Kr	2.81e+02	3.12e+02	0.90
^{90}Sr	4.81e+03	5.38e+03	0.89

Nuclide	Activity (Ci/MTU)		Ratio (TI-009/Model)
	HNF-SD-SNF-TI-009	Predictive Model	
^{90}Y	4.81e+03	5.38e+03	0.89
^{99}Tc	1.37e+00	1.55e+00	0.88
^{106}Ru	8.67e-01	1.02e+00	0.85
^{106}Rh	8.67e-01	1.02e+00	0.85
^{113m}Cd	1.69e+00	1.95e+00	0.87
^{125}Sb	1.60e+01	1.72e+01	0.93
^{125m}Te	3.90e+00	4.20e+00	0.93
^{129}I	3.03e-03	3.48e-03	0.87
^{134}Cs	7.57e+00	9.31e+00	0.81
^{137}Cs	6.29e+03	7.09e+03	0.89
^{137m}Ba	5.95e+03	6.73e+03	0.88
^{144}Ce	4.35e-01	5.02e-01	0.87
^{144}Pr	4.30e-01	4.96e-01	0.87
^{147}Pm	2.20e+02	2.36e+02	0.93
^{151}Sm	8.38e+01	8.83e+01	0.95
^{152}Eu	4.50e-01	1.99e+00	0.23
^{154}Eu	5.09e+01	6.52e+01	0.78
^{155}Eu	1.05e+01	1.15e+01	0.91
^{234}U	4.16e-01	4.08e-01	1.02
^{235}U	1.60e-02	1.53e-02	1.05
^{236}U	6.05e-02	6.34e-02	0.95
^{238}U	3.31e-01	3.30e-01	1.00
^{238}Pu	5.28e+01	6.79e+01	0.78
^{239}Pu	1.04e+02	1.31e+02	0.79
^{240}Pu	5.67e+01	8.20e+01	0.69
^{241}Pu	3.18e+03	3.96e+03	0.80

Nuclide	Activity (Ci/MTU)		Ratio (TI-009/Model)
	HNF-SD-SNF-TI-009	Predictive Model	
^{241}Am	1.79e+02	2.25e+02	0.80
^{244}Cm	6.86e-01	1.18e+00	0.58
Total	2.61e+04	2.98e+04	0.88

6.6 Comparison with Safety/Regulatory Assessment Basis Summary (Packer 1999)

A comparison was made with the Safety/Regulatory basis inventory reported in Table 2.6 in Packer (1999). The Safety/Regulatory basis inventory of the predicted model was determined by selecting the top 20 percent of the fuel mass that possessed the highest specific activity. This reduced database provided basin inventories, discussed in Section 6.4, and was then decayed to May 31, 1998.

Table 9. Comparison with Maximum Radionuclide Inventory of HNF-SD-SNF-TI-009 Table 2.6 and Predicted Results.

Nuclide	Activity (Ci/MTU)		Ratio (TI-009/Model)
	HNF-SD-SNF-TI-009	Predictive Model	
^{238}Pu	1.33e+02	2.44e+02	0.55
^{239}Pu	1.73e+02	3.78e+02	0.46
^{240}Pu	1.37e+02	2.71e+02	0.51
^{241}Pu	6.82e+03	1.43e+04	0.48
^{242}Pu	8.71e-02	1.44e-01	0.61
^{241}Am	4.34e+02	7.73e+02	0.56
^{242}Cm	3.08e-01	4.59e-01	0.67
^{244}Cm	4.47e+00	5.68e+00	0.79
^{90}Sr	6.93e+03	1.66e+04	0.42
^{137}Cs	9.66e+03	2.24e+04	0.43
Total	2.43e+04	5.50e+04	0.44

7.0 Results

7.1 Design Basis Sludge Model

The Design Basis, or average, radionuclide inventory using the predictive model was determined from the total K Basin inventories decayed to May 31,2001. The results of this calculation are listed in Table 10.

Table 10. Average Radionuclide Inventory Results for Design Basis.

Nuclide	Activity (Ci/MTU)	Heating Rate (Btu/hr/MTU)
^{3}H	1.63e+01	1.87e-03
^{14}C	3.75e-01	3.75e-04
^{55}Fe	4.35e-01	4.96e-05
^{60}Co	1.01e+01	5.32e-01
^{63}Ni	2.38e+00	8.20e-04
^{85}Kr	2.56e+02	1.31e+00
^{90}Sr	4.99e+03	1.98e+01
^{90}Y	4.99e+03	9.43e+01
^{99}Tc	1.55e+00	2.66e-03
^{106}Ru	1.30e-01	2.65e-05
^{106}Rh	1.30e-01	4.23e-03
^{125}Sb	8.14e+00	8.71e-02
^{134}Cs	3.39e+00	1.18e-01
^{137}Cs	6.64e+03	2.28e+01
^{137m}Ba	6.28e+03	8.38e+01
^{144}Ce	3.45e-02	7.81e-05
^{151}Sm	8.62e+01	3.45e-02
^{152}Eu	1.71e+00	2.63e-02
^{154}Eu	5.14e+01	1.57e+00
^{155}Eu	7.57e+00	1.87e-02

Nuclide	Activity (Ci/MTU)	Heating Rate (Btu/hr/MTU)
^{237}Np	7.18e-02	7.05e-03
^{234}U	4.08e-01	3.96e-02
^{235}U	1.53e-02	1.41e-03
^{236}U	6.34e-02	5.80e-03
^{238}U	3.30e-01	2.82e-02
^{238}Pu	6.64e+01	7.39e+00
^{239}Pu	1.31e+02	1.36e+01
^{240}Pu	8.20e+01	8.56e+00
^{241}Pu	3.42e+03	3.63e-01
^{242}Pu	3.66e-02	3.63e-03
^{241}Am	2.41e+02	2.70e+01
^{242}Cm	1.11e-01	1.37e-02
^{244}Cm	1.05e+00	1.24e-01
Total	2.73e+04	2.82e+02

7.2 Safety Basis Sludge Model

The Safety/Regulatory Basis inventory of the predicted model was determined from the top 20 percent activity basin inventories discussed in Section 6.4, decayed to May 31,2001.

Table 11. Radionuclide Inventory Results for Safety Basis.		
Nuclide	Activity (Ci/MTU)	Heating Rate (Btu/hr/MTU)
^{60}Co	3.10e+01	1.64e+00
^{90}Y	1.55e+04	2.92e+02
^{99}Tc	4.84e+00	8.26e-03
^{134}Cs	1.05e+01	3.64e-01
^{137m}Ba	1.98e+04	2.65e+02
^{151}Sm	2.39e+02	9.53e-02
^{152}Eu	5.95e+00	9.19e-02

Nuclide	Activity (Ci/MTU)	Heating Rate (Btu/hr/MTU)
^{154}Eu	1.95e+02	5.96e+00
^{155}Eu	2.11e+01	5.19e-02
^{237}Np	2.23e-01	2.19e-02
^{234}U	9.74e-01	9.42e-02
^{235}U	3.42e-02	3.16e-03
^{236}U	1.72e-01	1.56e-02
^{238}U	8.01e-01	6.81e-02
^{238}Pu	2.38e+02	2.65e+01
^{239}Pu	3.78e+02	3.95e+01
^{240}Pu	2.71e+02	2.83e+01
^{241}Pu	1.24e+04	1.31e+00
^{242}Pu	1.44e-01	1.43e-02
^{241}Am	8.33e+02	9.32e+01
^{242}Cm	4.52e-01	5.58e-02
^{244}Cm	5.08e+00	5.96e-01
^{90}Sr	1.55e+04	6.14e+01
^{137}Cs	2.09e+04	7.20e+01
Total	8.62e+04	8.88e+02

8.0 Conclusions

This calculation note provides best-estimates for design basis and safety basis radioisotopic source terms for both K-East and K-West Basin sludge. The neutronics (physics) based modeling provides a first-principles, but conservative estimate for these source terms. The source terms should be applied to fuel wash, canister, and floor sludge, including the fuel piece slurry component of the wash sludge. The source terms are based on basic reactor physics principles, known N Reactor operating characteristics, observed fuel damage (which is the primary source of fuel related sludge), and comparison with sludge characterization measurements, and are provided on a per unit mass **of** uranium basis. Source terms on a per unit mass of the various sludge streams can be determined based on characterization data on the uranium concentration, in each sludge stream.

9.0 List of Symbols

$a/2$ = half-length of fuel assembly
D_g = neutron diffusion coefficient for energy group g
L = thermal neutron diffusion length
P_o = peaking factor for axial thermal flux distribution
P/A = peak to average ratio
V = corrosion volume at end of assembly
V_o = volume of radial corrosion penetration
z_v = penetration distance for corrosion into the end of a fuel assembly
= axial distance associated with corrosion volume V
Δz = length dimension (along assembly) of radial corrosion pit, and is assumed to start at $z = z_v$

Greek

φ_g = neutron flux for energy group g
Σ_{R_1} = removal cross section from energy group 1
$= \Sigma_{a_1} + \Sigma_{1\to 2}$
Σ_{a_g} = absorption cross section for group g
$\Sigma_{1\to 2}$ = scattering cross section group 1 to group 2
$\nu\Sigma_{f_g}$ = fission cross section for group g multiplied by number of neutrons per fission

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Attachment 1: Profile3.for Source Listing

```
      program peak
      implicit real*8 (a-h,o-z)
      real*4 pc
      character*7 answ
      dimension radi(40), fp(40,20), fi(40), voli(40), ri(42)
      dimension avi(20), avo(20), avt(20)
      dimension ve(20,20,2), fe(20,20,2), vae(40,20), fae(40,20)
      common /s1/ vs(20,2), fs(20,2), va(40), fa(40)
      common /s2/ pki(20,19), pko(20,19), pka(20,19),
     1            pa1(20,19), pa2(20,19), xbp(20), cbp(19)
      dimension dxbp(20)
      data dxbp / 2.,  12.,  22.,  32.,  42.,  52.,  62.,  72.,
     1           82.,  92., 102., 112., 122., 132., 142., 152.,
     2          162., 172., 182., 192. /
      data cbp  / 5., 10., 15., 20., 25., 30., 35., 40., 45., 50.,
     1           55., 60., 65., 70., 75., 80., 85., 90., 95. /
      pi = 3.141592654
      write (6,*) ' Do you want Mark IA or Mark IV analysis?'
      read  (5,7) answ
    7 format(a7)
      if(answ .eq. "Mark IV") then
       rate = 10.830
       open(unit=7, file='FPmkiv.txt', status='old', err=900)
      elseif(answ.eq. "Mark IA") then
       rate = 12.931
       open(unit=7, file='FPmkia.txt', status='old', err=900)
      endif
      open(unit=8, file='PAoutp.dat', status='unknown', err=900)
      do 8 i=1,20
       xbp(i) = rate*dxbp(i)
    8 continue
      read (7,*)
      read (7,*) (radi(i),i=1,40)
      read (7,*) (ri(i),i=1,42)
      do 10 j=1,20
       read (7,*) (fp(i,j),i=1,40)
   10 continue
      do 11 i=1,20
       ip = i + 1
       voli(i) = pi*(ri(ip)**2 - ri(i)**2)
   11 continue
      do 12 i=22,41
       ip = i + 1
       im = i - 1
       voli(im) = pi*(ri(ip)**2 - ri(i)**2)
   12 continue
c*********************************************************************
c     first calculate average of the fission distribution for each of
c     inner, outer, and total, as a function of exposure ...
c*********************************************************************
      vi = pi*(ri(21)**2 - ri(1)**2)
      vo = pi*(ri(42)**2 - ri(22)**2)
      vt = vi + vo
      do 20 j=1,20
       avi(j) = 0.
       avo(j) = 0.
       do 21 i=1,20
        ip = i + 20
        avi(j) = avi(j) + fp(i,j)*voli(i)
```

```
         avo(j) = avo(j) t fp(ip,j)*voli(ip)
 21     continue
        avt(j) = avi(j) + avo(j)
        avi(j) = avi(j)/vi
        avo(j) = avo(j)/vo
        avt(j) = avt(j)/vt
 20    continue
c**********************************************************************
c      now order (rank) radial distribution according to fissions ...
c      this will determine exposure adustment as a function of fraction
c      of fuel corroded off ...  loop over 20 exposure increments ...
c**********************************************************************
       do 30 j=1,20
        do 31 i=1,40
         fi(i) = fp(i,j)
 31     continue
        call sort(voli,fi)
        do 32 i=1,20
         ve(i,j,1) = vs(i,1)
         fe(i,j,1) = fs(i,1)
         ve(i,j,2) = vs(i,2)
         fe(i,j,2) = fs(i,2)
 32     continue
        do 33 i=1,40
         vae(i,j) = va(i)
         fae(i,j) = fa(i)
 33     continue
 30    continue
c**********************************************************************
c      now integrate over corroded-off outer regions for P/A ...
c**********************************************************************
       do 70 l = 1,19
        pc = float(5*l)
        vtst = pc*vt/100.
        do 40 j=1,20
         pki(j,l) = 0.
         pko(j,l) = 0.
         pka(j,l) = 0.
         v1 = 0.
         v2 = 0.
         do 41 i=1,l
          vl = v1 + ve(i,j,1)
          v2 = v2 + ve(i,j,2)
          pki(j,l) = pki(j,l) t fe(i,j,1)*ve(i,j,1)
          pko(j,l) = pko(j,l) + fe(i,j,2)*ve(i,j,2)
 41      continue
         vint = 0.
         do 42 i=1,40
          vint = vint + vae(i,j)
          if(vint .gt. vtst) goto 45
 42      continue
 45      na = i - 1
         v3 = 0.
         do 43 i=1,na
          v3 = v3 + vae(i,j)
          pka(j,l) = pka(j,l) + fae(i,j)*vae(i,j)
 43      continue
         pki(j,l) = (pki(j,l)/v1)/avi(j)
         pko(j,l) = (pko(j,l)/v2)/avo(j)
         pka(j,l) = (pka(j,l)/v3)/avt(j)
 40     continue
c**********************************************************************
```

```
c      now calculate suter-to-average and inner-to-average factors ...
c*********************************************************************
        write (8,*) ' Corrosion percent = ',cbp(1)
        do 50 j=1,20
         pa1(j,1) = avi(j)/avt(j)
         pa2(j,1) = avo(j)/avt(j)
         write (8,100) pki(j,1),pko(j,1),pka(j,1),pa1(j,1),pa2(j,1)
 50     continue
 70    continue
 100   format(1x,5(2x,f10.7))
       write (6,*) ' Now for 2D, 3-pt interpolation ...'
       write (6,*) ' Enter desired exposure:'
       read  (5,*) ex1
       write (6,*) ' Enter desired corrosion fraction:'
       read  (5,*) col
       ic = 1
       write (6,*) ' Inner peaking factor = ',pai(ic,ex1,co1)
       ic = 2
       write (6,*) ' Outer peaking factor = ',pai(ic,ex1,co1)
       ic = 3
       write (6,*) ' Assem peaking factor = ',pai(ic,ex1,co1)
       ic = 4
       write (6,*) ' Inner/Assem factor   = ',pai(ic,ex1,co1)
       ic = 5
       write (6,*) ' Outer/Assem factor   = ',pai(ic,ex1,co1)
 900   stop
       end


       subroutine sort(vi,fi)
       implicit real*8 (a-h,o-z)
       dimension vi(40), fi(40)
       common /s1/ vs(20,2), fs(20,2), va(40), fa(40)
c*********************************************************************
c      sort inner, outer elements and assembly by exposure ...
c*********************************************************************
       do 10 i=1,20
        ip = i + 20
        vs(i,1) = vi(i)
        fs(i,1) = fi(i)
        vs(i,2) = vi(ip)
        fs(i,2) = fi(ip)
        va(i)   = vi(i)
        va(ip)  = vi(ip)
        fa(i)   = fi(i)
        fa(ip)  = fi(ip)
 10    continue
c*********************************************************************
c      commence bubble sort loops ...
c*********************************************************************
       do 20 i=1,19
c       inner sort loop on inner ...
        do 21 k=1,20-i
         kp = k + 1
         if(fs(kp,1) .gt. fs(k,1)) then
          temv = vs(k,1)
          temf = fs(k,1)
          vs(k,1) = vs(kp,1)
          fs(k,1) = fs(kp,1)
          vs(kp,1) = temv
          fs(kp,1) = temf
         endif
```

```
 21     continue
c       inner sort loop on outer ...
        do 22 k=1,20-i
         kp = k + 1
         if(fs(kp,2) .gt. fs(k,2)) then
          temv = vs(k,2)
          temf = fs(k,2)
          vs(k,2) = vs(kp,2)
          fs(k,2) = fs(kp,2)
          vs(kp,2) = temv
          fs(kp,2) = temf
         endif
 22     continue
 20    continue
c      sort loops on assembly ...
       do 23 i=1,39
        do 24 k=1,40-i
         kp = k + 1
         if(fa(kp) .gt. fa(k)) then
          temv = va(k)
          temf = fa(k)
          va(k) = va(kp)
          fa(k) = fa(kp)
          va(kp) = temv
          fa(kp) = temf
         endif
 24     continue
 23    continue
       return
       end


      function pai(ic,ex,co)
      implicit real*8  (a-h, o-z)
      implicit integer*4 (i-n)
      common /s2/ pki(20,19), pko(20,19), pka(20,19),
     1            pa1(20,19), pa2(20,19), xbp(20), cbp(19)
      dimension bp(20), pex(20), pco(19)
c*****************************************************************
c
c     this function performs the lagrangian spline table interpolation
c     on the peaking factor data library, as a function of exposure and
c     % fuel element and/or assembly corrosion ...
c
c     first, determine initial and final indices for accessing data ...
c
c*****************************************************************
      if(ex .lt. xbp(1)) then
       mex  = 1
       mex2 = 3
       goto 11
      endif
      do 10 i = 1, 18
       if(ex.ge.xbp(i)  .and. ex.lt.xbp(i+1)) then
        mex  = i
        mex2 = mex t 2
        goto 11
       endif
 10   continue
      mex  = 18
      mex2 = mex + 2
      if(ex.ge.xbp(i+1)  .and. ex.le.xbp(i+2)) goto 11
```

```
c     write (6,*) ' WARNING: extrapolation used in 3-pt interpolation!'
 11   if(co .lt. cbp(1)) then
       mco  = 1
       mco2 = 3
       goto 31
      endif
      do 20 i = 1, 18
       if(co.ge.cbp(i) .and. co.lt.cbp(i+1)) then
        mco  = i
        mco2 = mco + 2
        goto 31
       endif
 20   continue
      mco  = 18
      mco2 = mco + 2
      if(co.ge.cbp(i+1) .and. co.le.cbp(i+2)) goto 31
c     write (6,*) ' WARNING: extrapolation used in 3-pt interpolation!'
c**********************************************************************
c
c     next, calculate lagrangian coefficients for all directions ...
c
c**********************************************************************
 31   do 40 i = mex, mex2
       pex(i) = 1.
       do 41 j = mex, mex2
        if(i .eq. j) goto 41
        pex(i) = pex(i)*(ex - xbp(j))/(xbp(i) - xbp(j))
 41    continue
 40   continue
      do 50 i = mco, mco2
       pco(i) = 1.
       do 51 j = mco, mco2
        if(i .eq. j) goto 51
        pco(i) = pco(i)*(co - cbp(j))/(cbp(i) - cbp(j))
 51    continue
 50   continue
c**********************************************************************
c
c     next, perform two-dimensional interpolation, with pre-calculated
c     product-term coefficients ...
c
c**********************************************************************
      do 70 il = mex,mex2
       sm = 0.
       do 80 i2 = mco,mco2
        if(ic .eq. 1) then
         sm = sm + pco(i2)*pki(i1,i2)
        elseif(ic .eq. 2) then
         sm = sm + pco(i2)*pko(i1,i2)
        elseif(ic .eq. 3) then
         sm = sm + pco(i2)*pka(i1,i2)
        elseif(ic .eq. 4) then
         sm = sm + pco(i2)*pa1(i1,i2)
        elseif(ic .eq. 5) then
         sm = sm + pco(i2)*pa2(i1,i2)
        endif
 80    continue
       bp(i1) = sm
 70   continue
      sm = 0.
      do 75 i1 = mex,mex2
       sm = sm + pex(i1)*bp(i1)
```

```
75    continue
      pai = sm
      return
      end
```

Attachment 2: Pradnuc2.for Source Listing

```
      program expmod
c*********************************************************************
c
c     this program performs quadratic interpolation/extrapolation on
c     pu240 vs exposure results generated from the wims-e code for both
c     N Reactor Mark IV and Mark IA fuel assemblies ...
c
c*********************************************************************
      implicit real*8 (a-h,o-z)
      character*4 mod
      character*1 typ, ans, ansr
      common /s1/ data(4,20), ii, ip, ml, m2
      common /s2/ pki(20,19,2), pko(20,19,2), pka(20,19,2),
     1            pa1(20,19,2), pa2(20,19,2), xbp(20), cbp(19)
      common /s3/ exi, exo, expr, el, a2, vli, vlo, vi, vo, pi,
     1            rl, r2, r3, r4, ityp
      dimension dxbp(20), dd(3,8)
      open(unit=9, file='pu240.txt', status='old', err=900)
      open(unit=8, file='Safe_Gds.', status='old', err=900)
      open(unit=7, file='outp.', status='unknown', err=900)
      open(unit=10, file='PAmkia.dat', status='old', err=900)
      open(unit=11, file='PAmkiv.dat', status='old', err=900)
      open(unit=12, file='damged.txt', status='old', err=900)
      data dxbp / 2.,  12.,  22.,  32.,  42.,  52.,  62.,  72.,
     1           82.,  92., 102., 112., 122., 132., 142., 152.,
     2          162., 172., 182., 192. /
      data cbp  / 5., 10., 15., 20., 25., 30., 35., 40., 45., 50.,
     1            55., 60., 65., 70., 75., E0., 85., 90.. 95. /
c*********************************************************************
c     input Mark IA exposure data ...
c*********************************************************************
      pi = 3.141592654
      do 10 i = 1,20
       read (9,*) data(1,i), data(2,i)
 10   continue
      do 11 j=1,19
       do 12 i=1,20
        read (10,*) pl, p2, p3, p4, p5
        pki(i,j,1) = pl
        pko(i,j,1) = p2
        pka(i,j,1) = p3
        pa1(i,j,1) = p4
        pa2(i,j,1) = p5
 12    continue
 11   continue
c*********************************************************************
c     input Mark IV exposure data ...
c*********************************************************************
      do 15 i = 1,20
       read (9,*) data(3,i), data(4,i)
 15   continue
      do 16 j=1,19
       do 17 i=1,20
        read (11,*) p1, p2, p3, p4, p5
        pki(i,j,2) = p1
        pko(i,j,2) = p2
        pka(i,j,2) = p3
        pa1(i,j,2) = p4
        pa2(i,j,2) = p5
```

```
 17     continue
 16    continue
c**********************************************************************
c      input pararnetreized fuel damage data ...
c**********************************************************************
       do 19 i=1,3
        read (12,*) (dd(i,j),j=1,8)
 19    continue
c**********************************************************************
c      define loop over desired exposures for model evaluation ...
c**********************************************************************
       write (7,*)
       write (7,*)  ""'105-K Basins charge data"'
       write (7,*)
       write (7,200)
       igrd = 1
       ipic = 0
       idt1 = 12
       idt2 = 99
       write (6,*) ' Adjust exposure for fuel damage? (y/n)'
       read  (5,300) ans
       write (6,*) ' Adjust exposure for reactor P/A factors? (y/n)'
       read  (5,300) ansr
       if(ansr .eq. "y") then
        write (6,*) ' What is the reactor exposure P/A factor?'
        read  (5,*) rpa
       endif
 20     read (8,*,end=900)id1,key,mod,id2,typ,p24,pmt,expr,gmt,umt,assm
        if(typ .eq. "I") then
         m1 = 1
         m2 = 2
         el = 2.99686
         a2 = 20.88*2.54/2.
         r1 = 0.6223
         r2 = 1.4808
         r3 = 2.2962
         r4 = 2.9896
         ifl = 1
         rate = 12.931
         ityp = 1
        elseif(typ .eq. "V") then
         m1 = 3
         m2 = 4
         el = 3.02565
         a2 = 26.1*2.54/2.
         r1 = 0.6605
         r2 = 1.5480
         r3 = 2.2110
         r4 = 3.0165
         ifl = 4
         rate = 10.830
         ityp = 2
        else
         write (6,*) ' non N Fuel detected'
         goto 900
        endif
        vi = pi*(r2**2 - r1**2)
        vo = pi*(r4**2 - r3**2)
        fi = vi/(vi + vo)
        fo = vo/(vi + vo)
        if(id1 .eq. 107) then
         bri = dd(1,3)
```

```
         bro = dd(1,4)
         dfi = dd(2,3)
         dfo = dd(2,4)
         bdi = dd(3,3)
         bdo = dd(3,4)
        elseif(id1 .eq. 108) then
         bri = dd(1,1)
         bro = dd(1,2)
         dfi = dd(2,1)
         dfo = dd(2,2)
         bdi = dd(3,1)
         bdo = dd(3,2)
        else
         write (6,*) ' Basin ID problem ...'
        endif
        do 8 i=1,20
         xbp(i) = rate*dxbp(i)
  8     continue
c*********************************************************************
c       now interpolate PROFILE3 data tables (WIMS-E radial P/A data),
c       and evaluate diffusion theory model axial profiles to estimate
c       exposure peaking vs. exp and extent of fuel corrosion ...
c*********************************************************************
        if(ans .eq. "y") then
c*********************************************************************
c        calculate exposure in the "breached" component ...
c*********************************************************************
         if(bri.eq.0.  .and. bro.eq.0.) then
          ffl = 0.
          expl = 0.
         else
          ffl  = dd(1,5)
          prl  = dd(1,6)
          pzl  = dd(1,7)
          ptl  = dd(1,8)
          call epe(ff1,prl,pzl,pt1)
          expl = (exi*vli*bri + exo*vlo*bro)/(vli*bri + vlo*bro)
         endif
c*********************************************************************
c        calculate exposure in the "defected" component ...
c*********************************************************************
         if(dfi.eq.0. .and. dfo.eq.0.) then
          ff2 = 0.
          exp2 = 0.
         else
          ff2  = dd(2,5)
          prl  = dd(2,6)
          pz1  = dd(2,7)
          ptl  = dd(2,8)
          call epe(ff2,prl,pz1,pt1)
          exp2 = (exi*vli*dfi + exo*vlo*dfo)/(vli*dfi + vlo*dfo)
         endif
c*********************************************************************
c        calculate exposure in the "bad" component ...
c*********************************************************************
         if(bdi.eq.0. .and. bdo.eq.0.) then
          ff3 = 0.
          exp3 = 0.
         else
          ff3  = dd(3,5)
          prl  = dd(3,6)
          pz1  = dd(3,7)
```

```
          ptl  = dd(3,8)
          call epe(ff3,prl,pzl,pt1)
          exp3 = (exi*vli*bdi + exo*vlo*bdo)/(vli*bdi + vlo*bdo)
         endif
         expr = (exp1*ff1 + exp2*ff2 + exp3*ff3)/(ff1 + ff2 + ff3)
         ufs = (bri*fi + bro*fo)*ff1 + (dfi*fi + dfo*fo)*ff2
         ufs = ufs + (bdi*fi + bdo*fo)*ff3
         umt = ufs*umt
        endif
        if(ansr .eq. "y") expr = expr * rpa
        call find(expr)
        write (7,100) key, igrd, ifl, ipic, pu240(expr), umt, idtl, idt2
       goto 20
100    format(1x,i5,5x,i1,6x,i1,6x,i3,5x,f6.2,4x,f11.7,2(3x,i2))
200    format(1x,' "Key" "Grade" "Fuel" "Pieces" "% Pu-240"  "Uranium"
     1 "Mo" "Yr" ')
300    format(a1)
900    stop
       end



       subroutine epe(ff,prl,pzl,pt1)
       implicit real*8 (a-h,o-z)
c**********************************************************************
c      this subroutine evaluates the exposure profile effects and
c      calculates the combined axial and radial exposure factor ...
c**********************************************************************
       common /s3/ exi, exo, expr, el, a2, vli, vlo, vi, vo, pi,
     1             r1, r2, r3, r4, ityp
c**********************************************************************
c      do inners ...
c**********************************************************************
       rad = r2 - pr1*(r2 - r1)
       dz  = (r2 - r1)*pz1
       vor = pt1*pi*(r2**2 - rad**2)*dz
       vax = ff*vi*a2 - vor
       zv  = vax/vi
       zp  = zv + dz
       pz  = 1.15
       co  = 100.*(r2**2 - rad**2)/(r2**2 - r1**2)
       avg =  1. + (el/a2)*(pz-1.)*(1. - exp(-a2/el))
       pax = (1. + (el/zv)*(pz-1.)*(1. - exp(-zv/el)))/avg
       pxl = (1. + (el/dz)*(pz-1.)*(exp(-zv/el) - exp(-zp/el)))/avg
       vli = vax + vor
       exi = ((pax*vax + px1*pai(1,ityp,expr,co)*vor)/vli)*expr
       exi = exi*pai(4,ityp,expr,co)
c**********************************************************************
c      do outers ...
c**********************************************************************
       rad = r4 - pr1*(r4 - r3)
       dz  = (r4 - r3)*pz1
       vor = pt1*pi*(r4**2 - rad**2)*dz
       vax = ff*vo*a2 - vor
       zv  = vax/vo
       zp  = zv + dz
       pz  = 1.09
       co  = 100.*(r4**2 - rad**2)/(r4**2 - r3**2)
       avg =  1. + (el/a2)*(pz-1.)*(1. - exp(-a2/el))
       pax = (1. + (el/zv)*(pz-1.)*(1. - exp(-zv/el)))/avg
       px1 = (1. + (el/dz)*(pz-1.)*(exp(-zv/el) - exp(-zp/el)))/avg
       vlo = vax + vor
```

```
      exo = ((pax*vax + px1*pai(2,ityp,expr,co)*vor)/vlo)*expr
      exo = exo*pai(5,ityp,expr,co)
      return
      end



      subroutine find(exp)
c**********************************************************************
c
c     find starting and final indices for exposure interpolation ...
c
c**********************************************************************
      implicit real*8 (a-h,o-z)
      common /s1/ data(4,20), ii, ip, ml, m2
      i = l
      if(exp .lt. data(m1,i)) goto 20
      do 10 i = 1,18
       ip = i + 1
       if(exp.ge.data(m1,i) .and. exp.lt.data(m1,ip)) goto 20
 10   continue
      i = i -1
 20   ii = i
      ip = ii + 2
      return
      end



      function pu240(exp)
c**********************************************************************
c
c    this function interpolates the exposure profile to get pu240(E) ...
c
c**********************************************************************
      implicit real*8 (a-h,o-z)
      common /s1/ data(4,20), ii, ip, ml, m2
      dimension cl(20)
      su = 0.
      do 30 i = ii, ip
        cl(i) = 1.
        do 40 j = ii, ip
          if (i .eq. j) goto 40
          cl(i) = cl(i)*(exp -  data(m1,j))/(data(m1,i) - data(m1,j))
 40     continue
        su = su + cl(i)*data(m2,i)
 30   continue
      pu240 = su
      return
      end



      function pai(ic,ityp,ex,co)
      implicit real*8  (a-h,o-z)
      implicit integer*4 (i-n)
      common /s2/ pki(20,19,2), pko(20,19,2), pka(20,19,2),
     1            pal(20,19,2), pa2(20,19,2), xbp(20), cbp(19)
      dimension bp(20), pex(20), pco(19)
c**********************************************************************
c
c     this function performs the lagrangian spline table interpolation
```

```
c     on the peaking factor data library, as a function of exposure and
c     % fuel element and/or assembly corrosion ...
c
c     first, determine initial and final indices for accessing data ...
c
c**********************************************************************
      if(ex .lt. xbp(1)) then
       mex  = 1
       mex2 = 3
       goto 11
      endif
      do 10 i = 1, 18
       if(ex.ge.xbp(i)  .and. ex.lt.xbp(i+1)) then
        mex  = i
        mex2 = mex + 2
        goto 11
       endif
 10   continue
      mex  = 18
      mex2 = mex + 2
      if(ex.ge.xbp(i+1)  .and. ex.le.xbp(i+2)) goto 11
c     write (6,*) ' WARNING: extrapolation used in 3-pt interpolation!'
 11   if(co .lt. cbp(1)) then
       mco  = 1
       mco2 = 3
       goto 31
      endif
      do 20 i = 1. 17
       if(co.ge.cbp(i)  and  co.lt.cbp(i+1)) then
        mco  = i
        mco2 = mco + 2
        goto 31
       endif
 20   continue
      mco  = 17
      mco2 = mco + 2
      if(co.ge.cbp(i+1)  .and. co.le.cbp(i+2)) goto 31
c     write (6,*) ' WARNING: extrapolation used in 3-pt interpolation!'
c**********************************************************************
c
c     next, calculate lagrangian coefficients for all directions ...
c
c**********************************************************************
 31   do 40 i = mex, mex2
       pex(i) = 1.
       do 41 j = mex, mex2
        if(i .eq. j) goto 41
        pex(i) = pex(i)*(ex - xbp(j))/(xbp(i) - xbp(j))
 41    continue
 40   continue
      do 50 i = mco, mco2
       pco(i) = 1.
       do 51 j = mco, mco2
        if(i .eq. j) goto 51
        pco(i) = pco(i)*(co - cbp(j))/(cbp(i) - cbp(j))
 51    continue
 50   continue
c**********************************************************************
c
c     next, perform two-dimensional interpolation, with pre-calculated
c     product-term coefficients ...
c
```

```
c**********************************************************************
      do 70 i1 = mex,mex2
       sm = 0.
       do 80 i2 = mco,mco2
        if(ic .eq. 1) then
         sm = sm + pco(i2)*pki(i1,i2,ityp)
        elseif(ic .eq. 2) then
         sm = sm + pco(i2)*pko(i1,i2,ityp)
        elseif(ic .eq. 3) then
         sm = sm + pco(i2)*pka(i1,i2,ityp)
        elseif(ic .eq. 4) then
         sm = sm + pco(i2)*pa1(i1,i2,ityp)
        elseif(ic .eq. 5) then
         sm = sm + pco(i2)*pa2(i1,i2,ityp)
        endif
 80    continue
       bp(i1) = sm
 70   continue
      sm = 0.
      do 75 i1 = mex,mex2
       sm = sm + pex(i1)*bp(i1)
 75   continue
      pai = sm
      return
      end
```

Attachment 3: WIMS-E TRU Validation

USE OF THE WIMS-E LATTICE CODE FOR PREDICTION OF THE TRANSURANIC SOURCE TERM FOR SPENT FUEL DOSE ESTIMATION

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ABSTRACT

A recent source term analysis has shown a discrepancy between ORIGEN2 transuranic isotopic production estimates and those produced with the WIMS-E lattice physics code. Excellent agreement between relevant experimental measurements and WIMS-E was shown, thus exposing an error in the cross section library used by ORIGEN2.

I. INTRODUCTION

The planned re-racking of N Reactor fuel assemblies and packing of scrap into multiple canister overpack (MCO) containers has generated some concern as to the size of the spontaneous neutron source term, important in characterizing the estimated dose. Previous calculations using the RADNUC code (an automated interpolator code using ORIGEN2 production tables) has possibly over-estimated the size of the ^{244}Cm contribution by over an order of magnitude. The overall over-estimation of the source term may be at least a factor of five; this will result in greater (and unnecessary) expense in shielding requirements.

The ORIGEN2 computer code uses effective one-group cross sections in its burnup equations. These cross sections must come from somewhere, and various libraries exist for different applications. At least one existing ORIGEN2 library uses cross sections extracted out of older WIMS-D calculations; another library (for ORIGEN-S) was created specifically for N Reactor MKIV and MKIA inners and outers, using the Oak Ridge SCALE system.

The latest version of WIMS-E, version 6a, has recently been obtained from the British AEA Technology. This latest version of the code comes with the latest cross section library (1994) and comes in both 69 and 172 energy groups. This cross section library was created from the latest cross section evaluations from the Joint European File (JEF2.2), from ENDF-BNI, and for the first time, includes extension of the transuranic burnup equations into the curium chains.

Preliminary results from WIMS-E 6a show a much smaller quantity of ^{244}Cm produced than the earlier ORIGEN calculations. In addition, WIMS-E 6a isotopic predictions for irradiated MKIV fuel (both inner and outer) are in excellent agreement with measured isotopic production data.'

In an attempt to upgrade ORIGEN2 capabilities for burnup analysis of N Reactor fuel types, new effective one-group microscopic cross sections have been extracted out of WIMS-E output for both MKIV and MKIA inners and outers as a function of burnup.

It is beleived that the discrepancy in the ^{244}Cm production is due to an error in the extraction of the one-group cross sections out of the earlier WIMS-D results.

II. ISOTOPIC PRODUCTION CALCULATIONS

The WIMS-E 6a computer code' was used in a burnup mode for both MKIV and MKIA N Reactor fuel types. Hot operating conditions (temperatures, thermally expanded dimensions and reduced densities) were taken from the DCODE fuels performance code, used extensively in the past in support of fuel design and operation of the N Reactor. To estimate the transuranic isotopic distribution of the spent fuel inventory, a database **is** required that contains information on the quantity of initial uranium metal and the total exposure present in each of the groups of spent fuel. A small FORTRAN post-processor program was written to extract the isotopic data out of the WIMS-E output files, and combine this data with the exposure

database. For every exposure group, the database contains the quantity of uranium metal and the exposure it has acquired. The WIMS-E production tables give the isotopic quantities (**e.g.**, gram per metric ton of initial uranium) as a function of exposure. The post-processor takes an exposure group and uses a three-point interpolation to calculate the grams per metric ton of each isotope at that exposure, and multiplies this by the initial uranium in the group; the result is the total quantity of each isotope, for each group of spent fuel.

As a conservative estimate for the source term prediction, the highest-exposure **270** MKIV fuel assemblies (five tiers **of 54** assemblies each) were assumed to be loaded into a single MCO. To treat non-linearities of isotopic quantities with burnup, it was decided to approximate these **270** fuel assemblies by equal mass quantities of MKIV fuel, each at five different exposures. The MKIA basis was **288** fuel assemblies (six tiers of **48** assemblies each). **A** FORTRAN program was used to interpolate the transuranic isotopics for each of the exposure bins, and sum over the five (or six) **bins** to find the total.

III. CALCULATION VALIDATION

Transuranic isotope quantities have been measured and documented for known burnups.' WIMS-E isotopic predictions agree very well for all of the isotopes that were compared. WIMS-E performs a cylindrical integral transport calculation in 69 neutron energy groups and then uses the transport solution to provide fluxes that drive the burnup equations in each burnable material. This is repeated for each bumup steps. WIMS-E therefore predicts the fraction of power (and exposure) produced in the inner and outer elements of the tube-in-tube geometry of N Reactor fuel. Power sharing ratios represent the ratio of either inner or outer element specific power (power per unit mass) to the assembly average specific power. These ratios are burnup dependent. Figure 1 shows how these ratios change with bumup; these values are consistent with the power sharing ratio assumed in the older ORIGEN model. Figures **2** and **3** illustrate the ^{235}U depletion in MKIV inner and outer elements, as predicted by WIMS-E and as measured. Figures **4** and 5 show the same comparison for ^{236}U buildup; the WIMS-E calculation assumed an initial ^{236}U content of 400 ppm. The plutonium isotope comparisons are shown in Figures ***6*** through **15.**

Further along the burnup chain are the curium isotopes. Figures 16 and 17 show predicted ^{244}Cm contents for both inner and outer elements. The agreement is very good.

Figure 1. Power Ratio vs Exposure. MKIV assemblies.

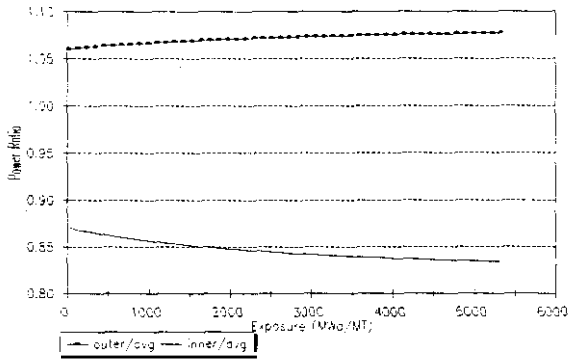


Figure 2. U-235 vs Exposure. N Reactor MKIV Inner.

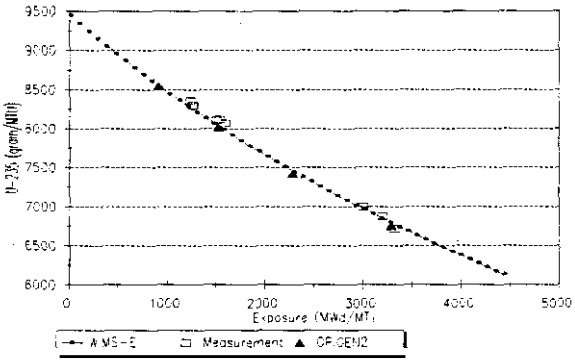


Figure 3. U-235 vs Exposure. N Reactor MKIV Outer.

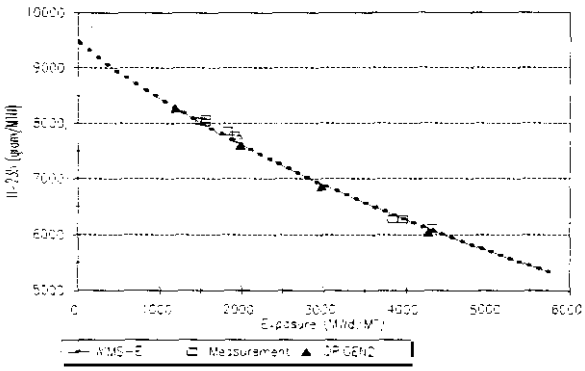


Figure 4. U-236 vs Exposure.
N Reactor MKIV Inner.

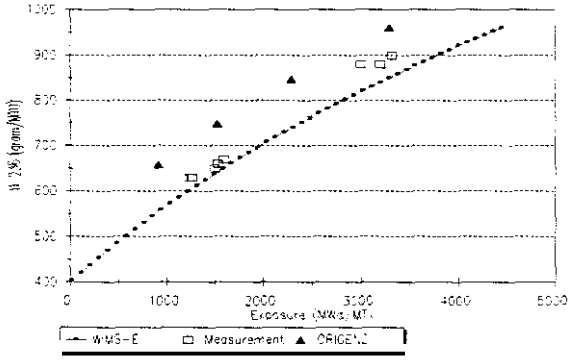


Figure 7. Pu-238 vs Exposure.
N Reactor MKIV Outer.

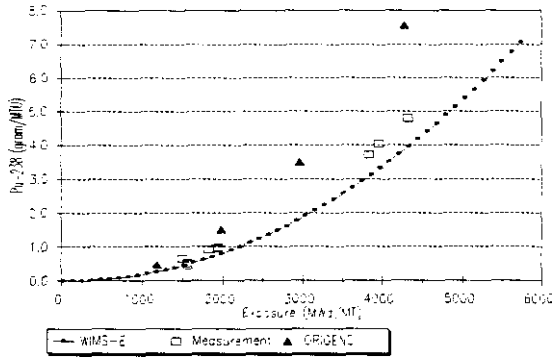


Figure 5. U-236 vs Exposure
N Reactor MKIV Outer.

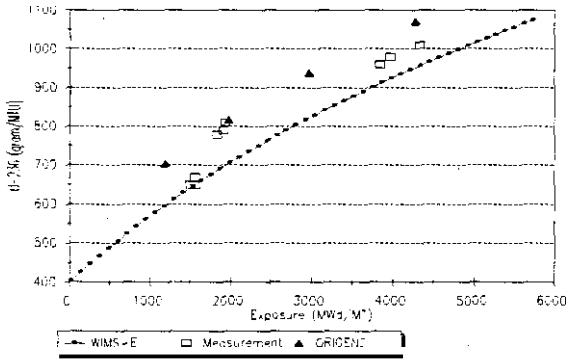


Figure 8. Pu-239 vs Exposure.
N Reactor MKIV Inner.

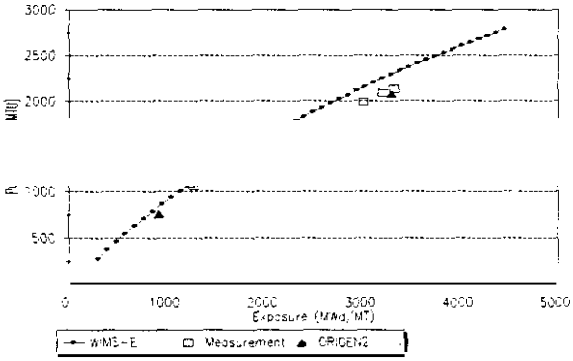


Figure 6. Pu-238 vs Exposure.
N Reactor MKIV Inner.

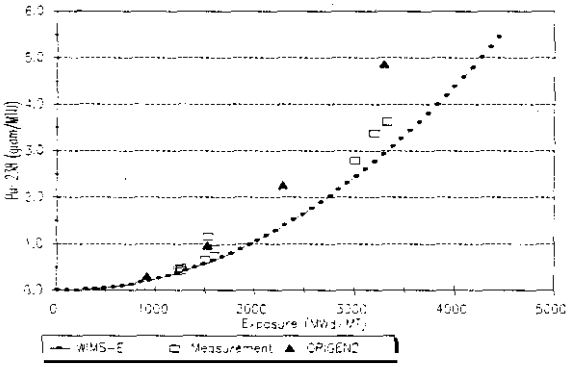


Figure 9. Pu-239 vs Exposure
N Reactor MKIV Outer.

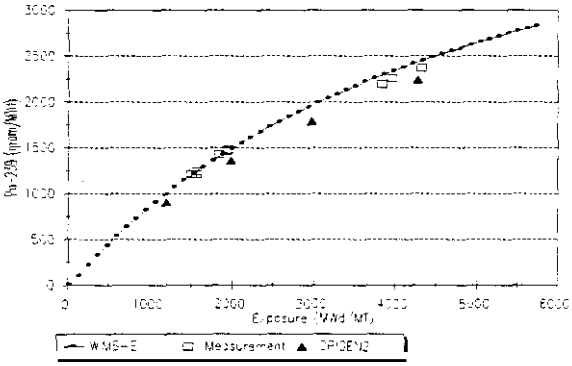


Figure 10. Pu-240 vs Exposure.
N Reactor MkIV Inner.

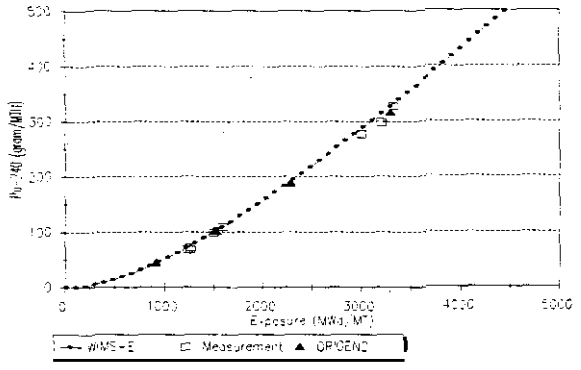


Figure 11. Pu-240 vs Exposure.
N Reactor MkIV Outer.

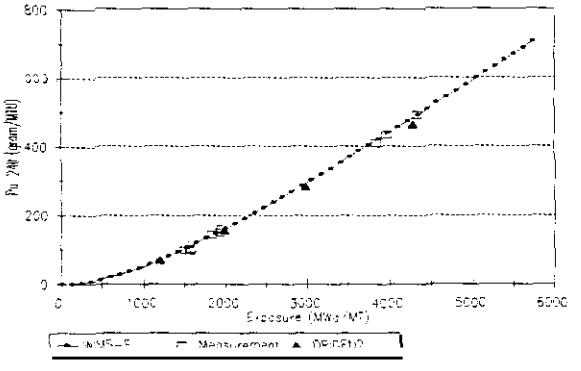


Figure 12. Pu-241 vs Exposure.
N Reactor MkIV Inner.

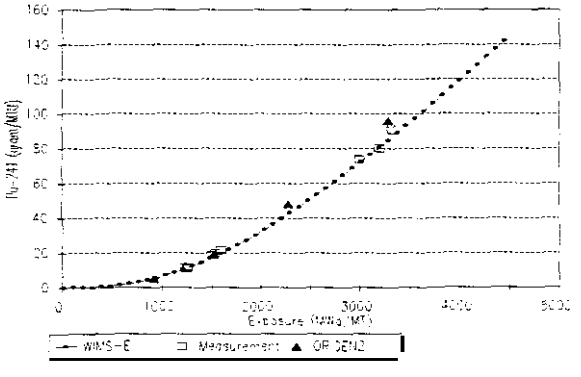


Figure 13. Pu-241 vs Exposure.
N Reactor MkIV Outer.

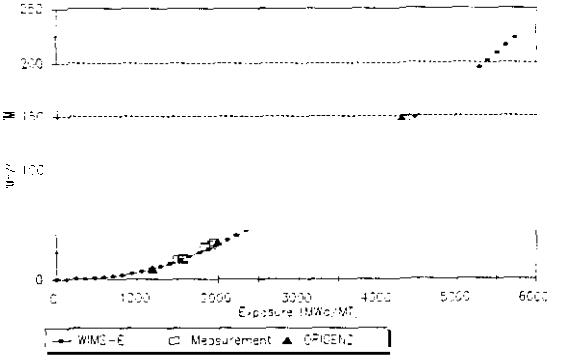


Figure 14. Pu-242 vs Exposure.
N Reactor MkIV Inner.

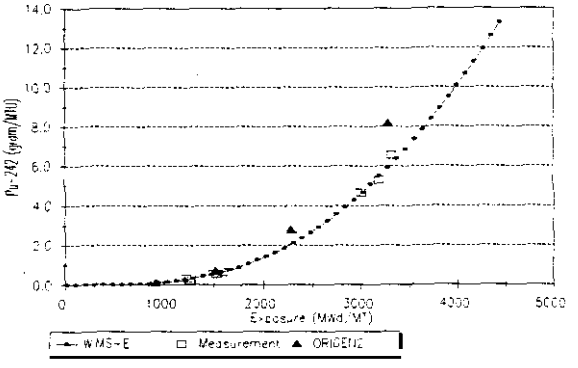


Figure 15. Pu-242 vs Exposure.
N Reactor MkIV Outer.

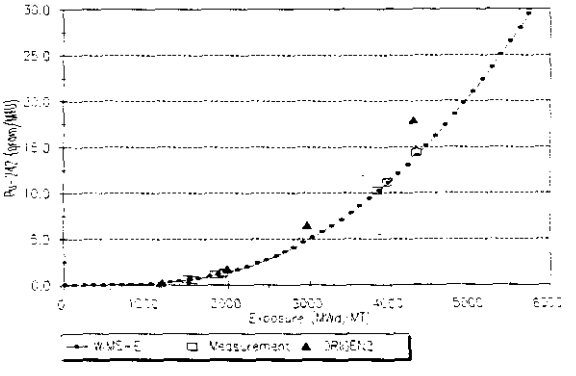


Figure 16. Cm-244 vs Exposure, N Reactor MkIV Inner.

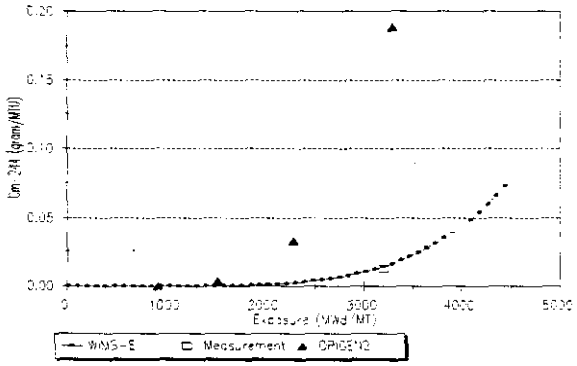
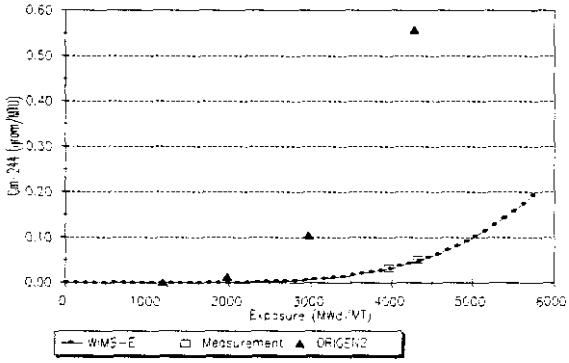


Figure 17. Cm-244 vs Exposure, N Reactor MkIV Outer.



IV. EFFECTIVE ONE-GROUP CROSS SECTIONS

The effective self-shielded one-group microscopic cross section is defined by the equation:

$$\bar{\sigma}_x = \frac{\sum_{g=1}^{G} \sigma_{x,g}\varphi_g}{\sum_{g=1}^{G} \varphi_g} \qquad (1)$$

In Equation, $\bar{\sigma}_x$ is the effective one-group microscopic cross section of reaction type **x.** The 69-group neutron **flux** spectrum, φ_g, is used as the weighting function to average the microscopic group-dependent cross section, $\sigma_{x,g}$. The summation in the numerator is performed automatically by using the reaction rate output edit module W-WIRE, contained within the WIMS-E code. The summation in the denominator is simply the one-group neutron flux, and is output by using the W-WED module. A small FORTRAN program was written to read the ASCII text file produced by WIMS-E, and collect the data required to evaluate $\bar{\sigma}_x$. This post-processing was performed for both inner and outer elements, and for both MKIV and MKlA fuel types, as a function of burnup; 50 bumup steps were performed. Effective one-group cross sections were calculated for several uranium and transuranium isotopes, listed in the table below:

Nuclide Evaluated	WIMS-E ID code
^{235}U	**2235**
^{236}U	**2236**
^{238}U	**2238**
^{237}U	**2237**
^{237}Np	**3237**
^{239}Np	**3239**
^{238}Pu	**4238**
^{239}Pu	**4239**
^{240}Pu	**4240**
^{241}Pu	**4241**
^{242}Pu	**4242**
^{241}Am	**5241**
^{242m}Am	**5242**
^{243}Am	**5243**
^{243}Cm	**6243**
^{244}Cm	**6244**

The final set of effective one-group microscopic cross sections was delivered for modification of the ORIGEN2 cross section library.

REFERENCES

1. Wittekind, W. D., ***Fuel Segregation Detector Calibration and DCODE Computer Modeling,*** **UNI-2384,** UNC Nuclear Industries, Inc., Richland, Washington **(1984).**

2. Gubbins, M. E., M. J. Roth, and C. J. Taubman, ***A General Introduction to the Use of the WIMS-E Modular Program,*** AEEW-R **1329,** Reactor Physics Division, AEE Winfrith, England **(1982)**

Attachment 4: Safeguards and Accountability Database

Safeguards **K Basin Data**

KW	Basin Key	Model		type	% Pu-240	MT Pu	Exposure (MWd/MTU)	gram/MTU	MTU	assemblies
107	09964	N09E	50	I	6.18	1.37E-05	1446.488	1099.107	0.0124641	1.66546
107	12823	A2T	50	I	13.11	0.0013456	3865.446	2425.940	0.5546198	35.51946
107	09964	A2M	50	I	6.18	1.703E-05	1446.488	1099.101	0.0154944	0.93021
107	12639	A2M	50	I	13.06	0.0494252	3801.271	2395.258	20.634586	1238.88110
107	09964	N09M	50	I	6.18	5.45E-06	1446.488	1099.101	0.0049536	0.89900
107	09964	N09F	50	I	6.18	3.86E-06	1446.488	1099.107	0.0035119	0.90030
101	09964	A2T	50	I	6.18	0.0002181	1446.488	1099.101	0.2530231	16.22999
101	09993	A2M	50	I	10.29	0.0076212	2691.800	1832.813	4.1614722	249.85086
101	09993	A2T	50	I	10.29	0.005865	2691.800	1832.813	3.1999992	205.26120
107	09993	A2F	50	I	10.29	0.0004049	2651.300	1832.813	0.2209063	18.13866
107	15555	A12F	50	I	4.0	4.55E-06	852.566	718.369	0.0063338	0.80297
107	15460	A2M	50	I	3.32	0.001042	747.609	611.377	1.704382	102.32948
107	15459	A2M	50	I	4.06	0.01519	9C5.898	128.044	20.864116	1252.66184
107	15459	A2T	50	I	4.06	0.0052097	905.898	123.044	1.1551737	459.00096
101	15457	A2M	50	I	2.85	1.544E-05	651.835	538.811	0.0286557	1.72046
107	15451	A2M	50	I	5.31	0.000387	1208.502	940.623	0.411387	24.69929
101	15448	N09F	50	I	4.54	2.52E-06	1016.354	801.168	0.003122	0.80034
101	15448	N09M	50	I	4.54	3.56E-06	1016.354	807.168	0.0044105	0.19963
101	15448	A12F	50	I	4.54	5.35E-06	1016.354	801.168	0.0066281	0.34028
101	15448	A2T	50	I	4.54	1.057E-05	1016.354	807.168	0.0130952	0.83998
107	10201	A2E	50	I	9.22	0.0003683	2361.750	1651.312	0.2230227	18.91818
107	10201	A2T	50	I	9.22	0.0018224	2361.150	1651.312	1.1036074	70.78995
107	10201	A2F	50	I	9.22	0.0007232	2361.750	1651.312	0.437979	37.15212
107	10201	A2M	50	I	9.22	0.0178973	2361.750	1651.312	10.838201	650.11535
107	10259	A2M	50	I	10.35	0.0036828	2710.113	1842.984	1.9982809	119.91490
107	10259	A2F	50	I	10.35	0.0012165	2710.713	1842.984	0.6600871	55.99271
101	10294	A2T	50	I	9.8	9.704E-05	2539.479	1150.015	0.055451	3.55685
107	10294	A2M	50	I	9.8	0.0299404	2539.479	1150.015	17.108654	1021.18143
107	10350	A2T	50	I	10.65	0.0015242	2806.555	1894.171	0.8047002	51.61680
101	10350	A2F	50	I	10.65	0.0022254	2806.555	1394.171	1.1748885	99.66138
107	10350	N09M	50	I	10.65	9.36E-06	2806.555	1894.171	0.0049415	0.89590
107	10350	A12M	50	I	10.65	1.872E-05	2806.555	1894.111	0.0098829	0.83715
107	10350	A2M	50	I	10.65	0.0231016	2806.555	1894.111	12.196151	732.24574
107	10385	A2M	50	I	10.42	0.0124668	2732.815	1854.813	6.7211293	403.53026
107	10385	A12M	50	I	10.42	1.868E-05	2132.875	1854.873	0.0100708	0.90401
107	10335	A2T	50	I	10.42	0.0012346	2132.875	1354.873	0.6655766	42.69284
107	10456	A2T	50	I	11.37	0.0017366	3050.163	2021.740	0.8589731	55.09809
101	10456	A2M	50	I	11.37	0.0283043	3050.163	2021.740	13.999982	840.54573
107	10602	A2T	50	I	11.11	0.0011521	2959.340	1914.589	0.5334429	37.42444
107	10602	A2M	50	I	11.11	0.0245821	2959.340	1914.589	12.449526	741.45778
107	10602	A12M	50	I	11.11	1.992E-05	2959.340	1974.589	0.0100882	0.90551
107	10619	A2M	50	I	11.76	0.01457	3194.384	2095.918	6.9516083	417.36800
101	10679	A2F	50	I	11.16	0.0003016	3194.884	2095.918	0.1467519	12.44842
107	10679	A2T	50	I	11.16	0.0066169	3194.884	2095.918	3.1856687	204.34199
107	10142	N09M	50	I	12.77	1.074E-05	3643.692	2319.135	0.004631	0.83962
107	10142	A2F	50	I	12.77	0.0004282	3643.692	2319.135	0.1846465	15.66287
107	10742	A12F	50	I	12.71	1.618E-05	3643.692	2319.135	0.0069761	0.88448
107	10142	A2T	50	I	12.17	0.0056514	3643.692	2319.135	2.4394443	156.47606
107	10142	A2M	50	I	12.71	0.0014163	3643.692	2319.135	3.1980121	192.00923
107	10110	N09T	50	I	13.16	1.069E-05	3859.505	2423.107	0.0044111	0.85467
107	10170	A12T	50	I	13.16	2.168E-05	3859.505	2423.107	0.0089412	0.85199
107	10110	A2T		I	13.16	0.0042055	3859.505	2423.107	1.7355816	111.32139
101	10110	A2M	50	I	13.16	0.0123946	3859.505	2423.107	5.3215191	319.49393
101	10832	A2M	50	I	12.92	0.0268805	3723.202	2351.682	11.401232	684.51922
107	10832	A2T	50	I	12.92	0.0015978	3123.202	2357.682	3.2225162	206.10939
107	10982	A2M	50	I	13.13	0.036006	4236.823	2600.038	13.848249	831.43582
107	10982	A2F	50	I	13.73	5.106E-05	4236.828	2600.033	0.0196382	1.66583
107	10932	A12T	50	I	13.13	4.58E-05	4236.828	2600.038	0.0116151	1.63921
101	10982	N09M	50	I	13.13	2.302E-05	4236.828	2600.038	0.0088531	1.60520
107	10982	A2T	50	I	13.13	0.0015152	4236.828	2600.038	0.5827416	37.31946
107	11036	A2M	50	I	13.6	0.0164703	4143.305	2556.147	6.4418958	386.76534
107	11109	A2M	50	I	13.1	0.0313792	4214.817	2589.883	12.30913	739.02853
107	11109	N09M		I	13.7	1.149E-05	4214.817	2589.383	0.0044365	0.80435
107	11109	A2F	50	I	13.7	0.00102	4214.817	2539.883	0.3938403	33.40199
107	11183	A12M	50		13.31	4.686E-05	3950.917	2466.558	0.0189981	1.10537
107	11133	A2T	50		13.31	0.0005235	3950.911	2466.558	0.2122472	13.61442
107	11183	A2F	50		13.31	0.001439	3950.977	2466.558	0.5833961	49.48730
107	11183	N09M	50		13.31	2.308E-05	3950.917	2466.553	0.0093572	1.69648

107	11183	A2M	50	I	13.31	0.0198573	3950.977	2466.558	8.0506046	483.35070
107	11372	A2T	50	I	13.77	0.0015557	4266.586	2613.735	0.5952095	38.17920
107	11372	A2F	50	I	13.77	0.0015128	4266.586	2613.735	0.5787733	49.09517
107	11372	A2M	50	I	13.77	0.0407072	4266.586	2613.735	15.574356	935.06964
107	11449	A2M	50	I	13.45	0.039825	4041.147	2509.037	15.872621	952.97718
107	11449	A2F	50	I	13.45	0.0002255	4041.147	2509.037	0.089891	7.62512
107	11449	A2T		I	13.45	0.0027829	4041.147	2509.037	1.1091584	71.14602
107	11540	A2M	50	I	13.26	0.0264071	3919.916	2451.843	10.770296	646.63840
107	11806	A2M	50	I	13.86	0.0425225	4335.304	2645.223	16.075205	965.14016
107	11806	A2T	50	I	13.86	0.001196	4335.304	2645.223	0.4521169	29.00065
107	11806	A2E	50	I	13.86	0.0004648	4335.304	2645.223	0.1756979	14.90379
107	11897	A12F	50	I	14.4	5.391E-05	4804.686	2854.901	0.0188833	2.39395
107	11897	N09F	50	I	14.4	8.85E-06	4804.686	2854.901	0.0030999	0.79468
107	11897	A2F	50	I	14.4	0.0045594	4804.686	2854.901	1.597043	135.47116
107	11897	A2M	50	I	14.4	0.0406074	4804.686	2854.901	14.223736	853.97966
107	11979	A2M	50	I	14.27	0.0329865	4682.037	2801.038	11.776514	707.05081
107	11979	A2F	50		14.27	0.0044422	4682.037	2801.038	1.5859123	134.52699
107	11979	A12M	50		14.27	2.557E-05	4682.037	2801.038	0.0091288	0.81945
107	11979	A12F	50		14.27	1.8173-05	4682.037	2801.038	0.0064869	0.82238
107	11979	A2T	50		14.27	0.0202228	4682.037	2801.038	7.2197352	463.10372
107	11979	N09M	50		14.27	2.442E-05	4682.037	2801.038	0.0087182	1.58063
107	11979	A12T	50		14.27	2.392E-05	4682.037	2801.038	0.0085397	0.81892
107	12127	A2F	50		14.22	0.0022302	4636.582	2780.906	0.8019687	68.02800
107	12127	A2T	50		14.22	0.0033658	4636.582	2780.906	1.2103104	77.63432
107	12127	A2M	50		14.22	0.0302383	4636.582	2780.906	10.873537	652.83691
107	12201	A2F	50		13.24	0.0015846	3907.653	2446.023	0.6478434	54.95412
107	12201	A2M	50		13.24	0.0516157	3907.653	2446.023	21.101893	1266.93775
107	12285	A2M	50		13.17	0.04124	3865.446	2425.940	16.999588	1020.63921
107	12285	A2F	50		13.17	0.0005189	3865.446	2425.940	0.2139006	18.14438
107	12480	A12M	50		13.78	4.89E-05	4274.100	2617.188	0.0186842	1.67719
107	12480	A2M	50		13.78	0.042851	4274.100	2617.188	16.372918	983.01456
107	12565	A2M	50	I	13.7	0.0553728	4214.817	2589.883	21.38041	1283.65962
107	12565	A12M	50	I	13.7	2.433E-05	4214.817	2589.883	0.0093942	0.84328
107	12639	A12M	50	I	13.06	2.323E-05	3801.277	2395.258	0.0096983	0.87057
107	15445	A2T	50	I	5.23	0.0005078	1187.681	926.408	0.5481708	35.16195
107	12639	N09M	50	I	13.06	1.1443-05	38C1.277	2395.258	0.0047761	0.86592
107	12823	A2M	50	I	13.17	0.0152468	3865.446	2425.940	6.2848834	377.33847
107	13525	A2E	50	I	13.52	0.002653	4088.081	2531.011	1.0482134	88.91601
107	13525	A2M	50	I	13.52	0.0356075	4088.081	2531.011	14.068495	844.65917
107	15555	A12M	50	I	4.0	6.44E-06	892.566	718.369	0.0089647	0.80472
107	13648	A2M	50	I	11.67	6.126E-05	3160.433	2078.363	0.0294751	1.76966
107	12852	A2T	50	I	13.01	0.0059996	3772.944	2381.654	2.5190692	161.58353
107	12852	A2M	50	I	13.01	0.022663	3772.944	2381.654	9.5156578	571.31111
107	13650	A2M	50	I	13.41	0.0268407	4014.891	2496.704	10.750471	645.44813
107	13650	A2T	50	I	13.41	0.0058854	4014.891	2496.704	2.3572842	151.20597
107	15445	A2M	50	I	5.23	0.0009844	1187.681	926.408	1.0625552	63.79481
107	15347	N09M	50	I	6.16	1.018E-05	1440.803	1095.403	0.0092934	1.68491
107	15347	A12F	50	I	6.16	7.613-06	1440.803	1095.403	0.0069472	0.88074
107	15347	A2T	50	I	6.16	2.98E-05	1440.803	1095.403	0.0272046	1.74502
107	12942	A2M		I	13.03	0.0364939	3784.216	2387.070	15.288146	917.88588
107	12942	A2T	50	I	13.03	0.0047096	3784.216	2387.070	1.9729624	126.55398
107	12942	A2E	50	I	13.03	0.0015498	3784.216	2387.070	0.6492477	55.07325
107	13686	A2T	50	I	12.41	0.0004957	3468.273	2233.057	0.2219737	14.23831
107	15347	A2M	50	I	6.16	7.955E-05	1440.803	1095.403	0.0726217	4.36014
107	15347	A2F	50	I	6.16	1.119E-05	1440.803	1095.403	0.0102154	0.86654
107	15244	N09F	50	I	5.44	6.2E-06	1242.744	963.874	0.0064324	1.64896
107	13650	A2F	50	I	13.41	0.0031082	4014.891	2496.704	1.2449255	105.60236
107	15244	A2M	50	I	5.44	0.0001097	1242.744	963.874	0.1137908	6.83189
107	13016	N09T	50	I	13.18	3.291E-05	3871.409	2428.782	0.01355	2.62503
107	13016	A2M	50	I	13.18	0.042032	3871.409	2428.782	17.30579	1039.02329
107	13016	A2F	50	I	13.18	0.0016387	3871.409	2428.782	0.6746798	57.23055
107	13016	N09M	50	I	13.18	1.124E-05	3871.409	2428.782	0.0046278	0.83904
107	13016	A2T	50	I	13.18	0.0005322	3871.409	2428.782	0.2191057	14.05435
107	13724	A2T	50	I	5.99	1.501E-05	1392.849	1064.007	0.0141071	0.90488
107	15244	A2F	50	I	5.44	1.936E-05	1242.744	963.874	0.0200856	1.70379
107	15244	N09T	50	I	5.44	4.11E-06	1242.744	963.874	0.004264	0.82607
107	13371	A2F	50	I	12.95	0.0005114	3739.607	2365.600	0.2161608	18.33611
107	13371	A12F	50	I	12.95	3.312E-05	3739.607	2365.600	0.0140007	1.77495
107	13371	N09T	50	I	12.95	2.132E-05	3739.607	2365.600	0.0090125	1.74598
107	13371	A2M	50	I	12.95	0.0098354	3739.607	2365.600	4.1576555	249.62171
107	15244	A12T	50	I	5.44	3.492E-05	1242.744	963.874	0.0362288	3.47417
107	15244	A12M	50	I	5.44	9.32E-06	1242.744	963.874	0.0096693	0.86797
107	15244	A12F	50	I	5.44	6.583-06	1242.744	963.874	0.0068266	0.86545
107	13859	A12F	50	I	12.28	1.57E-05	3409.611	2203.946	0.0071236	0.90310
107	13859	A2M	50	I	12.28	0.0512679	3409.611	2203.946	23.261879	1396.62127
107	13859	N09M	50		12.28	1.039E-05	3409.611	2203.946	0.0047143	0.85471
107	13859	A2F	50		12.28	2.309E-05	3409.611	2203.946	0.0104767	0.88870
107	13686	A2F	50		12.41	4.68E-05	3468.273	2233.057	0.0209578	1.77777

107	15244	A2T	50	I	5.44	0.0001027	1242.744	963.874	0.10657	6.83584
107	13686	A2M	50	I	12.41	0.0352515	3468.273	2233.057	15.786204	947.78878
107	13859	A2T	50	I	12.28	0.0074318	3409.611	2203.946	3.3720521	216.29739
107	10001	X09E	50	V	13.59	1.502E-05	3209.029	2309.956	0.0065023	0.86880
107	09964	BXA	50	V	6.26	3.776E-05	1196.456	1037.074	0.0364101	1.75417
107	12852	X09E	50	V	13.42	4.461E-05	3149.855	2277.799	0.0195847	2.61679
107	13015	X09C	50	V	13.19	9.8E-06	3071.004	2234.584	0.0043856	0.88622
107	13524	BXS	50	V	13.13	0.0090456	3050.659	2223.364	4.0684156	184.93542
107	12852	BXE	50	V	13.42	0.132468	3149.855	2277.799	58.156145	2484.74852
107	12852	B09E	50	I	13.42	9.48E-05	3149.855	2277.799	0.0416191	2.61410
107	13017	BXS	50	V	11.39	0.0006275	2498.466	1906.869	0.3290577	14.95777
107	13858	X09C	50	V	12.04	8.83E-06	2696.533	2023.210	0.0043644	0.88192
107	12942	BXA	50	V	12.82	0.0001024	2946.996	2165.745	0.3243041	15.62439
107	13858	BXE	50	V	12.04	0.0862149	2696.533	2023.210	42.612944	1820.65797
107	13858	BXC	50	V	12.04	0.0055752	2696.533	2023.210	2.7556215	178.15652
107	13858	B7E	50	V	12.01	0.0006682	2687.184	2017.793	0.331134	14.14785
107	13524	BXE	50	V	13.13	0.0506382	3050.659	2223.364	22.775485	973.09325
107	13524	BXC	50	V	13.13	0.0057116	3050.659	2223.364	2.5688908	166.08400
107	13372	B09S	50	V	13.02	2.887E-05	3013.598	2202.853	0.0131057	0.87609
107	13372	BXC	50	V	13.02	0.0061316	301.3.598	2202.853	2.7834591	179.95627
107	13015	BXE	50	V	13.19	0.0725192	3071.004	2234.584	32.453106	1386.57412
107	14055	BXE	50	V	2.39	0.0001106	417.626	395.459	0.2796752	11.94925
107	14065	X09C	50	V	5.67	3.65E-06	1068.855	939.415	0.0038854	0.78514
107	14065	BXE	50	V	5.67	5.88E-05	1068.855	939.415	0.0625921	2.67428
107	14065	B09E	50	V	5.67	1.3E-05	1068.855	939.415	0.0138384	0.86919
107	14065	X09S	50	V	5.67	5.74E-06	1068.855	939.415	0.0061102	0.86796
107	14065	X09E	50	V	5.67	1.983E-05	1068.855	939.415	0.0211089	2.82045
107	14448	B09S	50	V	5.99	1.1853-05	1137.627	992.380	0.011941	0.79823
107	14883	BXE	50	V	5.66	1.819E-05	1066.722	937.760	0.0193973	0.82876
107	15204	B09E	50	V	5.92	1.386E-05	1122.496	980.794	0.0141314	0.88759
107	13372	X09C	50	V	13.02	9.57E-06	3013.598	2202.853	0.0043444	0.87789
107	13372	BXS	50	V	13.02	0.0083627	3013.598	2202.853	3.7962822	172.56522
107	13372	BXE	50	V	13.02	0.0227556	3013.598	2202.853	10.33006	441.35666
107	13858	BXS	50	V	12.04	0.0018027	2696.533	2023.210	0.8910298	40.50298
107	13017	BXC	50	V	11.39	0.001898	2498.466	1906.869	0.9953489	64.35133
107	13017	BXE	50	V	11.39	0.0426255	2458.466	1906.869	22.35366	955.07056
107	15244	X09S	50	V	13.58	1.406E-05	3205.527	2308.059	0.0060917	0.86533
107	13015	BXS	50	V	13.19	0.0051717	3071.004	2234.584	2.3144087	105.20463
107	13015	BXC	50	V	13.19	0.0090882	3071.004	2234.584	4.0670663	262.94408
107	13015	B7E	50	V	12.13	0.000673	2724.701	2039.486	0.3299654	14.09793
107	13015	B09C	50	V	13.19	2.082E-05	3051.004	2234.584	0.0093172	0.88577
107	12942	BXC	50	V	12.82	0.0010566	2946.996	2165.745	0.4878691	31.54172
107	12942	BXE	50	V	12.82	0.0951093	2946.996	2165.745	43.915279	1876.30086
107	12942	B7E	50	V	12.1	0.0006706	2715.291	2034.056	0.3296664	14.08515
107	12942	BXS	50	V	12.82	0.0027912	2946.996	2165.745	1.2888036	58.58434
107	13524	BXA	50	V	13.13	0.0080051	3050.659	2223.364	3.6004626	173.46379
107	10001	BXE	50	V	13.59	0.0014548	3209.029	2309.956	0.6298085	26.90886
107	10001	X09S	50	V	13.59	2.822E-05	3209.029	2309.956	0.0122167	1.73539
107	10001	BXS	50	V	5.61	1.754E-05	1056.072	929.484	0.0188707	0.85779
107	10001	B09C	50	V	13.59	6.357E-05	3209.029	2309.956	0.02752	2.61628
107	10001	B09S	50	V	13.59	5.996E-05	3209.029	2309.956	0.0259572	1.73518
107	10001	BXR	50	V	5.61	1.571E-05	1056.072	929.484	0.0169019	0.85957
107	10001	X09R	50	V	5.61	5.03E-06	1056.072	929.484	0.0054116	0.85832
107	10001	B09R	50	V	5.61	1.0683-05	1056.072	929.484	0.0114902	0.86016
107	10001	B09E	50	V	13.59	6.3823-05	3209.029	2309.956	0.0276282	1.73533
107	09964	X09A	50	V	6.26	3.025E-05	1196.456	1037.074	0.0291686	4.39249
107	12852	BXS	50	V	13.42	0.0007427	3149.855	2277.799	0.3260736	14.82212
107	11540	X09S	50	V	16.49	0.0012799	4346.582	2889.935	0.4428646	62.90944
107	11540	X09E	50	V	16.49	0.009088	4346.582	2889.935	3.1446935	420.17567
107	11540	B09E	50	V	16.49	0.0192685	4346.582	2889.935	6.6674508	418.78318
107	11540	B09S	50	V	16.49	0.0027588	4346.582	2889.935	0.9546235	63.81430
107	11540	X09C	50	V	13.73	2.454E-05	3258.338	2336.579	0.0105025	2.12230
107	11540	B09C	50	V	16.49	8.865E-05	4346.582	2889.935	0.0306754	2.91626
107	12565	BXE	50	V	16.72	0.0192326	4448.012	2938.642	6.5447382	279.62700
107	12565	BXS	50	V	16.72	0.0005059	4448.012	2938.642	0.1721612	7.82582
107	12852	BXE	50	V	16.62	0.0120996	4403.697	2917.415	4.1473699	177.19832
						1.873652			829.75441	46262.85593

KE Basin

108	10001	B09C	50	V	12.4	7.756E-05	2810.334	2088.576	0.0371353	3.53039
108	10001	X09C	50	V	12.4	1.824E-05	2810.334	2088.576	0.0087332	1.76476
108	10001	X09A	50	V	12.4	1.222E-05	2813.334	2088.576	0.0058509	0.88108
108	10001	X09S	50	V	12.4	6.455E-05	2810.334	1088.576	0.0309062	4.39026
108	10001	X09E	50	V	12.4	5.512E-05	2810.334	2088.576	0.0263912	3.52624
108	10001	B09S	50	V	12.4	2.744E-05	2810.334	2088.576	0.0131381	0.87825
108	10201	N09A	50	V	9.09	0.0008492	1864.783	1509.206	0.562647	84.72888

108	10201	B09E	50	V	9.09	0.0005791	1864.783	1509.206	0.3837383	24.10264
108	10201	X09S	50	V	9.09	0.000256	1864.783	1509.206	0.169619	24.09458
108	10201	B09S	50	V	9.09	0.0005442	1864.783	1509.206	0.3605738	24.10350
108	10201	X09E	50	V	9.09	0.0002723	1864.783	1509.206	0.1804393	24.10925
108	10201	A09A	50	V	9.09	0.0017017	1864.783	1509.206	1.1275469	91.35716
108	10259	N09A	50	V	10.41	5.7E-05	2216.525	1735.083	0.0328515	4.94709
108	10259	B09E	50	V	10.41	0.022279	2216.525	1735.083	12.840284	806.49937
108	10259	A09A	50	V	10.41	9.132E-05	2216.525	1735.083	0.0526315	4.26436
108	10259	B09C	50	V	10.41	0.0026656	2216.525	1735.083	1.5362952	146.05299
108	10259	X09C	50	V	10.41	0.0012963	2216.525	1735.083	0.7471112	150.97221
108	10259	X09E	50	V	10.41	0.010395	2216.525	1735.083	5.9910673	800.49161
108	10294	B09E	50	V	10.4	0.0434755	2213.745	1733.350	25.081787	1575.38926
108	10294	B09C	50	V	10.4	0.0014622	2213.745	1733.350	0.843586	80.19830
108	10294	B09S	50	V	10.4	0.0013724	2213.745	1733.350	0.7917673	52.92775
108	10294	A09A	50	V	10.4	2.277E-05	2213.745	1733.350	0.0131364	1.06435
108	10294	A07B	50	V	8.94	4.941E-05	1826.632	1483.854	0.0332984	
108	10294	X09E	50	V	10.4	0.0204323	2213.745	1733.350	11.787739	1575.00922
108	10294	X09C	50	V	10.4	0.0006868	2213.745	1733.350	0.39625	80.07207
108	10294	N07B	50	V	8.94	4.115E-05	1826.632	1483.854	0.0277318	5.09913
108	10294	X09S	50	V	10.4	0.0006203	2213.745	1733.350	0.357885	50.83798
108	10294	N09A	50	V	10.4	1.137E-05	2213.745	1733.350	0.0065596	0.98780
108	10350	X09S	50	V	9.28	6.834E-05	1913.612	1541.399	0.0443363	6.29803
108	10350	X09E	50	V	9.28	0.0001817	1913.612	1541.399	0.1178475	15.14610
108	10350	B09S	50	V	9.28	0.0001453	1913.612	1541.399	0.0942391	6.29966
108	10350	B09C	50	V	9.28	5.121E-05	1913.612	1541.399	0.0332231	3.15846
108	10350	X09C	50	V	9.28	2.406E-05	1913.612	1541.399	0.0156092	3.15422
108	10350	B09E	50	V	9.28	0.0003864	1913.612	1541.399	0.2506814	15.74532
108	10385	A07B	50	V	10.21	0.0002338	2161.271	1700.494	0.1374659	
108	10385	X09S	50	V	11.21	0.0003007	2445.227	1875.008	0.160394	22.78415
108	10385	B09S	50	V	11.21	0.000581	2415.227	1875.008	0.3098653	20.71376
108	10385	B09E	50	V	11.21	0.0462872	2415.227	1875.008	24.68642	1550.55626
108	10385	X09A	50	V	11.21	0.0001161	2445.227	1875.008	0.0619197	9.32448
108	10385	N07B	50	V	10.21	0.0001362	2161.271	1700.494	0.0801061	14.72934
108	10385	B09A	50	V	11.21	0.0002741	2445.227	1875.008	0.146186	10.35626
108	10385	X09E	50	V	11.21	0.0217224	2445.227	1875.008	11.585203	1547.94748
108	10456	BXS	50	V	11.24	0.00609	2454.053	1880.308	3.2388309	147.22551
108	10456	A9D	50	V	11.24	1.825E-05	2454.053	1880.308	0.0097059	
108	10456	BXC	50	V	11.24	0.0025769	2454.053	1880.308	1.3704882	88.60484
108	10456	BXA	50	V	11.24	0.0007926	2454.053	1880.308	0.4215267	20.30839
108	10456	B09E	50	V	11.24	6.098E-05	2454.053	1880.308	0.0324309	2.03698
108	10456	BXE	50	V	11.24	0.0409716	2454.053	1880.308	21.789812	930.97990
108	10576	BXE	50	V	11.09	0.0073804	2410.108	1853.848	3.9811021	170.09445
108	10576	BXS	50	V	11.09	8.356E-05	2410.108	1853.848	0.0450738	2.04889
108	10602	BXS	50	V	13.75	0.0028392	3265.425	2340.393	1.2131296	55.14447
108	10602	A7B	50	V	13.75	0.0001883	3265.425	2340.393	0.0804352	
108	10602	BXE	50	V	13.75	0.057294	3265.425	2340.393	24.480505	1045.94101
108	10602	BXA	50	V	13.75	0.0012933	3265.425	2340.393	0.5525995	26.62325
108	10602	B09E	50	V	11.09	2.988E-05	2410.108	1853.848	0.0161178	1.01236
108	10602	BXC	50	V	11.09	2.896E-05	2410.108	1853.848	0.0156216	1.00997
108	10679	BXA	50	V	14.09	0.0002923	3387.581	2405.636	0.1215146	5.85435
108	10679	BXC	50	V	11.09	0.0023855	2410.108	1853.848	1.2867557	83.19136
108	10679	BXE	50	V	14.09	0.054006	3387.581	2405.636	22.449784	959.17753
108	10679	B09A	50	V	11.09	2.687E-05	2410.108	1853.848	0.0144942	1.02681
108	10679	A7B	50	V	14.09	0.0007279	3387.581	2405.636	0.3025769	
108	10679	BXS	50	V	14.09	0.0030491	3387.581	2405.636	1.2674899	57.61550
108	10742	X09S	50	V	10.8	0.0004467	2326.442	1802.969	0.2477691	35.19590
108	10742	B09C	50	V	14.25	0.0028183	3446.176	2436.612	1.1566431	109.96011
108	10742	B09S	50	V	14.25	0.0011151	3446.176	2436.612	0.4576314	30.59157
108	10742	B09E	50	V	14.25	0.0297741	3446.176	2436.612	12.219453	767.50491
108	10742	X09C	50	V	10.8	0.0010911	2326.442	1802.969	0.6051852	122.29257
108	10742	X09E	50	V	14.25	0.013986	3446.176	2436.612	5.7399382	766.93719
108	10770	BXS	50	V	13.91	0.0102838	3322.515	2370.999	4.3373364	197.15959
108	10770	BXE	50	V	13.91	0.0327126	3322.515	2370.999	13.796986	589.48270
108	10770	BXC	50	V	11.66	0.0013446	2579.614	1954.943	0.6878153	44.46866
108	10832	BXC	50	V	13.65	0.0047032	3230.097	2321.350	2.0260449	130.98791
108	10832	BXA	50	V	13.65	9.53E-05	3230.097	2321.350	0.0410537	1.97789
108	10832	A7B	50	V	13.65	0.0005997	3230.097	2321.350	0.2583324	
108	10832	BXS	50	V	13.65	0.0072201	3230.097	2321.350	3.1102889	141.38246
108	10832	BXE	50	V	13.65	0.1088438	3230.097	2321.350	46.88812	2003.31685
108	10982	X09A	50	V	11.7	0.0001215	2591.770	1962.095	0.0619236	9.32506
108	10982	A07B	50	V	14.97	0.0004334	3718.941	2578.240	0.1681147	
108	10982	X09C	50	V	11.7	0.0006747	2591.770	1962.095	0.343862	69.48579
108	10982	B09E	50	V	14.97	0.0378972	3718.941	2578.240	14.698863	923.23691
108	10982	X09E	50	V	14.97	0.0176799	3718.941	2578.240	6.8573401	916.23794
108	10982	B09A	50	V	14.97	0.0003164	3718.941	2578.240	0.1227	8.69243
108	10982	N07B	50	V	14.97	0.0002166	3713.941	2578.240	0.0840263	15.45015
108	10982	B09C	50	V	11.7	0.0014365	2591.770	1962.095	0.7321153	69.60097
108	10982	B09S	50	V	14.97	0.0023455	3718.941	2578.240	0.9097252	60.81295

108	10982	X09S	50	V	11.7	0.0010153	2591.770	1962.095	0.517457	73.50538
108	11036	X09A	50	V	14.37	3.192E-05	3490.596	2459.960	0.0129758	1.95403
108	11036	X09S	50	V	14.37	0.0007952	3490.596	2459.960	0.3232736	45.92139
108	11036	N09D	50	V	13.31	7.09E-06	3111.972	2257.089	0.0031412	0.47303
108	11036	B09S	50	V	14.37	0.0016537	3490.596	2459.960	0.6722468	44.93809
108	11036	X09C	50	V	13.31	0.0002763	3111.972	2257.089	0.1223921	24.73235
108	11036	A09D	50	V	14.37	1.534E-05	3490.596	2459.960	0.0062359	
108	11036	B09C	50	V	13.31	0.0007291	3111.972	2257.089	0.3230355	30.71044
108	11036	B09E	50	V	14.37	0.0188239	3490.596	2459.960	7.6521255	480.63069
108	11036	X09E	50	V	14.37	0.00891	3490.596	2459.960	3.6220106	483.95202
108	11109	B09E	50	V	14.62	0.0368988	3584.463	2508.928	14.706998	923.74788
108	11109	B09C	50	V	14.62	0.001648	3584.463	2508.928	0.6568542	62.44602
108	11109	X09E	50	V	14.62	0.0173193	3584.463	2508.928	6.9030478	922.34515
108	11109	X09A	50	V	10.32	0.0001505	2191.570	1719.500	0.0875138	13.17868
108	11109	X09S	50	V	14.62	0.0014071	3584.463	2508.928	0.5608451	79.66870
108	11109	B09A	50	V	14.62	0.0004133	3584.463	2508.928	0.1647237	11.66952
108	11109	B09S	50	V	14.62	0.0030254	3584.463	2508.928	1.2058337	80.60710
108	11109	X09C	50	V	10.32	0.0006278	2191.570	1719.500	0.3651003	73.77751
108	11183	X09E	50	V	14.49	0.0376037	3535.428	2483.409	15.141948	2023.17913
108	11183	X09S	50	V	14.49	0.0011984	3535.428	2483.409	0.4825625	68.54856
108	11183	B09E	50	V	14.49	0.0801891	3535.428	2483.409	32.289937	2028.13383
108	11183	A07B	50	V	14.49	0.0004497	3535.428	2483.409	0.1810616	
108	11183	BXC	50	V	14.49	7.558E-05	3535.428	2483.409	0.030434	1.96762
108	11183	B09S	50	V	14.49	0.0024725	3535.428	2483.409	0.9955992	66.55343
108	11183	X09A	50	V	14.49	0.0001614	3535.428	2483.409	0.0649913	9.78703
108	11183	BXE	50	V	14.49	0.0005124	3535.428	2483.409	0.2063172	8.81500
108	11183	BXS	50	V	14.49	0.000107	3535.428	2483.409	0.0430698	1.95780
108	11183	B09C	50	V	14.49	0.0004622	3535.428	2483.409	0.1861312	17.69518
108	11183	N07B	50	V	14.49	0.000238	3535.428	2483.409	0.0958199	17.61867
108	11183	B09A	50	V	14.49	0.0003431	3535.428	2483.409	0.1381569	9.78745
108	11183	X09C	50	V	11.02	0.0001825	2389.758	1841.534	0.099113	20.02822
108	11372	B09A	50	V	15.17	0.0001046	3797.422	2618.251	0.0399312	2.82885
108	11372	B09C	50	V	15.17	0.0010436	3797.422	2618.251	0.3985866	37.89296
108	11372	X09A	50	V	12.05	4.332E-05	2699.653	2025.016	0.0213924	3.22148
108	11372	N07B	50	V	15.17	0.0001478	3797.422	2618.251	0.0564652	10.38240
108	11372	X09S	50	V	15.17	0.0007652	3797.422	2618.251	0.2922408	41.51315
108	11372	B09S	50	V	15.17	0.0016992	3797.422	2618.251	0.648998	43.38397
108	11372	X09E	50	V	12.05	0.0205128	2699.653	2025.016	10.129697	1353.47130
108	11372	B09E	50	V	15.17	0.0492805	3797.422	2618.251	18.821909	1182.20577
108	11372	A07B	50	V	15.17	0.0003227	3797.422	2618.251	0.1232426	
108	11372	X09C	50	V	12.05	0.0003881	2699.653	2025.016	0.1916429	38.72617
108	11449	B09E	50	V	14.37	0.0388198	3490.596	2459.960	15.780682	991.18602
108	11449	B09C	50	V	14.37	0.0002264	3490.596	2459.960	0.0920137	8.74759
108	11449	X09S	50	V	11.03	0.0032545	2392.659	1843.292	1.7655909	250.80425
108	11449	X09C	50	V	11.03	7.968E-05	2392.659	1843.292	0.043227	8.73508
108	11449	X09A	50	V	14.37	0.0002057	3490.596	2459.960	0.083603	12.58976
108	11449	X09E	50	V	14.37	0.0182044	3490.596	2459.960	7.4002962	988.78458
108	11449	B09A	50	V	14.37	0.0004707	3490.596	2459.960	0.1913365	13.55485
108	11449	B09S	50	V	14.37	0.0080213	3450.596	2459.960	3.2607242	217.97162
108	11540	X09C	50	V	11.3	4.805E-05	2471.762	1890.920	0.0254109	5.13490
108	11540	B09C	50	V	11.3	8.188E-05	2471.762	1890.920	0.0433017	4.11662
108	11540	B09A	50	V	11.3	0.0002738	2471.762	1890.920	0.1447972	10.25787
108	11540	B09S	50	V	11.3	0.0011608	2471.762	1890.920	0.613881	41.03648
108	11540	N07B	50	V	11.66	0.0001501	2579.614	1954.943	0.0767695	14.11582
108	11540	X09E	50	V	11.3	0.006926	2471.762	1890.920	3.6627882	489.40048
108	11540	BXE	50	V	11.3	0.0019081	2471.762	1890.920	1.0090643	43.11274
108	11540	A07B	50	V	11.66	0.0003003	2579.614	1954.943	0.1536106	
108	11540	B09E	50	V	11.3	0.0147606	2471.762	1890.920	7.806062	490.29946
108	11540	X09A	50	V	11.3	0.0001417	2471.762	1890.920	0.0749265	11.28316
108	11540	X09S	50	V	11.3	0.0005324	2471.762	1890.920	0.2815296	39.99161
108	11733	X09S	50	V	10.36	9.534E-05	2202.642	1726.422	0.055224	7.84464
108	11733	B09S	50	V	12.82	0.0001952	2946.996	2165.745	0.0901214	6.02440
108	11733	X09E	50	V	10.36	0.0003041	2202.642	1726.422	0.1761331	23.53388
108	11733	B09E	50	V	12.82	0.0007616	2946.996	2165.745	0.3516757	22.08878
108	11806	A07B	50	V	15.03	0.000399	3742.359	2590.212	0.1540414	
108	11806	B09E	50	V	15.03	0.0447076	3742.359	2590.212	17.260202	1084.11484
108	11806	X09A	50	V	11.94	7.09E-05	2665.451	2005.174	0.0353585	5.32463
108	11806	B09C	50	V	11.94	4.508E-05	2665.451	2005.174	0.0224818	2.13731
108	11806	X09S	50	V	15.03	0.0003096	3742.359	2590.212	0.1195269	16.97893
108	11806	X09C	50	V	11.94	2.118E-05	2665.451	2005.174	0.0105627	2.13445
108	11806	BXE	50	V	11.94	0.0007003	2665.451	2005.174	0.3492366	14.92130
108	11806	B09A	50	V	11.94	0.0001809	2665.451	2005.174	0.0902166	6.39122
108	11806	B09S	50	V	15.03	0.0006574	3742.359	2590.212	0.2537861	16.96500
108	11806	X09E	50	V	11.94	0.0183974	2665.451	2005.174	9.1749851	1225.90820
108	11806	N07B	50	V	15.03	0.0001728	3742.359	2590.212	0.0667011	12.26451
108	11897	X09E	50	V	15.47	0.0249415	3917.424	2678.830	9.3106034	1244.02873
108	11897	B09S	50	V	15.47	0.0041936	3917.424	2678.830	1.5654747	104.64824
108	11897	X09S	50	V	15.47	0.001956	3917.424	2678.830	0.7301547	103.71933

108	11897	B09E	50	V	15.47	0.0530136	3917.424	2678.830	19.789822	1243.00046
108	11897	B09C		V	11.69	0.0060199	2588.728	1960.301	3.070882	291.94357
108	11897	X09C	50	V	11.69	0.0028293	2588.728	1960.307	1.4432998	291.65426
108	11897	X09A	50	V	15.47	1.725E-05	3917.424	2678.830	0.0064394	0.96970
108	11979	A7B	50	V	15.34	0.000208	3865.085	2652.496	0.0784167	
108	11979	B09C	50	V	15.34	0.0047344	3865.085	2652.496	1.784885	169.68600
108	11979	X09S	50	V	11.7	0.0018745	2591.770	1962.095	0.9553665	135.71092
108	11979	X09E	50	V	15.34	0.0170867	3865.085	2652.496	6.4417519	860.70946
108	11979	B09E	50	V	15.34	0.0363959	3865.085	2652.496	13.721394	861.84198
108	11979	BXE	50	V	15.34	0.0245593	3865.085	2652.496	9.2589476	395.59287
108	11979	BXC	50	V	15.34	0.0009487	3865.085	2652.496	0.3516707	23.12413
108	11979	X09C	50	V	11.7	0.0018824	2591.770	1962.095	0.9593826	193.86688
108	11979	BXS	50	V	15.34	0.0011768	3865.085	2652.496	0.4436727	20.16775
108	11979	B09S	50	V	15.34	0.0049162	3865.085	2652.496	1.8534204	123.89672
108	12127	BXA	50	V	14.73	0.0012374	3626.339	2530.616	0.4889877	23.55854
108	12127	BXS	50	V	14.73	0.0083022	3626.339	2530.616	3.2807192	149.12960
108	12127	BXE	50	V	14.73	0.0652688	3626.339	2530.616	25.791651	1101.96035
108	12127	BXC	50	V	14.73	0.0008477	3626.339	2530.616	0.3349619	21.65597
108	12127	A7B	50	V	14.73	0.0003645	3626.339	2530.616	0.1440361	
108	12201	A7B	50	V	13.98	0.0003046	3347.712	2384.443	0.1277279	
108	12201	X09E	50	V	11.38	1.374E-05	2495.490	1905.095	0.0072122	0.96366
108	12201	BXE	50	V	13.98	0.0372372	3347.712	2384.443	15.616729	667.23206
108	12201	B09C	50	V	11.38	1.939E-05	2495.490	1905.095	0.010178	0.96760
108	12201	BXC	50	V	11.38	0.0008221	2455.490	1905.095	0.4318577	27.92048
108	12201	BXS	50	V	13.98	0.013238	3347.712	2384.443	5.5518124	252.36526
108	12240	B09E	50	V	14.51	0.000146	3542.940	2487.327	0.0587136	3.68781
108	12240	X09E	50	V	11.22	5.968E-05	2448.167	1876.774	0.0317992	4.24883
108	12285	X09C	50	V	12.1	1.018E-05	2715.291	2034.056	0.0050048	1.01134
108	12285	BXE	50	V	14.45	0.140543	3520.438	2475.581	56.771718	2425.59823
108	12285	B09E	50	V	14.45	7.738E-05	3520.438	2475.581	0.0312573	1.96327
108	12285	BXC	50	V	12.1	0.0015548	2715.291	2034.056	0.7643693	49.41802
108	12285	B09A	50	V	14.45	3.429E-05	3520.438	2475.581	0.0138513	0.98127
108	12285	BXS	50	V	14.45	0.0148591	3520.438	2475.581	6.0022672	272.84130
108	12480	BXC	50	V	12.38	0.000509	2803.932	2084.927	0.2441141	15.78247
108	12480	BXS	50	V	14.29	0.0090253	3460.937	2444.383	3.6922608	167.83679
108	12480	BXA		V	14.29	0.0014025	3460.937	2444.383	0.5737726	27.64333
108	12480	BXE	50	V	14.29	0.1199848	3460.937	2444.383	49.085906	2097.21831
108	12565	BXA	50	V	14.15	0.0006899	3409.470	2417.231	0.2854174	13.75090
108	12565	X09E	50	V	0.0	1.2E-07	7.145	7.113	0.0168711	2.25421
108	12565	BXS	50	V	14.15	0.0086702	3409.470	2417.231	3.5868224	163.04394
108	12565	BXE	50	V	14.15	0.0826991	3409.470	2417.231	34.212305	1461.73673
108	12565	BXC	50	V	14.15	0.0003313	3409.470	2417.231	0.1370535	8.86079
108	12639	B7E	50	V	13.84	5.407E-05	3297.452	2357.588	0.0229345	0.97989
108	12639	BXS	50	V	13.84	0.0126469	3297.452	2357.588	5.3643219	243.84262
108	12639	BXE	50	V	13.84	0.0944467	3297.452	2357.588	40.060743	1711.61400
108	12639	B09E	50	V	13.84	7.442E-05	3297.452	2357.588	0.0315662	1.98267
108	12852	BXE	50	V	11.43	0.0047488	2510.389	1913.969	2.4811056	106.00640
108	13015	BXC	50	V	13.19	0.0004283	3071.004	2234.584	0.1916509	12.39062
108	13015	BXE	50	V	13.19	0.0012933	3071.004	2234.584	0.5787745	24.72841
108	13016	BXS	50	V	5.63	1.794E-05	1060.329	932.794	0.0192325	0.87424
108	13371	BXE	50	V	6.58	2.019E-05	1267.164	1090.067	0.0185218	0.79135
108	13649	BXC	50	V	13.25	0.001159	3091.442	2245.825	0.5160686	33.36488
108	13649	BXE	50	V	13.25	0.0078251	3091.442	2245.825	3.484287	148.86779
108	13649	B7E	50	V	11.4	0.000631	2501.443	1908.643	0.3306223	14.12599
108	13685	BXE	50	V	13.34	0.0051934	3122.273	2262.730	2.29521	98.06392
108	14065	X09E	50	V	5.62	1.905E-05	1058.200	931.139	0.0204588	2.73359
108	14355	X09S	50	V	15.74	0.0003938	4027.805	2733.933	0.1440233	20.45867
108	14355	B09E	50	V	12.0	0.0122538	2684.073	2015.989	6.0783066	381.77898
108	14355	B09S	50	V	15.74	0.0008362	4027.805	2733.933	0.305867	20.44648
108	14355	B09C	50	V	15.74	0.0002532	4027.805	2733.933	0.0926028	8.80360
108	14355	X09E	50	V	12.0	0.0057603	2684.073	2015.989	2.8573071	381.77677
108	14355	X09C	50	V	15.74	0.000119	4027.805	2733.933	0.0435197	8.79423
108	14356	BXA	50	V	11.28	0.012802	2465.850	1887.381	6.7829177	326.78872
108	14356	BXE	50	V	11.28	0.0021211	2465.850	1887.381	1.1238113	48.01536
108	14356	A09A	50	V	11.28	0.0002834	2465.850	1887.381	0.150134	12.16430
108	14356	B09S	50	V	11.28	3.456E-05	2465.850	1887.381	0.0183111	1.22405
108	14356	X09E	50	V	11.28	0.0001626	2465.850	1887.381	0.086167	11.51314
108	14356	BXS	50	V	11.28	0.0005845	2465.850	1887.381	0.3096672	14.07635
108	14356	N09A	50	V	11.28	0.0001334	2465.850	1887.381	0.0706905	10.64527
108	14356	B09C	50	V	11.28	1.642E-05	2465.850	1887.381	0.0086999	0.82708
108	14356	A9A	50	V	11.28	0.0050311	2465.850	1887.381	2.6656674	
108	14356	B09A	50	V	11.28	2.204E-05	2465.850	1887.381	0.0116776	0.82727
108	14722	B7E	50	V	5.05	5.007E-05	938.411	836.761	0.0598379	2.55660
108	15204	B7E	50	V	5.53	0.0002813	1039.082	916.241	0.3069606	13.11504
108	15204	BXA	50	V	6.01	0.0124502	1141.959	995.690	12.504117	602.42575
108	15204	BXC	50	V	6.01	0.002754	1141.959	995.690	2.7659197	178.82232
108	15204	X09E	50	V	6.01	6.52E-06	1141.959	995.690	0.0065482	0.87494
108	15204	BXS	50	V	6.01	0.0175031	1141.959	995.690	17.578856	799.07106

108	15204	B09E	50	V	6.01	1.386E-05	1141.959	995.690	0.01392	0.87432
108	15204	BXE	50	V	6.01	0.0517856	1141.959	995.690	52.009716	2222.13945
108	15240	B7E	50	V	5.71	0.0004296	1077.396	946.036	0.4541053	19.40186
108	15240	X09A	50	V	5.6	5.25E-06	1053.945	927.829	0.0056584	0.85209
108	15240	X09S	50	V	5.6	5.56E-06	1053.945	927.829	0.0059925	0.85124
108	15240	BXS	50	V	5.6	6.948E-05	1053.945	927.829	0.0748845	3.40398
108	15240	B09E	50	V	5.6	1.257E-05	1053.945	927.829	0.0135478	0.85094
108	15316	BXA	50	V	6.1	0.0087749	1161.504	1010.588	8.6829877	418.33066
108	15316	BXC	50	V	6.1	0.0001626	1161.504	1010.588	0.1608965	10.40228
108	15316	X09E	50	V	6.1	6.55E-06	1161.504	1010.588	0.0064814	0.86600
108	15316	BXS	50	V	**6.1**	0.0037863	1161.504	1010.588	3.7466716	170.31011
108	15316	BXE	**50**	V	6.1	0.0043375	1161.504	1010.588	4.2920771	183.38100
108	15444	BXA		V	4.7	5.995E-05	866.341	778.768	0.0769806	3.70878
108	15444	BXS	50	V	4.7	5.084E-05	866.341	778.768	0.0652826	2.96751
108	15444	BXE	50	V	4.7	6.76E-05	866.341	778.768	0.0868038	3.70873
108	15451	BXS	50	V	6.79	4.686E-05	1314.169	1124.866	0.0416583	1.89364
108	15451	BXA	50	V	6.79	0.007239	1314.169	1124.866	6.4353997	310.04594
108	15451	BXC	50	V	6.79	9.864E-05	1314.169	1124.866	0.0876905	5.66937
108	15451	B7E	50	V	4.97	0.0009139	921.840	823.509	1.1097875	47.41619
108	15455	BXS	50	V	4.94	0.0002258	915.641	818.539	0.2758085	12.53725
108	15455	BXA	50	V	4.94	0.000225	915.641	818.539	0.27488	13.24322
108	15455	BXE	50	V	4.94	0.0004515	915.641	818.539	0.551617	23.56810
108	15457	BXA	50	V	4.35	0.0001982	795.364	720.734	0.2750529	13.25155
108	15457	B7E	50	V	1.69	1.242E-05	291.111	279.875	0.0443769	1.89602
108	15458	BXR	50	V	4.26	0.0002056	777.286	705.804	0.2912705	14.81303
108	15458	BXS	50	V	4.26	0.0222156	777.286	705.804	31.475578	1430.76563
108	15458	BXE	50	V	4.26	0.0370944	777.286	705.804	52.556207	2245.48852
108	15458	B7E	50	V	3.44	0.0001811	615.819	569.682	0.3179317	13.58378
108	15458	BXA	50	V	4.26	0.0117067	7i7.286	705.804	16.586268	799.09641
108	15458	**BXC**	50	V	4.26	0.0014297	777.286	705.804	2.0256038	130.95939
108	15460	BXA	50	V	4.29	0.00972	783.304	710.781	13.675094	658.84134
108	15460	B7E	50	V	2.83	0.0009715	499.487	468.407	2.073967	88.61121
108	15461	BXE	50	V	1.55	0.0024698	266.383	256.869	9.6148447	410.79874
						2.1535358			1084.8809	65428.89371

Attachment **5:** Safeguards **and** Accountability Database - Upper 20% by Specific Activity

Safeguards K Basin Data ... upper 20% **of mass, sorted** by specific activity

KW Basin Key		Model		type	% Pu-240	MT Pu	Exp (MWd/MTU)	gram/MTU	MTU	assemblies
107	11897	A2F	50	I	14.4	0.0045594	4804.686	2854.901	1.597043	135.47116
107	11897	A2M	50	I	14.4	0.0406074	4804.686	2854.901	14.223736	853.97966
107	11897	N09F	50	I	14.4	8.85E-06	4804.686	2854.901	0.0030999	0.79468
107	11897	A12F	50	I	14.4	5.391E-05	4804.686	2854.901	0.0188833	2.39395
107	12127	A2F	50	I	14.22	0.0022302	4636.582	2780.906	0.8019687	68.02800
107	12127	A2T	50	I	14.22	0.0033658	4636.582	2780.906	1.2103104	77.63432
107	12127	A2M	50	I	14.22	0.0302383	4636.582	2780.906	10.873537	652.83691
107	11979	A12T	50	I	14.27	2.3923-05	4682.037	2801.038	0.0085397	0.81892
107	11979	A12M	50	I	14.27	2.557E-05	4682.037	2801.038	0.0091288	0.81945
107	11979	A2T	50	I	14.27	0.0202228	4682.037	2801.038	7.2197352	463.10372
107	11979	A2M	50	I	14.27	0.0329865	4682.037	2801.038	11.776514	707.05081
107	11979	A2F	50	I	14.27	0.0044422	4682.037	2801.038	1.5859123	134.52699
107	11979	A12F	50	I	14.27	1.817E-05	4682.037	2801.038	0.0064869	0.82238
107	11979	N09M	50	I	14.27	2.442E-05	4682.037	2801.038	0.0087182	1.58063
107	13525	A2F	50	I	13.52	0.002653	4088.081	2531.011	1.0482134	88.91601
107	13525	A2M	50	I	13.52	0.0356075	4088.081	2531.011	14.068495	844.65917
107	13650	A2F	50	I	13.41	0.0031082	4014.891	2496.704	1.2449255	105.60236
107	13650	A2T	50	I	13.41	0.0058854	4014.891	2496.704	2.3572842	151.20597
107	13650	A2M	50	I	13.41	0.0268407	4014.891	2496.704	10.750471	645.44813
107	12852	BXE	50	V	16.62	0.0120996	4403.697	2917.415	4.1473699	177.19832
107	12480	A2M	50	I	13.78	0.042851	4274.100	2617.188	16.372918	983.01456
107	12480	A12M	50	I	13.78	4.89E-05	4274.100	2617.188	0.0186842	1.67719
107	12565	A12M	50	I	13.7	2.433E-05	4214.817	2589.883	0.0093942	0.84328
107	12565	A2M	50	I	13.7	0.0553728	4214.817	2589.883	21.38041	1283.65962
107	12565	BXS	50	V	16.72	0.0005059	4448.012	2938.642	0.1721612	7.82582
107	12565	BXE	50	V	16.72	0.0192326	4448.012	2938.642	6.5447382	279.62700
107	11806	A2F	50	I	13.86	0.0004648	4335.304	2645.223	0.1756979	14.90379
107	11806	A2M	50	I	13.86	0.0425225	4335.304	2645.223	16.075205	965.14016
107	11806	A2T	50	I	13.86	0.001196	4335.304	2645.223	0.4521169	29.00065
107	13016	N09T	50	I	13.18	3.291E-05	3871.409	2428.782	0.01355	2.62503
107	13016	A2T	50	I	13.18	0.0005322	3871.409	2428.782	0.2191057	14.05435
107	13016	A2M	50	I	13.18	0.042032	3871.409	2428.782	17.30579	1039.02329
107	13016	A2F	50	I	13.18	0.0016387	3871.409	2428.782	0.6746798	57.23055
107	13016	N09M	50	I	13.18	1.124E-05	3871.409	2428.782	0.0046278	0.83904
107	15244	X09S	50	V	13.58	1.406E-05	3205.527	2308.059	0.0060917	0.86533
107	13371	A2F	50	I	12.95	0.0005114	3739.607	2365.600	0.2161608	18.33611
107	13371	A2M	50	I	12.95	0.0098354	3739.607	2365.600	4.1576555	249.62171
KE Basin										
108	14355	X09C	50	V	15.74	0.000119	4027.805	2733.933	0.0435197	8.79423
108	14355	B09C	50	V	15.74	0.0002532	4027.805	2733.933	0.0926028	8.80360
108	14355	B09S	50	V	15.74	0.0008362	4027.805	2733.933	0.305867	20.44648
108	14355	X09S	50	V	15.74	0.0003938	4027.805	2733.933	0.1440233	20.45867
108	11897	B09S	50	V	15.47	0.0041936	3917.424	2678.830	1.5654747	104.64824
108	11897	X09S	50	V	15.47	0.001956	3917.424	2678.830	0.7301547	103.71933
108	11897	B09E	50	V	15.47	0.0530136	3917.424	2678.830	19.789822	1243.00046
108	11897	X09E	50	V	15.47	0.0249415	3917.424	2678.830	9.3106034	1244.02873
108	11897	X09A	50	V	15.47	1.725E-05	3917.424	2678.830	0.0064394	0.96970
108	11979	A7B	50	V	15.34	0.000208	3865.085	2652.496	0,0784167	
108	11979	B09S	50	V	15.34	0.0049162	3865.085	2652.496	1.8534204	123.89672
108	11979	BXC	50	V	15.34	0.0009487	3865.085	2652.496	0.3576707	23.12413
108	11979	B09C	50	V	15.34	0.0047344	3865.085	2652.496	1.784885	169.68600
108	11979	X09E	50	V	15.34	0.0170867	3865.085	2652.496	6.4417519	860.70946
108	11979	BXE	50	V	15.34	0.0245593	3865.085	2652.496	9.2589476	395.59287
108	11979	B09E	50	V	15.34	0.0363959	3865.085	2652.496	13.721394	861.84198
108	11979	BXS	50	V	15.34	0.0011768	3865.085	2652.496	0.4436727	20.16775
108	11806	A078	50	V	15.03	0.000399	3742.359	2590.212	0.1540414	
108	11806	B09E	50	V	15.03	0.0447076	3742.359	2590.212	17.260202	1084.11484
108	11806	B09S	50	V	15.03	0.0006574	3742.359	2590.212	0.2537861	16.96500
108	11806	X09S	50	V	15.03	0.0003096	3742.359	2590.212	0.1195269	16.97893
108	11806	N07B	50	V	15.03	0.0001728	3742.359	2590.212	0.0667011	12.26451
108	12127	BXE	50	V	14.73	0.0652688	3626.339	2530.616	25.791651	1101.96035
108	12127	BXS	50	V	14.73	0.0083022	3626.339	2530.616	3.2807192	149.12960
108	12127	BXA	50	V	14.73	0.0012374	3626.339	2530.616	0.4889877	23.55854
108	12127	BXC	50	V	14.73	0.0008477	3626.339	2530.616	0.3349619	21.65597
108	12127	A7B	50	V	14.73	0.0003645	3626.339	2530.616	0.1440361	

108	12240	B09E	50	V	14.51	0.000146	3542.940	2487.327	0.0587136	3.68781
108	12285	B09A	50	V	14.45	3.429E-05	3520.438	2475.581	0.0138513	0.98127
108	12285	B09E	50	V	14.45	7.738E-05	3520.438	2475.581	0.0312573	1.96327
108	12285	BXS	50	V	14.45	0.0148591	3520.438	2475.581	6.0022672	272.84130
108	12285	BXE	50	V	14.45	0.140543	3520.438	2475.581	56.771718	2425.59823
108	12480	BXA	50	V	14.25	0.0014025	3460.537	2444.383	0.5737726	27.64333
108	12480	BXE	50	V	14.29	0.1199848	3460.937	2444.383	49.085906	2097.21831

Attachment *6:* Radnuc Output for Table *6*

The following is a listing of the Radnuc output that produced the results in Table *6*. The keys processed included only those from K East Basin, and the decay date was September 1, 1995. Note that the decay heating column is labeled "BTUs", but is in fact BTU/hr. This is a minor cosmetic error in the output format, and Radnuc 2A should be fixed to output the correct units.

```
 This is KE Basin only ...
 Results decayed to 09/01/1995
 Total MTU              20.7
 Total Curies       5.96D+05
 Total RTU          5.82D+03

Isotope  Curies       BTUs
H-3      4.12D+02     4.72D-02
C-14     2.37D-04     2.37D-07
Se-79    8.70D-01     9.15D-04
Kr-85    6.71D+03     3.43D+01
Sr-89    1.06D-13     1.25D-15
Sr-90    1.05D+05     4.16D+02
Y-90     1.05D+05     1.99D+03
Y-91     4.72D-11     5.76D-13
Zr-93    3.86D+00     1.52D-03
Nb-93m   2.25D+00     1.37D-03
Zr-95    1.29D-09     2.22D-11
Nb-95    2.86D-09     4.68D-11
Nb-95m   9.56D-12     4.31D-14
Tc-99    2.91D+01     4.97D-02
Ru-103   4.67D-19     5.21D-21
Rh-103m  4.21D-19     3.31D-22
Ru-106   1.79D+02     3.64D-02
Rh-106   1.79D+02     5.85D+00
Pd-107   1.77D-01     3.33D-05
Ag-110   7.86D-05     2.01D-09
Ag-110m  5.91D-03     3.35D-04
Cd-113m  4.15D+01     1.56D-01
Cd-115m  4.72D-19     5.98D-21
Sn-119m  7.56D-03     1.33D-05
Sn-121m  2.92D-01     1.05D-03
Sn-123   5.92D-05     6.31D-07
Te-123m  1.65D-10     8.17D-13
Sb-124   4.91D-15     2.21D-16
Sb-125   6.37D+02     6.83D+00
Te-125m  1.55D+02     4.47D-01
Sn-126   1.63D+00     1.71D-03
Sb-126   2.29D-01     1.41D-02
Sb-126m  1.63D+00     7.13D-02
Te-127   8.66D-06     3.99D-08
Te-127m  8.84D-06     1.49D-08
Te-129   0.00D+00     0.00D+00
Te-129m  0.00D+00     0.00D+00
1-129    6.57D-02     1.05D-04
Cs-134   3.71D+02     1.29D+01
Cs-135   7.95D-01     9.07D-04
Cs-137   1.40D+05     4.81D+02
Ba-137m  1.32D+05     1.77D+03
Ce-141   0.00D+00     0.00D+00
```

Pr-143	0.00D+00	0.00D+00
Ce-144	1.64D+02	3.69D-01
Pr-144	1.62D+02	4.05D+00
Pr-144m	1.97D+00	2.25D-03
Pm-147	9.64D+03	1.21D+01
Pm-148	3.24D-21	8.50D-23
Pm-148m	5.75D-20	2.45D-21
Sm-151	1.75D+03	7.00D-01
Eu-152	1.12D+01	1.72D-01
Gd-153	3.93D-05	1.21D-07
Eu-154	1.41D+03	4.33D+01
Eu-155	3.18D+02	7.85D-01
Tb-160	6.71D-13	1.83D-14
H-3	9.24D+00	1.06D-03
C-14	7.27D+00	7.25D-03
Fe-55	3.89D+01	4.42D-03
Ni-59	4.22D-01	5.72D-05
Co-60	5.26D+01	2.77D+00
Ni-63	4.72D+01	1.63D-02
Zr-93	1.32D-01	5.19D-05
Nb-93m	7.68D-02	4.70D-05
Zr-95	1.26D-11	2.17D-13
Nb-95	2.80D-11	4.58D-13
Nb-95m	9.36D-14	4.22D-16
In-113m	1.37D-06	1.08D-08
Sn-113	1.37D-06	7.78D-10
Sn-119m	7.23D-02	1.27D-04
Sn-121m	5.47D-01	1.96D-03
Sb-125	2.30D+01	2.47D-01
Te-125m	5.62D+00	1.62D-02
U-234	8.33D+00	8.04D-01
U-235	3.09D-01	2.86D-02
U-236	1.24D+00	1.13D-01
U-238	6.86D+00	5.83D-01
Np-237	6.07D-01	5.97D-02
Pu-238	1.32D+03	1.47D+02
Pu-239	2.59D+03	2.70D+02
Pu-240	1.58D+03	1.65D+02
Pu-241	8.24D+04	8.72D+00
Pu-242	6.84D-01	6.79D-02
Am-241	4.03D+03	4.51D+02
Am-242m	2.63D+00	1.37D-02
Am-242	2.62D+00	7.44D-02
Am-243	1.67D+00	1.81D-01
Cm-242	2.17D+00	2.68D-01
Cm-244	2.39D+01	2.80D+00

Attachment 7: Radnuc Output for Table 7

The following is a listing of the Radnuc output that produced the results in Table 7. The keys processed included only the top 20% of specific decay heat keys from K East Basin, and the decay date was May 31, 1998. For the Safety Basis sludge comparison in Table 7, Radnuc 2A values below were adjusted by multiplying by the overall reactor power peaking factor of 2.4, **as** discussed in Section 6.4.

This is for KE Basin only ...
Results decayed to 05/31/1998
Total MTU 4.3
Total Curies 1.56D+05
Total BTU 1.55D+03

Isotope	Curies	BTUS
H-3	1.01D+02	1.16D-02
C-14	6.57D-05	6.55D-08
Se-79	2.40D-01	2.52D-04
Kr-85	1.55D+03	7.91D+00
Sr-89	0.00D+00	0.00D+00
Sr-90	2.70D+04	1.07D+02
Y-90	2.70D+04	5.10D+02
Y-91	0.00D+00	0.00D+00
Zr-93	1.06D+00	4.14D-04
Nb-93m	6.59D-01	4.03D-04
Zr-95	0.00D+00	0.00D+00
Nb-95	0.00D+00	0.00D+00
Nb-95m	0.00D+00	0.00D+00
Tc-99	8.02D+00	1.37D-02
Ru-103	0.00D+00	0.00D+00
Rh-103m	0.00D+00	0.00D+00
Ru-106	3.72D-01	7.55D-05
Rh-106	3.72D-01	1.21D-02
Pd-107	5.28D-02	9.91D-06
Ag-110	3.03D-08	7.75D-13
Ag-110m	2.28D-06	1.29D-07
Cd-113m	1.07D+01	4.01D-02
Cd-115m	0.00D+00	0.00D+00
Sn-119m	3.75D-07	6.59D-10
Sn-121m	8.30D-02	2.97D-04
Sn-123	6.73D-12	7.17D-14
Te-123m	1.59D-16	7.85D-19
Sb-124	0.00D+00	0.00D+00
Sb-125	6.50D+01	6.97D-01
Te-125m	1.59D+01	4.56D-02
Sn-126	4.62D-01	4.84D-04
Sb-126	6.471)-02	4.00D-03
Sb-126m	4.62D-01	2.02D-02
Te-127	1.35D-13	6.23D-16
Te-127m	1.38D-13	2.33D-16
Te-129	0.00D+00	0.00D+00
Te-129m	0.00D+00	0.00D+00
I-129	1.85D-02	2.96D-05
Cs-134	3.72D+01	1.29D+00
Cs-135	2.20D-01	2.51D-04
Cs-137	3.68D+04	1.27D+02

Ba-137m	3.48D+04	4.66D+02
Ce-141	0.00D+00	0.00D+00
Pr-143	0.00D+00	0.00D+00
Ce-144	2.46D-02	5.53D-05
Pr-144	2.43D-02	6.07D-04
Pr-144m	2.95D-04	3.38D-07
Pm-147	6.91D+02	8.66D-01
Pm-148	0.00D+00	0.00D+00
Pm-148m	0.00D+00	0.00D+00
Sm-151	4.19D+02	1.67D-01
Eu-152	3.11D+00	4.79D-02
Gd-153	2.49D-08	7.65D-11
Eu-154	3.93D+02	1.20D+01
Eu-155	5.10D+01	1.26D-01
Tb-160	7.96D-23	2.17D-24
H-3	2.63D+00	3.02D-04
C-14	2.02D+00	2.01D-03
Fe-55	3.25D+00	3.69D-04
Ni-59	1.16D-01	1.58D-05
Co-60	9.71D+00	5.11D-01
Ni-63	1.28D+01	4.43D-03
Zr-93	3.66D-02	1.44D-05
Nb-93m	2.28D-02	1.40D-05
zr-95	0.00D+00	0.00D+00
Nb-95	0.00D+00	0.00D+00
Nb-95m	0.00D+00	0.00D+00
In-113m	3.41D-14	2.69D-16
Sn-113	3.41D-14	1.93D-17
Sn-119m	3.19D-06	5.61D-09
Sn-121m	1.47D-01	5.28D-04
Sb-125	2.17D+00	2.32D-02
Te-125m	5.28D-01	1.52D-03
U-234	1.69D+00	1.63D-01
U-235	5.77D-02	5.34D-03
U-236	2.91D-01	2.66D-02
U-238	1.43D+00	1.22D-01
Np-237	1.69D-01	1.66D-02
Pu-238	4.16D+02	4.63D+01
Pu-239	6.72D+02	6.99D+01
Pu-240	4.68D+02	4.89D+01
Pu-241	2.38D+04	2.52D+00
Pu-242	2.36D-01	2.35D-02
Am-241	1.33D+03	1.49D+02
Am-242m	9.37D-01	4.90D-03
Am-242	9.32D-01	2.65D-02
Am-243	6.26D-01	6.75D-02
Cm-242	7.74D-01	9.56D-02
Cm-244	8.91D+00	1.05D+00

Attachment 8: Radnuc Output for Table 8

The following is a listing of the Radnuc output that produced the results in Table **8.** The keys processed included all keys from the Safeguards database, and the decay date was May **3**1, 1998.

```
 This is for all keys ...
 Results decaved to 05/31/1998
 Total MTU              33.3
 Total Curies       9.92D+05
 Total BTU          9.90D+03

Isotope  Curies       BTUs
H-3      6.44D+02     7.39D-02
C-14     4.23D-04     4.21D-07
Se-79    1.55D+00     1.63D-03
Kr-85    1.04D+04     5.30D+01
Sr-89    0.00D+00     0.00D+00
Sr-90    1.79D+05     7.08D+02
Y-90     1.79D+05     3.37D+03
Y-91     3.98D-16     4.87D-18
Zr-93    6.90D+00     2.71D-03
Nb-93m   4.29D+00     2.62D-03
Zr-95    2.98D-14     5.13D-16
Nb-95    6.63D-14     1.08D-15
Nb-95m   2.21D-16     9.98D-19
Tc-99    5.17D+01     8.85D-02
Ru-103   0.00D+00     0.00D+00
Rh-103m  0.00D+00     0.00D+00
Ru-106   3.41D+01     6.93D-03
Rh-106   3.41D+01     1.11D+00
Pd-107   3.10D-01     5.81D-05
Ag-110   5.85D-06     1.50D-10
Ag-110m  4.40D-04     2.49D-05
Cd-113m  6.49D+01     2.44D-01
Cd-115m  0.00D+00     0.00D+00
Sn-119m  5.10D-04     8.96D-07
Sn-121m  5.01D-01     1.79D-03
Sn-123   3.17D-07     3.37D-09
Te-123m  5.65D-13     2.80D-15
Sb-124   5.61D-20     2.53D-21
Sb-125   5.73D+02     6.15D+00
Te-125m  1.40D+02     4.02D-01
Sn-126   2.85D+00     2.99D-03
Sb-126   3.99D-01     2.47D-02
Sb-126m  2.85D+00     1.25D-01
Te-127   1.73D-08     7.96D-11
Te-127m  1.76D-08     2.98D-11
Te-129   0.00D+00     0.00D+00
Te-129m  0.00D+00     0.00D+00
1-129    1.16D-01     1.85D-04
Cs-134   3.10D+02     1.08D+01
Cs-135   1.40D+00     1.59D-03
Cs-137   2.36D+05     8.15D+02
Ba-137m  2.24D+05     2.99D+03
Ce-141   0.00D+00     0.00D+00
Pr-143   0.00D+00     0.00Dt00
Ce-144   1.67D+01     3.76D-02
Pr-144   1.65D+01     4.13D-01
```

Pr-144m	2.00D-01	2.30D-04
Pm-147	7.87D+03	9.86D+00
Pm-148	0.00D+00	0.00D+00
Pm-148m	0.00D+00	0.00D+00
Sm-151	2.94D+03	1.18D+00
Eu-152	1.79D+01	2.76D-01
Gd-153	2.82D-06	8.67D-09
Eu-154	2.17D+03	6.66D+01
Eu-155	3.83D+02	9.45D-01
Tb-160	5.24D-17	1.43D-18
H-3	1.43D+01	1.64D-03
C-14	1.25D+01	1.25D-02
Fe-55	3.22D+01	3.67D-03
Ni-59	7.37D-01	9.99D-05
CO-60	6.96D+01	3.66D+00
Ni-63	8.10D+01	2.79D-02
Zr-93	2.38D-01	9.36D-05
Nb-93m	1.48D-01	9.05D-05
Zr-95	2.93D-16	5.04D-18
Nb-95	6.50D-16	1.06D-17
Nb-95m	2.17D-18	9.79D-21
In-113m	3.88D-09	3.06D-11
Sn-113	3.87D-09	2.19D-12
Sn-119m	4.93D-03	8.67D-06
Sn-121m	9.48D-01	3.40D-03
Sb-125	2.08D+01	2.22D-01
Te-125m	5.06D+00	1.46D-02
U-234	1.36D+01	1.32D+00
U-235	5.08D-01	4.70D-02
U-236	2.11D+00	1.93D-01
U-238	1.10D+01	9.38D-01
Np-237	1.04D+00	1.02D-01
Pu-238	2.26D+03	2.52D+02
Pu-239	4.36D+03	4.54D+02
Pu-240	2.73D+03	2.85D+02
Pu-241	1.32D+05	1.39D+01
Pu-242	1.22D+00	1.21D-01
An-241	7.48D+03	8.38D+02
An-242m	4.53D+00	2.37D-02
Am-242	4.51D+00	1.28D-01
An-243	2.98D+00	3.22D-01
Cm-242	3.74D+00	4.62D-01
Cm-244	3.93D+01	4.62D+00

Attachment 9: Radnuc Output for Table 9

The following is a listing of the Radnuc output that produced the results in Table 9. The keys processed included only the top 20% of specific decay heat keys from the Safeguards database, and the decay date was May **3**1, 1998. For the Safety Basis sludge comparison in Table 9, Radnuc **2A** values below were adjusted by multiplying by the overall reactor power peaking factor of 2.4, as discussed in Section 6.4.

```
 This is the top 20% ...
 Results decayed to 05/31/1998
 Total MTU              6.8
 Total Curies      2.69D+05
 Total BTU         2.66D+03

Isotope  Curies      BTUs
H-3      1.76D+02    2.01D-02
C-14     1.12D-04    1.12D-07
Se-79    4.09D-01    4.30D-04
Kr-85    2.74D+03    1.40D+01
Sr-89    0.00D+00    0.00D+00
Sr-90    4.71D+04    1.86D+02
Y-90     4.71D+04    8.89D+02
Y-91     1.22D-21    1.49D-23
Zr-93    1.81D+00    7.12D-04
Nb-93m   1.12D+00    6.84D-04
Zr-95    1.29D-19    2.22D-21
Nb-95    2.86D-19    4.68D-21
Nb-95m   9.55D-22    4.31D-24
Tc-99    1.37D+01    2.34D-02
Ru-103   0.00D+00    0.00D+00
Rh-103m  0.00D+00    0.00D+00
Ru-106   1.16D+00    2.36D-04
Rh-106   1.16D+00    3.79D-02
Pd-107   8.75D-02    1.64D-05
Ag-110   1.21D-07    3.09D-12
Ag-110m  9.07D-06    5.14D-07
Cd-113m  1.80D+01    6.74D-02
Cd-115m  0.00D+00    0.00D+00
Sn-119m  1.59D-06    2.79D-09
Sn-12lm  1.40D-01    5.02D-04
Sn-123   1.79D-11    1.91D-13
Te-123m  3.60D-16    1.78D-18
Sb-124   1.04D-24    4.68D-26
Sb-125   1.24D+02    1.33D+00
Te-125m  3.03D+01    8.70D-02
Sn-126   7.69D-01    8.06D-04
Sb-126   1.08D-01    6.65D-03
Sb-126m  7.69D-01    3.36D-02
Te-127   4.77D-13    2.20D-15
Te-127m  4.87D-13    8.23D-16
Te-129   0.00D+00    0.00D+00
Te-129m  0.00D+00    0.00D+00
I-129    3.12D-02    4.99D-05
Cs-134   8.13D+01    2.83D+00
Cs-135   3.70D-01    4.22D-04
Cs-137   6.35D+04    2.19D+02
```

Ba-137m	6.01D+04	8.04D+02
Ce-141	0.00D+00	0.00D+00
Pr-143	0.00D+00	0.00D+00
Ce-144	1.05D-01	2.37D-04
Pr-144	1.04D-01	2.61D-03
Pr-144m	1.26D-03	1.45D-06
Pm-147	1.38D+03	1.73D+00
Pm-148	0.00D+00	0.00D+00
Pm-148m	0.00D+00	0.00D+00
Sm-151	6.92D+02	2.76D-01
Eu-152	5.31D+00	8.20D-02
Gd-153	9.99D-08	3.07D-10
Eu-154	7.04D+02	2.16D+01
Eu-155	9.08D+01	2.24D-01
Tb-160	2.43D-21	6.62D-23
H-3	4.42D+00	5.07D-04
C-14	3.31D+00	3.30D-03
Fe-55	6.28D+00	7.14D-04
Ni-59	1.94D-01	2.63D-05
CO-60	1.82D+01	9.55D-01
Ni-63	2.15D+01	7.41D-03
Zr-93	6.37D-02	2.50D-05
Nb-93m	3.92D-02	2.40D-05
Zr-95	1.36D-21	2.34D-23
Nb-95	3.02D-21	4.95D-23
Nb-95m	1.01D-23	4.55D-26
In-113m	1.08D-13	8.55D-16
Sn-113	1.08D-13	6.14D-17
Sn-119m	1.47D-05	2.59D-08
Sn-121m	2.54D-01	9.12D-04
Sb-125	4.32D+00	4.64D-02
Te-125m	1.06D+00	3.03D-03
U-234	2.76D+00	2.67D-01
U-235	9.68D-02	8.96D-03
U-236	4.86D-01	4.43D-02
U-238	2.27D+00	1.93D-01
Np-237	2.75D-01	2.70D-02
Pu-238	6.90D+02	7.69D+01
Pu-239	1.07D+03	1.12D+02
Pu-240	7.68D+02	8.02D+01
Pu-241	4.04D+04	4.28D+00
Pu-242	4.07D-01	4.04D-02
Am-241	2.19D+03	2.45D+02
Am-242m	1.57D+00	8.21D-03
Am-242	1.56D+00	4.44D-02
Am-243	1.09D+00	1.18D-01
Cm-242	1.30D+00	1.60D-01
Cm-244	1.61D+01	1.89D+00

Attachment 10: Radnuc Output for Table 10

The following is a listing of the Radnuc output that produced the results in Table 10. The keys processed included all keys from the Safeguards database, and the decay date was May 31,2001.

```
 This is for all keys ...
 Results decayed to 05/31/2001
 Total MTU              33.3
 Total Curies       9.12D+05
 Total BTU          9.37D+03

Isotope  Curies       BTUs
H-3      5.44D+02    6.24D-02
C-14     4.22D-04    4.21D-07
Se-79    1.55D+00    1.63D-03
Kr-85    8.53D+03    4.36D+01
Sr-89    0.00D+00    0.00D+00
Sr-90    1.66D+05    6.59D+02
Y-90     1.66D+05    3.14D+03
Y-91     0.00D+00    0.00D+00
Zr-93    6.90D+00    2.71D-03
Nb-93m   4.61D+00    2.82D-03
Zr-95    0.00D+00    0.00D+00
Nb-95    0.00D+00    0.00D+00
Nb-95m   0.00D+00    0.00D+00
Tc-99    5.17D+01    8.85D-02
Ru-103   0.00D+00    0.00D+00
Rh-103m  0.00D+00    0.00D+00
Ru-106   4.34D+00    8.81D-04
Rh-106   4.34D+00    1.41D-01
Pd-107   3.10D-01    5.81D-05
Ag-110   2.80D-07    7.16D-12
Ag-110m  2.10D-05    1.19D-06
Cd-113m  5.63D+01    2.11D-01
Cd-115m  0.00D+00    0.00D+00
Sn-119m  2.29D-05    4.03D-08
Sn-121m  4.80D-01    1.72D-03
Sn-123   8.84D-10    9.41D-12
Te-123m  9.89D-16    4.89D-18
Sb-124   0.00D+00    0.00D+00
Sb-125   2.71D+02    2.90D+00
Te-125m  6.60D+01    1.90D-01
Sn-126   2.85D+00    2.99D-03
Sb-126   3.99D-01    2.47D-02
Sb-126m  2.85D+00    1.25D-01
Te-127   1.62D-11    7.48D-14
Te-127m  1.66D-11    2.80D-14
Te-129   0.00D+00    0.00D+00
Te-129m  0.00D+00    0.00D+00
I-129    1.16D-01    1.85D-04
Cs-134   1.13D+02    3.94D+00
Cs-135   1.40D+00    1.59D-03
Cs-137   2.21D+05    7.60D+02
Ba-137m  2.09D+05    2.79D+03
Ce-141   0.00D+00    0.00D+00
Pr-143   0.00D+00    0.00D+00
Ce-144   1.15D+00    2.60D-03
Pr-144   1.14D+00    2.85D-02
```

Pr-144m	1.38D-02	1.59D-05
Pm-147	3.56D+03	4.46D+00
Pm-148	0.00D+00	0.00D+00
Pm-148m	0.00D+00	0.00D+00
Sm-151	2.87D+03	1.15D+00
Eu-152	1.54D+01	2.37D-01
Gd-153	1.22D-07	3.75D-10
Eu-154	1.71D+03	5.23D+01
Eu-155	2.52D+02	6.22D-01
Tb-160	1.43D-21	3.89D-23
H-3	1.21D+01	1.39D-03
C-14	1.25D+01	1.25D-02
Fe-55	1.45D+01	1.65D-03
Ni-59	7.37D-01	9.990-05
Co-60	4.69D+01	2.46D+00
Ni-63	7.92D+01	2.73D-02
Zr-93	2.38D-01	9.36D-05
Nb-93m	1.59D-01	9.73D-05
Zr-95	0.00D+00	0.00D+00
Nb-95	0.00D+00	0.00D+00
Nb-95m	0.00D+00	0.00D+00
In-113m	5.27D-12	4.16D-14
Sn-113	5.27D-12	2.99D-15
Sn-119m	2.22D-04	3.91D-07
Sn-121m	9.09D-01	3.26D-03
Sb-125	9.79D+00	1.05D-01
Te-125m	2.39D+00	6.87D-03
U-234	1.36D+01	1.32D+00
U-235	5.08D-01	4.70D-02
U-236	2.11D+00	1.93D-01
U-238	1.10D+01	9.38D-01
Np-237	1.04D+00	1.02D-01
Pu-238	2.21D+03	2.46D+02
Pu-239	4.36D+03	4.54D+02
Pu-240	2.73D+03	2.85D+02
Pu-241	1.14D+05	1.21D+01
Pu-242	1.22D+00	1.21D-01
Am-241	8.03D+03	8.99D+02
Am-242m	4.47D+00	2.34D-02
Am-242	4.45D+00	1.26D-01
Am-243	2.98D+00	3.22D-01
Cm-242	3.69D+00	4.56D-01
Cm-244	3.51D+01	4.12D+00

Attachment 11: Radnuc Output for Table 11

The following is a listing **of** the Radnuc output that produced the results in Table 11. The keys processed included only the top 20% of specific decay heat keys from the Safeguards database, and the decay date was May 31,2001. For the Safety Basis sludge predictions in Table 11, Radnuc **2A** values below were adjusted by multiplying by the overall reactor power peaking factor of **2.4.** as discussed in Section **6.4.**

```
 This is the top 20% ...
 Results decaved to 05/31/2001
 Total MTU              6.8
 Total Curies       2.47D+05
 Total BTU          2.52D+03

Isotope  Curies       BTUS
H-3      1.48D+02    1.70D-02
C-14     1.12D-04    1.12D-07
Se-79    4.09D-01    4.30D-04
Kr-85    2.26D+03    1.16D+01
Sr-89    0.00Dt00    0.00D+00
Sr-90    4.38D+04    1.74D+02
Y-90     4.38D+04    8.28D+02
Y-91     0.00D+00    0.00D+00
zr-93    1.81D+00    7.12D-04
Nb-93m   1.20D+00    7.36D-04
Zr-95    0.00D+00    0.00D+00
Nb-95    0.00D+00    0.00D+00
Nb-95m   0.00D+00    0.00D+00
Tc-99    1.37D+01    2.34D-02
Ru-103   0.00D+00    0.00D+00
Rh-103m  0.00D+00    0.00D+00
Ru-106   1.48D-01    3.00D-05
Rh-106   1.48D-01    4.82D-03
Pd-107   8.75D-02    1.64D-05
Ag-110   5.77D-09    1.48D-13
Ag-110m  4.34D-07    2.46D-08
Cd-113m  1.56D+01    5.85D-02
Cd-115m  0.00D+00    0.00D+00
Sn-119m  7.15D-08    1.26D-10
Sn-121m  1.34D-01    4.81D-04
Sn-123   5.01D-14    5.33D-16
Te-123m  6.29D-19    3.11D-21
Sb-124   0.00D+00    0.00D+00
Sb-125   5.86D+01    6.28D-01
Te-125m  1.43D+01    4.11D-02
Sn-126   7.69D-01    8.06D-04
Sb-126   1.08D-01    6.65D-03
Sb-126m  7.69D-01    3.36D-02
Te-127   4.48D-16    2.07D-18
Te-127m  4.58D-16    7.74D-19
Te-129   0.00D+00    0.00D+00
Te-129m  0.00D+00    0.00D+00
I-129    3.12D-02    4.99D-05
Cs-134   2.97D+01    1.03D+00
Cs-135   3.70D-01    4.22D-04
Cs-137   5.92D+04    2.04D+02
```

Ba-137m	5.60D+04	7.50D+02
Ce-141	0.00D+00	0.00D+00
Pr-143	0.00D+00	0.00D+00
Ce-144	7.28D-03	1.64D-05
Pr-144	7.20D-03	1.80D-04
Pr-144m	8.74D-05	1.00D-07
Pm-147	6.24D+02	7.81D-01
Pm-148	0.00D+00	0.00D+00
Pm-148m	0.00D+00	0.00D+00
Sm-151	6.76D+02	2.70D-01
Eu-152	4.56D+00	7.04D-02
Gd-153	4.33D-09	1.33D-11
Eu-154	5.53D+02	1.69D+01
Eu-155	5.97D+01	1.47D-01
Th-160	6.39D-26	1.74D-27
H-3	3.73D+00	4.28D-04
C-14	3.31D+00	3.30D-03
Fe-55	2.82D+00	3.21D-04
Ni-59	1.94D-01	2.63D-05
CO-60	1.22D+01	6.44D-01
Ni-63	2.10D+01	7.24D-03
Zr-93	6.37D-02	2.50D-05
Nb-93m	4.23D-02	2.58D-05
Zr-95	0.00D+00	0.00D+00
Nb-95	0.00D+00	0.00D+00
Nb-95m	0.00D+00	0.00D+00
In-113m	1.47D-16	1.16D-18
Sn-113	1.47D-16	8.35D-20
Sn-119m	6.63D-07	1.17D-09
Sn-121m	2.44D-01	8.75D-04
Sh-125	2.04D+00	2.19D-02
Te-125m	4.98D-01	1.43D-03
U-234	2.76D+00	2.67D-01
U-235	9.68D-02	8.96D-03
U-236	4.86D-01	4.43D-02
U-238	2.27D+00	1.93D-01
Np-237	2.75D-01	2.70D-02
Pu-238	6.74D+02	7.50D+01
Pu-239	1.07D+03	1.12D+02
Pu-240	7.68D+02	8.02D+01
Pu-241	3.50D+04	3.70D+00
Pu-242	4.07D-01	4.04D-02
Am-241	2.36D+03	2.64D+02
Am-242m	1.55D+00	8.09D-03
Am-242	1.54D+00	4.38D-02
Am-243	1.09D+00	1.18D-01
Cm-242	1.28D+00	1.58D-01
Cm-244	1.44D+01	1.69D+00

Attachment 12: Internal Memo from S.P. Roblyer to J. J. Irwin

Westinghouse Hanford Company — **Internal Memo**

From: Nuclear Analysis and Characterization 96005
Phone: 376-0436 HO-38
Date: February 16, 1996
Subject: POWER PROFILES IN N REACTOR MKIA AND MKIV FUELS.

To: J. J. Irwin HO-33

cc: T. D. Cooper 75-12
R. G. Cowan R3-86
F. J. Heard HO-34
K. N. Schwinkendorf HO-38
W. L. Willis R3-86
SPR File/LB

The power profiles in N Reactor MKIA and MKIV fuels were determined as a task to support the Multiple Cannister Overpack (MCO) project. The applications of these profiles are for the radioisotope release modeling and the flammability ignition tasks. The models of the power profiles are represented by the product of two polynomials. One polynomial describes the axial power distribution, the other polynomial describes the radial power distribution. These power distributions apply to both of the inner and outer fuel tubes. The polynomials are normalized to the combined or average power of the fuels assembly.. The distribution of power or exposure can therefore be determined by multiplying the total fuel assembly power or exposure by the product of these two polynomials.

The results of these models are shown in the attached Figures 1 through 6 and Tables 1 and 2. Figure 1 and 2 show the normalized inner and outer tube axial power distribution of the MKIA and MKIV fuels, respectively. Figures 3 and 4 show the normalized radial power distributions in the MKIA fuel inner and outer tubes, respectively. Figures 5 and 6 show the normalized power distributions in the MKIV inner and outer tubes, respectively. A summary of the polynomials representing radial and axial powers and their coefficients are listed in Table 1. The summary of relative powers and peaking factors in the fuel element inner and outer tubes are listed in Table 2. The peak power or exposure, for example, occurs in the outer surface adjacent to the end cap of the outer tube in both the MKIA and MKIV fuels. The peaking factors to element average power or exposure are 1.515 and 1.519 for MKIA and MKIV fuels, respectively.

The power calculations in the fuel regions were based on neutron balance calculations in a unit reactor lattice of N Reactor by the WIMS-E one-dimensional transport code and the 2DB4 two-dimensional diffusion code. The hot fuel dimensions used in these calculations are listed in table 3. The transport code gave the best representation of the radial power distribution and relative power of the inner and outer fuel element tubes.

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The axial power distribution near the end caps was obtained from the 2DB4 code because of geometry limitations in the more accurate WIMS-E code. Even so, the radial profiles calculated by 2DB4 agreed reasonably well with the corresponding radial shapes from WIMS-E. For example, the ratios of outer and inner tube powers agreed within 1% between the 2DB4 and WIMS-E codes. Similar agreement was shown for the k-infinity between the two codes; k-infinity was within 15 mk between WIMS-E and 2DB4.

I assume these results satisfy the requirements of the MCO program. If you have any questions, please call me.

SP Roblyer

Steven P. Roblyer
Principal Engineer

raw

Attachment

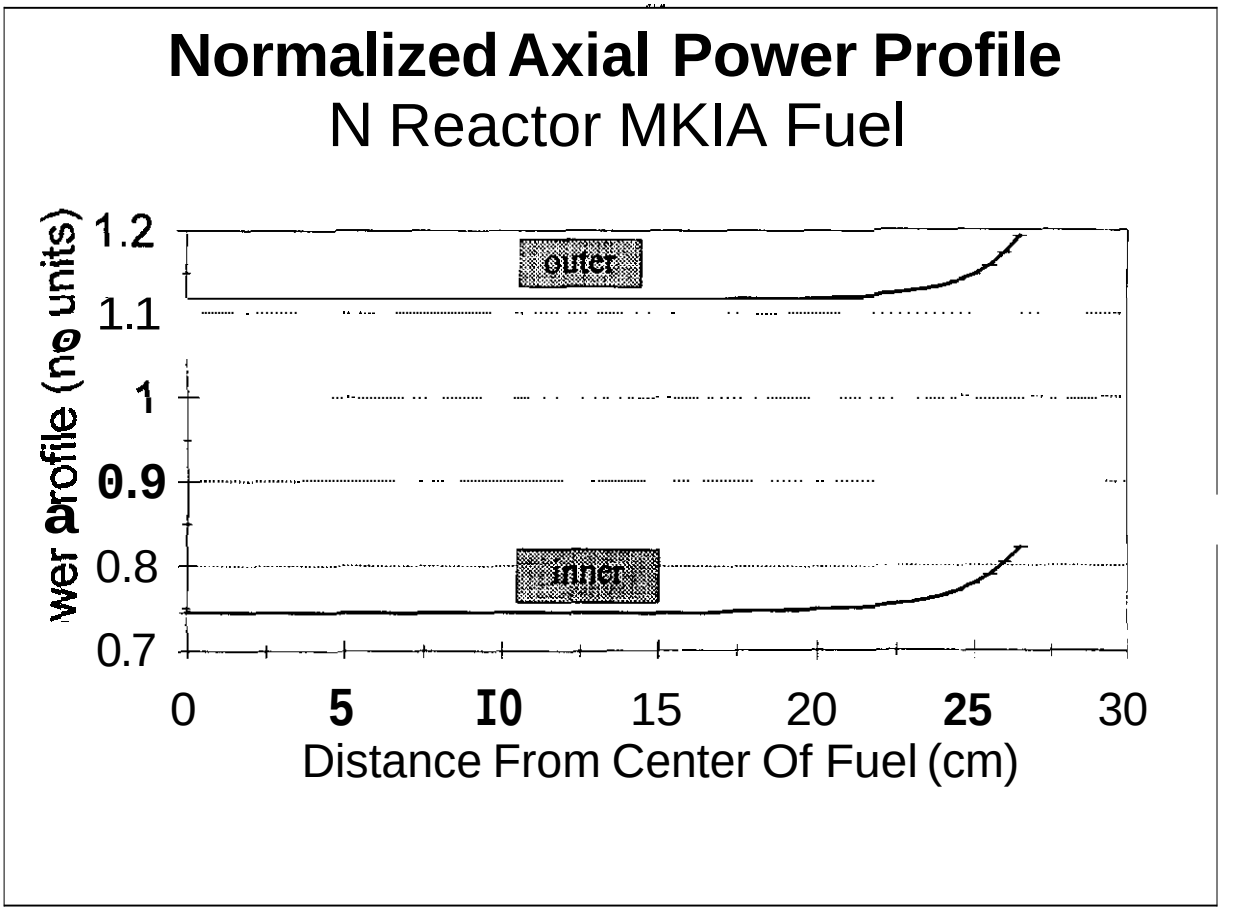
Normalized Axial Power Profile
N Reactor MKIA Fuel
wer profile (no units)
1.2
1.1
1
0.9
0.8
0.7
outer
inner
0
5
10
15
20
25
30
Distance From Center Of Fuel (cm)

Figure 1

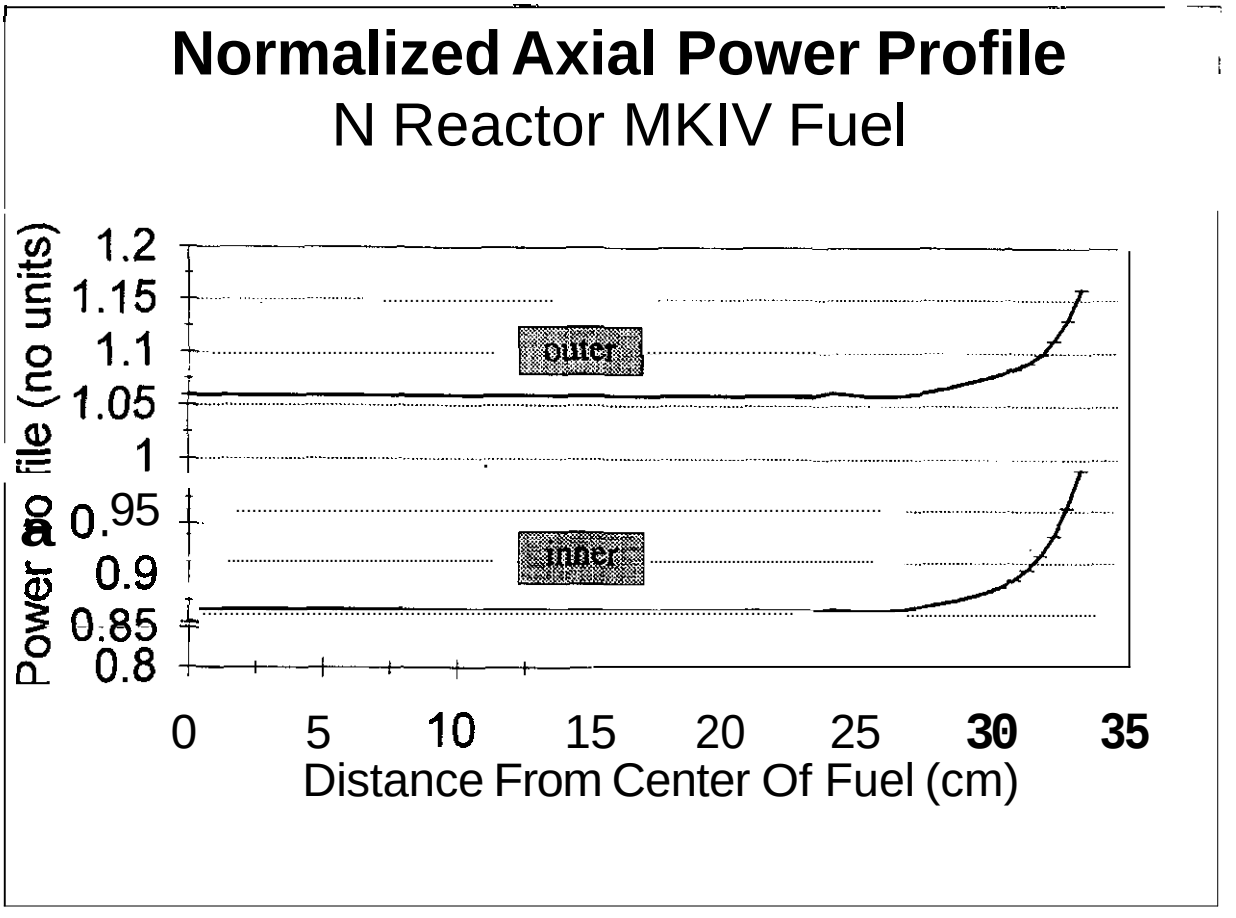
Normalized Axial Power Profile
N Reactor MKIV Fuel
Power Profile (no units)
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
outer
inner
0
5
10
15
20
25
30
35
Distance From Center Of Fuel (cm)

Figure 2

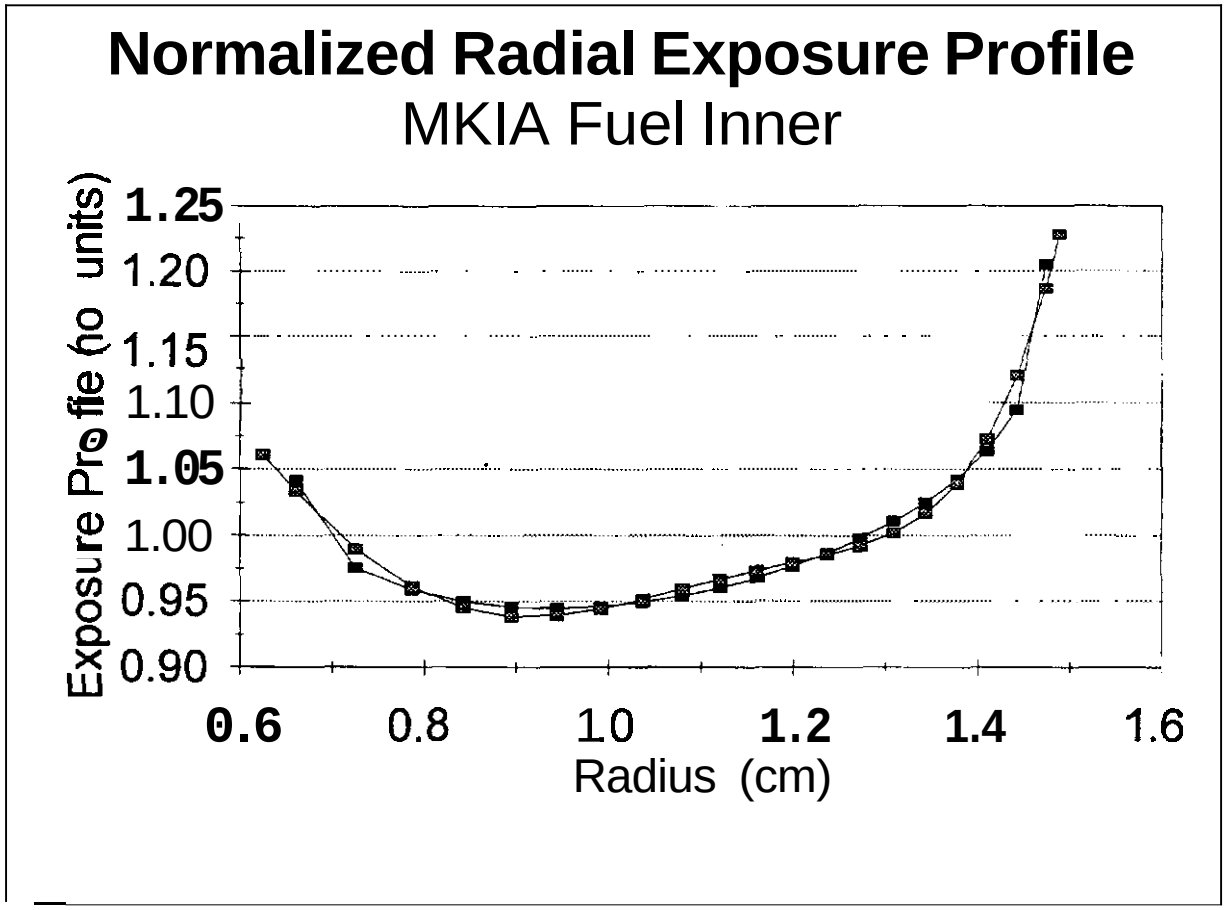
Normalized Radial Exposure Profile
MKIA Fuel Inner
Exposure Profile (no units)
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.6
0.8
1.0
1.2
1.4
1.6
Radius (cm)

Figure 3

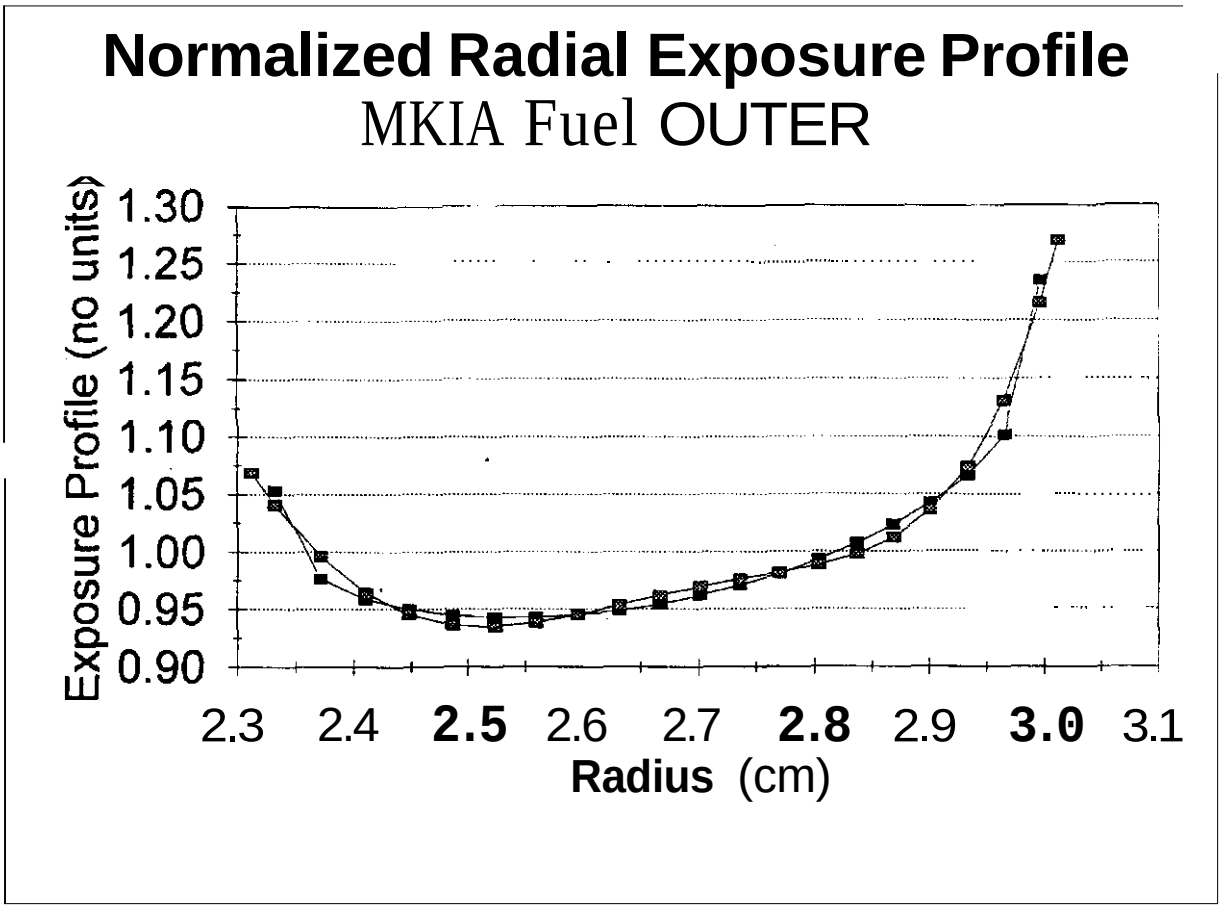
Normalized Radial Exposure Profile
MKIA Fuel OUTER
Exposure Profile (no units)
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
Radius (cm)

Figure 4

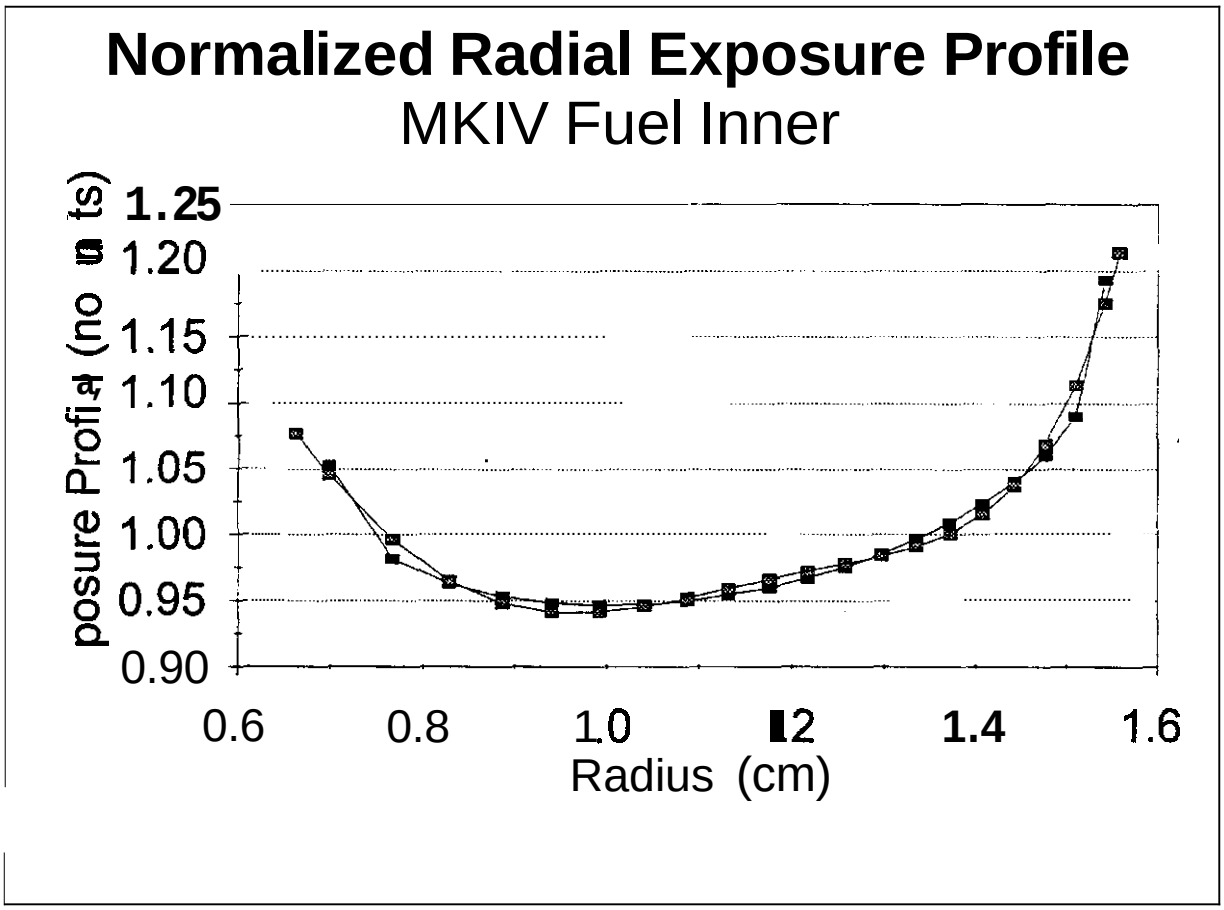
Normalized Radial Exposure Profile
MKIV Fuel Inner
posure Profi a (no u ts)
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.6
0.8
1.0
1.2
1.4
1.6
Radius (cm)

Figure 5

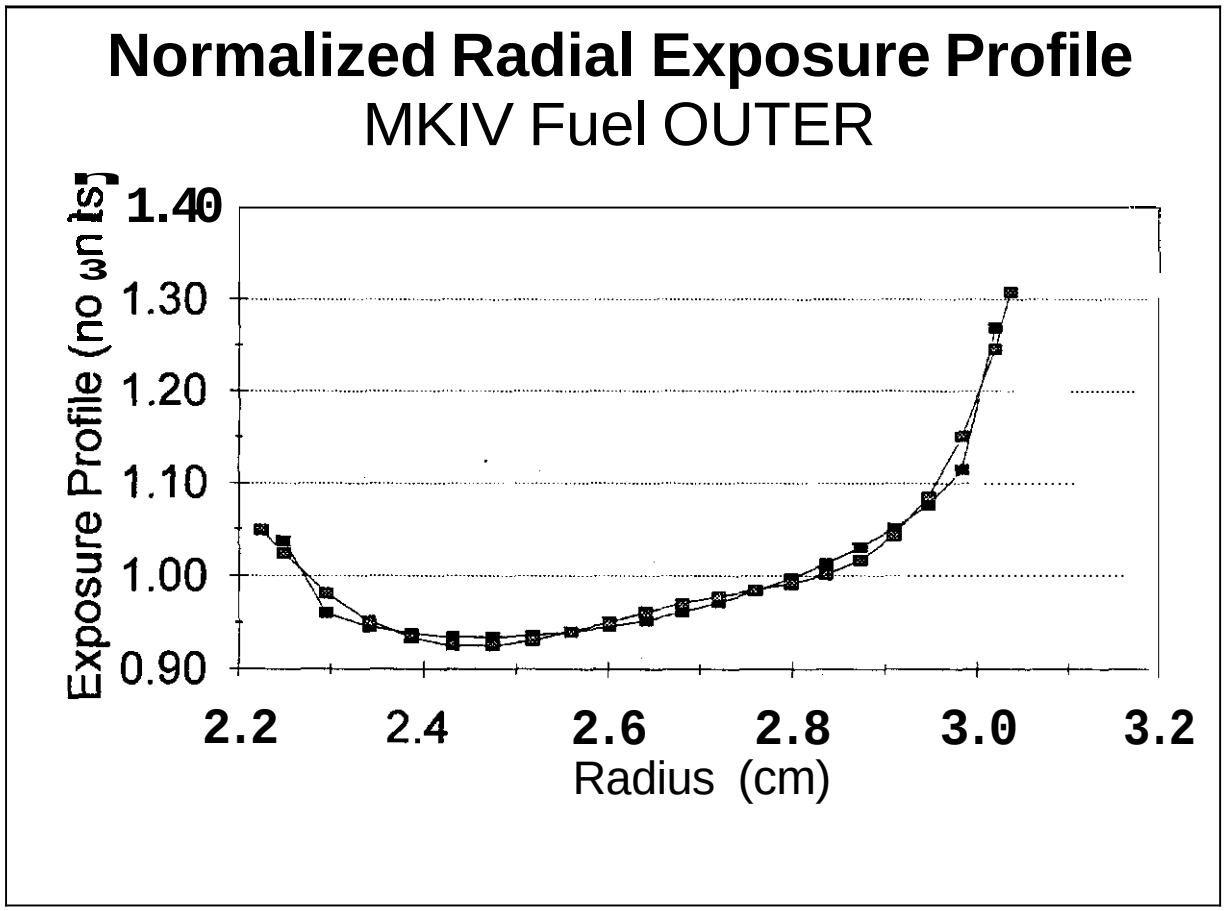
Normalized Radial Exposure Profile
MKIV Fuel OUTER
Exposure Profile (no units)
1.40
1.30
1.20
1.10
1.00
0.90
2.2
2.4
2.6
2.8
3.0
3.2
Radius (cm)

Figure *6*

Table 1 Radial And Axial Power Profiles In N Reactor MKIA And MKIV Fuels

Normalized Radial Profile Coefficients

		C1	C2	c 3	c 4	C5	C6
MKIA	**inner**	1.1104	7.8177	-31.3502	44.4425	-27.2421	6.1674
MKIA	**Outer**	-282.5552	759.0056	762.0539	322.2239	84.4805	5.0317
MKIV	**Inner**	1.4756	14.0879	34.4696	34.9871	16.5708	3.0206
MKIV	**Outer**	-104.3496	410.5845	417.5199	178.6896	36.1693	2.8532

$$R(r) = C1 + C2 * r^2 + C3 * r^3 + C4 * r^4 + C5 * r^5 + C6 * r^6$$

Normalized Axial Profile Coefficients

		D1	D2	D3	D4	D5	D6
MKIA	**Inner**	0.7454	2.3297E-03	-4.9835E-04	1.1229E-04	-1.9874E-05	1.8992E-06
MKIA	**Outer**	1.1163	6.0008E-03	-3.7431E-03	1.0499E-03	-1.3046E-04	6.4615E-06
MKIV	**Inner**	0.8542	2.5286E-03	-3.3591 E-03	1.3679E-03	-2.0035E-04	1.0822E-05
MKIV	**Outer**	1.0593	9.4811E-03	-9.2043E-03	2.9964E-03	-3.8033E-04	1.7339E-05

$$A(l) = D1 + D2 * l + D3 * l^2 + D4 * l^3 + D5 * l^4 + D6 * l^5$$

Note: The above polynomial applies to the end 10 cm of fuel region length. The remainder of the fuel region power is described by D1.

Table 2 Summary Of Power Profiles In N Reactor MKIA And MKIV Fuels

		Axial Power Ratio average	Axial Power Ratio peak	Radial Peak	Combined Peak
MKIA	Inner	0.745	0.822	1.228	1.010
MKIA	Outer	1.116	1.193	1.270	1.515
MKIV	Inner	0.854	0.990	1.214	1.202
MKIV	Outer	1.059	1.161	1.309	1.519

Table 3 Hot Dimensions Of N Reactor MKIA And MKIV Fuel

		Fuel Region Radius Inner (cm)	Fuel Region Radius outer (cm)	Fuel Cladding Inner (cm)	Fuel Cladding outer (cm)	Fuel Tube Length (cm)	End Cap Thickness (cm)
MKIA	Inner	0.625	1.488	0.063	0.101	52.80	0.33
MKIA	Outer	2.312	3.012	0.057	0.065	53.04	0.33
MKIV	Inner	0.664	1.559	0.050	0.076	66.14	0.56
MKIV	Outer	2.225	3.036	0.051	0.065	66.29	0.56

Desk Instruction 2.0, Rev. 1

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - HNF-8760

Title: Design and Safety Basis Sludge Characterization from Exposure-Adjusted Radioisotopic Source Terms for N Reactor Fuel Stored at K-East and K-West Basins

Author: K.N. Schwinkendorf and S.P. Roblver

Date: September 24.2001

Yes	No*.	NA		
[✓]	[ ]	[ ]		Referenced analyses appropriate.
[✓]	[ ]	[ ]		Problem completely defined and all potential configurations considered.
[ ]	[ ]	[✓]		Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]		Computer codes and data files documented.
[✓]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]		Mathematical derivations checked including dimensional consistency of results
[✓]	[ ]	[ ]		Models appropriate and used within range of validity, or use outside range of established validity justified.
[✓]	[ ]	[ ]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]		Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]		Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[✓]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[✓]		Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]		Format consistent with applicable guides or other standards.
[ ]	[ ]	[✓]	**	Review calculations, comments, and/or notes are attached.
[✓]	1 1	[ ]		Document approved (for example, the reviewer affirms the technical accuracy of the document).

D. W Wootan [signature]
Technical Peer Reviewer (printed name and signature)

9/25/01
Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as pad of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.