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Page 1 of 2

1. EDT 605518

35 Station 21

2. To: (Receiving Organization) Distribution		3. From: (Originating Organization) TWRS Thermal Hydraulics		4. Related EDT No.: N/A	
5. Proj./Prog./Dept./Div.: KBasin		6. Cog. Engr.: T. R. Beaver		7. Purchase Order No.: N/A	
8. Originator Remarks: Issue for approval, release, and distribution.				9. Equip./Component No.: N/A	
				10. System/Bldg./Facility: N/A	
11. Receiver Remarks:				12. Major Assm. Dwg. No.: N/A	
				13. Permit/Permit Application No.: N/A	
				14. Required Response Date: September 30, 1994	

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-SNF-ER-003		0	K-East & K-West Basin Thermal analysis for Dry Conditions	SQ	1,2	2	

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	1. Approved	4. Reviewed no/comment
		2. Release	5. Post-Review	2. Approved w/comment	5. Reviewed w/comment
		3. Information	6. Dist. (Receipt Acknow. Required)	3. Disapproved w/comment	6. Receipt acknowledged

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1	1	Cog. Eng. T. R. Beaver 9/14/94 HO-33									
1	1	Cog. Mgr. T. B. McCall 9/23/94 HO-33									
1	1	QA D. W. Smith 9/28/94 R3-85									
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18. Signature of EDT Originator T. R. Beaver 9/14/94		19. Authorized Representative Date for Receiving Organization E. L. Bennett 9/28/94		20. Cognizant Manager Date T. B. McCall 9/14/94		21. DOE APPROVAL (if required) Ctrl. No. [] Approved [] Approved w/comments [] Disapproved w/comments	
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REVIEW COMMENT RECORD (RCR)

1. Date

Sept 21, 1994

2. Review No.

gmd010

3. Project No.

K Basins

4. Page

1 of 1

5. Document Number(s)/Title(s)

EDT 605518/WHC-SD-SNF-ER-003/K-East
& K-West Basin Thermal analysis for
Dry Conditions

6. Program/Project/
Building Number

K Basins

7. Reviewer

G.M. Davis

8. Organization/Group

QA/SNFPQA

9. Location/Phone

1135tr1/100N/373
-1362

17. Comment Submittal Approval:

10. Agreement with indicated comment disposition(s)

11. CLOSED

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Date

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13. Comment(s)/Discrepancy(s) (Provide technical justification for the
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15. Disposition (Provide justification if NOT accepted.)

16.
Status

NO COMMENTS

RELEASE AUTHORIZATION

Document Number: WHC-SD-SNF-ER-003, REV. 0

Document Title: K-West & K-East Basin Thermal Analyses For Dry Conditions

Release Date: 9/29/94

* * * * *

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SUPPORTING DOCUMENT		1. Total Pages 506
2. Title K-West & K-East Basin Thermal Analyses for Dry Conditions	3. Number WHC-SD-SNF-ER-003	4. Rev No. 0
5. Key Words K-Basin, thermal analysis, loss of water event, dewatering event APPROVED FOR PUBLIC RELEASE	6. Author Name: T. R. Beaver <i>T R Beaver</i> Signature Organization/Charge Code 7E870/E31234	
7. Abstract <i>U. Burkland 9/28/94</i> Detailed 3 dimensional thermal analyses of the 100K East and 100 K West basins were conducted to determine the peak fuel temperature for intact fuel in the event of a complete loss of water from the basins. Thermal models for the building, an array of fuel encapsulation canisters on the basin floor, and the fuel within a single canister are described along with conservative predictions for the maximum expected temperatures for the loss of water event.		
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9. Impact Level SQ		

K-WEST & K-EAST BASIN THERMAL ANALYSES FOR DRY CONDITIONS

August 25, 1994

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K-WEST & K-EAST BASIN THERMAL ANALYSES FOR DRY CONDITIONS.

1.0 INTRODUCTION

The purpose of these analyses was to determine the peak fuel temperature for intact fuel in both the 100K East (K-East) and 100K West (K-West) storage basins following a loss of water event. The loss of water event was defined as a rapid and complete loss of basin water. The storage basin building, fuel encapsulation canisters and stored fuel temperatures were calculated for a conservative set of boundary conditions and decay heat generation rates. This report documents the analysis methodology, model development and results of the analyses.

At the current time irradiated N Reactor fuel is being stored in canisters in two storage basins in the 100K East and 100K West areas. The fuel stored in these canisters is Zircaloy-2 clad uranium metal. All of the fuel in the K-West storage basin is in closed canisters while the 100K-East basin fuel is in open canisters.

Because of the size of the storage basin, the surrounding building and the total number of canisters involved it is not feasible to provide the desired temperature detail with a single model of the entire facility. Therefore, the approach used for this analysis was to divide the facility and contents into three separate models. Each model could then concentrate on a separate aspect of the problem and the results could be integrated to meet the stated objective. Thus the first model concentrated on determining the internal temperatures for the building, the second on temperatures within the array of canisters on the basin floor and the third on the temperature internal to the hottest canister in the array from the second model.

This particular event, the complete loss of basin cooling water, has been the subject of previous analyses (Krajicek, 1975) and (Buchanan, 1983). Both of these analyses assumed much higher decay heat loads for the storage basin than currently exist today. In addition, these analyses modeled only a single canister and did not include the interaction with adjacent canisters or the surrounding basin structure. Section 2.0 of this report presents a summary of the results and conclusions. Section 3.0 presents a description of the analytical models and Section 4.0 the detailed results of the analysis.

2.0 CONCLUSIONS

A series of P3/THERMAL analyses were performed to determine temperature for the K-East and K-West fuel storage basins, the fuel encapsulation canisters and contained fuel elements. The analyses were performed assuming the following:

- 1) Only radiation heat transfer within the canisters.

- 2) External convective heat loss from the canister lids only (not side).
- 3) Seven fuel elements per canister. Each fuel element is at the maximum decay heat.
- 4) Intact fuel only. No partial elements or fuel fines were modeled.
- 5) No heat conduction from bottom of canister to concrete floor.
- 6) Transient effects of water evaporation from the canisters are not considered.

The following conclusions are based on the analytical results:

- 1) Without any air exchange between the building and the surrounding atmosphere and constant worst-case ambient conditions, the peak air temperature is predicted to reach 157 °F (at steady-state) in the K-West Building and 163 °F in K-East.
- 2) Due to the large mass and low heat generation, the building and fuel heatup rate is sufficiently slow (~2.4 °F/day) that Facility Operators have time (~days) to ameliorate the hypothetical accident, e.g. open the building to allow natural circulation within.
- 3) If some convection cooling is provided, dramatic decreases in maximum fuel temperature are possible (~50 °F).
- 4) Steady-state bounding calculations are very conservative because of the effects noted in conclusions 1 and 2 above and the effect of seasonal changes in ambient conditions. The steady-state calculation herein assumed constant ambient conditions of temperature and solar insolation for the hottest month conditions.
- 5) The worst-case maximum fuel temperature for the K-West Basin which has intact fuel in closed canisters is 358 °F. This precludes the possibility of cladding failure and radionuclide release.
- 6) The worst-case maximum fuel temperature for the K-East Basin fuel which is intact in closed canisters is 363 °F. With 8 inches of sludge on the bottom of the basin this temperature is increased to 367 °F. This precludes the possibility of cladding failure and radionuclide release.
- 7) For the K-East Basin the worst-case maximum fuel temperature for fuel with failed cladding is 366 °F. This temperature is based on the assumption that all fuel elements in the maximum decay heat canister are broken through the middle and indicates a very low probability that fuel ignition could occur following a loss of all basin water.

The results are summarized in Table 1.

Table 1. Results of Thermal Analysis.

	K-West Basin	K-East Basin
Worst-Case Building Air Temp (°F)	157	163
Worst-Case Intact Fuel Temperature (°F)	358	363
Worst-Case Failed Fuel Temperature (°F)	N/A ¹	366
Conservative Building Air Temp (°F)	109 ²	N/A
Intact Fuel Temperature With Sludge (°F)	N/A ³	367

¹Failed fuel was not considered for K-West Basin, See Section 4.3.2.

²Calculations include infiltration heat loss, See Section 4.1.1.

³Sludge levels in K-West Basin are not significant.

3.0 NUMERICAL MODELS

Following is a description of each of the three thermal models used to analyze the loss of water event for the 100 K storage basins. All three of the models were constructed using the PATRAN solids modeling program (PATRAN 1990). The resulting models with the appropriate material properties and boundary conditions were input into the P/THERMAL computer code (Valdiviez 1991) for solution.

3.1 Building Model

The building model was used to calculate the building wall temperatures, the ceiling temperature, and the average air temperature inside the building.

3.1.1 Building Model Geometry

The building model is a three-dimensional representation of the basin and the surrounding structure including the bay areas at both ends, and a substantial amount of surrounding soil. The thermal mass of the equipment located in the bay areas is not included in the model.

The storage basins have a steel grating suspended over them at floor level to allow personnel access for canister storage or removal operations. This grating acts as a "semi-transparent" screen for radiant heat transfer between the canisters on the basin floor and the building side walls and ceiling. It was thought that this grating could significantly reduce the direct heat transfer from the fuel canisters and was simulated in the model as an alternating set of approximately 4 foot square plates. This grating model results in a 50 percent blockage between the fuel canisters and the surrounding building. The building model is shown in Figure 3-1.

The fuel canisters were represented as a flat plate on the basin floor with a distributed heat source on the top surface of the plate. The thermal conductivity of the plate was adjusted to give an appropriate temperature difference from the top to the bottom of the fuel.

A solar heat load was applied to the building roof in the model. The separate new roof on the K-West basin was included in the model for the K-West basin only.

The soil underneath and around the basin was included to account for heat absorption during the transient following the loss-of-water event. The soil was included to a depth of 20 ft and extending out from the basin to a distance of 10 ft.

Thermal radiation and convection were included on all surfaces.

3.1.2 Material Properties

Thermophysical properties used for the basin and structure are included in Table 2 which contains materials data for all three models. Note that the heat capacity of the building walls does not include the steel structure that is in the walls because there is insulating material on the inside surface thus the steel will remain at approximately the ambient temperature.

The heat capacity of the 5-inch pipes that support the steel grating were included in the heat capacity of the grating. The heat capacity of the rest of the structure within the building was included with the roof.

Figure 3-1. K-West Basin Building.

3.1.3 Boundary Conditions

The ambient air temperature was set at 77 °F for the building analysis. This is the maximum monthly average for Hanford (Stone 1983). The temperature of the soil 20 ft below the bottom of the basin was set at 55 °F.

A heat load of 74.7 kW was calculated for the decay heat of the K-West basin for July 1994 (Wittekind 1994). Wittekind estimates that the uncertainty in the calculation of decay heat is 7% to 9%. Accordingly, 10% was added to the above decay heat load to be conservative, i.e., a bounding heat load of 82.2 kW was used in the analysis).

A solar heat load of 105 Btu/hr-ft² was applied to the outermost roof. This is the 24-hour averaged maximum solar insolation for the historically hottest month at the Hanford site (May, June, July). The highest monthly solar input occurs when no clouds or dust obscure the full radiation of the sun. (PNL, 1983).

Convection coefficients for the outer building surfaces were set to a conservative 1.0 Btu/hr-ft²-°F. The building surfaces are so tightly coupled by convection and radiation that a more precise calculation of heat transfer coefficients will not affect the results.

Table 2. Material Property Data.

Material	Thermal Conductivity Btu/hr/ft/°F	Density lbm/ft ³	Specific Heat Btu/lbm/°F	Emissivity	Reference Document
Building Wall Insulation	0.020	2.50	0.40	0.95	---
Transite Siding	0.35	87.4	0.20	0.95	---
Building Roof Transite	0.35	87.4	0.20	0.95	---
Lightweight Concrete on Roof	0.25	87.4	0.23	---	---
Roof Insulation	0.020	---	---	---	---
Carbon Steel Grating	29.2	489.0	0.116	0.80	---
New Roof (K-West)	26.0	490.0	0.11	0.95	---
Structural Concrete	0.6	141.0	0.2105	0.94	RHO-C-27
Soil	0.33	98.0	0.44	---	---
Stainless Steel (304)	(1)	(1)	(1)	0.6	TID-26666
Zircaloy-2 Clad	(1)	409.54	0.07	0.436	UNI-M-61
Uranium Fuel	(1)	1180.0	0.031	---	UNI-M-61
Aluminum 5086	---	---	---	0.55	<i>Journal of Heat Transfer</i> , Feb. 1991, Vol. 113, p.185
Ambient Air	(1)	(1)	(1)	---	Kreith, 3rd Edition

(1) Properties are functions of temperature.
Values are obtained from the Reference Documents.

3.2 Canister Array Model

The canister array model was set up to use the structure and air temperature results from the building model to predict detailed surface temperatures for an array of fuel canisters emplaced on the basin floor.

3.2.1 Model Geometry

The model comprises a three-dimensional representation for the storage basin, the interior of the surrounding structure and an array of 30 individual fuel storage canisters. The storage canisters, which represent a subset of the inventory of fuel canisters, are placed on the basin floor approximately half way between one of the baffles and the end closest to the high bay. The model includes only one-half the basin and building structure because the depth of the basin and the basin interior baffles limit the amount of interior structure that the canisters can "see" or directly transfer heat too. Figures 3-2 through 3-6 indicate the modeled geometry, the dimensions used for the building and the location of the subset of fuel canisters included in the model. Note that the upper portion of the high bay is not included in the model since that portion of the building is not visible to the fuel canisters and it is also conservative to neglect it.

The actual fuel storage basins have a steel grating suspended over them at floor level to allow personnel access for canister storage or removal operations. This grating acts as a "semi-transparent" screen for radiant heat transfer between the canisters on the basin floor and the building side walls and ceiling. It was thought that this grating could significantly reduce the direct heat transfer from the fuel canisters and was therefore simulated in the model as an alternating set of approximately 4 foot square plates. This grating model results in a 50 percent blockage between the fuel canisters and the surrounding building. The grating model is shown included on Figure 3-4.

An array of 30 canisters was chosen to represent current fuel storage conditions in the basins. This configuration provides a central canister which is sufficiently isolated from model induced boundary conditions applied at the edge of the array that it conservatively represents the basin inventory. The array of canisters included in the model are shown in Figures 3-5 and 3-6. The fuel elements internal to the canisters were simulated in this model as a uniform heat generating solid with an equivalent thermal conductivity determined from the detailed canister model.

There are two different fuel storage canisters of approximately the same dimensions used in the K-basins. The original MARK-I canisters are located in the K-East basin and are constructed of aluminum with either aluminum or stainless steel lids and perforated base plates. The perforated base plates can allow direct communication between the fuel elements and the basin water. The MARK-II canisters are located primarily in the K-West basin and have essentially the same dimensions as the MARK-I canisters. However, the MARK-II canisters are constructed of stainless steel, have a locking top plate, a sealed bottom plate and have a vent system which limits contact

between the contents and basin water. The MARK-I fuel encapsulation canisters are simulated in the array model by a series of cylinders having a diameter of 8.76 inches and a height of 28 inches. Spacing for the canisters on the basin floor are shown in Figure 3-7.

Figure 3-2. Basin Model with Surrounding Building.

Figure 3-3. Basin Model with Building Interior.

Figure 3-4. Basin Model with Floor Grating.

Figure 3-5. Basin Model with Location of Canister Array.

Figure 3-6. Basin Model with Dimensions.

Figure 3-7. Canister Placement on Basin Floor.

Cut-Away Top View

Note: All Dimensions in Inches.

3.2.2 Material Properties

Thermophysical properties used for the basin and structure are included in Table 1 which contains materials data for all three models. MARK-I fuel encapsulation canisters were simulated because they were fabricated from aluminum and would have the worst radiation heat transfer performance of any canisters in the basin. Material specified for the canisters is Aluminum 5086 which is an alloy of Aluminum plus Magnesium with additional trace elements. Emissivity data for this alloy was not directly obtainable. However, data for Aluminum 6061, which has the same composition except for differences in the trace elements, is available (Kollie 1991). Therefore, the worst case (least) emissivity for Aluminum 6061 was used for this model.

3.2.3 Boundary Conditions

For the canister array model it was assumed that heat is transferred from the canisters to the surroundings mainly by radiation. Natural convection heat transfer is included only for the top surface of the canister lids. Convective heat transfer from the side walls of the canisters is neglected in this model. While it is recognized that heat transfer by natural convection from the side walls of the canisters would occur for this event it is difficult to determine the exact magnitude because of the interaction of flow fields from adjacent canisters and the overall extent of the flow field involved (size of the basin). Therefore, because of the difficulty in defining a reasonable and defensible value for the side wall convective heat transfer it was conservatively neglected. Conduction through the base of the canister to the concrete floor of the basin was also conservatively neglected.

Boundary conditions for the canister array model include temperatures for the building interior surfaces and internal air temperature. These values are obtained directly from the building model results. Additional inputs are the radiation view factors, the convective heat transfer coefficients and the decay heat generation within the canisters.

Radiation viewfactors for the model are calculated directly by the P/THERMAL software based on the finite element representation of the input geometry.

Natural convection heat transfer from the lids of the canisters is calculated based on the following empirical correlations for hot horizontal plates facing upward.

$$Nu = 0.15Ra^{0.33} \quad \text{for} \quad 1.0E+07 < Ra < 3.0E+10,$$

and

$$Nu = 0.54Ra^{0.25} \quad \text{for} \quad 2.6E+04 < Ra < 1.0E+07,$$

where Nu is the Nusselt Number, Ra is the Rayleigh Number, and the characteristic length was taken to be the diameter of the canister lid.

Decay heat generation within the canisters is derived from Wittekind 1994 which gives the updated decay heat totals for both the K-East and K-West basins. Decay heat totals for the individual basin "keys" as a function of time are provided in the reference document. The basin keys are inventory information based on storage location and are primarily groups of fuel canisters made up from individual N Reactor fuel discharges. These data were searched to determine the highest power "keys" for both K-East and K-West basin. The number of fuel elements associated with each key and the average decay power were then calculated assuming MARK-IA elements contain 16.843 kg of uranium and MARK-IV contain 23.830 kg. An axial peaking factor of 1.60 and a radial peaking factor of 1.24 were applied to the average decay power to determine the current maximum decay power for an individual fuel element. The results are shown in Table 3 and 4. Interpolation of the data shown on the table give a current (July 1994) maximum decay power of 5.63 watts/element for K-East and 5.64 watts/element for K-West. Assuming 7 peak power elements in each canister and a canister volume of 0.977 ft³ gives an average volumetric heating rate of 137.87 BTU/hr/ft³ for each canister.

Table 3. Decay Heat Generation Rate for 100 K-East.

YEAR	DECAY POWER (At Jan. 31) watts/key	AVERAGE POWER watts/ element	PEAK POWER* watts/element
1994	117.15	2.86	5.67
1995	115.04	2.81	5.58
1996	113.00	2.76	5.48
1997	111.05	2.71	5.38
2002	102.02	2.49	4.94

Values are calculated for KEY No. 11540, MARK-IV fuel, 977.119 kg Uranium.
Number of fuel elements is 41.

Table 4. Decay Heat Generation Rate for 100 K-West.

YEAR	DECAY POWER (At Jan. 31) watts/key	AVERAGE POWER watts/element	PEAK POWER* watts/element
1994	823.71	2.87	5.69
1995	808.26	2.82	5.59
1996	793.37	2.76	5.48
1997	778.89	2.71	5.38
2002	713.24	2.49	4.93

Values are calculated for KEY No. 12565, MARK-IV fuel, 6833.329 Kg Uranium.
Number of fuel elements is 287.

* Assumes an axial peaking factor of 1.60 and radial peaking factor of 1.24.

3.3 Canister Model

A detailed model of a single Mark-II fuel canister was also constructed. This model uses canister surface temperatures from the canister array model to calculate the expected peak temperature within the encapsulated fuel.

3.3.1 Model Geometry

A Mark-II fuel encapsulation assembly consists of two parallel 8.194 inch OD cylinders capped at both ends. The upper end cap (locking plate) is removable. The lower end cap is welded in place. The cylinders are positioned relative to each other by use of cross trunnions. A maximum of seven fuel elements can be stored within each canister. Figures 3-8 and 3-9 present simplified views of the encapsulation assembly and a single canister with the internal fuel configuration. Geometric symmetry would reduce the model of a canister to a 30 degree pie slice. Radiation symmetry considerations increase this to a 60 degree slice, as shown on Figure 3-10. Canister and Mark-IV fuel dimensions used in the model are shown on Table 5.

Figure 3-8. Fuel Encapsulation Canister.

NOT TO SCALE
DIMENSIONS IN INCHES

Figure 3-9. Fuel Placement in MARK II Canister.

NOT TO SCALE
DIMENSIONS IN INCHES

Figure 3-10. Canister Model.

CANISTER MODEL

CANISTER MODEL
LID SECTION

CANISTER MODEL
BASE SECTION

Table 5. Canister & Fuel Dimensions.

Canister Dimensions (inches)	
Outside Diameter	8.194
Inside Diameter	8.074
Overall height	27.375
Upper end cap (Lid) thickness	0.50
Lower end cap thickness	0.25
Mark-IV Fuel Dimensions (inches)	
Outer cylinder OD	2.425
Outer cylinder ID	1.701
Inner cylinder OD	1.279
Inner cylinder	0.479
Cladding Thickness (mils)	
Outer cylinder, outer clad	25
Outer cylinder, inner clad	20
Inner cylinder, outer clad	30
Inner cylinder, inner clad	20
Fuel Element Length (inches)	
Outer cylinder (total)	26.10
Inner cylinder (total)	26.04
Outer cylinder end cap	0.200
Inner cylinder end cap	0.200

3.3.2 Material Properties

Thermophysical properties used for the canister model are included in Table 1 which contains materials data used for all three models. The Mark-II fuel canister was used for the model because it is constructed from 304 stainless-steel which has a smaller thermal conductivity than the aluminum Mark-I canisters and therefore should tend to give conservative temperature results. The Zircaloy-2 cladding was not specifically modeled since the cladding is thin and the fuel and cladding conductivities are large compared with the conductance between the fuel elements and the canister walls. The outer dimensions of the fuel elements were not revised. The Zircaloy-2 end caps, which are much thicker, were included in the model.

3.3.3 Boundary Conditions

Outer surface temperatures for the canisters were determined from the canister array model assuming radiation heat transfer from the sides and top plus natural convection from the top only. Conduction from the base of the canister to the concrete floor of the basin was neglected. Temperatures interior to the canister were calculated assuming radiation heat transfer only between the surfaces of the fuel elements and the canister walls. Conduction and convection of the enclosed gas was neglected. Any water within the canister at the initiation of the "dewatering event" was assumed to have leaked out or evaporated away.

Internal surfaces were assumed to radiate to each other; cladding-to-cladding, cladding to canister, and end caps to top and bottom plates. Radiation viewfactors between all of these surfaces were calculated directly by the P/THERMAL software based on the finite element representation of the input geometry.

For Mark-IV fuel elements, the maximum decay heat for both the K-East and K-West basins was determined to be 5.64 watts per element (Section 3.2.3). Fuel volumes for the inner and outer cylinders is calculated to be 0.0513 ft³, which includes the side wall cladding. The resulting volumetric heat generation rate is 375.10 BTU/hr/ft³.

The majority of the fuel encapsulation canisters in the K-East basin are of the Mark-I type which have perforated base plates. Many are without lids. These open canisters will allow atmospheric oxygen to enter the canisters during the "dewatering event" and would be free to enter into an oxidation reaction with any uranium fuel which has lost cladding integrity. The calculations performed for the K-East fuel canisters assumes the fuel is intact, except for the cladding, and that the oxygen and water vapor concentration around the fuel elements is uniform. This conservatively ignores the finite

diffusion rate of oxygen and water vapor into the lower region of the canister. The equation for the oxidation rate of uranium fuel in the presence of water vapor for temperatures below 350 °C was taken from Epstein et al. (1994) and is given below:

$$\dot{m}_{ox} = \frac{0.4195 p_v \exp\left(\frac{-6432}{T}\right)}{1 + 2.48 \times 10^{-7} p_v \exp\left(\frac{5237}{T}\right)} + 10.95 \exp\left(\frac{-8077}{T}\right),$$

where $\dot{m}_{ox}$ is in kilograms of oxygen per square meter per second, p_v is the partial pressure of water vapor in kPa, and T is temperature in degrees Kelvin. The heat of reaction was taken as 3.4×10^7 Joules per kilogram of oxygen.

4.0 ANALYTICAL RESULTS

The results for each of the three thermal models of the K-Basins (building, canister array and single canister) are presented in the following sections.

4.1 K-West and K-East Building

Two sets of steady-state cases and a thermal transient were investigated for the K-East and K-West basin and its associated building structure. The first steady-state case obtained building temperatures assuming no air in-leakage to the building. The other steady-state calculation studied the consequences of relatively small quantities of air exchange or forced airflow into the building. The thermal transient study attempted to follow the building temperatures after the loss of the shielding/cooling water from the basin (the "dewatering" seismic event).

4.1.1 Steady-State Temperatures

Two steady-state PThermal calculations using the 3D building model determined the maximum expected temperatures for the surfaces within line-of-sight view of the fuel canisters in the K-East and K-West basins for the beginning and end of the transient. These calculated temperatures were subsequently used in the canister array model to predict canister surface temperatures.

The first steady-state case determined the thermal conditions at the start of the transient using the full building model. In this calculation, the fuel region was held constant at 65 °F and no heat generation was used, simulating the instantaneous uncovering of the fuel canisters by the 65 °F basin water. The second steady-state case computed the end-point temperatures for the ambient conditions with the full fuel

heat load. Both of these steady-state cases simulated a fictitious situation because the ambient conditions vary seasonably and the transient thermal rise-time for the K basin systems is quite long due to the large mass of the building and the soil under it.

Table 6 contains representative results from these two steady-state cases for the K-West basin plus an additional case of end-point temperatures for the K-East Basin. The K-East temperatures are slightly higher than the K-West temperatures because of the loss of the heat-shielding effect of the double roof of K-West.

Table 6. Typical Results from Steady-State Heat Transfer Analyses for K-West and K-East Basins.

Location	T, °F			
	Fuel	Walls	Ceiling	Building Air
K-West Basin (initial conditions)	71	71	73	72
K-West Basin (end-point)	167	158	157	157
K-East Basin (end-point)	173	164	163	163

The steady-state calculations discussed above assume that the K-West and K-East basin buildings are air-tight, i.e., there was no removal of interior heat by advection to the ambient. However, these buildings are not air-tight; there is an interchange of air due to normal atmospheric pressure changes thermal buoyancy and effects of winds through openings (cracks, doors, vents, etc.) that exist for all buildings. Because of the slow transient heating rates that were calculated (see next section), there will be sufficient time (days) to establish airflow through the building to significantly decrease the temperatures inside. For example, the bay doors could be opened or, in case they are inoperable, openings could be made by cutting the thin walls or roof. Table 7 contains the results of the steady-state end-point temperatures for a number of different airflow rates, from no airflow (as in Table 6 above) to 7000 cfm. For each of these cases for the K-West basin building, an airflow of half the value shown in the table was allocated to the space between the old and new roofs (the attic). Peak temperatures decrease almost 50 °F for the 7000 cfm case. Figure 4-1 shows a plot of the information in Table 7.

Table 7. Effects of Airflow in K-West Basin Building.

AirFlow cfm	T, °F			
	Fuel	Walls	Ceiling	Building Air
0	167	158	157	157
1000	154	144	144	143
1750	146	136	136	135
4000	131	121	121	120
7000	120	110	110	109

Figure 4-1. Effect of Airflow on Building Temperature.

4.1.2 Transient Studies

An attempt was made to conduct a transient study of the K-West and K-East building response to the loss of basin water. Because of the complexities involved in the convective and radiation heat transfer mechanisms of the model, a suitably efficient model has not yet been developed. The real/model time ratios are presently running about 2/1, making a calculation for the transient period of interest infeasible (on the order of months). However, a transient up to 60 hours was obtained for constant ambient conditions and shows a settling into a heating rate on the order of 0.1 °F/hr, or less than 3 °F per day, as shown in Figures 4-2 and 4-3. This 0.1 °F/hr heating rate will decrease with time under constant ambient conditions as the building heats up toward the final steady-state condition shown in Table 6. The steady-state calculations discussed in section 4.1.1 show an end-point temperature rise of about 85 °F. For a constant heating rate of 0.1 °F/hr, it would take over 35 days to reach the final steady-state temperature, if the ambient conditions remained constant. However, this is not the case. The outdoor temperatures and solar heating were assumed to be at their peak values for these steady-state cases. Therefore, all of the ambient boundary conditions will decrease in severity as the transient continues, creating a higher heat removal condition from the building and decreasing or even reversing the positive-valued heating rate calculated above in the preliminary transient study. The result will be an even longer time to reach at least quasi-steady conditions.

4.2 K-West Fuel Temperatures

A series of steady-state calculations were performed to determine the maximum expected fuel temperature for the maximum decay heat canister in the Kwest basin. The calculations were performed using the building and bulk air temperatures predicted by the building model. Calculations were iterated between the canister array model and the detailed single canister model until the peak fuel temperatures between the two models agreed. The parameter which was iterated on is the effective thermal conductivity of the canister contents used in the canister array model (See Figure 4-4).

Steady state building temperatures calculated for the KW basin geometry were input to the canister array model. Building temperature values used in the calculations are listed in Table 8.

Table 8. K-West Steady-State Building Temperatures:

Basin Floor	Basin Walls	Building Floor	Building Walls	Building Ceiling	Ambient Air
395	158	156	152	156	157

Note that the basin floor temperature was increased above the value calculated by the building model ("Fuel" entry in Table 6). This increased temperature for the basin floor simulates the canisters that would be adjacent to the edge canisters of the array modeled. The temperature value used causes the model to calculate nearly uniform internal temperatures along the rows of canisters, as would be the case if all 5012 canisters in the basin were modeled.

Figure 4-2. K-West Basin Building Transient Temperatures.

Figure 4-3. K-West Basin Building Heat Up Rate.

Figure 4-4. Analysis Iteration Procedures.

Calculated building temperatures (with the roof removed for viewing) are shown on Figure 4-5. Note the simulated grating over the basin. Surface temperatures calculated for the complete array of thirty canisters is shown on Figure 4-6. Temperatures for the row of canisters through the center of the array are shown on Figure 4-7. Surface temperatures for the two canisters in the middle appear to be nearly identical and no significant temperature gradient exists between these and the adjacent canisters. These results indicate that temperatures of the central canisters reflect what is expected for the highest decay heat canister in the basin should a dewatering event occur. A cut-away of the center row of canisters is shown on Figure 4-8. This figure indicates a peak temperature of about 350 °F on the canister surface at the base and a lid surface temperature of 257 °F at the center. A peak temperature in the canister of 358 °F occurs at the center of the base.

Surface temperatures for the hottest canister in the KW basin as calculated by the canister array model were input to the single canister model. The same maximum decay heat value of 5.64 watts per element was used for both calculations. Peak temperature for the encapsulated fuel at steady state was then compared with the maximum value predicted by the canister array model. If the values did not match within 1 °F the effective conductivity used for the canisters in the array model was modified and the process repeated (Figure 4-4).

The resulting maximum temperatures for the encapsulated fuel are shown on Figure 4-9. Note that the maximum temperature occurs at the base of the inner cylinder on the central fuel element, as would be expected. The calculated value is 357 °F, which is within one degree of the value predicted by the canister array model. The peak to surface temperature for the canister is on the order of 7 °F and indicates that radiation heat transfer provides good thermal coupling between the fuel elements and canister walls. Should a dewatering event actually occur, conduction and convection within the gas in the canister would reduce this temperature difference even further. The temperature difference between top and bottom of the canister is on the order of 100 °F and in the actual case would probably be less due to natural convection from the sides of the canister and fuel and conduction to the basin floor.

The fuel temperatures predicted for K-West are well below the 662 °F (350 °C) worst case (lowest) ignition temperature for uranium metal that is cited in Epstein et al. (1994) and indicate almost no chance for combustion of intact fuel elements. Also, since the canisters in K-West are all sealed there is no ready source of oxygen to sustain combustion even if the predicted temperatures were much higher. The gas trap built into the Mark-II canisters would allow the venting of steam during heatup of the canisters, but the 1/8 inch ID tubing would allow only a limited back diffusion of atmospheric oxygen. Because of this, any additional heating due to surface oxidation of uranium was not included in these calculations.

Figure 4-5. K-West Building Temperatures.

Figure 4-6. K-West Canister Array Temperatures.

Figure 4-7. K-West Center Canister Temperatures.

CENTER COLUMN TEMPERATURES

Figure 4-8. K-West Center Canister Interior Temperatures.

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4.3 K-East Fuel Temperatures

4.3.1 Intact Fuel

Similar calculations as those outlined previously were conducted for the intact fuel and canisters in the K-East basin using building temperatures for the revised K-East building geometry. Intact fuel is defined as fuel elements which are upright in the canister and not broken. Temperatures from the K-East building model are only slightly higher than those predicted for the K-West basin and the values used in the analysis are shown below. The same maximum decay heat level of 5.64 watts per element was used since the K-East and K-West values are nearly identical with the K-West value being slightly higher.

Table 9. K-East Steady-State Building Temperatures.

Basin Floor	Basin Walls	Building Floor	Building Walls	Building Ceiling	Ambient Air
401	164	156	158	163	163

Again note that the basin floor temperature was adjusted to simulate the canisters adjacent to the array modeled.

The Mark-I canisters used in the K-East basin are vented either through the perforated base and/or through the top for those that have no lids. Use of the same thermal model (K-West) to simulate this configuration was considered conservative since the presence of a lid will effectively reduce the radiant heat transfer from the fuel elements to the surrounding building. Also, heat conduction through the base to the concrete basin floor has been neglected in the model.

For those intact fuel elements in the K-East basin which maintain cladding integrity and therefore are not expected to experience an oxidation reaction, the predicted peak temperature is only slightly higher than that predicted for the K-West basin (363 °F versus 358 °F). This difference is due to the slightly higher building temperature since the maximum decay heat was conservatively assumed to be the same. A cut-away view of the center row of canisters for this case is shown on Figure 4-10. Note that peak temperatures of adjacent canisters are the same indicating a good representation for the entire complement of canisters in the basin. The maximum temperature distribution within the canister is shown on Figure 4-11. The peak temperature is 363 °F which is essentially the same as the K-West basin prediction with the slight increase reflecting the small difference in building temperatures.

Because of the conservative building temperatures and maximum decay heat values used, these results should envelope the hottest intact fuel canister in the K-East basin following a complete loss of water. As before the maximum temperature predicted is well below the 662 °F worst-case ignition temperature for uranium metal and indicates almost no chance for combustion.

Video mapping to determine the sludge volume in the K-East basin has determined the sludge depth at 300 points within the basin. The mean depth was determined to be 2.0 inches with a maximum measured depth of 7.9 inches. Because of the conservative set of assumptions already built into the heat transfer model for the fuel canisters, the presence of sludge was not expected to have a significant effect on the predicted temperatures for the loss of water event. To verify this, additional calculations were performed taking into account this condition.

The canister array model was modified assuming all 30 canisters to be buried in sludge to a depth of 8 inches. The sludge was assumed to be non-conducting effectively limiting any heat transfer from the bottom and first 8 inches of the sides of the canisters. The single canister model was similarly modified and the same iterative procedure as described in Section 4.2 was used to calculate the maximum fuel temperature for this configuration. A cut-away view of the predicted temperatures for the center row of canisters for this case is shown in Figure 4-12. The maximum predicted temperature at the base of the canister is 367 °F. The temperature distribution within the fuel elements is shown in Figure 4-13. Because of the assumptions of radiation heat transfer only from the outside surface of the canisters, the majority of the decay heat is transferred from the lid and upper sides of the canister. Therefore, the presence of sludge on the basin floor has little impact on the predicted maximum temperature as indicated on the figures (367 °F compared with 363 °F without sludge).

Figure 4-10. K-East Center Canister Temperatures.

Figure 4-11. K-East Center Canister Fuel Temperatures.

CANISTER TEMPERATURES
K-East Basin

Figure 4-12. K-East Center Canister Interior Temperatures with Sludge.

Figure 4-13. K-East Center Canister Fuel Temperatures with Sludge.

CANISTER TEMPERATURES
K-East Basin with 8 inch Sludge Layer

4.3.2 Failed Fuel

Canisters in the K-East basin that do not have lids and which have the possibility for breached cladding could undergo a slow oxidation reaction following loss of basin water and canister dryout. Surface oxidation calculations were performed using the detailed canister model and the expression for uranium oxidation listed in Section 3.3.

The maximum surface area of the fuel that could be exposed to an oxidation reaction is currently not known. For intact fuel elements this area is most probably associated with a pinhole leak in the cladding. However, a conservative estimate for the surface area available for oxidation was made by assuming that all 7 fuel elements in the maximum decay heat canister are broken in the middle on a 45° plane through the element. This break exposes a total oxidation surface area of 9.27 in² per fuel element. It was also assumed that all fuel elements in the canisters surrounding the maximum decay heat canister are similarly broken. This is equivalent to assuming that all canisters in the basin (several thousand) are broken. Sufficient oxygen and water vapor were assumed to be available to sustain the reaction. The amount of water vapor in the air at Hanford is nearly constant with an average yearly value of approximately 0.0035 pounds of water per pound of dry air. The present calculations for the K-East basin assumed 0.0040 pounds of water per pound of dry air. Since the finite element model described in Section 3.3 assumes intact fuel, the oxidizing surface was chosen to be the band of finite element faces on the outside of both the inner and outer cylinders at the midpoint of the fuel element (see Figure 4-14). This results in a surface area of 11.99 in² which adds further conservatism to the calculations.

Surface temperatures for the hottest canister in the K-East basin were calculated by the canister array model assuming the worst-case building temperatures and maximum decay heat. These temperatures were input as boundary conditions to the single-canister model along with the relationship for heat input due to surface oxidation. Steady-state temperatures and the amount of oxidation heating were calculated. The incremental heat generation due to oxidation was then input to the canister array model and a revised set of surface temperatures calculated. These revised surface temperatures were used to repeat the single canister calculations. This process was repeated until the predicted temperatures converged. These calculations make the conservative assumption that fuel elements in open-top canisters do not radiate directly to the building structure as the model incorporates a lid as a radiation barrier while assuming the fuel elements have free access to oxygen and water vapor.

The result of these calculations was that the heatup transient for the fuel was minimal. The additional heat generated by the oxidation reaction for all seven fuel elements was calculated to be only 2.4% of the total decay heat. This resulted in an increase in peak temperature within the fuel elements of only 3 °F over that without an oxidation reaction (366 °F versus 363 °F). Steady state temperatures calculated by the canister array model for this case are shown on Figure 4-15. The single canister model results are shown on Figure 4-16. Note in Figure 4-16 that heat generation from the oxidation reaction is small enough that heat conduction within the fuel elements and

radiation from the surface to the canister walls is sufficient to eliminate any localized hot spots. These results are considered conservative in that the predicted temperatures are higher than would be expected should an actual loss of water event occur. The results also indicate a large margin between the predicted temperature and the minimum temperature required for combustion of the uranium fuel. Therefore the likelihood that any intact fuel elements having a breach in the cladding would ignite during a loss-of-water event are considered small.

Figure 4-14. Fuel Elements with Oxidation Heating.

FUEL ELEMENTS With Oxidation Heating

Figure 4-15. Array Model Results with Oxidation Heating.

Figure 4-16. Fuel Temperatures with Oxidation Heating.

CANISTER TEMPERATURES
K-East Basin with Oxidation

REFERENCES

- 1) Krajicek, J. A., February 1975, "Thermal Analysis for KE Basin Fuel Storage Under Complete Cooling Water Loss Conditions," UNI-293 Rev 1.
- 2) Buchanan, D. T. "Consequence of Loss of Water in a K-Basin," UNC Memo, March 4, 1983.
- 3) PATRAN Plus User Manual, Release 2.5, 1990, PDA Engineering, Westinghouse Hanford Company, Richland Washington.
- 4) Valdiviez, R., 1991, "Verification Report for the P/THERMAL Computer Code," WHC-SD-GN-CSWD-319, Rev 0, Westinghouse Hanford Company, Richland Washington.
- 5) Stone, W. A., J. M. Thorp, O.P. Gifford, D.J. Hotink, 1983, "Climatological Summary for the Hanford Area," PNL-4622.
- 6) Wittekind, W. D., 1994, "Consolidated Fuel Decay Heat Calculations," WHC-SD-NR-ANAL-014 Rev 0, Westinghouse Hanford Company, Richland Washington.
- 7) Epstein, M. ,et al., 1994, "K-Basin Severe Accident Analysis: Preliminary Fuel Heatup and Ignition Potential", FAI/94-62, Fauske & Associates, Inc., Burr Ridge, Illinois.