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The attached document (WHC-SD-NR-ANAL-014) provides revised decay heat calculations for irradiated N-Reactor fuel stored in the K basins. It supercedes WHC-SD-NR-ANAL-002, "100K Basins Spent Fuel Decay Heat" which is based on uniform fuel exposure. WHC-SD-NR-ANAL-014 is based on exposure measurements of segregated spent fuel elements.

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EXECUTIVE SUMMARY

The radiological decay heat generated from all irradiated fuel presently in K East (KE) and K West (KW) Basins was calculated in support of consolidated fuel storage.

There are four sources of heat inflow into the fuel storage basins:

- Radiological decay heat from irradiated fuel
- Mechanical heat from operating machinery (e.g., pumps)
- Heat flow from surroundings (mainly the ground through the concrete walls into the basin water if it is maintained below ambient)
- Exothermic chemical reactions of uranium oxidation (although at basin temperatures this reaction rate is slow).

This report details the radiological decay heat from irradiated fuel source in the K basins.

Decay heat calculations using ORIGEN2 (Wittekind 1994 and Schmittroth 1993) for irradiated fuel presently (April 1994) in KE and KW Basins gave results for January 31 of each year:

Area	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
KE Basin	78.7	76.4	74.4	72.6	70.9	69.4	63.3	58.0	53.2	49.0
KW Basin	79.9	77.4	75.6	73.8	72.2	70.7	64.2	58.5	53.5	49.0
Combined	158.6	153.8	149.9	146.4	143.1	140.2	127.5	116.5	106.7	98.0

NOTE: All amounts are given in kilowatts.

Mechanical heat generation has been estimated as:

Recirculation pump work	17 kW
Skimmer pump work	15 kW
Total	32 kW.

Decay heat totals are listed separately by basin key. The calculational method of using ORIGEN2 is described. Comparisons are made, where appropriate, to an ORIGEN-S calculation, to ANSI/ANS-5.1, to another decay heat calculation in WHC-SD-NR-ANAL-002, Rev. 0, (Conn 1990) and reasons for differences given.

The fuel segregation program separated N Reactor fuel in KE Basin on the basis of its ^{240}Pu content. A neutron detector was used to count fuel elements or assemblies separately (Wittekind 1984). The neutron count on four standard elements of known wt% ^{240}Pu composition calibrated the neutron count into a wt% ^{240}Pu assay. These elements or assemblies were then placed in a ^{240}Pu exposure category on the basis of this neutron count inferred assay. These assays were incorporated into the reconstructed SCATS (Safeguards Control and Accountability Iransactions System) material accountability database (Schlosser 1990, 1992a, and 1992b).

This study used the reconstructed SCATS fissile material inventory database. The reconstructed SCATS database is different than the 100 Area

unclassified accountability material inventory because it incorporates the neutron count assigned different exposures for the segregated N Reactor fuel in KE Basin. The 100 Area accountability inventory simply apportioned the exposure uniformly with fuel mass. The difference in decay heat resulting from not using the reconstructed SCATS database is approximately -16% for the KE Basin, with the more correct reconstructed SCATS material compositions giving a higher decay heat.

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LIST OF TERMS

ANS	American Nuclear Society
ppm	parts per million
PNL	Pacific Northwest Laboratory
PUREX	Plutonium-Uranium Extraction (Plant)
PWR	pressurized water reactor
SCALE	<u>Standardized Computer Analyses for Licensing Evaluation</u>
SCATS	<u>Safeguards Control and Accountability Transactions System</u>
SPR	single pass reactor

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CONSOLIDATED FUEL DECAY HEAT CALCULATIONS

1.0 INTRODUCTION

1.1 PURPOSE

Radiological decay heat generated from all irradiated fuel presently in 105-KE and 105-KW Basins was calculated in support of consolidated fuel storage.

There are four sources of heat inflow into the K Area fuel storage basins: (1) radiological decay heat from irradiated fuel, (2) mechanical heat from operating machinery (e.g., pumps), (3) heat flow from surroundings, mainly the ground through the concrete walls, into the basin water if it is maintained at lower than ambient temperature, and (4) exothermic chemical reactions of uranium oxidation, although at basin temperatures this reaction rate is slow. This report details the radiological decay heat from irradiated fuel source.

1.2 RESULTS

Decay heat calculations for irradiated fuel presently (March 1994) in the KE and KW Basins gave results shown in Table 1-1.

Table 1-1. Decay Heat ORIGEN2 Results by Basin
(Reference Date is January 31 of Given Year) (kW).

Area	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
KE Basin	78.7	76.4	74.4	72.6	70.9	69.4	63.3	58.0	53.2	49.0
KW Basin	79.9	77.4	75.6	73.8	72.2	70.7	64.2	58.5	53.5	49.0
Combined	158.6	153.8	149.9	146.4	143.1	140.2	127.5	116.5	106.7	98.0

Mechanical heat generation in both KE and KW Basins has been estimated as: recirculation pump work of 17 kW and skimmer pump work of 15 kW, for a total of 32 kW.

Figure 1-1 is a graph of decay heat to the year 2017.

Decay heat totals are listed separately by basin key in Table 1-2. The categorization is a little crude, only MKIA (listed as MIA) and MKIV (listed as MIV) and MKIVB (listed as NAT) are included. There is also some single pass reactor (SPR) fuel in key 9621 in KE Basin, which is listed as MIA.

Figure 1-1. Decay Heat ORIGEN2 Results for KE and KW Basins.

ACT = Actinides, AP = Activation Products, and FP = Fission Products. These isotopic categories are defined in ORIGEN2 and decay heat calculated for each category separately. The largest contributor is fission products.

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
E	9621	MIA	6.151	105497	21.01	3.09	3.03	2.96	2.90	2.84	2.78	2.50	2.26	2.04	1.85
E	10001	MIV	9.746	139198	19.96	6.66	6.53	6.40	6.28	6.16	6.04	5.50	5.01	4.58	4.20
E	10201	MIV	8.941	2652109	19.42	112.92	110.66	108.48	106.35	104.27	102.24	92.85	84.50	77.05	70.45
E	10259	MIV	10.245	19809019	19.26	1035.73	1015.44	996.01	977.02	958.46	940.33	856.34	781.73	714.98	655.58
E	10259	MIV	9.503	534953	19.26	25.01	24.51	24.04	23.57	23.11	22.67	20.61	18.78	17.15	15.70
E	10294	MIV	12.447	966821	19.16	68.91	67.62	66.38	65.17	63.99	62.84	57.49	52.73	48.47	44.65
E	10294	MIV	9.167	2180106	19.16	96.84	94.90	93.04	91.22	89.44	87.71	79.68	72.55	66.18	60.53
E	10294	MIV	10.192	34667159	19.16	1802.00	1766.54	1732.69	1699.60	1667.26	1635.68	1489.33	1359.35	1243.07	1139.61
E	10350	MIV	9.100	528507	19.01	23.30	22.83	22.38	21.94	21.51	21.09	19.16	17.44	15.91	14.55
E	10385	MIV	10.128	1922669	18.91	99.50	97.52	95.65	93.82	92.03	90.28	82.18	74.99	68.56	62.83
E	10385	MIV	11.026	33857167	18.91	1997.60	1958.70	1921.72	1885.64	1850.38	1815.94	1656.28	1514.43	1387.43	1274.18
E	10456	MIV	12.139	3079307	18.72	212.90	208.84	204.96	201.20	197.52	193.93	177.27	162.46	149.19	137.33
E	10456	MIV	10.824	23303779	18.72	1340.87	1314.59	1289.52	1265.20	1241.41	1218.18	1110.47	1014.82	929.22	852.90
E	10576	MIV	10.866	3918270	18.39	228.37	223.88	219.57	215.43	211.38	207.42	189.06	172.77	158.19	145.19
E	10602	MIV	10.899	8768292	18.32	514.25	504.15	494.42	485.10	475.98	467.07	425.75	389.08	356.26	326.99
E	10602	MIV	13.524	10733446	18.32	886.80	870.22	854.27	838.97	824.02	809.41	741.71	681.47	627.53	579.20
E	10602	MIV	15.128	7161085	18.32	722.37	709.22	696.57	684.42	672.56	660.97	607.31	559.49	516.65	478.20
E	10679	MIV	15.022	14240295	18.11	1423.47	1397.46	1372.29	1348.31	1324.86	1301.96	1195.91	1101.45	1016.86	940.94
E	10679	MIV	10.902	11663890	18.11	687.31	673.78	660.69	648.22	636.03	624.11	568.84	519.79	475.91	436.77
E	10742	MIV	10.978	5656473	17.94	338.19	331.53	325.07	318.93	312.94	307.08	279.90	255.79	234.22	214.98
E	10742	MIV	13.558	8775180	17.94	733.75	719.99	706.64	693.95	681.57	669.46	613.37	563.49	518.83	478.82
E	10742	MIV	15.535	6093171	17.94	652.58	640.72	629.22	618.28	607.61	597.18	548.90	505.90	467.39	432.81
E	10764	MIV	0.000	1971998	17.88	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
E	10770	MIV	10.837	9353974	17.86	548.94	538.09	527.57	517.55	507.80	498.26	454.01	414.75	379.65	348.34
E	10770	MIV	15.085	9831858	17.86	995.68	977.45	959.76	942.93	926.53	910.50	836.29	770.22	711.06	657.96
E	10832	MIV	15.713	8434916	17.69	929.13	912.24	895.86	880.21	865.04	850.21	781.55	720.43	665.69	616.54
E	10832	MIV	10.784	17902129	17.69	1046.32	1025.59	1005.47	986.27	967.64	949.44	864.93	789.99	723.00	663.23
E	10832	MIV	13.588	26344620	17.69	2222.08	2180.32	2139.79	2101.10	2063.59	2026.92	1856.90	1705.79	1570.52	1449.34
E	10982	MIV	10.920	9815888	17.28	590.09	578.38	567.02	556.07	545.59	535.34	487.72	445.51	407.80	374.13
E	10982	MIV	15.684	15338466	17.28	1697.54	1666.54	1636.45	1607.46	1579.68	1552.53	1426.69	1314.81	1214.63	1124.71

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
E	11036	MIV	10.563	4009618	17.13	229.63	225.04	220.58	216.27	212.16	208.14	189.46	172.92	158.14	144.96
E	11036	MIV	15.245	6369285	17.13	668.23	655.93	643.98	632.44	621.43	610.67	560.75	516.41	476.71	441.08
E	11036	MIV	13.758	2595920	17.13	226.14	221.88	217.74	213.74	209.93	206.20	188.89	173.53	159.78	147.46
E	11109	MIV	10.757	9329956	16.93	551.86	540.85	530.15	519.77	509.91	500.29	455.54	415.90	380.50	348.89
E	11109	MIV	15.347	15877672	16.93	1694.64	1663.42	1633.12	1603.72	1575.77	1548.49	1421.95	1309.58	1208.98	1118.73
E	11183	MIV	13.705	16792401	16.73	1465.60	1437.84	1410.89	1384.74	1359.78	1335.57	1223.04	1123.25	1033.99	954.01
E	11183	MIV	10.610	12623759	16.73	734.12	719.40	705.10	691.23	677.99	665.14	605.39	552.47	505.24	463.07
E	11183	MIV	15.477	21352389	16.73	2326.99	2284.12	2242.50	2202.11	2163.56	2126.15	1952.49	1798.38	1660.41	1536.63
E	11372	MIV	10.789	13402918	16.21	808.63	792.40	776.63	761.33	746.56	732.44	666.71	608.52	556.63	510.25
E	11372	MIV	15.337	17694772	16.21	1914.63	1879.10	1844.60	1811.10	1778.78	1747.87	1604.19	1476.92	1363.00	1260.84
E	11449	MIV	15.522	14755244	16.00	1642.06	1611.62	1582.04	1553.32	1525.46	1499.01	1375.94	1267.01	1169.49	1082.05
E	11449	MIV	11.006	14469777	16.00	904.71	886.59	868.99	851.91	835.33	819.60	746.29	681.42	623.57	571.84
E	11540	MIV	10.883	12526831	15.75	773.61	758.05	742.93	728.25	714.01	700.43	637.52	581.87	532.29	487.93
E	11540	MIV	16.333	977119	15.75	121.56	119.32	117.15	115.04	113.00	111.05	102.02	94.05	86.90	80.49
E	11733	MIV	11.789	644304	15.22	45.70	44.79	43.91	43.05	42.22	41.42	37.76	34.52	31.63	29.05
E	11806	MIV	15.592	13660314	15.02	1565.98	1536.72	1508.27	1480.62	1453.79	1427.78	1309.73	1205.64	1112.46	1028.97
E	11806	MIV	10.922	14244511	15.02	898.52	880.37	862.72	845.57	828.92	812.78	739.54	674.80	617.20	565.61
E	11897	MIV	15.700	24995636	14.77	2922.80	2866.28	2813.17	2761.56	2711.45	2662.83	2442.45	2248.38	2074.70	1919.09
E	11897	MIV	10.653	11718211	14.77	715.35	700.42	686.28	672.53	659.19	646.24	587.54	535.72	489.64	448.39
E	11979	MIV	15.758	25342304	14.55	3002.32	2942.14	2887.56	2834.50	2782.98	2732.99	2506.44	2307.17	2128.92	1969.21
E	11979	MIV	10.608	11622882	14.55	708.75	693.53	679.49	665.84	652.59	639.73	581.45	530.05	484.36	443.46
E	12127	MIV	13.539	8265227	14.14	748.28	731.89	717.80	704.10	690.79	677.87	619.34	567.90	522.04	480.96
E	12127	MIV	10.627	6749344	14.14	416.76	407.33	399.06	391.03	383.22	375.64	341.29	311.07	284.22	260.19
E	12127	MIV	15.508	15461223	14.14	1791.33	1752.79	1720.04	1688.21	1657.27	1627.25	1491.23	1371.83	1265.15	1169.58
E	12201	MIV	10.634	10062637	13.94	625.12	610.65	598.17	586.10	574.38	562.99	511.43	466.10	425.84	389.80
E	12201	MIV	15.075	12083482	13.94	1331.24	1301.71	1276.99	1253.16	1230.00	1207.52	1105.67	1016.35	936.61	865.19
E	12240	MIV	15.486	46555	13.83	5.42	5.30	5.20	5.10	5.01	4.92	4.50	4.14	3.82	3.53
E	12240	MIV	9.033	46716	13.83	2.28	2.23	2.18	2.14	2.09	2.05	1.85	1.68	1.53	1.40
E	12285	MIV	13.674	26878645	13.71	2500.81	2444.12	2395.11	2349.33	2304.83	2261.62	2065.88	1894.27	1741.41	1604.48
E	12285	MIV	15.922	20275908	13.71	2506.63	2450.74	2403.01	2358.61	2315.46	2273.55	2083.71	1917.52	1769.12	1636.19

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
E	12285	MIV	10.747	17301537	13.71	1098.95	1073.34	1050.80	1029.62	1009.03	989.03	898.45	818.92	748.30	685.10
E	12480	MIV	10.580	14539725	13.18	913.70	891.95	871.83	854.13	836.92	820.20	744.39	678.06	619.20	566.57
E	12480	MIV	13.618	17814026	13.18	1668.59	1629.88	1594.40	1563.76	1533.97	1505.02	1373.83	1259.18	1157.17	1065.83
E	12480	MIV	15.336	21695365	13.18	2520.31	2462.51	2409.76	2364.66	2320.80	2278.20	2085.06	1916.47	1766.21	1631.65
E	12565	MIV	15.916	11320298	12.94	1426.65	1393.70	1362.98	1337.42	1312.76	1288.81	1180.16	1085.48	1001.12	925.57
E	12565	MIV	13.505	15160125	12.94	1408.97	1375.95	1345.03	1318.90	1293.67	1269.16	1158.00	1060.99	974.74	897.51
E	12565	MIV	10.647	12303842	12.94	785.43	766.59	748.86	733.56	718.77	704.40	639.22	582.27	531.76	486.59
E	12639	MIV	15.288	14494721	12.74	1692.76	1653.19	1616.23	1584.67	1555.14	1526.45	1396.24	1282.89	1181.99	1091.64
E	12639	MIV	13.380	15883496	12.74	1461.41	1426.87	1394.49	1366.54	1340.30	1314.80	1199.11	1098.27	1008.65	928.44
E	12639	MIV	10.734	15276436	12.74	992.75	968.79	946.24	926.45	907.77	889.62	807.27	735.41	671.68	614.70
E	12852	MIV	12.849	653048	12.16	57.20	55.81	54.51	53.31	52.27	51.26	46.68	42.69	39.16	36.00
E	12852	MIV	10.464	1867496	12.16	118.49	115.57	112.82	110.26	108.02	105.84	95.92	87.30	79.67	72.85
E	13015	MIV	12.677	868927	11.71	75.43	73.57	71.82	70.18	68.75	67.41	61.33	56.06	51.39	47.22
E	13016	MIV	6.470	21982	11.71	0.71	0.69	0.67	0.66	0.64	0.63	0.56	0.51	0.46	0.42
E	13371	MIV	6.698	23416	10.74	0.81	0.79	0.77	0.75	0.73	0.72	0.64	0.58	0.52	0.48
E	13649	MIV	12.393	4553938	9.98	401.03	390.25	380.41	371.12	362.36	354.15	321.25	293.18	268.38	246.28
E	13685	MIV	12.707	2612622	9.88	240.72	233.22	227.33	221.77	216.53	211.62	192.01	175.32	160.58	147.45
E	14065	MIV	4.383	22392	8.84	0.52	0.48	0.46	0.45	0.44	0.43	0.38	0.34	0.31	0.28
E	14355	MIV	13.567	1902037	8.04	227.00	208.36	193.66	188.66	183.94	179.48	161.78	147.67	135.34	124.38
E	14355	MIV	15.273	1912582	8.04	283.22	260.13	241.92	235.70	229.84	224.31	202.63	185.44	170.44	157.08
E	14355	MIV	9.412	5883984	8.04	397.99	364.73	338.50	329.62	321.18	313.16	280.39	253.81	230.59	210.00
E	14356	MIV	10.983	13422869	8.04	1145.32	1050.08	974.87	949.52	925.45	902.67	810.42	736.08	671.09	613.42
E	15204	MIV	5.891	97003403	5.72	4277.74	3867.65	3511.62	3209.67	2961.78	2845.82	2509.02	2249.75	2025.64	1829.12
E	15240	MIV	5.493	117525	5.62	4.80	4.34	3.94	3.59	3.31	3.17	2.79	2.50	2.25	2.03
E	15316	MIV	5.781	19521885	5.41	867.53	783.69	710.48	647.88	595.91	563.97	496.44	444.92	400.42	361.46
E	15399	MIV	0.000	374484	5.19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
E	15444	MIV	4.722	308420	5.06	11.15	10.07	9.12	8.30	7.61	7.07	6.21	5.55	4.98	4.49
E	15451	MIV	6.715	6928841	5.04	389.47	351.46	318.06	289.27	265.08	245.96	216.28	194.08	174.96	158.21
E	15455	MIV	4.900	1494662	5.03	56.56	51.06	46.22	42.05	38.54	35.75	31.39	28.09	25.23	22.74
E	15457	MIV	4.322	290174	5.03	9.55	8.62	7.81	7.10	6.51	6.04	5.30	4.74	4.26	3.83

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
E	15458	MIV	4.229	131914028	5.02	424.25	383.06	346.84	315.58	289.29	268.24	235.52	210.55	188.99	170.17
E	15460	MIV	4.262	14924340	5.02	484.34	437.31	395.94	360.24	330.21	306.09	268.74	240.26	215.66	194.19
E	15461	MIV	1.548	12727531	5.02	141.44	127.83	115.84	105.50	96.79	89.77	78.83	70.27	62.91	56.47
E	9621	NAT	5.464	218710	21.01	4.58	4.49	4.39	4.30	4.21	4.12	3.72	3.36	3.04	2.76
E	10764	NAT	0.000	46747	17.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E	12639	NAT	11.745	23371	12.74	1.75	1.71	1.67	1.64	1.60	1.57	1.43	1.30	1.19	1.10
E	13649	NAT	11.061	374046	9.98	27.48	26.74	26.06	25.41	24.81	24.24	21.93	19.96	18.22	16.67
E	14722	NAT	5.417	70194	7.04	2.44	2.22	2.04	1.89	1.84	1.79	1.59	1.42	1.28	1.16
E	15204	NAT	5.450	350966	5.72	14.05	12.70	11.53	10.54	9.73	9.35	8.24	7.38	6.64	5.99
E	15240	NAT	4.530	374466	5.62	12.21	11.04	10.02	9.15	8.44	8.07	7.10	6.36	5.71	5.14
E	15451	NAT	4.922	1496213	5.04	56.85	51.32	46.46	42.27	38.75	35.96	31.58	28.25	25.38	22.87
E	15457	NAT	1.703	46788	5.03	0.57	0.52	0.47	0.43	0.39	0.36	0.32	0.29	0.26	0.23
E	15458	NAT	3.429	374151	5.02	9.74	8.79	7.96	7.25	6.65	6.17	5.42	4.84	4.34	3.91
E	15460	NAT	2.809	2947297	5.02	61.72	55.75	50.50	45.97	42.16	39.10	34.34	30.66	27.50	24.73
W	9964	MIA	10.689	317853	20.07	19.94	19.54	19.16	18.78	18.41	18.05	16.39	14.91	13.59	12.41
W	9993	MIA	10.118	8448591	19.99	490.53	480.71	471.12	461.75	452.60	443.68	402.34	365.64	332.96	303.76
W	10201	MIA	9.021	14095261	19.42	705.65	691.03	676.95	663.19	649.76	636.65	576.00	522.26	474.46	431.78
W	10259	MIA	10.207	2959754	19.26	176.71	173.10	169.65	166.27	162.98	159.76	144.85	131.62	119.84	109.32
W	10294	MIA	9.631	19118454	19.16	1054.51	1032.70	1011.87	991.51	971.63	952.22	862.40	782.78	711.93	648.64
W	10350	MIA	10.333	15780231	19.01	964.00	944.19	925.38	906.99	889.03	871.49	790.23	718.16	653.98	596.66
W	10385	MIA	10.212	8233858	18.91	495.63	485.42	475.70	466.23	456.97	447.93	406.06	368.92	335.87	306.34
W	10456	MIA	11.072	16539921	18.72	1123.79	1100.90	1079.07	1057.90	1037.20	1016.99	923.30	840.13	766.05	699.88
W	10602	MIA	10.856	14500718	18.32	965.48	945.66	926.60	908.33	890.47	873.02	792.12	720.36	656.47	599.40
W	10679	MIA	11.457	11465965	18.11	830.41	813.49	797.13	781.57	766.35	751.48	682.53	621.33	566.82	518.14
W	10742	MIA	12.412	6643225	17.94	545.27	534.30	523.67	513.58	503.74	494.12	449.51	409.89	374.57	343.02
W	10764	MIA	0.000	16574	17.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W	10770	MIA	12.753	8167463	17.86	699.64	685.64	672.06	659.15	646.58	634.30	577.36	526.78	481.68	441.38
W	10832	MIA	12.518	16740732	17.69	1399.55	1371.39	1344.07	1318.03	1292.78	1268.11	1153.70	1052.10	961.53	880.63
W	10982	MIA	13.239	17205672	17.28	1572.80	1541.38	1510.89	1481.54	1453.44	1425.98	1298.68	1185.68	1084.88	994.84
W	11036	MIA	13.122	7596656	17.13	687.86	674.08	660.70	647.77	635.46	623.43	567.61	518.08	473.91	434.45

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
W	11109	MIA	13.212	15071409	16.93	1383.94	1356.19	1329.26	1303.15	1278.35	1254.15	1141.90	1042.34	953.55	874.23
W	11183	MIA	12.900	10295431	16.73	918.00	899.47	881.48	864.04	847.42	831.29	756.38	689.99	630.79	577.92
W	11372	MIA	13.264	19925907	16.21	1869.04	1831.35	1794.76	1759.26	1725.02	1692.31	1540.28	1405.74	1285.70	1178.53
W	11449	MIA	12.952	19942117	16.00	1816.56	1779.69	1743.89	1709.15	1675.47	1643.53	1494.91	1363.43	1246.18	1141.52
W	11540	MIA	12.815	12460510	15.75	1124.40	1101.49	1079.23	1057.63	1036.69	1016.73	924.43	842.83	770.07	705.13
W	11806	MIA	13.333	19944998	15.02	1934.34	1895.02	1856.80	1819.68	1783.66	1748.76	1590.59	1451.19	1326.74	1215.73
W	11897	MIA	13.838	19665221	14.77	2028.04	1985.86	1946.03	1907.33	1869.76	1833.33	1668.40	1523.37	1393.80	1278.23
W	11979	MIA	13.735	25316563	14.55	2595.80	2540.04	2488.93	2439.26	2391.04	2344.26	2132.57	1946.61	1780.57	1632.47
W	12127	MIA	13.663	15749024	14.14	1618.40	1581.53	1549.57	1518.51	1488.34	1459.07	1326.62	1210.52	1106.95	1014.57
W	12201	MIA	12.753	25068613	13.94	2344.96	2289.91	2242.62	2196.96	2152.61	2109.58	1914.99	1744.28	1592.30	1456.78
W	12285	MIA	12.743	19722250	13.71	1853.67	1809.75	1771.26	1735.13	1700.03	1665.97	1511.90	1376.93	1256.82	1149.71
W	12480	MIA	13.263	19408815	13.18	1957.08	1909.92	1866.48	1828.56	1791.70	1755.91	1593.88	1452.57	1326.84	1214.71
W	12565	MIA	13.189	25194953	12.94	2535.75	2474.11	2416.22	2366.67	2318.82	2272.35	2061.88	1878.58	1715.59	1570.23
W	12639	MIA	12.617	23574213	12.74	2240.73	2185.72	2133.96	2088.68	2046.01	2004.56	1816.83	1653.38	1508.20	1378.77
W	12823	MIA	12.687	7833936	12.24	760.69	741.71	723.82	707.41	692.92	678.84	614.96	559.55	510.38	466.54
W	12852	MIA	12.575	13705471	12.16	1316.41	1283.46	1252.40	1223.67	1198.55	1174.13	1063.35	967.30	882.09	806.13
W	12942	MIA	12.610	20393642	11.91	1980.31	1930.37	1883.25	1838.95	1800.76	1764.02	1597.17	1452.79	1324.76	1210.63
W	13016	MIA	12.820	20602277	11.71	2058.81	2006.60	1957.33	1910.99	1870.40	1832.30	1659.13	1509.53	1376.95	1258.73
W	13371	MIA	12.533	4984956	10.74	495.31	482.39	470.16	458.61	447.75	438.23	396.12	360.01	328.09	299.63
W	13525	MIA	13.022	17551514	10.32	1864.10	1814.99	1768.46	1724.50	1683.12	1645.51	1487.67	1352.84	1233.83	1127.66
W	13648	MIA	7.166	33109	9.98	1.54	1.49	1.45	1.42	1.38	1.35	1.21	1.09	0.98	0.88
W	13650	MIA	12.960	16546691	9.97	1764.54	1715.79	1671.37	1629.36	1589.75	1552.55	1402.73	1275.18	1162.72	1062.38
W	13686	MIA	12.033	17856028	9.88	1717.05	1662.32	1619.07	1578.10	1539.41	1502.99	1355.49	1230.24	1119.70	1021.28
W	13724	MIA	5.919	15506	9.77	0.57	0.55	0.54	0.52	0.51	0.50	0.45	0.40	0.36	0.32
W	13859	MIA	11.914	29593348	9.40	29.05	27.50	26.77	26.09	25.44	24.82	22.35	20.27	18.44	16.81
W	15244	MIA	10.405	352789	5.61	40.44	36.58	33.23	30.37	28.02	26.79	23.64	21.30	19.28	17.50
W	15347	MIA	10.405	144356	5.33	17.03	15.40	13.97	12.74	11.72	11.05	9.74	8.77	7.94	7.20
W	15445	MIA	5.250	1965907	5.06	97.73	88.30	80.00	72.84	66.82	62.10	54.47	48.66	43.66	39.26
W	15448	MIA	10.405	32580	5.05	3.96	3.57	3.24	2.95	2.70	2.51	2.21	1.99	1.80	1.63
W	15451	MIA	5.256	465448	5.04	23.21	20.97	18.99	17.29	15.86	14.73	12.92	11.54	10.35	9.31

Table 1-2. Decay Heat ORIGEN2 Results by Individual Key (W). (6 sheets)

Basin	Key	Type	wt%Pu240	U	DT (yrs)	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
W	15457	MIA	2.818	33277	5.03	0.84	0.76	0.69	0.63	0.58	0.54	0.47	0.42	0.37	0.34
W	15459	MIA	4.032	33920632	5.02	1259.89	1138.44	1031.56	939.27	861.55	799.14	700.65	625.21	560.17	503.10
W	15460	MIA	3.304	2096245	5.02	63.19	57.11	51.76	47.14	43.25	40.12	35.18	31.38	28.10	25.24
W	15555	MIA	10.405	19267	4.76	405.65	2.18	1.97	1.79	1.64	1.51	1.32	1.18	1.07	0.97
W	9964	MIV	6.014	74851	20.07	1.80	1.77	1.73	1.69	1.66	1.62	1.47	1.33	1.20	1.09
W	10001	MIV	9.746	902459	19.96	43.15	42.31	41.50	40.70	39.92	39.16	35.64	32.50	29.70	27.21
W	10764	MIV	0.000	303855	17.88	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
W	11540	MIV	15.733	11563392	15.75	1329.36	1304.73	1280.79	1257.55	1235.00	1213.49	1113.99	1026.00	947.22	876.58
W	12565	MIV	15.925	6833329	12.94	862.18	842.27	823.71	808.26	793.37	778.89	713.24	656.03	605.05	559.40
W	12852	MIV	12.849	66913666	12.16	5860.60	5718.61	5585.11	5462.21	5355.85	5252.44	4782.49	4374.38	4012.25	3688.35
W	12852	MIV	15.856	4188918	12.16	534.97	522.20	510.25	499.34	490.06	481.04	440.04	404.49	372.89	344.60
W	12942	MIV	12.285	52443235	11.91	4318.44	4212.60	4112.89	4019.32	3939.24	3862.22	3511.91	3208.13	2938.79	2698.02
W	13015	MIV	12.677	43798910	11.71	3801.89	3708.30	3620.13	3537.38	3465.43	3398.06	3091.35	2825.83	2590.46	2380.07
W	13017	MIV	11.006	26850174	11.71	1864.28	1817.92	1774.11	1732.88	1696.65	1662.62	1507.68	1373.49	1254.63	1148.50
W	13372	MIV	12.371	19284082	10.74	1656.51	1614.45	1574.67	1537.18	1501.98	1471.39	1336.11	1219.89	1117.05	1025.28
W	13524	MIV	12.546	37578854	10.32	3335.62	3250.00	3168.94	3092.47	3020.56	2955.45	2683.10	2449.90	2243.75	2059.87
W	13858	MIV	11.576	52407413	9.40	4321.35	4091.13	3985.97	3886.32	3792.18	3703.55	3347.57	3048.51	2784.96	2550.52
W	14055	MIV	6.391	326333	8.87	11.84	10.95	10.59	10.31	10.05	9.80	8.76	7.88	7.12	6.44
W	14065	MIV	4.383	120190	8.84	2.78	2.57	2.48	2.42	2.36	2.30	2.05	1.84	1.65	1.49
W	14448	MIV	6.080	14947	7.79	0.56	0.51	0.47	0.46	0.44	0.43	0.38	0.35	0.31	0.28
W	14883	MIV	5.791	23391	6.60	0.92	0.84	0.77	0.71	0.67	0.66	0.58	0.52	0.47	0.42
W	15204	MIV	5.891	15906	5.72	0.70	0.63	0.58	0.53	0.49	0.47	0.41	0.37	0.33	0.30
W	15244	MIV	9.746	7027	5.61	0.64	0.58	0.52	0.48	0.44	0.42	0.37	0.34	0.30	0.28
W	12942	NAT	11.725	373942	11.91	28.56	27.86	27.19	26.57	26.04	25.52	23.18	21.15	19.36	17.75
W	13015	NAT	11.755	373936	11.71	28.83	28.12	27.44	26.81	26.26	25.74	23.37	21.33	19.51	17.89
W	13858	NAT	11.634	373952	9.40	31.08	29.43	28.67	27.96	27.28	26.64	24.08	21.93	20.04	18.36

Uranium (table heading U) has units of grams. The decay time from the key date to January 31, 1992, has table heading DT. The decay heat generation (table headings in years) has units of watts.

1.3 METHOD

Decay heat calculations were performed for irradiated N Reactor and some SPR fuel presently (March 1994) stored in the 105-KE and 105-KW Basins. The calculation of decay heat incorporated:

- Reconstructed SCATS (the Safeguards Control and Accountability Transactions System) irradiated fuel accountability records
- ORIGEN2 calculations using N Reactor MKIV and MKIA cross sections
- Interpolation on ORIGEN2 results in a FORTRAN program
- Output of decay heat, key by key, out to January 31, 2017.

The decay heat calculations began with the reconstructed SCATS database (Schlosser 1990, 1992a, and 1992b), which had been assembled and maintained by Jim Schlosser (Information Resource Management). This fuel inventory database, besides being unclassified, is considered by the author to be the most accurate of irradiated fuel isotopic accountability records. This database is concerned with present actinide isotopics for uranium isotopes, ^{237}Np , and plutonium isotopes. The irradiation exposure is not included because segregated fuel was converted, through counts in a calibrated neutron detector, into plutonium isotopics, and plutonium isotopics are maintained. Comparisons are made, where appropriate, to other decay heat calculations, and reasons for differences are given.

The N Reactor fuel elements have a tube-in-tube geometry. There is an outer fuel cylinder and an inner fuel cylinder, which has a cooling hole down the center. The neutron spectrum is more thermal in the outer element and less thermal in the inner element. The ORIGEN2 calculations used the MKIV inner and outer cross section libraries to mathematically irradiate these elements separately before being summed for the complete MKIV assembly at approximately 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu . The MKIV (0.947 wt% ^{235}U) calculations were used for the MKIVB (0.71 wt% ^{235}U) fuel. Similarly, the MKIA inner and outer cross section libraries were employed to calculate the complete MKIA assembly at approximately 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu . An 85% time operating efficiency was used in ORIGEN2.

ORIGEN2 values for ^{240}Pu , uranium, plutonium, and the total decay heat resulting from activation products, actinides and daughters, and fission products were calculated for decay times from 5 years, by 5 year increments, to 55 years. The ORIGEN2 values were interpolated by decay time and ^{240}Pu wt% to yield the decay heat per metric ton of initial heavy metal. The ORIGEN2 calculated remaining uranium was used to scale the reconstructed SCATS database total uranium for the metric tons of initial heavy metal in each irradiated fuel storage key.

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2.0 DISCUSSION

This section discusses the reconstructed SCATS irradiated fuel inventory, ORIGEN2 calculation, and interpolation on ORIGEN2 results.

2.1 RECONSTRUCTED SCATS DATABASE

The reconstructed SCATS database (Schlosser 1990) contains an inventory of the KE and KW irradiated fuel in mass and isotopic composition. The Advanced Planning organization of the United Nuclear Corporation was located in the 480 classified computing complex and had access to the, then secret, isotopic tables for calculating N Reactor fuel isotopic composition for delivery to the Plutonium-Uranium Extraction (PUREX) Plant. Two isotopic tables were used to calculate fuel composition: isotopic production tables (Schlosser 1992a) and isotopic segregation tables (Schlosser 1992b).

The isotopic production tables used N Reactor measured heat generation to infer exposure and, thus, uranium and plutonium isotopics. These isotopic compositions were referenced to PUREX D-5 mass spectrometer analyses performed by Pacific Northwest Laboratory (PNL) on special dissolver batches with known N Reactor discharged fuel.

The isotopic segregation tables used neutron count rates in the fuel segregation detector in the KE Basin. The fuel segregation program, which counted irradiated fuel elements in an underwater neutron detector, inferred the ^{240}Pu wt% for irradiated uranium (Wittekind 1984). This was done element by element, then later on when the inners and outers were not separated by whole assemblies. The neutron counts were referenced to neutron counts in calibration elements of known ^{240}Pu wt% assay. These standard elements were paired with other N Reactor fuel elements, which were destructively analyzed. The destructive analysis yielded isotopic compositions from about nine different mass spectrometer analyses performed by PNL on sections.

The N Reactor fuel discharges were accounted for separately from previous fuel discharges and called "keys." The keys were originally discharge keys, but with intrabasin and interbasin "heel" transfers, these keys acquired a different identity, that of a basin key based on storage locations. Heel transfers were a convenience to transfer some fuel elements from one discharge key into another discharge key because of basin transfers, canister filling, or some other reason. The basin key could maintain about 90% to 95% of the discharge key identity. The reconstructed SCATS fuel accountability tables were originally discharge key-based and depended on N Reactor production computing results. The goal of the reconstructed SCATS database was accurate isotopic quantity records. Later on, Jim Schlosser made adjustments to match the accountability records for basin keys, which involved some heel transfers from one discharge key to another discharge key. The more accurate decay heat calculation would ignore the heel transfers to correctly calculate the decay time for fuel, which must be somewhere in the irradiated fuel storage basins.

The 100 Area accountability records, such as WHC-IP-0069, Rev. 155 (Blehm 1990), are unclassified records of irradiated fuel stored at KE and KW Basins and include unexposed weights, fuel model, and assigned exposure in megawatt days (MWd). The purpose of the 100 Area accountability records is to maintain piece counts in all the cubicle storage locations, it is not meant to be an accurate isotopic inventory. WHC-IP-0069 has not incorporated the fuel segregation results. The 100 Area accountability records simply distributed one key's total heat generation equally over the neutron detector segregated fuel. Actually, the segregated fuel was sorted by exposure into low and high ^{240}Pu fuel assemblies. The low ^{240}Pu fuel assemblies were sent to PUREX, while the high ^{240}Pu fuel assemblies remain in the KE Basin. This is a major difference between these two accountability records.

The reconstructed SCATS database formed the starting point for the decay heat calculations. This database resides in a QUATTRO PRO spreadsheet with quantities and compositions for each separate basin key. The key date was used to calculate the decay time; this is not accurate, but it is conservative. For example, the key 14355 (or 4355B, 4355C, 4355D, and 4356D) is composed of fuel in canisters believed to contain MKIA spike column MKIV ends taken from a number of older keys, which were then designated as this new basin key 14355. Also, key 09621 contains SPR fuel elements that were discovered at different times and under different conditions and are simply combined together as this basin key.

A comparison was made between the reconstructed SCATS irradiated fuel database and the WHC-IP-0069 (Blehm 1990) accountability records database. This was done by using the key numbers for decay times and ^{240}Pu wt% values to interpolate using the ORIGEN2 calculations for an estimated key discharge exposure. The calculated MWds were then summed up by fuel type and basin for comparison to the 100N accountability records maintained MWds by fuel type and basin. One limitation is that MKIV (0.947 wt% ^{235}U) ORIGEN2 calculations were also used for MKIVB (0.71 wt% ^{235}U) fuel. This comparison is shown in Table 2-1.

The major difference between these two decay heat calculational approaches can be seen to be the higher MWd irradiation exposure assigned to the segregated 0.95 wt% ^{235}U fuel in KE Basin. WHC-IP-0069 is:

$$(1 - (2,290,000.39 \text{ MWd}) / (2,731,210. \text{ MWd})) * 100\% = (1 - 0.838) = 16.2\%$$

lower than the reconstructed SCATS database, which incorporates the segregated fuel isotopics instead of evenly apportioning the MWd heat generation among the low and high ^{240}Pu fuel. This more accurate accommodation of segregated MKIV fuel has the effect of raising the KE calculated decay heat above the 100N accountability records values.

The effect of using MKIV (0.947 wt% ^{235}U) ORIGEN2 calculations for MKIVB (0.71 wt% ^{235}U) fuel is to infer too high a MWd heat generation because more ^{235}U would mathematically be assumed to fission, when in fact they would be absent. This effect can be seen in the KW Basin results in Table 2-1. MKIVB fuel is less than 1% of the basin inventory, and the discrepancy between these two decay heat calculations is less than 0.5%. This 0.5% decay heat discrepancy is not considered significant.

Table 2-1. KE and KW Basins Irradiated Fuel Inventory Comparison
(Reconstructed SCATS Inventory Converted to MWd by
ORIGEN2 Interpolation).

Reconstructed SCATS+ORIGEN2		Accountability (WHC-IP-0069 REV 155)
KE Basin		
0.71 wt%	4,575.09 MWd 14,172.3 lb	7,920.05 MWd 19,308.83 lb
0.95 wt%	2,731,210.0 MWd 2,512,521.0 lb	2,290,000.39 MWd 2,515,049.33 lb
KW Basin		
0.71 wt%	2,899.57 MWd 2,473.21 lb	2,156.73 MWd 2,476.80 lb
0.95 wt%	925,696.0 MWd 713,528.0 lb	806,435.86 MWd 714,888.25 lb
1.25 wt%	1,822,105.0 MWd 1,382,999.0 lb	1,893,009.21 MWd 1,395,010.78 lb

2.2 ORIGEN2 CALCULATIONS

The ORIGEN2 computer code simulated irradiation of MKIV and MKIA fuel. ORIGEN2 input, elemental composition, cladding quantity, impurity content, and operating cycles were taken from ORIGEN2 calculations (Hedegren and Goldberg 1987). Six different exposures, with decay times to 55 years, were calculated to span the KE and KW Basin irradiated fuel population. Different exposures and decay times formed a two-dimensional matrix of decay heat power versus wt% ^{240}Pu and decay time. This ORIGEN2-generated decay heat power matrix formed the basis for the decay heat calculation from the reconstructed SCATS database. The next step would be to interpolate, first according to decay time, and second according to ^{240}Pu wt% composition for exposure to determine the decay heat most closely representing any particular basin key in KE and KW Basin.

There is a small effect on the calculated decay heat, depending on the assumed initial ^{236}U . The initial ^{236}U has an effect because ^{238}Pu has a short (87.7 years) half-life and has a high specific heat generation rate. The ^{236}U is part of the $^{236}\text{U}(n,\beta^-)^{237}\text{Np}(n,\beta^-)^{238}\text{Pu}$ buildup chain. This effect is mitigated somewhat because of the $^{238}\text{U}(n,2n+\beta^-)^{237}\text{Np}(n,\beta^-)^{238}\text{Pu}$ competing buildup chain. N Reactor input ^{236}U slowly increased over the years from 200 parts per million (ppm) to about 400 ppm, where it remained for years (Wittekind and Morey 1985). The initial ^{236}U increased until the time of N Reactor shutdown when the initial ^{236}U was about 560 ppm. The ORIGEN2 input used the representative historical value of 400 ppm for ^{236}U instead of choosing any bounding value. Figure 1-1, showing decay heat by basin out to 2017 AD, also shows that the total of both actinide and activation product decay heat is a

relatively small proportion of the total decay heat. The main contributors to decay heat are the fission products: $^{90}\text{Sr}/^{90}\text{Y}$ and $^{137}\text{Cs}/^{137\text{m}}\text{Ba}$.

As a demonstration of the magnitude of the initial ^{236}U , consider the 16 wt% ^{240}Pu MKIV ORIGEN2 case with its 400 ppm ^{236}U input. At a representative 20 years decay, decay heat by isotopic category and significant isotopic decay heat contributors are listed in Table 2-2.

Table 2-2. ORIGEN2 Decay Heat from Selected Isotopes (MKIV Fuel Irradiated to 16 Wt% ^{240}Pu 400 ppm ^{236}U in Uranium, 20 Years Decay Time).

Isotope category	Decay heat (W/MT)
Activation products total	0.03231
^{238}Pu	3.347
^{239}Pu	4.255
^{240}Pu	3.019
^{241}Am	9.938
^{244}Cm	0.6668
Actinides and daughters total	21.44
^{90}Sr	7.052
^{90}Y	33.68
^{137}Cs	9.047
$^{137\text{m}}\text{Ba}$	30.38
Fission products total	81.69
Decay heat grand total	103.2

The ^{238}Pu contribution is only 3% of the total decay heat. This could be changed to perhaps 4% of the total decay heat by using an input of 550 ppm ^{236}U . The ^{238}Pu decay heat would be less than $(550 \text{ ppm}/400 \text{ ppm}) \times 3\% = 4.125\%$ because of the fixed buildup of ^{238}Pu , which comes from ^{238}U through the $(n,2n+\beta^-)$ reaction. This demonstrates that there is less than 1% effect on calculated decay heat from assumed initial ^{236}U composition.

The isotopic composition/irradiation exposure spread of ORIGEN2 results was chosen to be 3, 6, 9, 12, and 16 wt% ^{240}Pu . This formed the basis for quadratic interpolation. The first interpolation, decay heat as a function of decay time, was, at more than 5 years after reactor discharge, adequately accommodated by quadratic interpolation. At more than 5 years after reactor discharge, the decay heat changes very slowly as a function of decay time. The second interpolation, decay heat versus wt% ^{240}Pu , is described in Figures 2-1, 2-2, and 2-3. Decay heat as a function of irradiation time, is shown in Figure 2-1. The reconstructed SCATS database had plutonium isotopics, but not the irradiation time. The relationship between irradiation time and wt% ^{240}Pu is shown in Figure 2-2. The effect of interpolating ORIGEN2 decay heat by wt% ^{240}Pu , instead of irradiation time, is shown in Figure 2-3.

Figure 2-1. Decay Heat Interpolation by Exposure (MKIV Fuel Calculated for 3, 6, 9, 12, and 16 wt% ^{240}Pu).

Figure 2-2. Weight Percent Plutonium-240 Interpolation by Exposure
(MKIV Fuel Calculated for 3, 6, 9, 12, and 16 wt% ^{240}Pu).

Figure 2-3. Decay Heat Interpolation by Weight Percent Plutonium-240
(MKIV Fuel Calculated for 3, 6, 9, 12, and 16 wt% ^{240}Pu).

2.3 ORIGEN2 TABLE INTERPOLATION

The ORIGEN2 code was executed for a series of decay heat cases with both total irradiation and decay time varied. Both MKIV and MKIA fuel types were exposed, at representative specific powers, to exposures that were typical of 3, 6, 9, 12, and 16 wt% ^{240}Pu in total plutonium. Each of these cases were decayed using 5-year increments from discharge to 55 years.

The ORIGEN2 output files were scanned by shell scripts, with pertinent data sent to other files. Extracted output included decay heat (in watts per metric ton of initial heavy metal), for (1) activation products plus actinides and (2) activation products, actinides, plus fission products. Extracted output also included plutonium, ^{240}Pu , and remaining uranium. The extracted data were collected in a compact table shown in Table 2-3. Decay heat information for zero exposure was inserted into this compact table to interpolate, not extrapolate, the lowest exposure desired information.

Reconstructed SCATS data, obtained in the form of a QUATTRO PRO spreadsheet, contained isotopic production information for each fuel key. This data allowed for the calculation of decay time (from discharge key-date to January 31, 1992). This spreadsheet also contained uranium and plutonium isotopics for individual keys, including the ^{240}Pu wt% and total uranium, which were used for interpolation.

A FORTRAN routine, TERP (Appendixes C and D), was written by Kevin Schwinkendorf to combine the information from ORIGEN2 and reconstructed SCATS, add the decay heat from all keys, and to project the decay heat into the future. The TERP routine, listing in Appendix C, validation in Appendix D, performs a series of three-point Lagrangian polynomial interpolations to extract decay heat for each key as a function of decay time and ^{240}Pu wt% indicated fuel exposure from the ORIGEN2 tabulated results.

The first step was to take the decay time for each key, t_k , and go into the ORIGEN2 tables and interpolate ^{240}Pu , decay heat, and remaining uranium for each of the six ^{240}Pu exposures (including zero exposure). This reduced the two-dimensional tabulated ORIGEN2 results, say $H_b(\underline{t}, \underline{P})$, where both decay time and ^{240}Pu exposure are vectors, into one dimensional interpolated ORIGEN2 results, say $H_b(t_k, \underline{P})$, a function of ^{240}Pu only. The ^{240}Pu is a weak function of decay time, because of the changing isotopic distributions as ^{241}Pu ($t_{1/2}$ equal to 14.40 years) decays into ^{241}Am . These interpolation formulae take the form:

$$H_b(t_k + \Delta t_m, \underline{P}_n) = \sum_{i=i_0}^{i_0+2} H_b(\underline{t}_i, \underline{P}_n) \prod_{\substack{j=i_0 \\ i \neq j}}^{i_0+2} \frac{(t_k + \Delta t_m - t_j)}{(t_i - t_j)}$$

$$U(t_k, \underline{P}_n) = \sum_{i=i_0}^{i_0+2} U(\underline{t}_i, \underline{P}_n) \prod_{\substack{j=i_0 \\ i \neq j}}^{i_0+2} \frac{(t_k - t_j)}{(t_i - t_j)}$$

$$P(t_k, \underline{P}_n) = \sum_{i=i_0}^{i_0+2} P(\underline{t}_i, \underline{P}_n) \prod_{\substack{j=i_0 \\ i \neq j}}^{i_0+2} \frac{(t_k - t_j)}{(t_i - t_j)}$$

Table 2-3. ORIGEN2 Output Arranged For Interpolation Program Input.

[illegible]

The Δt_m term for the decay heat interpolation represents extension of decay heat into the future. The Δt_m extend from 0 to 5 years in 1-year increments, followed by 5-year increments out to 25 years. These interpolations were performed using a quadratic interpolating polynomial, where, for any particular decay time, t_k :

$$t_{i_0} \leq t_k < t_{i_0+1}$$

That is, one table point at or below and two points above t_k were always selected to perform the quadratic interpolation.

The interpolated values for decay heat, ^{240}Pu , and remaining uranium are used as interpolation base points in the exposure domain. The wt% ^{240}Pu for key k (i.e., $P_k = \text{wt\% } ^{240}\text{Pu}_k$) is used to find the decay heat and remaining uranium for that key:

$$H_b(t_k + \Delta t_m, P_k) = \sum_{i=i_0}^{i_0+2} H_b(t_k + \Delta t_m, P_i) \prod_{\substack{j=i_0 \\ i \neq j}}^{i_0+2} \frac{(P_k - P_j)}{(P_i - P_j)}$$

$$U(t_k, P_k) = \sum_{i=i_0}^{i_0+2} U(t_k, P_i) \prod_{\substack{j=i_0 \\ i \neq j}}^{i_0+2} \frac{(P_k - P_j)}{(P_i - P_j)}$$

These results normalize decay heat for that key:

$$\text{Decay Heat}(t_k + \Delta t_m, P_k) = H_b(t_k + \Delta t_m, P_k) \times (\text{Total Uranium})_k / U(t_k, P_k)$$

The total decay heat for a particular grouping of fuel (i.e., for a basin or fuel type, etc.) is obtained by summing over k . This leaves integral decay heat as a function of decay time from January 31, 1992. All decay times in Δt_m were calculated from this time because that time is where the reconstructed SCATS database had calculated isotopic compositions.

Table 2-3 lists the input file ORIG_OUT for total decay heat (activation and fission products, plus actinides). The units, except for the first and second lines, which are nominal wt% ^{240}Pu and decay time (years) respectively, are ORIGEN2 output units for one metric ton. ORIG_OUT has these first two lines for internal code accounting.

The ORIGEN2 output portion of ORIG_OUT is first MKIV:

1. Decay heat in watts per metric ton (6 lines)
2. ^{240}Pu isotope in grams per metric ton (6 lines)

3. Plutonium element in grams per metric ton (6 lines)
4. Uranium element in grams per metric ton (6 lines).

This series repeats for MKIA. The six lines cover six fuel exposures: 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu . The first column is discharge or day of last irradiation, then decay time is in 5-year increment to 55 years decay.

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3.0 COMPARISON WITH ORIGEN-S

ORIGEN2 had N Reactor cross section libraries generated by WIMS-D (Roth 1967). Isotopes and cross sections absent in WIMS-D defaulted to an ORIGEN2 cross section library for a PWR (pressurized water reactor) (^{235}U enriched UO_2 : 33,000 MWd/MT). ORIGEN2 required (n,2n) and (n,3n) cross sections not present in WIMS-D, so these defaulted to PWR cross section library values, even though the isotope was present in WIMS-D. In the case of the $^{238}\text{U}(n,2n)^{237}\text{U}$ reaction, the PWR value may be high by 55% because of the harder PWR neutron spectrum. For activation products and fission products, ORIGEN2 has (n, α) and (n,p) cross sections, which are not present in WIMS-D.

ORIGEN-S is the ORIGEN2 equivalent module that is part of the SCALE (a modular code system for performing Standardized Computer Analyses for Licensing Evaluation) system. The advantage of ORIGEN-S is that the ORIGEN-S cross section libraries can be generated directly from lattice codes through BONAMI-NITAWL-XSDRNPM-(FIXZA)-COUPLE-ORIGEN-S. This carries cross sections for all isotopes whether they are actinides or fission products or activation products. The approximately 50-line FIXZA routine simply makes it possible to have the same isotope in two different regions, such as uranium in an inner fuel element and in the outer fuel element, and to have COUPLE prepare these for the ORIGEN-S library correctly. This approach calculates all cross sections present in ORIGEN-S and all isotopes used in ORIGEN-S, according to the basic lattice description in NITAWL and XSDRNPM.

The comparison of decay heat calculations between ORIGEN2 and ORIGEN-S is basically a comparison of the production of ^{90}Sr , ^{90}Y , ^{137}Cs , and $^{137\text{m}}\text{Ba}$, which together, for MKIV fuel at 20 years decay time, account for $(7.052 + 33.68 + 9.047 + 30.38 \text{ Watts/MT})/103.6 \text{ Watts/MT} = 0.7737$ of the total decay heat generation. An additional feature of this calculation is that not one of these four isotopes were in the WIMS-E cross section library, which is an update to the WIMS-D cross section library.

An ORIGEN-S calculation for the KE Basin, 1,150 MT of uranium, referenced to January 31, 1992, calculated the KE Basin totals, which are shown in Table 3-1.

Table 3-1. ORIGEN-S Calculated KE Basin Isotope Totals.

Isotope	Curies	Grams
^{90}Sr	4.76 E+06	3.49 E+04
^{90}Y	4.76 E+06	8.75 E+00
^{137}Cs	5.99 E+06	6.92 E+04
$^{137\text{m}}\text{Ba}$	5.66 E+06	1.05 E-02

ORIGEN2 for 1 MT (2,752.0625 MWd/MT, 10 years decay) results are in Table 3-2. The average basin decay time depends on some average, which could be as low as 13 years or as long as 14.7 years.

Table 3-2. ORIGEN2 Inferred KE Basin Isotope Totals (MKIV Fuel Irradiated to 12 Wt% ^{240}Pu , Decayed 10 Years 1 MT Scaled to KE Basin Total, Decayed Average Decay Times).

ORIGEN2 Isotope	2,752. MWds (Ci)	2,731,210 MWds (Ci)	Decayed to		
			13 yr	13.6 yr	14.7 yr
^{90}Sr	5.519 E+03	5.477 E+06	5.096 E+06	5.023 E+06	4.892 E+06
^{90}Y	5.520 E+03	5.478 E+06	5.096 E+06	5.023 E+06	4.892 E+06
^{137}Cs	7.014 E+03	6.961 E+06	6.497 E+06	6.408 E+06	6.249 E+06
$^{137\text{m}}\text{Ba}$	6.636 E+03	6.586 E+06	6.147 E+06	6.063 E+06	5.912 E+06

The 13-year decay time resulted from simply adding up all the key dates in KE Basin and taking the average. This is the least reasonable average basin decay time. The 13.6-year decay time was weighted according to uranium mass in the key, but does not account for fuel exposure. The 14.7-year decay time is the plutonium mass weighted key date, which does factor in the key quantity and the key exposure and is believed to be a reasonable average decay time, although the ^{137}Cs quantity, because of the decaying exponential form of radioactive decay, would weight the exposure toward a more recent decay time. The difference between these curie quantities converted into decay heat, using Tables 2-2, 3-1, and 3-2, can be calculated as follows:

13.6-year decay time (uranium mass weighted average key date) assumed

$((4.76\text{E}+6/5.023\text{E}+6)*7.052)+((4.76\text{E}+6/5.023\text{E}+6)*33.68)+$
 $((5.99\text{E}+6/6.408\text{E}+6)*9.047)+((5.66\text{E}+6/6.063\text{E}+6)*30.38)=75.417 \text{ kW}$
 instead of 80.159 kW for a difference of 4.742 or $(4.742/80.159*100\%)=5.92\%$.

14.7-year decay time (plutonium mass weighted average key date) assumed

$((4.76\text{E}+6/4.892\text{E}+6)*7.052)+((4.76\text{E}+6/4.892\text{E}+6)*33.68)+$
 $((5.99\text{E}+6/6.249\text{E}+6)*9.047)+((5.66\text{E}+6/5.912\text{E}+6)*30.38)=77.390 \text{ kW}$
 instead of 80.159 kW for a difference of 2.769 or $(2.769/80.159*100\%)=3.45\%$.

These results indicate that for a softer N Reactor neutron spectrum, which is believed to be more accurately calculated in the SCALE suite of codes culminating in ORIGEN-S, the decay heat calculated result would be between 3.5% and 6% lower than the ORIGEN2 result. The ORIGEN2 N Reactor library did not change the fission product yield, some cross sections such as (n,2n), and left many isotope cross sections the same as the harder PWR-U neutron spectrum in ORIGEN2. This difference is considered to be good agreement.

4.0 COMPARISON WITH ANSI/ANS-5.1

Decay heat power in light water reactors is an American Nuclear Society (ANS) standard that was derived from least squares fits to experimental results, which have been demonstrated to have the same result as using the well known code, ORIGEN. This standard (ANS-5.1-1979) has stated uncertainty according to fissionable isotopes separately of:

²³⁵ U	≈ 2 % from Tables 1-1 and 2-2 ($1.5 \text{ E}+5 \text{ s} \leq t_s \leq 1.0 \text{ E}+9 \text{ s}$),
²³⁹ Pu	≈ 5 % from Tables 1-2 and 2-3 ($1.0 \text{ E}+5 \text{ s} \leq t_s \leq 1.0 \text{ E}+9 \text{ s}$),
²³⁸ U	≤ 5 % from Tables 2-1 and 3-1 ($1.5 \text{ E}+5 \text{ s} \leq t_s \leq 1.0 \text{ E}+9 \text{ s}$),

where t_s is the time after reactor shutdown (irradiated fuel discharge).

In addition, there are some uncertainties, such as ΔQ_i , the uncertainty in the heat of fission for each fissionable isotope, which is estimated at ≈ 1 to 1.5%, and ΔP , the uncertainty in the measured power level, that could also be ≈ 3 to 4%. An accurate propagation of uncertainty is not intended, but could reasonably be estimated in the 7% to 9% range.

Dickens et al. (1991) in their description of this same standard stated: "This present standard does not apply to cooling periods $>10^9$ seconds (≈ 30 years)." The present decay heat calculation, using ORIGEN2, is applied to 7 years to 50 years after last irradiation, and falls in the range, or well into the range in which it is stated that ANS-5.1 does not apply.

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5.0 COMPARISON WITH WHC-SD-NR-ANAL-002

The comparison to WHC-SD-NR-ANAL-002 (Conn 1990) will be made in two stages: first the final total basin results at different future times, and second, the individual MKIV and MKIA decay heat per metric ton of fuel.

5.1 FULL BASIN DECAY HEAT COMPARISON

The full basin decay heat comparison is shown in Table 5-1.

Table 5-1. ORIGEN2 Decay Heat Compared to WHC-SD-NR-ANAL-002
(Tabulated Different Dates Available From Each Study).

Date	HAP0 day	This study (kW)	WHC-SD-NR-ANAL-002 (kW)
KE Basin			
01/01/91	17629	81.37*	67.346
01/31/92	18024	78.67	62.1 (from graph)
07/01/92	18176	77.70*	60.963
01/31/93	18390	76.40	--
01/31/94	18755	74.36	--
01/01/95	19090	72.70*	55.753
01/31/95	19120	72.56	55.6 (from graph)
01/31/96	19485	70.89	--
01/31/97	19851	69.44	52.4 (from graph)
07/01/97	20002	68.86*	51.813
01/01/00	20916	65.64*	47.860
01/31/02	21677	63.31	--
01/31/07	23503	57.98	--
01/31/12	25329	53.24	--
01/31/17	27156	49.00	--
KW Basin			
07/01/92	17629	83.32*	83.474
01/31/92	18024	79.89	80.3 (from graph)
07/01/92	18176	78.77*	79.233
01/31/93	18390	77.39	--
01/31/94	18755	75.55	--
01/01/95	19090	73.97*	73.970
01/31/95	19120	73.83	73.8 (from graph)
01/31/96	19485	72.24	--
01/31/97	19851	70.73	69.8 (from graph)
07/01/97	20002	70.13*	68.976
01/01/00	20916	66.72*	64.037
01/31/02	21677	64.21	--
01/31/07	23503	58.54	--
01/31/12	25329	53.50	--
01/31/17	27156	49.01	--

*Quadratic interpolation from closest reconstructed
SCATS-ORIGEN2-TERP calculated decay heat.

Basically, within the range of applicability of WHC-SD-NR-ANAL-002 (Conn 1990), the KW Basin results between this study and WHC-SD-NR-ANAL-002 have a maximum difference of:

$$(1 - (64.037 \text{ kW}/66.72 \text{ kW})) * 100\% = (1 - 0.95979) * 100\% = 4.0\%.$$

Comparing this study and WHC-SD-NR-ANAL-002 for KE Basin infers that WHC-SD-NR-ANAL-002 results are too low (at 1/1/95) by:

$$(1 - (55.753 \text{ kW}/72.70 \text{ kW})) * 100\% = (1 - 0.76689) * 100\% = 23.3\%.$$

One limitation of the WHC-SD-NR-ANAL-002 study is that accountability records have incorrectly uniformly distributed irradiation exposure evenly over all segregated fuel. This causes WHC-SD-NR-ANAL-002 to underpredict the KE Basin decay heat compared to this study, which apportions exposure according to isotopics calculated from neutron detector counts. The amount too low is:

$$(1 - (2,290,000.39 \text{ MWd}) / (2,731,210. \text{ MWd})) * 100\% = (1 - 0.838) = 16.2\%$$

The factor by which this study calculated the total radiation exposure accounts for $(16.2\%/23.3\%) = 0.695$, about seven tenths of the difference between results of this study and WHC-SD-NR-ANAL-002 for KE Basin. There was no fuel segregation program in the KW Basin, so this does not bias WHC-SD-NR-ANAL-002 KW Basin decay heat calculations.

Another limitation of the WHC-SD-NR-ANAL-002 study is the least squares fits for decay heat, which were advertised as appropriate for 1,000 to 3,500 days decay or 3,500 to 8,000 days decay. The oldest keys have already decayed almost 20 years to get to January 31, 1992, as listed in Table 1-2. The ultimate disposition of this irradiated fuel is not known at present (May 1994), and longer decay times, such as out to 2017, are realistic to consider.

5.2 MKIV AND MKIA DECAY HEAT PER METRIC TON COMPARISON

Figures 5-1 (MKIV) and 5-2 (MKIA) show decay heat as a function of total decay time for six different fuel exposures. After 10 years decay time, radiological decay heat changes slowly. Figure 5-3 shows MKIV decay heat in a three-dimensional plot as a function of both decay time and wt% ^{240}Pu .

Table 5-2 shows the coefficients and power levels used from the WHC-SD-NR-ANAL-002 (Conn 1990) computer fit for MKIV and MKIA. The fuel power level factors into the equation two ways, one as the operating power, the other as the number of days at this power level to achieve the MWd/MT used in ORIGEN2 calculations. Table 5-2 is necessary to detail the computer fit calculation from WHC-SD-NR-ANAL-002. Table 5-3 shows the results of this WHC-SD-NR-ANAL-002 computer fit compared directly with ORIGEN2 calculations at the same total heat generation and the same total decay times.

Figure 5-1. ORIGEN2 MKIV Decay Heat by Time (MKIV Fuel for 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu).

Figure 5-2. ORIGEN2 MKIA Decay Heat by Time (MKIA Fuel for 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu).

Figure 5-3. ORIGEN2 MKIV Decay Heat by Time, Weight Percent Plutonium-240 (MKIV Fuel for 0, 3, 6, 9, 12, and 16 wt% ^{240}Pu).

Table 5-2. WHC-SD-NR-ANAL-002 Computer Fitted Coefficients.

PDECAY=(PD/PO)*(OP POWER) (PD/OP) = DH = A + B*TD + C*TD ² + D*TD ³ + E*TD ⁴ Where TD = Time of Decay (Days since Discharge), TIR = Time in Reactor (Days) e.g.: A = -1.49E-6 +5.46E-7*TIR +8.86E-10*TIR ² -9.71E-12*TIR ³ +1.72E-14*TIR ⁴					
TIR ⁰	TIR ¹	TIR ²	TIR ³	TIR ⁴	Designator
1,000 to 3,500 days					
-1.495924e-06	5.465728e-07	8.859639e-10	-9.705579e-12	1.715302e-14	A
5.290197e-09	-8.341637e-10	-4.572349e-13	1.231059e-14	-2.405726e-17	B
-4.298306e-12	4.973782e-13	1.607978e-17	-6.828378e-18	1.422228e-20	C
1.301705e-15	-1.278131e-16	3.086212e-22	1.919792e-21	-4.043835e-24	D
-1.336619e-19	1.189909e-20	3.893399e-24	-2.163752e-25	4.452773e-28	E
3,500 to 8,000 days					
7.124530e-07	-6.076498e-10	8.115292e-10	-4.244873e-12	6.251870e-15	A
-3.268461e-10	1.638697e-11	-3.971908e-13	2.055575e-15	-3.018281e-18	B
5.017138e-14	-2.901091e-15	6.239853e-17	-3.210796e-19	4.695990e-22	C
-2.387156e-18	1.444433e-19	-3.088867e-21	1.584396e-23	-2.309935e-26	D

MKIV fuel (MWd/MT)	MKIA fuel (MWd/MT)	Power (MW/MT)	MKIV (days in reactor)	MKIA (days in reactor)
550.4125	660.0935	10.689079379 for MKIV	51.49298	54.89245
1100.825	320.187		102.986	109.7849
1833.97445	2199.431542	12.025214301 for MKIA	171.5746	182.9017
2752.0625	3300.4675		257.4649	274.4623
3991.59145	4786.998062		373.4271	398.0801

NOTES:

MKIV Power was modeled as 4 MW/tube of 825 lb.

MKIA Power was modeled as 3 MW/tube of 550 lb.

From the ORIGEN2 calculated MWd/MT and the WHC-SD-NR-ANAL-002-assumed power levels, the time in reactor to match the ORIGEN2 exposure exactly is calculated for comparison.

Table 5-3. MKIV and MKIA Decay Heat by ORIGEN2, WHC-SD-NR-ANAL-002
(WHC-SD-NR-ANAL-002 Computer fit: 1,000 to 3,500 days and 3,500 to 8,000 days).

Fuel Irradiation at comparable 3 wt%, 6 wt%, 9 wt%, 12 wt%, and 16 wt% ²⁴⁰ Pu Compositions Decay Times from 5 years to 55 years Inclusive												
Composition (wt%)		5 yr	10 yr	15 yr	20 yr	25 yr	30 yr	35 yr	40 yr	45 yr	50 yr	55 yr
MKIV decay heat (kW) by WHC-SD-NR-ANAL-002												
3	²⁴⁰ Pu	25.94	16.82	14.59	12.86	--	--	--	--	--	--	--
6	²⁴⁰ Pu	52.27	33.51	28.72	25.62	--	--	--	--	--	--	--
9	²⁴⁰ Pu	86.51	54.79	47.22	42.10	--	--	--	--	--	--	--
12	²⁴⁰ Pu	123.90	78.88	69.66	60.87	--	--	--	--	--	--	--
16	²⁴⁰ Pu	176.35	112.58	98.42	86.09	--	--	--	--	--	--	--
MKIV decay heat (kW) by ORIGEN2												
3	²⁴⁰ Pu	26.79	16.93	14.87	13.29	11.93	10.74	9.69	8.75	7.92	7.18	6.53
6	²⁴⁰ Pu	53.51	33.70	29.62	26.57	23.94	21.64	19.59	17.77	16.16	14.72	13.44
9	²⁴⁰ Pu	89.62	56.40	49.71	44.82	40.64	36.95	33.67	30.74	28.14	25.81	23.73
12	²⁴⁰ Pu	135.50	85.65	75.71	68.66	62.64	57.32	52.58	48.33	44.53	41.12	38.07
16	²⁴⁰ Pu	200.90	127.80	113.20	103.20	94.66	87.13	80.39	74.35	68.92	64.03	59.65
MKIA decay heat (kW) by WHC-SD-NR-ANAL-002												
3	²⁴⁰ Pu	31.08	20.16	17.47	15.41	--	--	--	--	--	--	--
6	²⁴⁰ Pu	62.75	40.16	34.39	30.71	--	--	--	--	--	--	--
9	²⁴⁰ Pu	103.27	65.38	56.51	50.29	--	--	--	--	--	--	--
12	²⁴⁰ Pu	147.17	93.89	83.24	72.46	--	--	--	--	--	--	--
16	²⁴⁰ Pu	215.60	136.73	117.35	104.04	--	--	--	--	--	--	--
MKIA decay heat (kW) by ORIGEN2												
3	²⁴⁰ Pu	31.88	20.21	17.72	15.81	14.16	12.72	11.44	10.31	9.30	8.41	7.61
6	²⁴⁰ Pu	63.67	40.26	35.32	31.60	28.41	25.59	23.10	20.89	18.93	17.18	15.67
9	²⁴⁰ Pu	106.40	67.31	59.15	53.15	48.02	43.50	39.49	35.92	32.73	29.89	27.36
12	²⁴⁰ Pu	160.60	101.90	89.75	81.05	73.64	67.10	61.27	56.07	51.42	47.26	43.54
16	²⁴⁰ Pu	236.50	150.90	133.10	120.80	110.30	101.10	92.84	85.47	78.86	72.23	67.61

The MKIA computer fit ranges from 7 to 10% below the ORIGEN2 calculation for decay heat within its region of applicability for 12 wt% ^{240}Pu . The MKIV computer fit ranges from 8 to 12% below the ORIGEN2 calculation for decay heat within its region of applicability for 12 wt% ^{240}Pu . This variation in the decay heat per ton of MKIV accounts for a smaller part of the discrepancy between the calculations in this study and the WHC-SD-NR-ANAL-002 (Conn 1990) decay heat calculations for KE Basin.

6.0 CONCLUSIONS

The radiological decay heat for irradiated fuel in KE and KW Basins was calculated out to 2017 AD. The decay heat calculation used the reconstructed SCATS nuclear material inventory database, standard ORIGEN2 models for N Reactor irradiation and decay, and combined these two sources by using the FORTRAN routine, TERP, to perform quadratic interpolation on ORIGEN2 data.

The reconstructed SCATS database was used because of its accuracy in calculating the plutonium isotopes in KE Basin where a fuel segregation program performed neutron counts for a ^{240}Pu assay on elements and assemblies.

There are four sources of heat inflow into the K Area fuel storage basins: (1) radiological decay heat from irradiated fuel, (2) mechanical heat from operating machinery, such as pumps, (3) heat flow from surroundings, mainly the ground through the concrete walls, into the basin water if it is maintained at lower than ambient temperature, and (4) exothermic chemical reactions of uranium oxidation, although at basin temperatures this reaction rate is slow.

Table 6-1. Decay Heat ORIGEN2 Results by Basin
Reference Date is January 31 of Given Year (kW).

Area	1992	1993	1994	1995	1996	1997	2002	2007	2012	2017
KE Basin	78.7	76.4	74.4	72.6	70.9	69.4	63.3	58.0	53.2	49.0
KW Basin	79.9	77.4	75.6	73.8	72.2	70.7	64.2	58.5	53.5	49.0
Combined	158.6	153.8	149.9	146.4	143.1	140.2	127.5	116.5	106.7	98.0

Mechanical heat generation in both KE and KW Basins has been estimated as: recirculation pump work of 17 kW and skimmer pump work of 15 kW, for a total of 32 kW.

Comparisons were not made with ANSI/ANS-5.1, but uncertainties of one standard deviation were estimated to be in the 7% to 9% range where the decay time overlaps the decay time considered in this study.

Comparisons made with ORIGEN-S showed that ORIGEN-S decay heat calculations may be about 4% lower than these ORIGEN2 decay heat results.

Comparisons with decay heat calculations performed in WHC-SD-NR-ANAL-002 (Conn 1990) for KW Basin showed a maximum difference of 4%. Comparisons with decay heat calculations performed in WHC-SD-NR-ANAL-002 for KE Basin showed a difference of 20 to 25%, mostly as a result of reconstructed SCATS database as compared to WHC-IP-0069 (Blehm 1990) accountability records.

Decay heat calculations were made out to 2017 A.D., compared to other sources, and shown to be consistent or reasons for discrepancy given.

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APPENDIX A

REVIEWER'S INFORMAL COMMENTS

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REVIEWER'S INFORMAL COMMENTS
(By K. Conn)

INFORMAL COMMENTS ON WHC-SD-NR-ANAL-014

1. The analysis results in essentially equal heat loads for the two basins. During the past winter the recirculation pump and chiller were shut down at both basins for about 1 1/2 months. During this time the basin heatups to steady state and drawdown rates were essentially identical. This tends to confirm that the heat loads at the two basins are about the same, rather than different as calculated in Conn (1990).
2. The primary difference in the results of this analysis and Conn (1990) is the result of the difference in the "Reconstructed SCATS+ORIGEN2" Mwd data and the Mwd data from the Accountability records. Conn (1990) was based on the latter.

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APPENDIX B

TYPICAL ORIGEN2 INPUT

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ORIGEN2 INPUT FOR MKIA 16 WT% PLUTONIUM-240

```

-1
-1
-1
TIT      N-REACTOR Composite (Inner+Outer) MK1A: (12 PERCENT PU 240)
LIB      0 0 0
LIB      0 1 2 3 441 442 443 9 3 0 1 44
RDA      1 METRIC TON U(1.25 PCT ENRICHED) FOR MK 1A OUTER FUEL
INP      -1 1 -1 -1 1 1
RDA      1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV FUEL
INP      -2 1 -1 -1 1 1
RDA      1 METRIC TON U(1.15 PCT ENRICHED) FOR MK 1A AVE. FUEL
INP      -3 1 -1 -1 1 1
RDA      TRACE IMPURITIES IN A METRIC TON OF URANIUM
INP      -4 1 -1 -1 1 1
RDA      1 METRIC TON ZIRCALOY
INP      -5 1 -1 -1 1 1
RDA
BAS      ONE METRIC TON OF URANIUM, MARK 1A FUEL
RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK 1A (OUTER) FUEL
MOV      -1 1 0 1.0      URANIUM VECTOR
RDA      ADD TRACE IMPURITIES IN URANIUM
ADD      -4 1 0 1.0
RDA      ADD 171.3 LB ZIRCALOY / SHORT TON URANIUM
ADD      -5 1 0 0.08565      FRACTION BY WEIGHT
RDA
RDA      NOTE: BURNUP IS MWd/SHORT TON; FUEL WEIGHT IS METRIC TON
RDA      IRRADIATE MK 1A FOR 3000MWd/TON (85 PCT CAPACITY FACTOR)
RDA
RDA      IRRADIATE MK 1A OUTER.
BUP
IRP      125.0      15.07      1 2 4 2      BURN FOR 125.0 DAYS
DEC      169.0      2 3 4 0      DECAY FOR 44.0 DAYS
IRP      294.0      15.07      3 4 4 0      BURN FOR 125.0 DAYS
BUP
MOV      4 -7 0 1.0      SAVE RESULTS.
MOV      1 -8 0 1.0      SAVE INITIAL VECTOR.
RDA
STP      2
2 922350 0.01250E+6 922380 0.98702E+6 0 0.0
2 922340 0.00008E+6 922360 0.00040E+6 0 0.0
0
2 922350 0.00947E+6 922380 0.99005E+6 0 0.0
2 922340 0.00008E+6 922360 0.00040E+6 0 0.0
0
2 922350 0.01150E+6 922380 0.98802E+6 0 0.0
2 922340 0.00008E+6 922360 0.00040E+6 0 0.0
0
4 400000 65. 290000 75. 480000 0.25 40000 10. IMPURITIES IN
4 130000 800. 10000 2. 140000 125. 280000 100. 1 METRIC TON
4 250000 25. 120000 25. 260000 350. 240000 65. OF
4 50000 2.25 70000 75. 60000 550. 0 0.0 URANIUM
0
4 130000 75. 500000 1.45E+4 260000 1350. 240000 1000. ZIRCALOY
4 280000 550. 60000 275. 920000 2.5 400000 0.9814E+6 ZIRCALOY
4 50000 0.5 480000 0.5 270000 10. 290000 50. ZIRCALOY
4 720000 200. 10000 25. 820000 100. 120000 20. ZIRCALOY
4 250000 50. 420000 50. 70000 80. 140000 100. ZIRCALOY
4 110000 20. 220000 50. 740000 50. 230000 50. ZIRCALOY
0
RDA
LIB      0 1 2 3 431 432 433 9 3 0 1 43
RDA
RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK 1A (INNER) FUEL
MOV      -2 1 0 1.0      URANIUM VECTOR
RDA      ADD TRACE IMPURITIES IN URANIUM
ADD      -4 1 0 1.0
RDA      ADD 171.3 LB ZIRCALOY / SHORT TON URANIUM
ADD      -5 1 0 0.08565      FRACTION BY WEIGHT
RDA      IRRADIATE MK 1A INNER.
BUP
IRP      125.0      9.46      1 2 4 2      BURN FOR 125.0 DAYS

```

WHC-SD-NR-ANAL-014 REV 0

```

DEC      169.0      2 3 4 0      DECAY FOR 44.0 DAYS
IRP      294.0      3 4 4 0      BURN FOR 125.0 DAYS
BUP
RDA      COMBINE FOR COMPOSITE
RDA      VECTOR
RDA      4      INNER FINAL
RDA      -7     OUTER FINAL
RDA
MOV      4 2 0 0.333
ADD      -7 2 0 0.667
MOV      2 1 0 1.000
RDA
DEC      5.0      1 2 5 1
DEC      10.0     2 3 5 0
DEC      15.0     3 4 5 0
DEC      20.0     4 5 5 0
DEC      25.0     5 6 5 0
DEC      30.0     6 7 5 0
DEC      35.0     7 8 5 0
DEC      40.0     8 9 5 0
DEC      45.0     9 10 5 0
DEC      50.0     10 11 5 0
DEC      55.0     11 12 5 0
CUT      5 1.E-05 7 1.E-05 9 1.E-05 10 1.E-05 27 1.0 -1
HED      1 DISCHARGE
OPTA     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTL     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT      12 1 -1 0
RDA
STP      4
END

```

ORIGEN2 INPUT FOR MKIV 6 WT% PLUTONIUM-240

```

-1
-1
-1
TIT      N-REACTOR Composite (Inner+Outer) MKIV: ( 6 PERCENT  PU 240)
LIP      0 0 0
LIB      0 1 2 3 421 422 423 9 3 0 1 42
RDA      1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV OUTER FUEL
INP      -1 1 -1 -1 1 1
RDA      1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV FUEL
INP      -2 1 -1 -1 1 1
RDA      1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV AVE. FUEL
INP      -3 1 -1 -1 1 1
RDA      TRACE IMPURITIES IN A METRIC TON OF URANIUM
INP      -4 1 -1 -1 1 1
RDA      1 METRIC TON ZIRCALOY
INP      -5 1 -1 -1 1 1
RDA
BAS      ONE METRIC TON OF URANIUM, MARK IV FUEL
RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK IV (OUTER) FUEL
MOV      -1 1 0 1.0      URANIUM VECTOR
RDA      ADD TRACE IMPURITIES IN URANIUM
ADD      -4 1 0 1.0
RDA      ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
ADD      -5 1 0 0.07035  FRACTION BY WEIGHT
RDA
RDA      NOTE: BURNUP IS MWd/SHORT TON; FUEL WEIGHT IS METRIC TON
RDA      IRRADIATE MK IV FOR 3000MWd/TON (85 PCT CAPACITY FACTOR)
RDA
RDA      IRRADIATE MK IV OUTER.
BUP
IRP      50.0      11.88      1 2 4 2      BURN FOR 50.0 DAYS
DEC      68.0      2 3 4 0      DECAY FOR 18.0 DAYS
IRP      118.0      11.88      3 4 4 0      BURN FOR 50.0 DAYS
BUP
MOV      4 -7 0 1.0      SAVE RESULTS.
MOV      1 -8 0 1.0      SAVE INITIAL VECTOR.
RDA
STP      2
2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0
2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0
2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0
4 400000 65. 290000 75. 480000 0.25 40000 10. IMPURITIES IN
4 130000 800. 10000 2. 140000 125. 280000 100. 1 METRIC TON
4 250000 25. 120000 25. 260000 350. 240000 65. OF
4 50000 2.25 70000 75. 60000 550. 0 0.0 URANIUM
0
4 130000 75. 500000 1.45E+4 260000 1350. 240000 1000. ZIRCALOY
4 280000 550. 60000 275. 920000 2.5 400000 0.9814E+6 ZIRCALOY
4 50000 0.5 480000 0.5 270000 10. 290000 50. ZIRCALOY
4 720000 200. 10000 25. 820000 100. 120000 20. ZIRCALOY
4 250000 50. 420000 50. 70000 80. 140000 100. ZIRCALOY
4 110000 20. 220000 50. 740000 50. 230000 50. ZIRCALOY
0
RDA
LIB      0 1 2 3 411 412 413 9 3 0 1 41
RDA
RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK IV (INNER) FUEL
MOV      -2 1 0 1.0      URANIUM VECTOR
RDA      ADD TRACE IMPURITIES IN URANIUM
ADD      -4 1 0 1.0
RDA      ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
ADD      -5 1 0 0.07035  FRACTION BY WEIGHT
RDA      IRRADIATE MK IV INNER.
BUP
IRP      50.0      9.13      1 2 4 2      BURN FOR 50.0 DAYS

```

WHC-SD-NR-ANAL-014 REV 0

```

DEC      68.0      2 3 4 0      DECAY FOR 18.0 DAYS
IRP      118.0     9.13      3 4 4 0      BURN FOR 50.0 DAYS
BUP
RDA      COMBINE FOR COMPOSITE
RDA      VECTOR
RDA      4      INNER FINAL
RDA      -7     OUTER FINAL
RDA
MOV      4  2  0  0.317
ADD      -7  2  0  0.683
MOV      2  1  0  1.000
RDA
DEC      5.0      1  2  5  1
DEC      10.0     2  3  5  0
DEC      15.0     3  4  5  0
DEC      20.0     4  5  5  0
DEC      25.0     5  6  5  0
DEC      30.0     6  7  5  0
DEC      35.0     7  8  5  0
DEC      40.0     8  9  5  0
DEC      45.0     9 10  5  0
DEC      50.0    10 11  5  0
DEC      55.0    11 12  5  0
CUT      5 1.E-05  7 1.E-05  9 1.E-05 10 1.E-05 27 1.0 -1
HED      1 DISCHARGE
OPTA     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTL     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 4 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT      12 1 -1 0
RDA
STP      4
END

```


APPENDIX C

ORIGEN2 INTERPOLATION FORTRAN CODE LISTING

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ORIGEN2 INTERPOLATION FORTRAN CODE LISTING (K. N. Schwinkendorf, Code Author)

```

program terp
real kd8
common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
common /s3/ delt(10),dkh(10),pmkiv(6),pmkia(6)
character*3 ftp(200)
character*1 bid(200)
open(unit=7,file='orig_out.',status='old',err=99)
open(unit=8,file='key_dat.',status='old',err=99)
open(unit=9,file='terp_out.',status='unknown',err=99)
open(unit=10,file='terp_out.too',status='unknown',err=99)
data delt /0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 10.0, 15.0, 20.0, 25.0/
data pmkiv /0.0, 550.41, 1100.83, 1833.97, 2752.06, 3991.59/
data pmkia /0.0, 660.09, 1320.19, 2199.43, 3300.47, 4787.00/
c*****
c      input date ...
c*****
      read(7,*) (puwt(i),i=1,6)
      read(7,*) (dect(i),i=1,12)
      do 10 i = 1,2
        do 20 j = 1,4
          read(7,*) ((ordat(j,k,m,i),m=1,12),k=1,6)
20      continue
10     continue
      do 30 i=1,200
        read(8,100,end=40) bid(i),kd8(i),ftp(i),p240(i),umt(i),dt(i)
30      continue
100     format(a1,f7.0,2x,a3,f15.10,f11.2,f8.4)
40      np = i-1
c*****
c
c      calculate all of the wt% pu-240 ...
c
c*****
      do 41 m=1,2
        do 45 i = 1,6
          do 46 j = 1,12
            if(i .ne. 1) then
              dt240(i,j,m) = 100.*ordat(2,i,j,m)/ordat(3,i,j,m)
            else
              dt240(i,j,m) = 0.
            endif
46      continue
45      continue
41      continue
200     format(12(1pe10.3))
      do 50 i = 1,np
        if(ftp(i) .eq. 'MIA') then
          m=2
        else
          m=1
        endif
        do 51 j = 1,6
          do 52 k=1,10
            if(dt(i).ge.dect(k) .and. dt(i).lt.dect(k+1)) goto 53
52      continue
53      if(j .eq. 1) then
        pui(1) = 0.
      else
        pui(j) = t11(1,dt(i),k,j,m)
      endif
        do 54 l = 1,10
          ddt = dt(i) + delt(l)
          do 55 kl=1,10
            if(ddt.ge.dect(kl) .and. ddt.lt.dect(kl+1)) goto 59
55      continue
59      hui(j,l) = t11(2,ddt,kl,j,m)
54      continue
          ui(j) = t11(3,dt(i),k,j,m)
51      continue

```

```

do 56 k=1,4
  if(p240(i).ge.pui(k) .and. p240(i).lt.pui(k+1)) goto 58
56  continue
58  uor = tl2(2,p240(i),k,1,m)
  do 57 l = 1,10
    dkh(l) = umt(i)*tl2(1,p240(i),k,l,m)/uor
57  continue
  write (9,300) (dkh(l),l=1,10)
  pmwd = umt(i)*tl2(3,p240(i),k,1,m)/uor
  write (10,301) bid(i), kd8(i), ftp(i), pmwd
50  continue
300 format(10(1x,1pe12.5))
301 format(1x,'',a1,'',f7.0,2x,'',a3,'',1x,1pe12.5)
99  stop
end

function tl1(ipl,dti,in,n,it)
  real kd8
c*****
c  function tl1 evaluates lagrangian interpolation over decay time ...
c
c*****
  common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
  common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
  dimension cl(3)
  su = 0.
  do 10 i = 1, 3
    ii = in + i - 1
    cl(i) = 1.
    do 20 j = 1, 3
      jj = in + j - 1
      if (i.eq.j) goto 20
      cl(i) = cl(i)*(dti - dect(jj))/(dect(ii) - dect(jj))
20    continue
    if(ipl .eq. 1) then
      su = su + cl(i)*dt240(n,ii,it)
    elseif(ipl .eq. 2) then
      su = su + cl(i)*ordat(1,n,ii,it)
    else
      su = su + cl(i)*ordat(4,n,ii,it)
    endif
10  continue
  tl1 = su
  return
end

function tl2(ipl,pwt,in,l,ip)
  real kd8
c*****
c  this function evaluates lagrangian interpolation on decay heat and
c  uranium, as a function of pu-240 wt% ...
c
c*****
  common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
  common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
  common /s3/ delat(10), dkh(10), pmkiv(6), pmkia(6)
  dimension cl(3)
  su = 0.
  do 10 i = 1, 3
    ii = in + i - 1
    cl(i) = 1.
    do 20 j = 1, 3
      jj = in + j - 1
      if (i.eq.j) goto 20
      cl(i) = cl(i)*(pwt - pui(jj))/(pui(ii) - pui(jj))
20    continue
    if(ipl .eq. 1) then
      su = su + cl(i)*hui(ii,l)
    elseif(ipl .eq. 2) then
      su = su + cl(i)*ui(ii)
    else

```

```
      if(ip .eq. 2) then
        su = su + cl(i)*pmkia(ii)
      else
        su = su + cl(i)*pmkiv(ii)
      endif
10    continue
      tl2 = su
      return
      end
```

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APPENDIX D

ORIGEN2 INTERPOLATION FORTRAN CODE VALIDATION

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ORIGEN2 INTERPOLATION FORTRAN CODE VALIDATION

This validation was performed by including some extra write statements in the TERP code and executing TERP on the first key in the KE Basin.

TERP Code Input, Code Output, Validation Code Listings

TERP input orig_out., which was read on FORTRAN unit 7 in Table D-1.
 TERP input key_dat., which was read on FORTRAN unit 8 in Table D-2.
 TERP output terp_out., which was written on FORTRAN unit 9 in Table D-3.
 TERP output terp_out.too, which was written on FORTRAN unit 10 in Table D-4.

The TERP code validation listing with included write statements follows these data files.

Additional TERP validation output was written to FORTRAN unit 6, which follows the TERP validation listing.

Comments on TERP Validation output on FORTRAN Unit 6

The first line is simply the first line of key_dat., printed out immediately after being read in. This validates that KE Basin key data is being read into TERP in the correct format. A "key" is a grouping of irradiated uranium fuel with some common feature, usually the decay time, but not always the decay time. KE Basin fuel is accounted for in terms of these keys.

Orig out. has four blocks of data in matrix format: (1) decay heat (watts/MTIHM), (2) ^{240}Pu isotope (grams/MTIHM), (3) plutonium element (grams/MTIHM), and (4) uranium element (grams/MTIHM). All blocks of data are matrices; that is, they are dependent on decay time (horizontal in Table D-1) and exposure (vertical in Table D-1). ORIGEN2 output is now in four blocks of data in matrix format.

 ^{240}Pu Wt% Calculation

The lines with "Pu-240 Calc" at the end is where TERP combines the ^{240}Pu isotope and plutonium element data into ^{240}Pu wt%. Consider in the TERP validation output to FORTRAN unit 6 the first line of the ^{240}Pu calculation:

```
1 2 1      1.844E+01  4.870E+02      3.78644753  Pu-240 Calc.
```

By hand calculation:

$1.844\text{E}+01 / 4.870\text{E}+02 \times 100. = 3.786447639 \text{ wt\% } ^{240}\text{Pu},$

which matches to 7 significant figures, demonstrating that division is correctly performed. ORIGEN2 output has now been converted into three blocks of data in matrix format.

Interpolation For Decay Times

The next lines of TERP validation output, which have been reduced to the "small" font size, perform quadratic interpolation using Lagrangian format. The TERP validation output to FORTRAN unit 6 lines read:

```

1  7.18597E-01    2.10054E+01    2.00000E+01    2.50000E+01    3.00000E+01 in t11 subr.
2  3.61727E-01    2.10054E+01    2.00000E+01    2.50000E+01    3.00000E+01 in t11 subr.
3  -8.03234E-02    2.10054E+01    2.00000E+01    2.50000E+01    3.00000E+01 in t11 subr.
1  1  2.41100E-02    interpol. decay heats(Pu-240)

```

By hand calculations:

$$\begin{aligned}
 & (21.0054-25.0) \times (21.0054-30.0) / ((20.0-25.0) \times (20.0-30.0)) = 0.7185965832, \\
 & (21.0054-20.0) \times (21.0054-30.0) / ((25.0-20.0) \times (25.0-30.0)) = 0.3617268336, \\
 & (21.0054-20.0) \times (21.0054-25.0) / ((30.0-20.0) \times (30.0-25.0)) = -0.0803234168.
 \end{aligned}$$

Now consider decay heat for MKIA, because key 9621 is designated MIA. For the first line, because exposure is zero, and locations 5, 6, and 7, because these are for decay times equal to 20 years, 25 years, and 30 years, the results are:

$$0.7185965832 \times 0.02411 + 0.3617268336 \times 0.02411 + (-0.0803234168) \times 0.02411 = 0.0241100 \text{ Watts/MTIHM},$$

which matches to the 6 significant figures output, demonstrating that Lagrangian interpolation is correctly performed. ORIGEN2 output has now been converted into three blocks of data, decay heat is in reduced matrix format (10 decays by 6 exposures), while the uranium and ^{240}Pu are in vector format (6 exposures).

Interpolation for ^{240}Pu Wt% Exposure

The next lines of TERP output to unit 6, also reduced to "small" font size, perform quadratic interpolation using Lagrangian format. This interpolation uses ^{240}Pu , instead of decay time, and uses subroutine tl2, instead of t11. The TERP validation output to FORTRAN unit 6 lines read:

```

1  5.32445E-02    6.15077E+00    3.47420E+00    6.43328E+00    9.52547E+00 in tl2 subr.
2  9.87168E-01    6.15077E+00    3.47420E+00    6.43328E+00    9.52547E+00 in tl2 subr.
3  -4.04121E-02    6.15077E+00    3.47420E+00    6.43328E+00    9.52547E+00 in tl2 subr.
9.97748E+05    interpolated uranium

```

By hand calculations:

$$\begin{aligned}
 & (6.15077-6.43328) \times (6.15077-9.52547) / ((3.47420-6.43328) \times (3.47420-9.52547)) = 0.05324339733, \\
 & (6.15077-3.47420) \times (6.15077-9.52547) / ((6.43328-3.47420) \times (6.43328-9.52547)) = 0.9871676149, \\
 & (6.15077-3.47420) \times (6.15077-6.43328) / ((9.52547-3.47420) \times (9.52547-6.43328)) = -0.0404110122.
 \end{aligned}$$

These coefficients use different exposure times. These are from lines preceded by 2, 3, and 4, and followed by "interpolated uranium" so we can calculate:

$$0.05324339733 \times 9.98800E+05 + 0.9871676149 \times 9.97628E+05 + (-0.0404110122) \times 9.96200E+05 = 9.977481082E+05 \text{ U grams/MTIHM}.$$

This matches to the 6 significant figures output, demonstrating that Lagrangian interpolation is correctly performed. ORIGEN2 output has now been converted into two blocks of data, decay heat is in vector format (10 decays), while the uranium is in scaler format.

Scaling for Uranium Quantity In Each Key

Next, the decay heat is scaled by the quantity of uranium remaining in the key. For the validation calculation key, 9621, this is 105496.71 uranium grams. The TERP validation output to FORTRAN unit 6 lines read:

1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
1	0.0	3.09284E+00	scaled decay heat(time)		

By hand calculations:

$(0.05324339733 \times 1.54613E+01 + 0.9871676149 \times 3.09288E+01 + (-0.0404110122) \times 5.20695E+01) \times 105496.71 \text{ U grams} / 9.97748E+05 \text{ U grams/MTIHM} = 3.092843088 \text{ Watts for key 9621 at 0 years decay time from January 31, 1992.}$

This matches to the 6 significant figures output, demonstrating that Lagrangian interpolation and scaling by the key uranium quantity is correctly performed. ORIGEN2 output and the key dat. file has now been converted into one block of data, decay heat in vector format (10 different decay times).

Final Listing of Calculated Results

Finally, picking these decay times out of TERP validation output to FORTRAN unit 6, we have:

1	0.0	3.09284E+00	scaled decay heat(time)
2	1.0	3.02730E+00	scaled decay heat(time)
3	2.0	2.96324E+00	scaled decay heat(time)
4	3.0	2.90067E+00	scaled decay heat(time)
5	4.0	2.83958E+00	scaled decay heat(time)
6	5.0	2.78031E+00	scaled decay heat(time)
7	10.0	2.50424E+00	scaled decay heat(time)
8	15.0	2.26018E+00	scaled decay heat(time)
9	20.0	2.04378E+00	scaled decay heat(time)
10	25.0	1.85154E+00	scaled decay heat(time).

This matches, to all the listed significant figures, the Table 1-2 key data output in the first line for key 9621. All other calculations performed by the TERP code consist of simply adding up these separate keys for each basin and summing to get an overall total.

Conclusion

This completes this TERP validation.

Table D-1. TERP Input orig_out. Read on FORTRAN Unit 7.

0.	3.	6.	9.	12.	16.	20.	25.	30.	35.	40.	45.	50.	55.
0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229	0.02229
7.063E+05	2.679E+01	1.693E+01	1.487E+01	1.329E+01	1.193E+01	1.074E+01	9.686E+00	8.750E+00	7.920E+00	7.182E+00	6.526E+00	6.526E+00	6.526E+00
7.016E+05	5.351E+01	3.370E+01	2.962E+01	2.657E+01	2.394E+01	2.164E+01	1.959E+01	1.777E+01	1.616E+01	1.472E+01	1.344E+01	1.344E+01	1.344E+01
6.990E+05	8.962E+01	5.640E+01	4.971E+01	4.482E+01	4.064E+01	3.695E+01	3.367E+01	3.074E+01	2.814E+01	2.581E+01	2.373E+01	2.373E+01	2.373E+01
6.939E+05	1.355E+02	8.565E+01	7.571E+01	6.866E+01	6.264E+01	5.732E+01	5.258E+01	4.833E+01	4.453E+01	4.112E+01	3.807E+01	3.807E+01	3.807E+01
6.891E+05	2.009E+02	1.278E+02	1.132E+02	1.032E+02	9.466E+01	8.713E+01	8.039E+01	7.435E+01	6.892E+01	6.403E+01	5.965E+01	5.965E+01	5.965E+01
0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.44	18.43	18.42	18.41	18.4	18.39	18.38	18.38	18.37	18.36	18.35	18.34	18.34	18.34
62.53	62.5	62.46	62.43	62.4	62.36	62.33	62.3	62.26	62.23	62.2	62.17	62.17	62.17
139.9	139.8	139.7	139.7	139.6	139.5	139.4	139.4	139.3	139.2	139.1	139.1	139.1	139.1
253.5	253.4	253.3	253.2	253.1	252.9	252.8	252.7	252.5	252.4	252.3	252.1	252.1	252.1
425.9	425.8	425.7	425.5	425.3	425.1	424.9	424.7	424.5	424.3	424.1	423.9	423.9	423.9
0	0	0	0	0	0	0	0	0	0	0	0	0	0
487	524.1	523.8	523.6	523.4	523.2	523	522.9	522.7	522.6	522.5	522.4	522.4	522.4
931.9	966.5	965	963.7	962.7	961.9	961.2	960.6	960.1	959.6	959.3	958.9	958.9	958.9
1475	1506	1501	1496	1493	1490	1488	1487	1485	1484	1483	1482	1482	1482
2063	2085	2073	2063	2055	2049	2044	2037	2034	2032	2030	2030	2030	2030
2774	2781	2756	2737	2722	2709	2700	2692	2685	2680	2676	2673	2673	2673
1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000
998900	998900	998900	998900	998900	998900	998900	998900	998900	998900	998900	998900	998900	998900
997900	997900	997900	997900	997900	997900	997900	997900	997900	997900	997900	997900	997900	997900
996600	996600	996600	996600	996600	996600	996600	996600	996600	996600	996600	996600	996600	996600
995000	995000	995000	995000	995000	995000	995000	995000	995000	995000	995000	995000	995000	995000
992900	992900	992900	992900	992900	992900	992900	992900	992900	992900	992900	992900	992900	992900
0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411	0.02411
8.362E+05	3.188E+01	2.021E+01	1.772E+01	1.581E+01	1.416E+01	1.272E+01	1.144E+01	1.031E+01	9.299E+00	8.406E+00	7.612E+00	7.612E+00	7.612E+00
8.319E+05	6.367E+01	4.026E+01	3.532E+01	3.160E+01	2.841E+01	2.559E+01	2.310E+01	2.089E+01	1.893E+01	1.718E+01	1.562E+01	1.562E+01	1.562E+01
8.258E+05	1.064E+02	6.731E+01	5.915E+01	5.315E+01	4.802E+01	4.350E+01	3.949E+01	3.592E+01	3.273E+01	2.989E+01	2.736E+01	2.736E+01	2.736E+01
8.176E+05	1.606E+02	1.019E+02	8.975E+01	8.105E+01	7.364E+01	6.710E+01	6.127E+01	5.607E+01	5.142E+01	4.726E+01	4.354E+01	4.354E+01	4.354E+01
8.079E+05	2.365E+02	1.509E+02	1.331E+02	1.208E+02	1.103E+02	1.011E+02	9.284E+01	8.547E+01	7.886E+01	7.293E+01	6.761E+01	6.761E+01	6.761E+01
0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.03	18.02	18.01	18	17.99	17.98	17.97	17.96	17.95	17.94	17.93	17.92	17.92	17.92
62.3	62.26	62.23	62.2	62.16	62.13	62.1	62.07	62.03	62	61.97	61.93	61.93	61.93
142.6	142.5	142.4	142.4	142.3	142.2	142.1	142.1	142	141.9	141.8	141.8	141.8	141.8
262.3	262.2	262.1	261.9	261.8	261.7	261.5	261.4	261.3	261.1	261	260.9	260.9	260.9
442.5	442.3	442.2	442	441.8	441.6	441.4	441.2	441	440.8	440.6	440.3	440.3	440.3
0	0	0	0	0	0	0	0	0	0	0	0	0	0
481.5	518.5	518.2	518	517.8	517.6	517.4	517.3	517.1	517	516.9	516.8	516.8	516.8
934.8	970.1	968.6	967.3	966.3	965.5	964.8	964.2	963.7	963.3	962.9	962.6	962.6	962.6
1476	1507	1502	1498	1494	1492	1489	1488	1486	1485	1484	1483	1483	1483
2068	2090	2078	2068	2060	2054	2049	2045	2042	2039	2037	2035	2035	2035
2767	2775	2750	2730	2714	2701	2691	2683	2677	2672	2667	2664	2664	2664
1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000
998800	998800	998800	998800	998800	998800	998800	998800	998800	998800	998800	998800	998800	998800
997700	997600	997600	997600	997600	997600	997700	997700	997700	997700	997700	997700	997700	997700
996200	996200	996200	996200	996200	996200	996200	996200	996200	996200	996200	996200	996200	996200
994400	994400	994400	994400	994400	994400	994400	994400	994400	994400	994400	994400	994400	994400
992100	992100	992100	992100	992100	992100	992100	992100	992100	992100	992100	992100	992100	992100

Table D-2. TERP Input key_dat. Read on FORTRAN Unit 8.

E 9621. MIA 6.150767636 105496.71 21.0054

Table D-3. TERP Output terp_out. Written on FORTRAN Unit 9.

3.09284E+00 3.02730E+00 2.96324E+00 2.90067E+00 2.83958E+00 2.78031E+00 2.50424E+00 2.26018E+00 2.04378E+00 1.85154E+00

Table D-4. TERP Output terp_out.too Written on FORTRAN Unit 10.

"E" 9621. "MIA" 1.32117E+02

TERP, ORIGEN2 Interpolation FORTRAN Validation Code Listing

```

program terp
real kd8
common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
common /s3/ delt(10), dkh(10), pmkiv(6), pmkia(6)
character*3 ftp(200)
character*1 bid(200)
open(unit=7,file='orig_out.',status='old',err=99)
open(unit=8,file='key_dat.',status='old',err=99)
open(unit=9,file='terp_out.',status='unknown',err=99)
open(unit=10,file='terp_out.too',status='unknown',err=99)
data delt /0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 10.0, 15.0, 20.0, 25.0/
data pmkiv /0.0, 550.41, 1100.83, 1833.97, 2752.06, 3991.59/
data pmkia /0.0, 660.09, 1320.19, 2199.43, 3300.47, 4787.00/
c*****
c      input date ...
c*****
      read(7,*) (puwt(i),i=1,6)
      read(7,*) (dect(i),i=1,12)
      do 10 i = 1,2
        do 20 j = 1,4
          read(7,*) ((ordat(j,k,m,i),m=1,12),k=1,6)
20      continue
10      continue
      do 30 i=1,200
        read(8,101) bid(i),kd8(i),ftp(i),p240(i),umt(i),dt(i)
        write(6,101) i,bid(i),kd8(i),ftp(i),p240(i),umt(i),dt(i)
30      continue
100     format(a1,f7.0,2x,a3,f15.10,f11.2,f8.4)
101     format(1x,i3,2x,a1,f7.0,2x,a3,f15.10,f11.2,f8.4,2x,'key_dat')
40      np = i-1
c*****
c
c      calculate all of the wt% pu-240 ...
c
c*****
      do 41 m=1,2
        do 45 i = 1,6
          do 46 j = 1,12
            if(i .ne. 1) then
              dt240(i,j,m) = 100.*ordat(2,i,j,m)/ordat(3,i,j,m)
              if (m.eq.1)
                & write (6,110) m,i,j,ordat(2,i,j,m),ordat(3,i,j,m),dt240(i,j,m)
110         format(2x,i3,2x,2(1pe12.3),3x,0pf12.8,2x,'Pu-240 Calc')
              else
                dt240(i,j,m) = 0.
                if (m.eq.1)
                  & write (6,110) m,i,j,ordat(2,i,j,m),ordat(3,i,j,m),dt240(i,j,m)
            endif
46      continue
45      continue
41      continue

```

```

200  format(12(1p10.3))
      do 50 i = 1,np
        if(ftp(i) .eq. 'MIA') then
          m=2
        else
          m=1
        endif
        do 51 j = 1,6
          do 52 k=1,10
            if(dt(i).ge.dect(k) .and. dt(i).lt.dect(k+1)) goto 53
52      continue
53      if(j .eq. 1) then
        pui(1) = 0.
      else
        pui(j) = t11(1,dt(i),k,j,m)
        write (6,120) j, pui(j)
120     format (2x,i3,1p15.5,3x,'interpolated Pu-240s')
      endif
        do 54 l = 1,10
          ddt = dt(i) + delt(1)
          do 55 kl=1,10
            if(ddt.ge.dect(kl) .and. ddt.lt.dect(kl+1)) goto 59
55      continue
59      hui(j,l) = t11(2,ddt,kl,j,m)
        write (6,130) j,l,hui(j,l)
130     format (2x,2i3,1p15.5,3x,'interpol. decay heats(Pu-240)')
54      continue
        ui(j) = t11(3,dt(i),k,j,m)
        write (6,140) j, ui(j)
140     format (2x,i3,1p15.5,3x,'interpolated uranium(Pu-240)')
51      continue
        do 56 k=1,4
          if(p240(i).ge.pui(k) .and. p240(i).lt.pui(k+1)) goto 58
56      continue
58      uor = t12(2,p240(i),k,1,m)
        write (6,150) uor
150     format (2x,1p15.5,3x,'interpolated uranium')
        do 57 l = 1,10
          dkh(l) = umt(i)*t12(1,p240(i),k,1,m)/uor
          write (6,160) l,delt(1),dkh(l)
160     format (2x,i3,f6.1,1p15.5,3x,'scaled decay heat(time)')
57      continue
        write (9,300) (dkh(l),l=1,10)
        pmwd = umt(i)*t12(3,p240(i),k,1,m)/uor
        write (10,301) bid(i), kd8(i), ftp(i), pmwd
50      continue
300     format(10(1x,1p12.5))
301     format(1x,'"',a1,'"',f7.0,2x,'"',a3,'"',1x,1p12.5)
99      stop
      end

```

```

function t11(ipl,dti,in,n,it)
real kd8

```

```

C*****
C
C   function t11 evaluates lagrangian interpolation over decay time ...
C
C*****
      common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
      common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
      dimension cl(3)
      su = 0.
      do 10 i = 1, 3
        ii = in + i - 1
        cl(i) = 1.
        do 20 j = 1, 3
          jj = in + j - 1
          if (i.eq.j) goto 20
          cl(i) = cl(i)*(dti - dect(jj))/(dect(ii) - dect(jj))
20      continue
      write (6,110) i,cl(i),dti,dect(in),dect(in+1),dect(in+2)
110   format (2x,i3,1p15.5,2x,1p15.5,2x,3(1p15.5),' in t11 subr.')
      if (ipl .eq. 1) then
        su = su + cl(i)*dt240(n,ii,it)
      elseif (ipl .eq. 2) then
        su = su + cl(i)*ordat(1,n,ii,it)
      else
        su = su + cl(i)*ordat(4,n,ii,it)
      endif
10    continue
      t11 = su
      return
      end

```

```

      function t12(ipl,pwt,in,l,ip)
      real kd8

```

```

C*****
C
C   this function evaluates lagrangian interpolation on decay heat and
C   uranium, as a function of pu-240 wt% ...
C
C*****
      common /s1/ puwt(6),dect(12),ordat(4,6,12,2),dt240(6,12,2), ui(6)
      common /s2/ kd8(200),p240(200),umt(200),dt(200),pui(6),hui(6,10)
      common /s3/ delt(10), dkh(10), pmkiv(6), pmkia(6)
      dimension cl(3)
      su = 0.
      do 10 i = 1, 3
        ii = in + i - 1
        cl(i) = 1.
        do 20 j = 1, 3
          jj = in + j - 1
          if (i.eq.j) goto 20
          cl(i) = cl(i)*(pwt - pui(jj))/(pui(ii) - pui(jj))
20      continue

```



```
      write (6,110) i,cl(i),pwt,pui(in),puj(in+1),puj(in+2)
110  format (2x,i3,1pe15.5,2x,1pe15.5,2x,3(1pe15.5),' in t12 subr.')
```

```
      if(ip1 .eq. 1) then
        su = su + cl(i)*hui(ii,1)
      elseif(ip1 .eq. 2) then
        su = su + cl(i)*ui(ii)
      else
        if(ip .eq. 2) then
          su = su + cl(i)*pmkia(ii)
        else
          su = su + cl(i)*pmkiv(ii)
        endif
      endif
10  continue
    t12 = su
    return
end
```

TERP, ORIGEN2 Interpolation FORTRAN Code, Validation Output on Unit 6

```

1 E 9621. MIA 6.1507678032 105496.71 21.0054 key dat
1 1 1 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 2 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 3 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 4 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 5 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 6 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 7 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 8 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 9 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 10 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 11 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 1 12 0.000E+00 0.000E+00 0.00000000 Pu-240 Calc
1 2 1 1.844E+01 4.870E+02 3.78644753 Pu-240 Calc
1 2 2 1.843E+01 5.241E+02 3.51650476 Pu-240 Calc
1 2 3 1.842E+01 5.238E+02 3.51660943 Pu-240 Calc
1 2 4 1.841E+01 5.236E+02 3.51604295 Pu-240 Calc
1 2 5 1.840E+01 5.234E+02 3.51547551 Pu-240 Calc
1 2 6 1.839E+01 5.232E+02 3.51490808 Pu-240 Calc
1 2 7 1.838E+01 5.230E+02 3.51434016 Pu-240 Calc
1 2 8 1.838E+01 5.229E+02 3.51501203 Pu-240 Calc
1 2 9 1.837E+01 5.227E+02 3.51444435 Pu-240 Calc
1 2 10 1.836E+01 5.226E+02 3.51320338 Pu-240 Calc
1 2 11 1.835E+01 5.225E+02 3.51196170 Pu-240 Calc
1 2 12 1.834E+01 5.224E+02 3.51071954 Pu-240 Calc
1 3 1 6.253E+01 9.319E+02 6.70994711 Pu-240 Calc
1 3 2 6.250E+01 9.665E+02 6.46663237 Pu-240 Calc
1 3 3 6.246E+01 9.650E+02 6.47253895 Pu-240 Calc
1 3 4 6.243E+01 9.637E+02 6.47815704 Pu-240 Calc
1 3 5 6.240E+01 9.627E+02 6.48177004 Pu-240 Calc
1 3 6 6.236E+01 9.619E+02 6.48300219 Pu-240 Calc
1 3 7 6.233E+01 9.612E+02 6.48460245 Pu-240 Calc
1 3 8 6.230E+01 9.606E+02 6.48552990 Pu-240 Calc
1 3 9 6.226E+01 9.601E+02 6.48474121 Pu-240 Calc
1 3 10 6.223E+01 9.596E+02 6.48499393 Pu-240 Calc
1 3 11 6.220E+01 9.593E+02 6.48389482 Pu-240 Calc
1 3 12 6.217E+01 9.589E+02 6.48347044 Pu-240 Calc
1 4 1 1.399E+02 1.475E+03 9.48474503 Pu-240 Calc
1 4 2 1.398E+02 1.506E+03 9.28286839 Pu-240 Calc
1 4 3 1.397E+02 1.501E+03 9.30712891 Pu-240 Calc
1 4 4 1.397E+02 1.496E+03 9.33823490 Pu-240 Calc
1 4 5 1.396E+02 1.493E+03 9.35030174 Pu-240 Calc
1 4 6 1.395E+02 1.490E+03 9.36241627 Pu-240 Calc
1 4 7 1.394E+02 1.488E+03 9.36827850 Pu-240 Calc
1 4 8 1.394E+02 1.487E+03 9.37457943 Pu-240 Calc
1 4 9 1.393E+02 1.485E+03 9.38047123 Pu-240 Calc
1 4 10 1.392E+02 1.484E+03 9.38005352 Pu-240 Calc
1 4 11 1.391E+02 1.483E+03 9.37963676 Pu-240 Calc
1 4 12 1.391E+02 1.482E+03 9.38596535 Pu-240 Calc
1 5 1 2.535E+02 2.063E+03 12.28793049 Pu-240 Calc
1 5 2 2.534E+02 2.085E+03 12.15347767 Pu-240 Calc
1 5 3 2.533E+02 2.073E+03 12.21900654 Pu-240 Calc
1 5 4 2.532E+02 2.063E+03 12.27338791 Pu-240 Calc
1 5 5 2.531E+02 2.055E+03 12.31630135 Pu-240 Calc
1 5 6 2.529E+02 2.049E+03 12.34260654 Pu-240 Calc
1 5 7 2.528E+02 2.044E+03 12.36790562 Pu-240 Calc
1 5 8 2.527E+02 2.040E+03 12.38725471 Pu-240 Calc
1 5 9 2.525E+02 2.037E+03 12.39567947 Pu-240 Calc
1 5 10 2.524E+02 2.034E+03 12.40904617 Pu-240 Calc
1 5 11 2.523E+02 2.032E+03 12.41633892 Pu-240 Calc
1 5 12 2.521E+02 2.030E+03 12.41871929 Pu-240 Calc
1 6 1 4.259E+02 2.774E+03 15.35328007 Pu-240 Calc
1 6 2 4.258E+02 2.781E+03 15.31103897 Pu-240 Calc
1 6 3 4.257E+02 2.756E+03 15.44629860 Pu-240 Calc
1 6 4 4.255E+02 2.737E+03 15.54621887 Pu-240 Calc
1 6 5 4.253E+02 2.722E+03 15.62454033 Pu-240 Calc
1 6 6 4.251E+02 2.709E+03 15.69213772 Pu-240 Calc
1 6 7 4.249E+02 2.700E+03 15.73703671 Pu-240 Calc
1 6 8 4.247E+02 2.692E+03 15.77637482 Pu-240 Calc
1 6 9 4.245E+02 2.685E+03 15.81005573 Pu-240 Calc
1 6 10 4.243E+02 2.680E+03 15.83208942 Pu-240 Calc
1 6 11 4.241E+02 2.676E+03 15.84828091 Pu-240 Calc
1 6 12 4.239E+02 2.673E+03 15.85858631 Pu-240 Calc

```

WHC-SD-NR-ANAL-014 REV 0

1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	4.78813E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	6.41295E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-1.20107E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	2.79029E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	8.40863E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-1.19891E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	1.19245E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	9.60431E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-7.96754E-02	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	9.98381E-01	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
2	2.15872E-03	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
3	-5.39387E-04	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	7.18597E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
2	3.61727E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
3	-8.03234E-02	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	7.18597E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
2	3.61727E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
3	-8.03234E-02	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	7.18597E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
2	3.61727E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
3	-8.03235E-02	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	7.18597E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
2	3.61727E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
3	-8.03235E-02	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
1	2.41100E-02	interpol. decay heats(Pu-240)					
1	7.18597E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
1	2.41100E-02	interpol. decay					

WHC-SD-NR-ANAL-014 REV 0

1	7.18596E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
2	3.61727E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
3	-8.03235E-02	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
2 8	1.12032E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
2	3.61727E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
3	-8.03235E-02	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
2 9	1.00972E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
2 10	9.11148E+00	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	9.98800E+05	interpolated uranium(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	6.43328E+00	interpolated Pu-240s				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3 1	3.09288E+01	interpol. decay heats(Pu-240)				
1	4.78813E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	6.41295E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-1.20107E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3 2	3.02761E+01	interpol. decay heats(Pu-240)				
1	2.79029E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	8.40863E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-1.19891E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3 3	2.96382E+01	interpol. decay heats(Pu-240)				
1	1.19245E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	9.60431E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-7.96754E-02	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3 4	2.90151E+01	interpol. decay heats(Pu-240)				
1	9.98381E-01	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
2	2.15872E-03	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3	-5.39387E-04	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3 5	2.84068E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
2	3.61727E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3	-8.03234E-02	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3 6	2.78164E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
2	3.61727E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
3	-8.03234E-02	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
3 7	2.50668E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
2	3.61727E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
3	-8.03235E-02	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
3 8	2.26355E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
2	3.61727E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
3	-8.03235E-02	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
3 9	2.04790E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
3 10	1.85628E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	9.97628E+05	interpolated uranium(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
4	9.52547E+00	interpolated Pu-240s				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
4 1	5.20695E+01	interpol. decay heats(Pu-240)				
1	4.78813E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	6.41295E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-1.20107E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
4 2	5.10192E+01	interpol. decay heats(Pu-240)				

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2	2.79029E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	8.40863E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-1.19891E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
4	3	4.99933E+01	interpol. decay heats(Pu-240)				
1	1.19245E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	9.60431E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-7.96754E-02	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
4	4	4.89919E+01	interpol. decay heats(Pu-240)				
1	9.98381E-01	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
2	2.15872E-03	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
3	-5.39387E-04	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
4	5	4.80148E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
2	3.61727E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
3	-8.03234E-02	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11	subr.
4	6	4.70702E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
2	3.61727E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
3	-8.03234E-02	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11	subr.
4	7	4.26583E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
2	3.61727E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
3	-8.03235E-02	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11	subr.
4	8	3.87416E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
2	3.61727E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
3	-8.03235E-02	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11	subr.
4	9	3.52504E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11	subr.
4	10	3.21340E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
4	9.96200E+05	interpolated uranium(Pu-240)					
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
5	1.27161E+01	interpolated Pu-240s					
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11	subr.
3	-8.03234E-						

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1	7.18596E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
5 10	5.05482E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
5	9.94400E+05	interpolated uranium(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6	1.62942E+01	interpolated Pu-240s				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6 1	1.18584E+02	interpol. decay heats(Pu-240)				
1	4.78813E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	6.41295E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-1.20107E-01	2.20054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6 2	1.16433E+02	interpol. decay heats(Pu-240)				
1	2.79029E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	8.40863E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-1.19891E-01	2.30054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6 3	1.14333E+02	interpol. decay heats(Pu-240)				
1	1.19245E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	9.60431E-01	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-7.96754E-02	2.40054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6 4	1.12285E+02	interpol. decay heats(Pu-240)				
1	9.98381E-01	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
2	2.15872E-03	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3	-5.39387E-04	2.50054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
6 5	1.10290E+02	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
2	3.61727E-01	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
3	-8.03234E-02	2.60054E+01	2.50000E+01	3.00000E+01	3.50000E+01	in t11 subr.
6 6	1.08375E+02	interpol. decay heats(Pu-240)				
1	7.18597E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
2	3.61727E-01	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
3	-8.03234E-02	3.10054E+01	3.00000E+01	3.50000E+01	4.00000E+01	in t11 subr.
6 7	9.93676E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
2	3.61727E-01	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
3	-8.03235E-02	3.60054E+01	3.50000E+01	4.00000E+01	4.50000E+01	in t11 subr.
6 8	9.12970E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
2	3.61727E-01	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
3	-8.03235E-02	4.10054E+01	4.00000E+01	4.50000E+01	5.00000E+01	in t11 subr.
6 9	8.40862E+01	interpol. decay heats(Pu-240)				
1	7.18596E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
2	3.61727E-01	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
3	-8.03235E-02	4.60054E+01	4.50000E+01	5.00000E+01	5.50000E+01	in t11 subr.
6 10	7.76186E+01	interpol. decay heats(Pu-240)				
1	7.18597E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
2	3.61727E-01	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
3	-8.03234E-02	2.10054E+01	2.00000E+01	2.50000E+01	3.00000E+01	in t11 subr.
6	9.92100E+05	interpolated uranium(Pu-240)				
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
9.97748E+05	interpolated uranium					
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
1	0.0	3.09284E+00	scaled decay heat(time)			
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	1.0	3.02730E+00	scaled decay heat(time)			
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	2.0	2.96324E+00	scaled decay heat(time)			
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00	in t12 subr.
4	3.0	2.90067E+00	scaled decay heat(time)			

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1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
5	4.0	2.83958E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
6	5.0	2.78031E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
7	10.0	2.50424E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
8	15.0	2.26018E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
9	20.0	2.04378E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
10	25.0	1.85154E+00	scaled decay heat(time)		
1	5.32445E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
2	9.87168E-01	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.
3	-4.04121E-02	6.15077E+00	3.47420E+00	6.43328E+00	9.52547E+00 in tl2 subr.

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: WHC-SD-NR-ANAL-014
 Author: W. D. Wittekind

Yes No N/A

☒	☐	☐	Problem completely defined.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	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.
☒	☐	☐	Code run streams correct and consistent with analysis documentation.
☒	☐	☐	Code output consistent with input and with results reported in analysis documentation.
☒	☐	☐	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
☒	☐	☐	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.
☐	☐	☒	Have all reasonable accidents been considered?
☐	☐	☒	Has low density water (steam) been evaluated as a moderator?
☒	☐	☐	Is the fuel and other hardware composition correct?
☒	☐	☐	Are the cases considered conservative? Too conservative?
☐	☐	☒	Do the computer models adequately reflect the actual geometry? Have cross sectional cuts of the geometry been made and do they show the desired geometry?
☒	☐	☐	Has the analysis been reviewed by Safety? This may not be required in a preliminary design.
☒	☐	☐	Has the reviewer completed the Criticality Safety Course for Managers and Engineers?
- Date completed 3-15-94

Reviewed by: Paul B. Epi Date 5-20-94

NOTE: Any hand calculations, notes, or summaries generated as part of this review should be signed, dated, and attached to this checklist. Materials should be labeled and recorded so that it is intelligible to a technically-qualified third party.