CALCULATION 2013-07050, REVISION 2

MAXIMUM CLADDING TEMPERATURE ANALYSIS FOR AN UNCOVERED SPENT FUEL POOL WITH NO AIR COOLING

Dominion

Calculation Review Checklist

Calculation # 2013-07050 Rev. 2 Add. N/A

NOTE: If "Yes" is not answered, an explanation may be provided below. Reference may be made to explanations contained in the calculation or addendum.

Questions:	Yes	N/A
1. Have the sources of design inputs been correctly selected and referenced in the calculation?	[X]	[ ]
2. Are the sources of design inputs up-to-date and retrievable/attached to the calculation?	[X]	[ ]
3. Where appropriate, have the other disciplines reviewed or provided the design inputs for which they are responsible?	[X]	[ ]
4. Have design inputs been confirmed by analysis, test, measurement, field walkdown, or other pertinent means as appropriate for the configuration analyzed?	[ ]	[X]
5. Have the bases for assumptions been adequately and clearly presented and are they bounded by the Station Design Basis?	[X]	[ ]
6. Were appropriate calculation/analytic methods used and are outputs reasonable when compared to inputs?	[X]	[ ]
7. Are computations technically accurate?	[X]	[ ]
8. Has the calculation made appropriate allowances for instrument errors and calibration equipment errors?	[X]	[ ]
9. Have those computer codes used in the analysis been referenced in the calculation?	[X]	[ ]
10. Have all exceptions to station design basis criteria and regulatory requirements been identified and justified in accordance with NQA-1-1994?	[ ]	[X]
11. Has the design authority/original preparer for this calculation been informed of its revision or addendum, if required?	[ ]	[X]

Comments provided to S & L resolved in the final draft of the calculation to Dominion's satisfaction.

Item # 4 – Input data is from the literature or provided in ETE-NAF-2013-0077, Rev. 0 (documented in S & L calc).

#10 – Calculation provides information and is not used for design basis criteria.

11 – The original preparer of Rev. 2 is the same as Rev. 0 and 1.

Signature: N/A Date: N/A
(Preparer)

Signature: M. S. Lico [signature] Date: 8/28/13
(Reviewer)

Note: Physical or electronic signatures are acceptable.

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1. Purpose and Scope

1.1. Purpose

The purpose of this calculation is to conservatively evaluate the length of time (number of hours) it takes for uncovered spent fuel assemblies to reach the temperature where the zirconium cladding would fail. This analysis conservatively assumes that there is no air cooling of the assemblies: the flow paths that would provide natural circulation cooling are assumed to be blocked.

1.2. Scope

The length of time for the fuel to heat up (the heat-up time) is determined as a function of the day that the analysis is performed (the decay time). The heat load from Westinghouse 422V+ fuel is used in this analysis (Reference 2.5 and Assumption 5.1).

The zirconium cladding must remain below the temperature where it will fail. Per NUREG/CR-6451 (Ref. 2.1, see Design Input 4.1), 565 °C (1049 °F) is the lowest temperature where incipient cladding failure might occur. NUREG-1738 (Ref. 2.7, pg. 3-7) states that runaway oxidation of zirconium occurs at 900 °C. For this analysis, the NUREG/CR-6451 temperature (565 °C, 1049 °F) and the NUREG-1738 temperature (900 °C, 1652 °F) are the temperatures of interest for the zirconium cladding.

There are no specific acceptance criteria for this analysis, however, SECY-99-168 (Ref. 2.4) suggests that "10 hours (is) sufficient time to take mitigative action" and that for PWRs, 2.5 years is expected to be the decay time needed to reach a 10 hour heat-up time from 30 °C to 900 °C. NUREG-1738 shows that a 10 hour heat up time to 900 °C for a PWR would occur at less than 2 years (Ref. 2.7, Fig. 2-2).

2. References

2.1. NUREG/CR-6451, "A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants," August 1997.

2.2. Incropera, Frank P., and David P. DeWitt, Introduction to Heat Transfer, Fourth Edition, John Wiley & Sons.

2.3. Kewaunee USAR, Chapter 3: Reactor, Revision 24.02 – Updated Online 04/15/13.

2.4. SECY-99-168, "Improving Decommissioning Regulations for Nuclear Power Plants," June 30, 1999.

2.5. Document No. ETE-NAF-2013-0077, "Information for Kewaunee Spent Fuel Pool Postulated Loss of Inventory Calculation," Rev. 0, July 10, 2013.

2.6. Email from Michael Lico (Dominion) to Matthew Ross (S&L), "KPS sfp temp today," July 22nd, 2013. Included as Attachment C.

2.7. NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," February 2001.

3. Definitions

3.1. Decay Time
The decay time is the time since the reactor was shut down (May 7th, 2013).

3.2. Heat-up Time
The heat-up time is the amount of time between when the fuel becomes uncovered and when the zirconium cladding reaches the failure temperatures of interest, 565 °C (1049 °F) and 900 °C (1652 °F).

4. Input Data

4.1. Maximum Zirconium Temperature

Several studies are presented in NUREG/CR-6451 (Ref. 2.1) discussing the maximum allowable temperature of zirconium cladding that will ensure that failure of the zirconium cladding will not occur. Per NUREG/CR-6451 (Ref. 2.1, see Design Input 4.1), 565 °C (1049 °F) is the lowest temperature where incipient cladding failure might occur. NUREG-1738 uses 900 °C (1652 °F) as the temperature where "runaway oxidation" is expected to occur (Ref. 2.7, pg. 3-7). These two temperatures are the failure temperatures of interest for this calculation

4.2. Zirconium Properties

The specific heat of zirconium at 600 K (620 °F) is 322 J/kg-K and the density of zirconium is 6570 kg/m^3 (Ref. 2.2, pg. 822). A temperature of 620 °F is in the temperature range (less than the midpoint for both ranges) of this analysis. From Reference 2.2, the specific heat slightly increases with an increase in temperature. At higher temperatures, the zirconium would heat up more slowly. This temperature is representative of the full temperature range for this analysis.

4.3. Uranium Properties

The specific heat of uranium at 600 K (620 °F) is 146 J/kg-K and the density of uranium is 19070 kg/m^3 (Ref. 2.2, pg. 822). A temperature of 620 °F is in the temperature range (less than the midpoint for both ranges) of this analysis. From Reference 2.2, the specific heat slightly increases with an increase in temperature. At higher temperatures, the uranium would heat up more slowly. This temperature is representative of the full temperature range for this analysis.

4.4. Geometry for Westinghouse 422V+ Assemblies

The table below shows the geometry inputs for the fuel assemblies used in this analysis.

Table 4-1: Fuel Assembly Inputs (from USAR Table 3.2-8, Ref. 2.3)

Uranium Pellet Diameter	0.3659 inches
Inner Diameter of Cladding	0.3734 inches
Outer Diameter of Cladding	0.422 inches
Rod Configuration and Total Rods	14 x 14, 196 total spaces
Number of Guide Tubes, Instrument Tubes	16 guide, 1 instrument
Total Number of Heated Rods	179 rods
Inner Diameter of Guide Tubes (Above Dashpot)	0.492 inches
Outer Diameter of Guide Tubes (Above Dashpot)	0.526 inches

Table 4-1 Continued

Heated Height of Rods	143.25 inches
Cladding and Guide Tube Material	ZIRLO Zirconium
Theoretical Uranium Density Percentage	96.56%

4.5. Heat Load

Reference 2.5 determines the maximum heat load from a single assembly. The assembly with the highest heat load will have the shortest heat-up time. The table showing the maximum fuel assembly heat generation rate for several years is located in Attachment A. The heat generation rates were calculated using the computer program HEATUP. Per Reference 2.5, the results in HEATUP are conservative compared to ORIGEN models.

5. **Assumptions**

5.1. All of the fuel assemblies are assumed to be Westinghouse 422V+ fuel. This is appropriate because the most recent design consisted of a full core of 422V+ assemblies (Ref. 2.3, pg. 3.2-22). The most recently offloaded assemblies are limiting in terms of heat generation.

5.2. The properties of pure zirconium are used for the specific heat and density of the zirconium alloy cladding. Based on an examination of alloys of some metals (e.g. aluminum, nickel, or steel) in Table A.1 of Reference 2.2, the density and specific heat are not significantly impacted by alloying.

5.3. Details of the thermal mass of the instrument tube are unavailable. For simplicity, the instrument tube is assumed to be identical to the guide tubes. This is appropriate because there are 16 guide tubes and one instrument tube, and the guide tubes are hollow while the instrument tube may have other thermal mass of the instruments.

5.4. The starting temperature for the heat-up analysis is assumed to be uniform and 90 °F (32 °C). A temperature of 90 °F is selected as representative of the current pool conditions (see Attachment C). The water temperature in the pool will continue to decrease over time due to a reduction in the heat load. It is appropriate to use a realistic value for the initial temperature due to the inherently conservative methodology (i.e. no heat transfer to the environment). In addition, this temperature is consistent with the sample analysis performed in SECY-99-168, where the starting temperature was 30 °C (86 °F).

5.5. The heat-up time is assumed to start when the spent fuel pool has been completely drained. This is conservative. It is likely that site personnel will start to respond to an incident when draindown starts.

6. Methodology

This analysis determines the heat-up time of the fuel assembly using the thermal capacity of materials (Based on Section 2.3 of Ref. 2.2).

$$\dot{q} = \rho \times V \times c_p \times \frac{\Delta T}{t} \qquad \text{Equation 6-1}$$

Where:

$\dot{q}$ is the heat generation rate in BTU/hr
ρ is the density of the material in lb/ft^3
V is the volume of the material in ft^3
c_p is the specific heat in BTU/lb-°F
ΔT is the temperature increase in °F
t is the heat-up time in hr

For this analysis, there are two materials being heated: the uranium fuel pellets and the ZIRLO zirconium alloy cladding. The zirconium is in the cladding and the instrument tubes, which are also being heated. The zirconium and the uranium are modeled as heating up at the same rate, so the $\Delta T/t$ will be the same for both materials.

$$\dot{q} = \frac{\Delta T}{t} \times \left(\rho_u \times V_u \times c_{p,u} + \rho_z \times V_z \times c_{p,z}\right) \qquad \text{Equation 6-2}$$

Where:

X_u signifies the property is for uranium
X_z signifies the property is for zirconium

This calculation seeks the heat-up time, so Equation 6-2 is solved for t.

$$t = \frac{\Delta T}{\dot{q}} \times \left(\rho_u \times V_u \times c_{p,u} + \rho_z \times V_z \times c_{p,z}\right) \qquad \text{Equation 6-3}$$

The volume of uranium is given below.

$$V_u = \left(\pi \times \frac{D_p^{\,2}}{4}\right) N_{hr} \times L \qquad \text{Equation 6-4}$$

Where:

D_p is the diameter of the uranium pellet
N_{hr} is the number of heated rods
L is the heated length of the rods

The volumes of zirconium in the heated rods and in the guide tubes are given below. The length of the cladding and guide tubes that are heated is conservatively modeled as being the same as the heated length of uranium. The guide tubes and cladding are longer than the length of the uranium pellets.

$$V_{z,c} = \left(\pi \times \frac{D_{c,o}^{\ 2} - D_{c,i}^{\ 2}}{4} \right) N_{hr} \times L$$ Equation 6-5

$$V_{z,g} = \left(\pi \times \frac{D_{g,o}^{\ 2} - D_{g,i}^{\ 2}}{4} \right) N_{gt} \times L$$ Equation 6-6

$$V_z = V_{z,g} + V_{z,c}$$ Equation 6-7

Where:

$V_{z,c}$ is the volume of zirconium in the cladding of heated tubes
$V_{z,g}$ is the volume of zirconium in the guide tubes
$D_{c,o}$ is the outer diameter of the cladding
$D_{c,i}$ is the inner diameter of the cladding
$D_{g,o}$ is the outer diameter of the guide tubes
$D_{g,i}$ is the inner diameter of the guide tubes
N_{gt} is the number of guide tubes

The temperature increase (ΔT) for this analysis is taken to be from the initial temperature of the pool, 90 °F (Assumption 5.4), to the zirconium cladding failure temperatures of interest, 1049 °F and 1652 °F (Input 4.1).

The heat-up time is calculated as a function of the decay time.

To avoid rounding, the Hottest Assembly column is recalculated in Attachment A based on the equations presented in Reference 2.5. Per Reference 2.5, the hottest assembly is calculated as:

$$Hottest\ Assembly = \left(\frac{Heat\ Load\ from\ Cycle\ 32\ Discharge\ Assemblies}{121} \right) \times 1.449$$

7. Results

The results are shown in Table 7-1 below (from Attachment B).

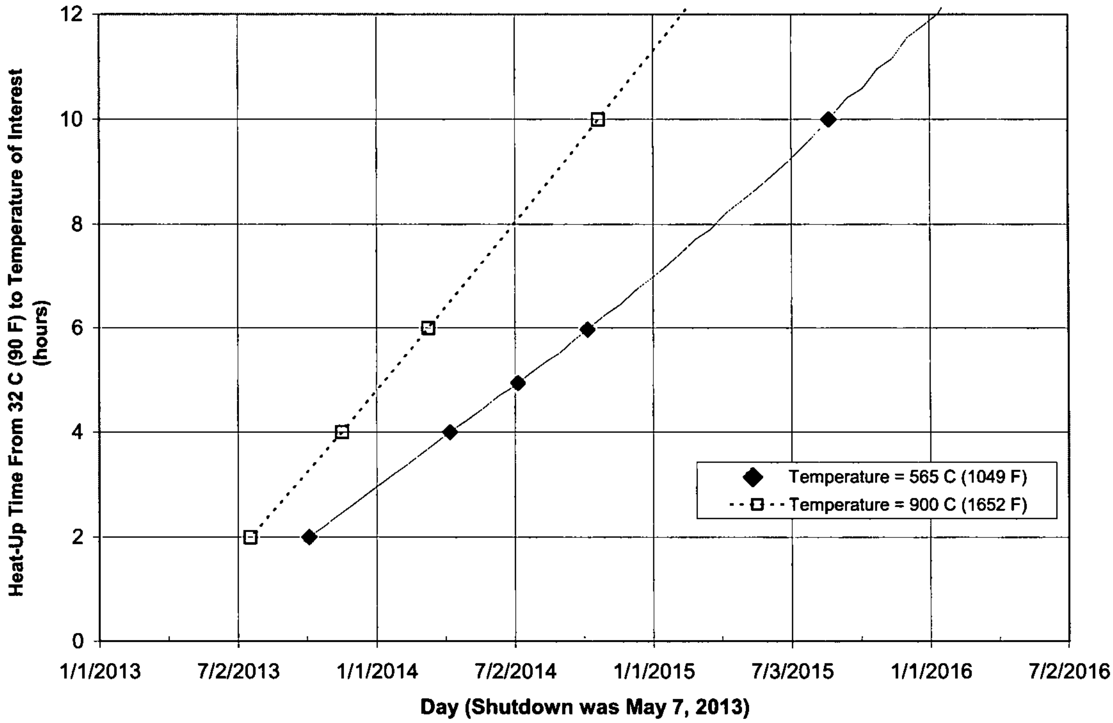
Table 7-1: Results

Date	End Temperature (°C, °F)	Decay Time (months)	Heat-Up Time (hours)
October 4th, 2013	565, 1049	~ 5	2.0
April 8th, 2014	565, 1049	~ 11	4.0
July 7th, 2014	565, 1049	14	4.9
October 7th, 2014	565, 1049	17	6.0
August 21st, 2015	565, 1049	~ 28	10.0
July 18th, 2013	900, 1652	~2	2.0
November 16th, 2013	900, 1652	~6	4.0
March 11th, 2014	900, 1652	~10	6.0
October 21st, 2014	900, 1652	~17	10.0

The 10 hour heat-up time to a temperature of 565 °C (1049 °F) occurs at a decay time of under 2.5 years, which is the expected decay time to a temperature of 900 °C (1652 °F) stated in SECY-99-168 (Ref. 2.4). The 10 hour heat-up time to a temperature of 900 °C (1652 °F) occurs at a decay time of roughly 1.5 years, which is less than the expected decay time calculated in NUREG-1738 (Ref. 2.7, pg. 2-3).

A plot showing the heat-up time to the temperatures of interest as a function of decay time is Figure 7-1.

Figure 7-1: Heat-Up Time vs. Decay Time



8. Conclusions and Recommendations

The Kewaunee results are more favorable than the analyses performed for SECY-99-168 (Ref. 2.4) and NUREG-1738 (Ref. 2.7). There are no acceptance criteria for this analysis. There are no specific recommendations for this analysis.

The primary input to this analysis is the heat generation rate, which is conservative. The heat generation rates were calculated using the computer program HEATUP. Per Reference 2.5, the results in HEATUP are conservative compared to ORIGEN models.

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
5/8/2013	0:00	32.25	0.386		5/8/2013	0	0.3862
5/8/2013	8:00	28.23	0.338		5/8/2013	0.33	0.3381
5/8/2013	16:00	26.62	0.319		5/8/2013	0.67	0.3188
5/9/2013	0:00	25.39	0.304		5/9/2013	1	0.3041
5/9/2013	8:00	24.36	0.292		5/9/2013	1.33	0.2917
5/9/2013	16:00	23.45	0.281		5/9/2013	1.67	0.2808
5/10/2013	0:00	22.62	0.271		5/10/2013	2	0.2709
5/10/2013	8:00	21.86	0.262		5/10/2013	2.33	0.2618
5/10/2013	16:00	21.15	0.253		5/10/2013	2.67	0.2533
5/11/2013	0:00	20.5	0.246		5/11/2013	3	0.2455
5/11/2013	8:00	19.9	0.238		5/11/2013	3.33	0.2383
5/11/2013	16:00	19.33	0.232		5/11/2013	3.67	0.2315
5/12/2013	0:00	18.81	0.225		5/12/2013	4	0.2253
5/13/2013	0:00	17.44	0.209		5/13/2013	5	0.2088
5/14/2013	0:00	16.3	0.195		5/14/2013	6	0.1952
5/15/2013	0:00	15.34	0.184		5/15/2013	7	0.1837
5/16/2013	0:00	14.52	0.174		5/16/2013	8	0.1739
5/17/2013	0:00	13.81	0.165		5/17/2013	9	0.1654
5/18/2013	0:00	13.19	0.158		5/18/2013	10	0.1580
5/19/2013	0:00	12.65	0.151		5/19/2013	11	0.1515
5/20/2013	0:00	12.16	0.146		5/20/2013	12	0.1456
5/21/2013	0:00	11.73	0.140		5/21/2013	13	0.1405
5/22/2013	0:00	11.34	0.136		5/22/2013	14	0.1358
5/23/2013	0:00	10.99	0.132		5/23/2013	15	0.1316
5/24/2013	0:00	10.67	0.128		5/24/2013	16	0.1278
5/25/2013	0:00	10.38	0.124		5/25/2013	17	0.1243
5/26/2013	0:00	10.11	0.121		5/26/2013	18	0.1211
5/27/2013	0:00	9.87	0.118		5/27/2013	19	0.1182
5/28/2013	0:00	9.64	0.115		5/28/2013	20	0.1154
5/29/2013	0:00	9.43	0.113		5/29/2013	21	0.1129
5/30/2013	0:00	9.24	0.111		5/30/2013	22	0.1107
5/31/2013	0:00	9.06	0.108		5/31/2013	23	0.1085
6/1/2013	0:00	8.88	0.106		6/1/2013	24	0.1063
6/3/2013	0:00	8.57	0.103		6/3/2013	26	0.1026
6/5/2013	0:00	8.29	0.099		6/5/2013	28	0.0993
6/7/2013	0:00	8.04	0.096		6/7/2013	30	0.0963
6/9/2013	0:00	7.8	0.093		6/9/2013	32	0.0934
6/11/2013	0:00	7.59	0.091		6/11/2013	34	0.0909
6/13/2013	0:00	7.38	0.088		6/13/2013	36	0.0884
6/15/2013	0:00	7.19	0.086		6/15/2013	38	0.0861
6/17/2013	0:00	7.01	0.084		6/17/2013	40	0.0839
6/19/2013	0:00	6.84	0.082		6/19/2013	42	0.0819
6/21/2013	0:00	6.68	0.080		6/21/2013	44	0.0800
6/25/2013	0:00	6.38	0.076		6/25/2013	48	0.0764
6/29/2013	0:00	6.11	0.073		6/29/2013	52	0.0732
7/3/2013	0:00	5.86	0.070		7/3/2013	56	0.0702

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
7/7/2013	0:00	5.64	0.068		7/7/2013	60	0.0675
7/11/2013	0:00	5.43	0.065		7/11/2013	64	0.0650
7/15/2013	0:00	5.24	0.063		7/15/2013	68	0.0628
7/19/2013	0:00	5.07	0.061		7/19/2013	72	0.0607
7/23/2013	0:00	4.91	0.059		7/23/2013	76	0.0588
7/27/2013	0:00	4.76	0.057		7/27/2013	80	0.0570
8/6/2013	0:00	4.42	0.053		8/6/2013	90	0.0529
8/16/2013	0:00	4.13	0.049		8/16/2013	100	0.0495
8/26/2013	0:00	3.88	0.046		8/26/2013	110	0.0465
9/5/2013	0:00	3.66	0.044		9/5/2013	120	0.0438
9/15/2013	0:00	3.46	0.041		9/15/2013	130	0.0414
9/25/2013	0:00	3.27	0.039		9/25/2013	140	0.0392
10/5/2013	0:00	3.11	0.037		10/5/2013	150	0.0372
10/15/2013	0:00	2.96	0.035		10/15/2013	160	0.0354
10/25/2013	0:00	2.82	0.034		10/25/2013	170	0.0338
11/4/2013	0:00	2.69	0.032		11/4/2013	180	0.0322
11/24/2013	0:00	2.46	0.030		11/24/2013	200	0.0295
12/14/2013	0:00	2.27	0.027		12/14/2013	220	0.0272
1/3/2014	0:00	2.1	0.025		1/3/2014	240	0.0251
1/23/2014	0:00	1.96	0.023		1/23/2014	260	0.0235
2/12/2014	0:00	1.84	0.022		2/12/2014	280	0.0220
3/4/2014	0:00	1.73	0.021		3/4/2014	300	0.0207
3/24/2014	0:00	1.63	0.020		3/24/2014	320	0.0195
4/13/2014	0:00	1.54	0.018		4/13/2014	340	0.0184
5/3/2014	0:00	1.47	0.018		5/3/2014	360	0.0176
5/23/2014	0:00	1.4	0.017		5/23/2014	380	0.0168
6/12/2014	0:00	1.33	0.016		6/12/2014	400	0.0159
7/2/2014	0:00	1.28	0.015		7/2/2014	420	0.0153
7/22/2014	0:00	1.22	0.015		7/22/2014	440	0.0146
8/11/2014	0:00	1.17	0.014		8/11/2014	460	0.0140
8/31/2014	0:00	1.13	0.013		8/31/2014	480	0.0135
9/20/2014	0:00	1.08	0.013		9/20/2014	500	0.0129
10/10/2014	0:00	1.04	0.012		10/10/2014	520	0.0125
10/30/2014	0:00	1	0.012		10/30/2014	540	0.0120
11/19/2014	0:00	0.97	0.012		11/19/2014	560	0.0116
12/9/2014	0:00	0.93	0.011		12/9/2014	580	0.0111
12/29/2014	0:00	0.9	0.011		12/29/2014	600	0.0108
1/18/2015	0:00	0.87	0.010		1/18/2015	620	0.0104
2/7/2015	0:00	0.84	0.010		2/7/2015	640	0.0101
2/27/2015	0:00	0.81	0.010		2/27/2015	660	0.0097
3/19/2015	0:00	0.79	0.009		3/19/2015	680	0.0095
4/8/2015	0:00	0.76	0.009		4/8/2015	700	0.0091
4/28/2015	0:00	0.74	0.009		4/28/2015	720	0.0089
5/18/2015	0:00	0.72	0.009		5/18/2015	740	0.0086
6/7/2015	0:00	0.7	0.008		6/7/2015	760	0.0084
6/27/2015	0:00	0.68	0.008		6/27/2015	780	0.0081

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
7/17/2015	0:00	0.66	0.008		7/17/2015	800	0.0079
8/6/2015	0:00	0.64	0.008		8/6/2015	820	0.0077
8/26/2015	0:00	0.62	0.007		8/26/2015	840	0.0074
9/15/2015	0:00	0.6	0.007		9/15/2015	860	0.0072
10/5/2015	0:00	0.59	0.007		10/5/2015	880	0.0071
10/25/2015	0:00	0.57	0.007		10/25/2015	900	0.0068
11/14/2015	0:00	0.56	0.007		11/14/2015	920	0.0067
12/4/2015	0:00	0.54	0.007		12/4/2015	940	0.0065
12/24/2015	0:00	0.53	0.006		12/24/2015	960	0.0063
1/13/2016	0:00	0.52	0.006		1/13/2016	980	0.0062
2/2/2016	0:00	0.5	0.006		2/2/2016	1000	0.0060
2/22/2016	0:00	0.49	0.006		2/22/2016	1020	0.0059
3/13/2016	0:00	0.48	0.006		3/13/2016	1040	0.0057
4/2/2016	0:00	0.47	0.006		4/2/2016	1060	0.0056
4/22/2016	0:00	0.46	0.005		4/22/2016	1080	0.0055

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
41402	0	32.25	0.386		=A3+B3	=0	=(C3/121)*1.449
41402	0.33333333	28.23	0.338		=A4+B4	=F4-F$3	=(C4/121)*1.449
41402	0.66666666	26.62	0.319		=A5+B5	=F5-F$3	=(C5/121)*1.449
41403	0	25.39	0.304		=A6+B6	=F6-F$3	=(C6/121)*1.449
41403	0.33333333	24.36	0.292		=A7+B7	=F7-F$3	=(C7/121)*1.449
41403	0.66666666	23.45	0.281		=A8+B8	=F8-F$3	=(C8/121)*1.449
41404	0	22.62	0.271		=A9+B9	=F9-F$3	=(C9/121)*1.449
41404	0.33333333	21.86	0.262		=A10+B10	=F10-F$3	=(C10/121)*1.449
41404	0.66666666	21.15	0.253		=A11+B11	=F11-F$3	=(C11/121)*1.449
41405	0	20.5	0.246		=A12+B12	=F12-F$3	=(C12/121)*1.449
41405	0.33333333	19.9	0.238		=A13+B13	=F13-F$3	=(C13/121)*1.449
41405	0.66666666	19.33	0.232		=A14+B14	=F14-F$3	=(C14/121)*1.449
41406	0	18.81	0.225		=A15+B15	=F15-F$3	=(C15/121)*1.449
41407	0	17.44	0.209		=A16+B16	=F16-F$3	=(C16/121)*1.449
41408	0	16.3	0.195		=A17+B17	=F17-F$3	=(C17/121)*1.449
41409	0	15.34	0.184		=A18+B18	=F18-F$3	=(C18/121)*1.449
41410	0	14.52	0.174		=A19+B19	=F19-F$3	=(C19/121)*1.449
41411	0	13.81	0.165		=A20+B20	=F20-F$3	=(C20/121)*1.449
41412	0	13.19	0.158		=A21+B21	=F21-F$3	=(C21/121)*1.449
41413	0	12.65	0.151		=A22+B22	=F22-F$3	=(C22/121)*1.449
41414	0	12.16	0.146		=A23+B23	=F23-F$3	=(C23/121)*1.449
41415	0	11.73	0.14		=A24+B24	=F24-F$3	=(C24/121)*1.449
41416	0	11.34	0.136		=A25+B25	=F25-F$3	=(C25/121)*1.449
41417	0	10.99	0.132		=A26+B26	=F26-F$3	=(C26/121)*1.449
41418	0	10.67	0.128		=A27+B27	=F27-F$3	=(C27/121)*1.449
41419	0	10.38	0.124		=A28+B28	=F28-F$3	=(C28/121)*1.449
41420	0	10.11	0.121		=A29+B29	=F29-F$3	=(C29/121)*1.449
41421	0	9.87	0.118		=A30+B30	=F30-F$3	=(C30/121)*1.449
41422	0	9.64	0.115		=A31+B31	=F31-F$3	=(C31/121)*1.449
41423	0	9.43	0.113		=A32+B32	=F32-F$3	=(C32/121)*1.449
41424	0	9.24	0.111		=A33+B33	=F33-F$3	=(C33/121)*1.449
41425	0	9.06	0.108		=A34+B34	=F34-F$3	=(C34/121)*1.449
41426	0	8.88	0.106		=A35+B35	=F35-F$3	=(C35/121)*1.449
41428	0	8.57	0.103		=A36+B36	=F36-F$3	=(C36/121)*1.449
41430	0	8.29	0.099		=A37+B37	=F37-F$3	=(C37/121)*1.449
41432	0	8.04	0.096		=A38+B38	=F38-F$3	=(C38/121)*1.449
41434	0	7.8	0.093		=A39+B39	=F39-F$3	=(C39/121)*1.449
41436	0	7.59	0.091		=A40+B40	=F40-F$3	=(C40/121)*1.449
41438	0	7.38	0.088		=A41+B41	=F41-F$3	=(C41/121)*1.449
41440	0	7.19	0.086		=A42+B42	=F42-F$3	=(C42/121)*1.449
41442	0	7.01	0.084		=A43+B43	=F43-F$3	=(C43/121)*1.449
41444	0	6.84	0.082		=A44+B44	=F44-F$3	=(C44/121)*1.449
41446	0	6.68	0.08		=A45+B45	=F45-F$3	=(C45/121)*1.449
41450	0	6.38	0.076		=A46+B46	=F46-F$3	=(C46/121)*1.449
41454	0	6.11	0.073		=A47+B47	=F47-F$3	=(C47/121)*1.449
41458	0	5.86	0.07		=A48+B48	=F48-F$3	=(C48/121)*1.449
41462	0	5.64	0.068		=A49+B49	=F49-F$3	=(C49/121)*1.449
41466	0	5.43	0.065		=A50+B50	=F50-F$3	=(C50/121)*1.449

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
41470	0	5.24	0.063		=A51+B51	=F51-F$3	=(C51/121)*1.449
41474	0	5.07	0.061		=A52+B52	=F52-F$3	=(C52/121)*1.449
41478	0	4.91	0.059		=A53+B53	=F53-F$3	=(C53/121)*1.449
41482	0	4.76	0.057		=A54+B54	=F54-F$3	=(C54/121)*1.449
41492	0	4.42	0.053		=A55+B55	=F55-F$3	=(C55/121)*1.449
41502	0	4.13	0.049		=A56+B56	=F56-F$3	=(C56/121)*1.449
41512	0	3.88	0.046		=A57+B57	=F57-F$3	=(C57/121)*1.449
41522	0	3.66	0.044		=A58+B58	=F58-F$3	=(C58/121)*1.449
41532	0	3.46	0.041		=A59+B59	=F59-F$3	=(C59/121)*1.449
41542	0	3.27	0.039		=A60+B60	=F60-F$3	=(C60/121)*1.449
41552	0	3.11	0.037		=A61+B61	=F61-F$3	=(C61/121)*1.449
41562	0	2.96	0.035		=A62+B62	=F62-F$3	=(C62/121)*1.449
41572	0	2.82	0.034		=A63+B63	=F63-F$3	=(C63/121)*1.449
41582	0	2.69	0.032		=A64+B64	=F64-F$3	=(C64/121)*1.449
41602	0	2.46	0.03		=A65+B65	=F65-F$3	=(C65/121)*1.449
41622	0	2.27	0.027		=A66+B66	=F66-F$3	=(C66/121)*1.449
41642	0	2.1	0.025		=A67+B67	=F67-F$3	=(C67/121)*1.449
41662	0	1.96	0.023		=A68+B68	=F68-F$3	=(C68/121)*1.449
41682	0	1.84	0.022		=A69+B69	=F69-F$3	=(C69/121)*1.449
41702	0	1.73	0.021		=A70+B70	=F70-F$3	=(C70/121)*1.449
41722	0	1.63	0.02		=A71+B71	=F71-F$3	=(C71/121)*1.449
41742	0	1.54	0.018		=A72+B72	=F72-F$3	=(C72/121)*1.449
41762	0	1.47	0.018		=A73+B73	=F73-F$3	=(C73/121)*1.449
41782	0	1.4	0.017		=A74+B74	=F74-F$3	=(C74/121)*1.449
41802	0	1.33	0.016		=A75+B75	=F75-F$3	=(C75/121)*1.449
41822	0	1.28	0.015		=A76+B76	=F76-F$3	=(C76/121)*1.449
41842	0	1.22	0.015		=A77+B77	=F77-F$3	=(C77/121)*1.449
41862	0	1.17	0.014		=A78+B78	=F78-F$3	=(C78/121)*1.449
41882	0	1.13	0.013		=A79+B79	=F79-F$3	=(C79/121)*1.449
41902	0	1.08	0.013		=A80+B80	=F80-F$3	=(C80/121)*1.449
41922	0	1.04	0.012		=A81+B81	=F81-F$3	=(C81/121)*1.449
41942	0	1	0.012		=A82+B82	=F82-F$3	=(C82/121)*1.449
41962	0	0.97	0.012		=A83+B83	=F83-F$3	=(C83/121)*1.449
41982	0	0.93	0.011		=A84+B84	=F84-F$3	=(C84/121)*1.449
42002	0	0.9	0.011		=A85+B85	=F85-F$3	=(C85/121)*1.449
42022	0	0.87	0.01		=A86+B86	=F86-F$3	=(C86/121)*1.449
42042	0	0.84	0.01		=A87+B87	=F87-F$3	=(C87/121)*1.449
42062	0	0.81	0.01		=A88+B88	=F88-F$3	=(C88/121)*1.449
42082	0	0.79	0.009		=A89+B89	=F89-F$3	=(C89/121)*1.449
42102	0	0.76	0.009		=A90+B90	=F90-F$3	=(C90/121)*1.449
42122	0	0.74	0.009		=A91+B91	=F91-F$3	=(C91/121)*1.449
42142	0	0.72	0.009		=A92+B92	=F92-F$3	=(C92/121)*1.449
42162	0	0.7	0.008		=A93+B93	=F93-F$3	=(C93/121)*1.449
42182	0	0.68	0.008		=A94+B94	=F94-F$3	=(C94/121)*1.449
42202	0	0.66	0.008		=A95+B95	=F95-F$3	=(C95/121)*1.449
42222	0	0.64	0.008		=A96+B96	=F96-F$3	=(C96/121)*1.449
42242	0	0.62	0.007		=A97+B97	=F97-F$3	=(C97/121)*1.449
42262	0	0.6	0.007		=A98+B98	=F98-F$3	=(C98/121)*1.449

Attachment A: Heat Generation Rate vs. Decay Time (from Ref. 2.5)

Date	Time	Heat Load from Cycle 32 Discharge Assemblies Only (MBTU/hr)	Hottest Fuel Assembly Estimate (MBTU/hr)		Date (Reprinted)	Days since May 8, 2013	Recalculated Hottest Assembly (MBTU/hr)
42282	0	0.59	0.007		=A99+B99	=F99-F$3	=(C99/121)*1.449
42302	0	0.57	0.007		=A100+B100	=F100-F$3	=(C100/121)*1.449
42322	0	0.56	0.007		=A101+B101	=F101-F$3	=(C101/121)*1.449
42342	0	0.54	0.007		=A102+B102	=F102-F$3	=(C102/121)*1.449
42362	0	0.53	0.006		=A103+B103	=F103-F$3	=(C103/121)*1.449
42382	0	0.52	0.006		=A104+B104	=F104-F$3	=(C104/121)*1.449
42402	0	0.5	0.006		=A105+B105	=F105-F$3	=(C105/121)*1.449
42422	0	0.49	0.006		=A106+B106	=F106-F$3	=(C106/121)*1.449
42442	0	0.48	0.006		=A107+B107	=F107-F$3	=(C107/121)*1.449
42462	0	0.47	0.006		=A108+B108	=F108-F$3	=(C108/121)*1.449
42482	0	0.46	0.005		=A109+B109	=F109-F$3	=(C109/121)*1.449

Attachment B: Analysis

Specific Heat of Uranium	146	J/kg-K	Input 4.3
Specific Heat of Uranium	0.035	BTU/lb-F	Conversion
Specific Heat of Zirconium	322	J/kg-K	Input 4.2
Specific Heat of Zirconium	0.077	BTU/lb-F	Conversion
Diameter of Fuel Uranium	0.3659	inches	Input 4.4
Inner Diameter of Zirconium	0.3734	inches	Input 4.4
Outer Diameter of Zirconium	0.422	inches	Input 4.4
Heated Rods per Assem	179	Rods	Input 4.4
Unheated Rods (Guide or Instrument Tubes)	17	Tubes	Input 4.4
ID of Guide Tubes	0.492	inches	Input 4.4
OD of Guide Tubes	0.526	inches	Input 4.4
Density of Uranium	19,070	kg/m^3	Input 4.3
Theoretical Density	96.56%		Input 4.4
Density of Uranium	1149.5	lb/ft^3	Conversion
Density of Zirconium	6570	kg/m^3	Input 4.2
Density of Zirconium	410.2	lb/ft^3	Conversion
Heated Length of Uranium	11.9375	feet	Input 4.4
Initial Temperature	90	F	Assumption 5.4
Final Temperature	1049	F	Input 4.1
Total temperature Increase	959	F	Initial Minus Final
Volume of Uranium	1.560	ft^3	Equation 6-4
Volume of Zirconium in a Heated Rod	0.451	ft^3	Equation 6-5
Volume of Zirconium in a Guide Tube	0.038	ft^3	Equation 6-6
Total Volume of Zirconium	0.489	ft^3	Equation 6-7
Assem Heat Generation at 14 Months	0.01515	MBTU/hr	Interpolated from Att. A
Time to Failure	4.94	hrs	Equation 6-3
Assem Heat Generation at 17 Months	0.01253	MBTU/hr	Interpolated from Att. A
Time to Failure	5.97	hrs	Equation 6-3
Heat Generation that Gives 2 Hour Heat-Up	0.03739	MBTU/hr	Iterated
Time to Failure	2.00	hrs	Equation 6-3
Date of Associated Heat Generation	10/4/2013		Interpolated from Att. A
Heat Generation that Gives 4 Hour Heat-Up	0.01869	MBTU/hr	Iterated
Time to Failure	4.00	hrs	Equation 6-3
Date of Associated Heat Generation	4/8/2014		Interpolated from Att. A
Heat Generation that Gives 10 Hour Heat-Up	0.00748	MBTU/hr	Iterated
Time to Failure	10.00	hrs	Equation 6-3
Date of Associated Heat Generation	8/21/2015		Interpolated from Att. A
NUREG-1783 Maximum Temperature (900 C)	1652	F	Input 4.1
Temperature Increase	1562	F	Initial Minus Final
Heat Generation that Gives 10 Hour Heat-Up	0.01218	MBTU/hr	Iterated
Time to Failure	10.00	hrs	Equation 6-3
Date of Associated Heat Generation	10/21/2014		Interpolated from Att. A
Heat Generation that Gives 6 Hour Heat-Up	0.02030	MBTU/hr	Iterated
Time to Failure	6.00	hrs	Equation 6-3
Date of Associated Heat Generation	3/11/2014		Interpolated from Att. A
Heat Generation that Gives 4 Hour Heat-Up	0.03045	MBTU/hr	Iterated
Time to Failure	4.00	hrs	Equation 6-3
Date of Associated Heat Generation	11/16/2013		Interpolated from Att. A
Heat Generation that Gives 2 Hour Heat-Up	0.06089	MBTU/hr	Iterated
Time to Failure	2.00	hrs	Equation 6-3
Date of Associated Heat Generation	7/18/2013		Interpolated from Att. A

	A	B	C	D	E	F
1	**Attachment B: Analysis**					
2						
3	Specific Heat of Uranium	146	J/kg-K	Input 4.3		
4	Specific Heat of Uranium	=B3*0.0009478/2.20462/(9/5)	BTU/lb-F	Conversion		
5	Specific Heat of Zirconium	322	J/kg-K	Input 4.2		
6	Specific Heat of Zirconium	=B5*0.0009478/2.20462/(9/5)	BTU/lb-F	Conversion		
7	*Diameter of Fuel Uranium*	*0.3659*	*inches*	*Input 4.4*		
8	Inner Diameter of Zirconium	0.3734	inches	Input 4.4		
9	Outer Diameter of Zirconium	0.422	inches	Input 4.4		
10	Heated Rods per Assem	179	Rods	Input 4.4		
11	Unheated Rods (Guide or Instrument Tubes)	17	Tubes	Input 4.4		
12	ID of Guide Tubes	0.492	inches	Input 4.4		
13	OD of Guide Tubes	0.526	inches	Input 4.4		
14	Density of Uranium	19070	kg/m^3	Input 4.3		
15	*Theoretical Density*	*0.9656*		*Input 4.4*		
16	Density of Uranium	=B14*2.20462/3.28084^3*B15	lb/ft^3	Conversion		
17	Density of Zirconium	6570	kg/m^3	Input 4.2		
18	Density of Zirconium	=B17*2.20462/3.28084^3	lb/ft^3	Conversion		
19	Heated Length of Uranium	=143.25/12	feet	Input 4.4		
20	Initial Temperature	90	F	Assumption 5.4		
21	Final Temperature	1049	F	Input 4.1		
22	Total temperature Increase	=B21-B20	F	Initial Minus Final		
23						
24	Volume of Uranium	=PI()*B7^2/4*B19/144*B10	ft^3	Equation 6-4		
25	Volume of Zirconium in a Heated Rod	=PI()*(B9^2-B8^2)/4*B19/144*B10	ft^3	Equation 6-5		
26	Volume of Zirconium in a Guide Tube	=PI()*(B13^2-B12^2)/4*B19/144*B11	ft^3	Equation 6-6		
27	Total Volume of Zirconium	=B25+B26	ft^3	Equation 6-7		
28						
29	Assem Heat Generation at 14 Months	='Attachment A'!H76-(5/20)*('Attachment A'!H76-'Attachment A'!H77)	MBTU/hr	Interpolated from Att. A		
30	Time to Failure	=$B$22/(B29*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
31						
32	Assem Heat Generation at 17 Months	='Attachment A'!H80-(17/20)*('Attachment A'!H80-'Attachment A'!H81)	MBTU/hr	Interpolated from Att. A		
33	Time to Failure	=$B$22/(B32*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
34						
35	Heat Generation that Gives 2 Hour Heat-Up	0.0373850764604915	MBTU/hr	Iterated		
36	Time to Failure	=$B$22/(B35*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
37	Date of Associated Heat Generation	='Attachment A'!F60+('Attachment A'!H60-B35)/('Attachment A'!H60-'Attachment A'!H61)*10		Interpolated from Att. A		
38						
39	Heat Generation that Gives 4 Hour Heat-Up	0.0186925354210505	MBTU/hr	Iterated		
40	Time to Failure	=$B$22/(B39*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
41	Date of Associated Heat Generation	='Attachment A'!F71+('Attachment A'!H71-B39)/('Attachment A'!H71-'Attachment A'!H72)*20		Interpolated from Att. A		
42						
43	Heat Generation that Gives 10 Hour Heat-Up	0.00747701366999636	MBTU/hr	Iterated		
44	Time to Failure	=$B$22/(B43*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
45	Date of Associated Heat Generation	='Attachment A'!F96+('Attachment A'!H96-B43)/('Attachment A'!H96-'Attachment A'!H97)*20		Interpolated from Att. A		
46						
47	NUREG-1783 Maximum Temperature (900 C)	1652	F	Input 4.1		
48	Temperature Increase	=B47-B20	F	Initial Minus Final		
49	Heat Generation that Gives 10 Hour Heat-Up	0.0121784105537324	MBTU/hr	Iterated		
50	Time to Failure	=$B$48/(B49*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
51	Date of Associated Heat Generation	='Attachment A'!F81+('Attachment A'!H81-B49)/('Attachment A'!H81-'Attachment A'!H82)*20		Interpolated from Att. A		
52						
53	Heat Generation that Gives 6 Hour Heat-Up	0.0202973514135572	MBTU/hr	Iterated		
54	*Time to Failure*	*=$B$48/(B53*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)*	*hrs*	*Equation 6-3*		
55	Date of Associated Heat Generation	='Attachment A'!F70+('Attachment A'!H70-B53)/('Attachment A'!H70-'Attachment A'!H71)*20		Interpolated from Att. A		
56						
57	Heat Generation that Gives 4 Hour Heat-Up	0.0304460281462153	MBTU/hr	Iterated		
58	Time to Failure	=$B$48/(B57*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)	hrs	Equation 6-3		
59	Date of Associated Heat Generation	='Attachment A'!F64+('Attachment A'!H64-B57)/('Attachment A'!H64-'Attachment A'!H65)*20		Interpolated from Att. A		
60						
61	Heat Generation that Gives 2 Hour Heat-Up	0.0608920616935551	MBTU/hr	Iterated		
62	*Time to Failure*	*=$B$48/(B61*10^6)*($B$16*$B$24*$B$4+$B$18*$B$27*$B$6)*	*hrs*	*Equation 6-3*		
63	Date of Associated Heat Generation	='Attachment A'!F51+('Attachment A'!H51-B61)/('Attachment A'!H51-'Attachment A'!H52)*4		Interpolated from Att. A		

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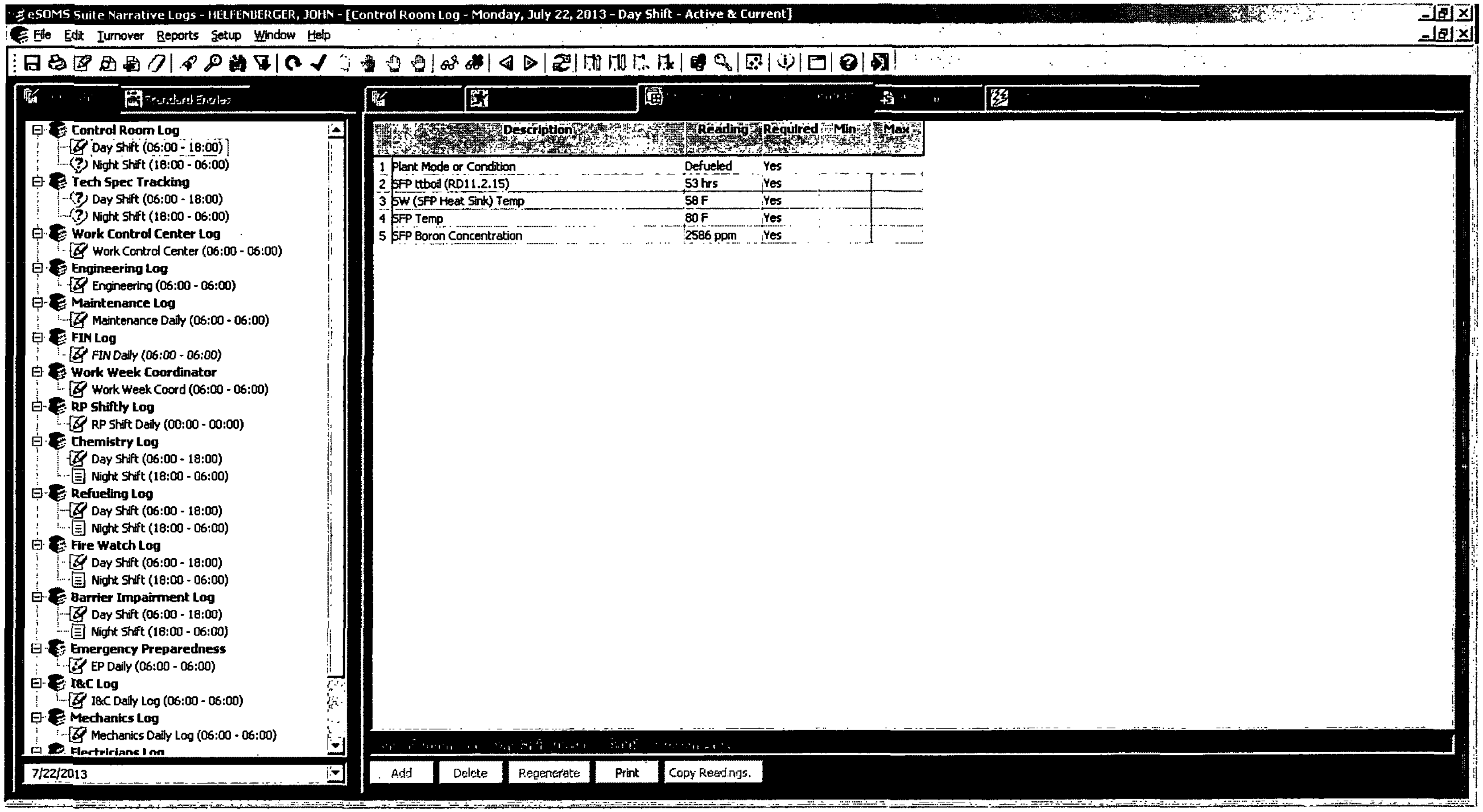
eSOMS Suite Narrative Logs - HELFENBERGER, JOHN - [Control Room Log - Monday, July 22, 2013 - Day Shift - Active & Current]
File Edit Turnover Reports Setup Window Help
Control Room Log
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Tech Spec Tracking
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Work Control Center Log
Work Control Center (06:00 - 06:00)
Engineering Log
Engineering (06:00 - 06:00)
Maintenance Log
Maintenance Daily (06:00 - 06:00)
FIN Log
FIN Daily (06:00 - 06:00)
Work Week Coordinator
Work Week Coord (06:00 - 06:00)
RP Shiftly Log
RP Shift Daily (00:00 - 00:00)
Chemistry Log
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Refueling Log
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Fire Watch Log
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Barrier Impairment Log
Day Shift (06:00 - 18:00)
Night Shift (18:00 - 06:00)
Emergency Preparedness
EP Daily (06:00 - 06:00)
I&C Log
I&C Daily Log (06:00 - 06:00)
Mechanics Log
Mechanics Daily Log (06:00 - 06:00)
7/22/2013
Description Reading Required Min Max
1 Plant Mode or Condition Defueled Yes
2 SFP ttboil (RD11.2.15) 53 hrs Yes
3 SW (SFP Heat Sink) Temp 58 F Yes
4 SFP Temp 80 F Yes
5 SFP Boron Concentration 2586 ppm Yes
Add Delete Regenerate Print Copy Readings