Nuclear Engineering
CALCULATION CONTROL SHEET

Nuclear Plant: IP3 ☑ JAF ☐

CALC. NO. IP3-CALC-SFP-02065 REVISION 0

CALCULATION IS: PRELIMINARY ___ FINAL x

	NAME	SIGNATURE	DATE
PREPARER:	F. Gumble	[signature]	11/18/96
CHECKER:	G. Canavan	G. Canavan	11/18/96
(DESIGN) VERIFIED/NA	M. Powers	[signature]	11/20/96
APPROVED:	G. Grochowski	[signature]	11/20/96

ORIGINATOR: NYPA ☑ OR OTHER ☐

SYSTEM NO./NAME Spent Fuel Pit

TITLE: Verification of SFP Thermal/Hydraulic Analyses

QA CATEGORY: I DISCIPLINE: Rx Eng STRUCTURE: SFP

MODIFICATION NO./TASK NO. N/A DBD REF. NO. ____

PROBLEM/OBJECTIVE/METHOD Formally confirm the conclusions of Refs. 7.1 and 7.2, which established that the increased fuel enrichment level of 5.0 w/o U-235 has no effect on the SFP thermal-hydraulic analyses performed to date. Also include results of Westinghouse's analysis for an ultimate heat sink temperature of 95°F.

DESIGN BASIS/ASSUMPTION See Section 3.0

SUMMARY/CONCLUSIONS Any incremental increase in decay heat load resulting from extended service with 5.0 w/o enriched fuel is more than compensated by the greater time period between refueling outages.

THIS CALC SUPERSEDES OR VOIDS CALC. NO. None

DISTRIBUTION: C= CONTROLLED I= INFO

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CALCULATION SHEET

New York Power Authority	
CALCULATION NO. IP3-CALC-SFP-02065	REVISION 0
Project N/A	Page 1 of 13
Title Verification of SFP T/H Analyses	Date Nov 12 ,1996
Preliminary ___ Prepared by F. Gumble FMG	Date 11/18/96
Final X Checked by [illegible]	Date 11/18/96

1.0 BACKGROUND AND PURPOSE

1.1 Using approved models and methodololgy, reconcile all outstanding thermal-hydraulic analyses of record for the Spent Fuel Pit (SFP), in light of the increased maximum fuel enrichment level of 5.0 weight percent (w/o) U-235.

1.2 This calculation also serves as a formal verification of the conclusions drawn in memoranda (Refs. 7.1 and 7.2) that show an increased fuel enrichment has no effect on the thermal-hydraulic analyses.

2.0 BACKGROUND

2.1 The original SFP racks at IP3 were replaced in 1978, prior to the first refuelling outage. The new racks were classified as high-density storage racks and held up to 854 fuel assemblies (FAs). In 1990, the SFP racks were again replaced, this time with maximum density racks holding up to 1345 FAs.

For both reracking projects, a thermal-hydraulic safety analysis was performed, showing that the decay heat load resulting from partial-core discharge would not result in the SFP temperature increasing above 150°F. Similarly, the decay heat load resulting from full-core discharge would not result in the SFP temperature increasing above 200°F. These limiting temperatures are taken from the design basis for the plant (Reference 7.3).

This analysis was revisited by Westinghouse in 1989, at which time the plant was analyzed for an increased Service Water System temperature of up to 95°F (Reference 7.5). Westinghouse found that there was adequate margin in the analysis of record to support increased service water temperature without SFP temperature exceeding design basis limits.

In 1996, NYPA proposed an amendment to the IP3 Technical Specifications (Tech Specs) allowing fuel enrichment level to be increased from 4.5 w/o to 5.0 w/o U-235. This is to support equilibrium 24-month fuel cycle designs. An accompanying criticality analysis was prepared by Westinghouse in support of this increased fuel enrichment. No formal thermal hydraulic analysis was performed because decay heat rate is a function of thermal power level and not fuel enrichment. Furthermore, the number of assemblies in the pool were not changing and the requirements for fuel discharge rate did not change (145 hours for partial core unload, 267 hours for full-core unload, per Tech Specs Section 3.8).

However, since the source term for decay heat load is asymptotic, operation for a longer period always increases decay heat load, even if by only a slight amount. However, as this calculation (consistent with past evaluations) will show, this is compensated for by the longer interval between refuelings.

This was originally demonstrated to be true in a report prepared in 1993 (Reference 7.1), assuming 72 FAs transferred to the SFP after 145 hours (72 hours was the Tech Spec limit at that time). This report was revisited in 1996 (Reference 7.2) to allow for the increased number of fuel assemblies (76) transferred to the SFP, as reflected in the proposed Tech Spec amendment (Reference 7.9).

This calcuation combines the results of all currently applicable thermal evaluations for the SFP and summarizes them in a single controlled document.

3.0 ASSUMPTIONS

3.1 This calculation is a variation on the SFP thermal-hydraulic analysis (Ref. 7.4), corrected for 95°F river water and expanded for larger core unloads. All assumptions used in this calculation are the same as those in Ref. 7.4. These assumptions include:

3.1 Instantaneous transportation of fuel from core to SFP (the margin resulting from this assumption is quantified in more detail in Section 4.4.2).

3.2 Decay heat load calculated in accordance with Branch Technical Position ASB 9-2, allowing for a 10% penalty on source term (Ref. 7.6). The decay heat program has been formally verified and validated in accordance with plant procedures (Ref 7.10).

3.3 SFP heat exchanger degradation of 10% (i.e, heat exchange capacity reduced by a multiple of 0.9) is routinely assumed in the analyses, even though this is not part of the IP3 design basis.

3.4 The SFP thermal model is extremely conservative, in that it presumes a point-source for decay heat loads and a linear heatup rate on loss of cooling, with no credit taken for natural circulation effects (although the model does evaluate natural circulation cooling effects for calculation of peak clad temperatures). Furthermore, the model does not credit heat transfer to the large air space over the SFP.

4.0 CALCULATIONS

4.1 As noted above, the original thermal-hydraulic analysis for the SFP racks presumes 76 fuel assemblies unloaded from the core and instantaneously transported to the SFP. Reference 7.1 repeats the original US Tool & Die analysis assuming 72 assemblies discharged after 145 hours (the current Tech Spec limit) and a burnup commensurate with 24-month operation, i.e.,

--- 48 assemblies at 1725 EFPD
--- 24 assemblies at 1150 EFPD

The resultant heat load is 16.86 MBTU/hr, which compares to the US Tool & Die value of 17.48 MBTU/hr and is therefore bounded by the existing calculation. The calculation assumes a completely filled SFP, with allowance for one full core offload, and the pit loading schedule appears on Table 2 of Reference 7.1.

4.2 Since the proposed Tech Spec amendment increases the number of unloaded assemblies from 72 to 76, this calculation is repeated here for:

--- 50 assemblies at 1725 EFPD
--- 26 assemblies at 1150 EFPD

As in Step 4.1, the calculation assumes a completely filled SFP, with allowance for one full core offload. The pit loading schedule appears on Table 1 of this calculation. Note that the offload schedule has been altered to allow for the long mid-cycle outage in Cycle 9. This reduces the total heat load slightly, as the fuel from the first 8 operating cycles has a longer decay time.

The total heat load resulting from this calculation is 17.38 MBTU/hr, which is again less than the design basis value of 17.48 MBTU/hr.

These two scenarios result in approximately the same decay heat load after 145 hours subcritical, and both are consistent with the existing thermal analysis of record, which proves that a SFP temperature of 150°F will not be exceeded with a decay heat load of $\leq$ 17.48 MBTU/hr.

4.3 The case of total core discharge was similarly re-evaluated in Reference 7.1, allowing for greater assembly burnup and two-year operating cycles. This calculation went further than the existing analysis of record in that it reviewed potential emergency core unloads for varying times in core life. A summary of the results appears on Table 3. The limiting condition turned out to be for a core burnup of 200 Effective Full-Power Days (EFPDs), but all scenarios resulted in heat sources less than the current design basis of 35.00 MBTU/hr.

4.4 The two scenarios described above must now be further extended for consistency with the Westinghouse analysis for an Ultimate Heat Sink temperature of 95°F. In their evaluation (Reference 7.5), Westinghouse independently verified that the heat loads and cooling capacity in the SFP would not result in SFP bulk temperature exceeding 150°F for an ultimate heat sink (Hudson River) temperature of ≤95°F.

For the purposes of consistency, the same comparison will be applied to this calculation. This provides an independent check of Westinghouse's conclusions and serves as an "apples to apples" comparison of the two thermal analyses.

4.4.1 For full-core unload, the greatest heat source is 30.32 MBTU/hr. The equation to determine SFP temperature is (from Reference 7.4):

$$T_{max\ SFP} = T_{c1} + (q / (C_m * \epsilon) \qquad \textbf{[Eq. 1]}$$

where T_{c1} = CCW Temperature of 100°F
q = Heat load in BTU/hr
C_m = Tube side HX flow, 1.1E+06 lb/hr
ϵ = Heat exchanger effectiveness, 0.3185

For q = 30.32E+06 BTU/hr, $T_{max\ SFP}$ = 186.5°F

The design basis requirement is a temperature no higher than 200°F for full-core unload.

The CCW temperature of 100°F was chosen to be conservatively high in the original thermal analysis. Westinghouse's reanalysis for 95°F river water concludes that the CCW temperature will be no greater than 101°F. Therefore, if we increase $T_{max\ SFP}$ by 1°F, it results in a temperature of 187.5°F, which is consistent with design basis requirements.

4.4.2 For partial core unloads, the limiting heat load as shown in Section 4.2 is 17.38 MBTU/hr. When this value of q is applied to the Equation 1, the resultant SFP temperature is:

$$T_{max\ SFP} = 149.6°F$$

This temperature is below the design basis value of 150°F, but if CCW temperature is increased by 1°F, design basis temperature will be exceeded.

To compensate for that, we consider the very conservative assumption (Section 3.1) that assumes instantaneous movement of fuel from the reactor core to the SFP exactly 145 hours after subcriticality. Needless to say, this is an impossible condition, but it has been used in the past to simplify the calculations.

If, on the other hand, this is replaced by a core unload of 5 assemblies per hour, the heat load is reduced to 17.116 MBTU/hr, with a resultant $T_{max\ SFP}$ of 148.9°F. Adding 1°F to this for a CCW temperature of 101°F keeps SFP temperature within the design basis.

The model demonstrating this unload process is shown on Table 4. In this model, ten fuel assemblies are added instantaneously to the SFP every other hour, beginning 145 hours after subcriticality. By point of comparison, a typical core unload takes from 48 to 72 hours (i.e., an average discharge rate of 3 to 4 FAs per hour), which is slower than the postulated 5 assemblies per hour. Therefore, the calculations for partial core unload remain consistent with the thermal analysis, allowing for increased CCW temperature.

4.4.3 As a final note, the reader is reminded of the extremely conservative assumptions involved in this calculation, as noted in Section 3.0. Assuming 10% degradation of the SFP heat exchanger adds a considerable margin of conservatism. Furthermore, not accounting for the effects of natural circulation or heat transfer to the air above the pool, adds a considerable penalty to the calculations for loss of cooling. Finally, it should be noted that the SFP heatup rate has been benchmarked against the standard model at SFP temperatures of 90 - 116°F (Reference 7.8). This was done during a 2-day period in 1994 when piping maintenance was being performed, at which time SFP cooling was secured and SFP heatup rate was being continuously monitored. For this particular case, it was shown that the actual heatup rate was approximately half of the predicted rate.

The results of this benchmark are attached as Figure 1.

5.0 SUMMARY AND CONCLUSION

This calculation concludes that the existing thermal analysis for the SFP remains valid and applicable, even when allowing for the effects of increased burnup fuel and an ultimate heat sink temperature of 95°F.

6.0 PROCEDURES AFFECTED BY THIS CALCULATION

NONE

CALCULATION SHEET

New York Power Authority	
CALCULATION NO. IP3-CALC-SFP-02065	REVISION 0
Project N/A	Page 8 of 13
Title Verification of SFP T/H Analyses	Date Nov 12, 1996
Preliminary ___ Prepared by F. Gumble [signature]	Date 11/21/96
Final X Checked by [signature]	Date 11/22/96

7.0 REFERENCES

7.1 Memorandum REC-93-115, Gumble to Green, "Tech Spec Amendment on Fuel Enrichment," 7/6/93

7.2 Memorandum RET-96-164, Gumble to distribution, "Full-Core Unload Analysis for IP3," 6/5/96

7.3 FSAR Section 9.3.1

7.4 Report 8721-00-0104, Thermal-Hydraulic Report, Spent Fuel Pit Storage Racks, Indian Point Unit #3," US Tool and Die, November 1987

7.5 WCAP-12313, "Safety Evaluation for an Ultimate Heat Sink Temperature Increased to 95 °F at IP-3", Westinghouse Electric Corp

7.6 Branch Technical Position ASB-9.2, "Residual Decay for Light-Water Reactors for Long-Term Cooling" USNRC Standard Review Plan

7.7 Computer program HOTPOOL, Software Item #201, CMM Procedure 5.1.5-REF, "Controlled Software Catalog"

7.8 Memorandum RET-94-169, Gumble to Canavan, "Spent Fuel Pit Temperature Transient", 8/12/94

7.9 Letter IPN-96-092, "Proposed Technical Specification Amendment Associated with Increased Fuel Pellet Enrichment to 5.0 w/o U-235," 8/23/96

7.10 IP3 Procedure ENG-308, "Decay Heat Power Computer Program Verification"

CALCULATION SHEET

New York Power Authority			
CALCULATION NO. IP3-CALC-SFP-02065		REVISION 0	
Project N/A		Page 9 of 13	
Title Verification of SFP T/H Analyses		Date Nov 12, 1996	
Preliminary	Prepared by F. Gumble	Date 11/13/96	
Final X	Checked by	Date 11/18/96	

Table 1
SFP Loading Schedule - Partial Core Unload of 72 Assemblies
24-Month Operation, 5.0 w/o Enrichment

(from Reference 7.1)

HEAT LOAD IN SPENT FUEL PIT

NO. OF ASSYS	T-OPERA-TING(EFPD)	T-COOL-ING(D)	HE* (BTU/HR)	HEAT LOAD (BTU/HR)	HEAT LOAD (MW)
64	505	10893	.00000E+00	.12670E+06	.37101E-01
76	833	10429	.00000E+00	.17917E+06	.52467E-01
53	1206	9507	.00000E+00	.15255E+06	.44672E-01
23	701	9507	.00000E+00	.54506E+05	.15961E-01
41	1112	8336	.00000E+00	.12329E+06	.36103E-01
31	784	8336	.00000E+00	.82161E+05	.24059E-01
41	1201	7642	.00000E+00	.13312E+06	.38983E-01
38	829	7642	.00000E+00	.10736E+06	.31439E-01
1	417	7642	.00000E+00	.23463E+04	.68707E-03
4	1220	7000	.00000E+00	.13634E+05	.39926E-02
38	1264	7000	.00000E+00	.13147E+06	.38500E-01
22	853	7000	.00000E+00	.65460E+05	.19169E-01
50	1247	6409	.00000E+00	.17880E+06	.52357E-01
20	830	6409	.00000E+00	.61288E+05	.17947E-01
2	394	6409	.00000E+00	.50287E+04	.14726E-02
59	1244	5830	.00000E+00	.21892E+06	.64105E-01
21	808	5830	.00000E+00	.66244E+05	.19398E-01
24	1150	5119	.00000E+00	.90319E+05	.26448E-01
48	1725	5119	.00000E+00	.21653E+06	.63407E-01
24	1150	4389	.00000E+00	.94751E+05	.27746E-01
48	1725	4389	.00000E+00	.22716E+06	.66518E-01
24	1150	3658	.00000E+00	.99443E+05	.29120E-01
48	1725	3658	.00000E+00	.23839E+06	.69808E-01
24	1150	2927	.00000E+00	.10460E+06	.30629E-01
48	1725	2927	.00000E+00	.25066E+06	.73399E-01
24	1150	2198	.00000E+00	.11147E+06	.32642E-01
48	1725	2198	.00000E+00	.26657E+06	.78059E-01
24	1150	1467	.00000E+00	.12833E+06	.37579E-01
48	1725	1467	.00000E+00	.30332E+06	.88821E-01
24	1150	737	.00000E+00	.20984E+06	.61448E-01
48	1725	737	.00000E+00	.47435E+06	.13890E+00
24	1150	6	.33121E+06	.40833E+07	.11957E+01
48	1725	6	.66241E+06	.82612E+07	.24191E+01

TOTAL HEAT LOAD = 1.686225E+07 BTU/HR
= 4.937773 MW

TEMPERATURE OF SFP AFTER 145 HOURS = 148.1827 DEG F.
ASSUMING 100 DEG F CCW TEMPERATURE AND 10% HX DEGRADATION.

10% MARGIN ON SOURCE INCLUDED AS PER ASB 9-2

*Note: On this and subsequent tables, "HE" refers to the heat load contributed by heavy elements U-239 and Np-239

CALCULATION SHEET

New York Power Authority
CALCULATION NO. IP3-CALC-SFP-02065 REVISION 0

Project N/A Page 10 of 13
Title Verification of SFP T/H Analyses Date Nov 12 , 1996
Preliminary_____ Prepared by F. Gumble Date 11/13/96
Final X Checked by Date 11/18/96

Table 2
SFP Loading Schedule - Partial Core Unload of 76 Assemblies
24-Month Operation, 5.0 w/o Enrichment

(from Reference 7.2)

HEAT LOAD IN SPENT FUEL PIT

NO. OF ASSYS	T-OPERATING(EFPD)	T-COOLING(D)	HE (BTU/HR)	HEAT LOAD (BTU/HR)	HEAT LOAD (MW)
64	505	10906	.00000E+00	.12659E+06	.37069E-01
76	833	10442	.00000E+00	.17902E+06	.52422E-01
53	1206	9522	.00000E+00	.15240E+06	.44628E-01
23	701	9522	.00000E+00	.54452E+05	.15945E-01
41	1112	8351	.00000E+00	.12317E+06	.36068E-01
31	784	8351	.00000E+00	.82080E+05	.24035E-01
41	1201	7655	.00000E+00	.13301E+06	.38949E-01
38	829	7655	.00000E+00	.10727E+06	.31413E-01
1	417	7655	.00000E+00	.23443E+04	.68649E-03
4	1220	7013	.00000E+00	.13623E+05	.39892E-02
38	1264	7013	.00000E+00	.13136E+06	.38467E-01
22	853	7013	.00000E+00	.65404E+05	.19152E-01
50	1247	6420	.00000E+00	.17867E+06	.52319E-01
20	830	6420	.00000E+00	.61243E+05	.17934E-01
2	394	6420	.00000E+00	.50251E+04	.14715E-02
59	1244	5843	.00000E+00	.21873E+06	.64051E-01
21	808	5843	.00000E+00	.66187E+05	.19382E-01
26	1150	4389	.00000E+00	.10265E+06	.30058E-01
50	1725	4389	.00000E+00	.23662E+06	.69290E-01
26	1150	3658	.00000E+00	.10773E+06	.31547E-01
50	1725	3658	.00000E+00	.24832E+06	.72717E-01
26	1150	2927	.00000E+00	.11331E+06	.33181E-01
50	1725	2927	.00000E+00	.26110E+06	.76458E-01
26	1150	2198	.00000E+00	.12076E+06	.35362E-01
50	1725	2198	.00000E+00	.27768E+06	.81312E-01
26	1150	1467	.00000E+00	.13902E+06	.40711E-01
50	1725	1467	.00000E+00	.31596E+06	.92521E-01
26	1150	737	.00000E+00	.22733E+06	.66568E-01
50	1725	737	.00000E+00	.49411E+06	.14469E+00
26	1150	6	.35881E+06	.44236E+07	.12954E+01
50	1725	6	.69001E+06	.86054E+07	.25199E+01

TOTAL HEAT LOAD = 1.737413E+07 BTU/HR
= 5.087667 MW

TEMPERATURE OF SFP AFTER 6.04167 DAYS = 149.6453 DEG F,
ASSUMING 100 DEG F CCW TEMPERATURE AND 10% HX DEGRADATION.

10% MARGIN ON SOURCE INCLUDED AS PER ASB 9-2

CALCULATION SHEET

New York Power Authority		
CALCULATION NO. IP3-CALC-SFP-02065		REVISION 0
Project N/A		Page 11 of 13
Title Verification of SFP T/H Analyses		Date Nov 12 ,1996
Preliminary	Prepared by F. Gumble	Date 11/13/96
Final X	Checked by	Date 11/18/96

Table 3
Heat Load for Various Postulated Full-Core Discharges
24-Month Operation, 5.0 w/0 Enrichment

(from Reference 7.1)

Scenario	Heat Source Strength (MBTU/hr) Existing Analysis*	New Evaluation
1	17.48	16.86
2 (30 EFPD)	35.00	28.49
2 (200 EFPD)	35.00	30.32
2 (350 EFPD)	35.00	29.99
2 (575 EFPD)	35.00	30.20

(*Existing analysis currently assumes one bounding case for each scenario)

CALCULATION SHEET

New York Power Authority
CALCULATION NO. IP3-CALC-SFP-02065 REVISION 0

Project N/A Page 12 of 13
Title Verification of SFP T/H Analyses Date Nov 12 ,1996
Preliminary ____ Prepared by F. Gumble [illegible] Date 11/13/96
Final X Checked by [illegible] Date 11/18/96

Table 4
SFP Loading Schedule - Partial Core Unload of 76 Assemblies
24-Month Operation, 5.0 w/o Enrichment

(Average Assembly Discharge Rate of 5 FAs per Hour)

HEAT LOAD IN SPENT FUEL PIT

NO. OF ASSYS	T-OPERA-TING(EFPD)	T-COOL-ING(D)	HE (BTU/HR)	HEAT LOAD (BTU/HR)	HEAT LOAD (MW)
64	505	10906.042	.00000E+00	.12659E+06	.37069E-01
76	833	10442.042	.00000E+00	.17902E+06	.52422E-01
53	1206	9522.042	.00000E+00	.15240E+06	.44628E-01
23	701	9522.042	.00000E+00	.54452E+05	.15945E-01
41	1112	8351.042	.00000E+00	.12317E+06	.36068E-01
31	784	8351.042	.00000E+00	.82080E+05	.24035E-01
41	1201	7655.042	.00000E+00	.13301E+06	.38949E-01
38	829	7655.042	.00000E+00	.10727E+06	.31413E-01
1	417	7655.042	.00000E+00	.23443E+04	.68649E-03
4	1220	7013.042	.00000E+00	.13623E+05	.39892E-02
38	1264	7013.042	.00000E+00	.13136E+06	.38467E-01
22	853	7013.042	.00000E+00	.65404E+05	.19152E-01
50	1247	6420.042	.00000E+00	.17867E+06	.52319E-01
20	830	6420.042	.00000E+00	.61243E+05	.17934E-01
2	394	6420.042	.00000E+00	.50251E+04	.14715E-02
59	1244	5843.042	.00000E+00	.21873E+06	.64051E-01
21	808	5843.042	.00000E+00	.66187E+05	.19382E-01
26	1150	4389.042	.00000E+00	.10265E+06	.30058E-01
50	1725	4389.042	.00000E+00	.23662E+06	.69290E-01
26	1150	3658.042	.00000E+00	.10773E+06	.31547E-01
50	1725	3658.042	.00000E+00	.24832E+06	.72717E-01
26	1150	2927.042	.00000E+00	.11331E+06	.33181E-01
50	1725	2927.042	.00000E+00	.26110E+06	.76458E-01
26	1150	2198.042	.00000E+00	.12076E+06	.35362E-01
50	1725	2198.042	.00000E+00	.27768E+06	.81312E-01
26	1150	1467.042	.00000E+00	.13902E+06	.40711E-01
50	1725	1467.042	.00000E+00	.31596E+06	.92521E-01
26	1150	737.042	.00000E+00	.22733E+06	.66568E-01
50	1725	737.042	.00000E+00	.49411E+06	.14469E+00
6	1150	6.625	.69725E+05	.98202E+06	.28757E+00
10	1150	6.542	.11910E+06	.16454E+07	.48181E+00
10	1150	6.458	.12208E+06	.16543E+07	.48443E+00
10	1150	6.375	.12511E+06	.16633E+07	.48706E+00
10	1725	6.292	.12820E+06	.16922E+07	.49552E+00
10	1725	6.208	.13139E+06	.17016E+07	.49828E+00
10	1725	6.125	.13466E+06	.17112E+07	.50110E+00
10	1725	6.042	.13800E+06	.17211E+07	.50398E+00

TOTAL HEAT LOAD = 1.71162E+07 BTU/HR
= 5.012136 MW

TEMPERATURE OF SFP AFTER 6.04167 DAYS = 148.9083 DEG F,
ASSUMING 100 DEG F CCW TEMPERATURE AND 10% HX DEGRADATION.

10% MARGIN ON SOURCE INCLUDED AS PER ASB 9-2

CALCULATION SHEET

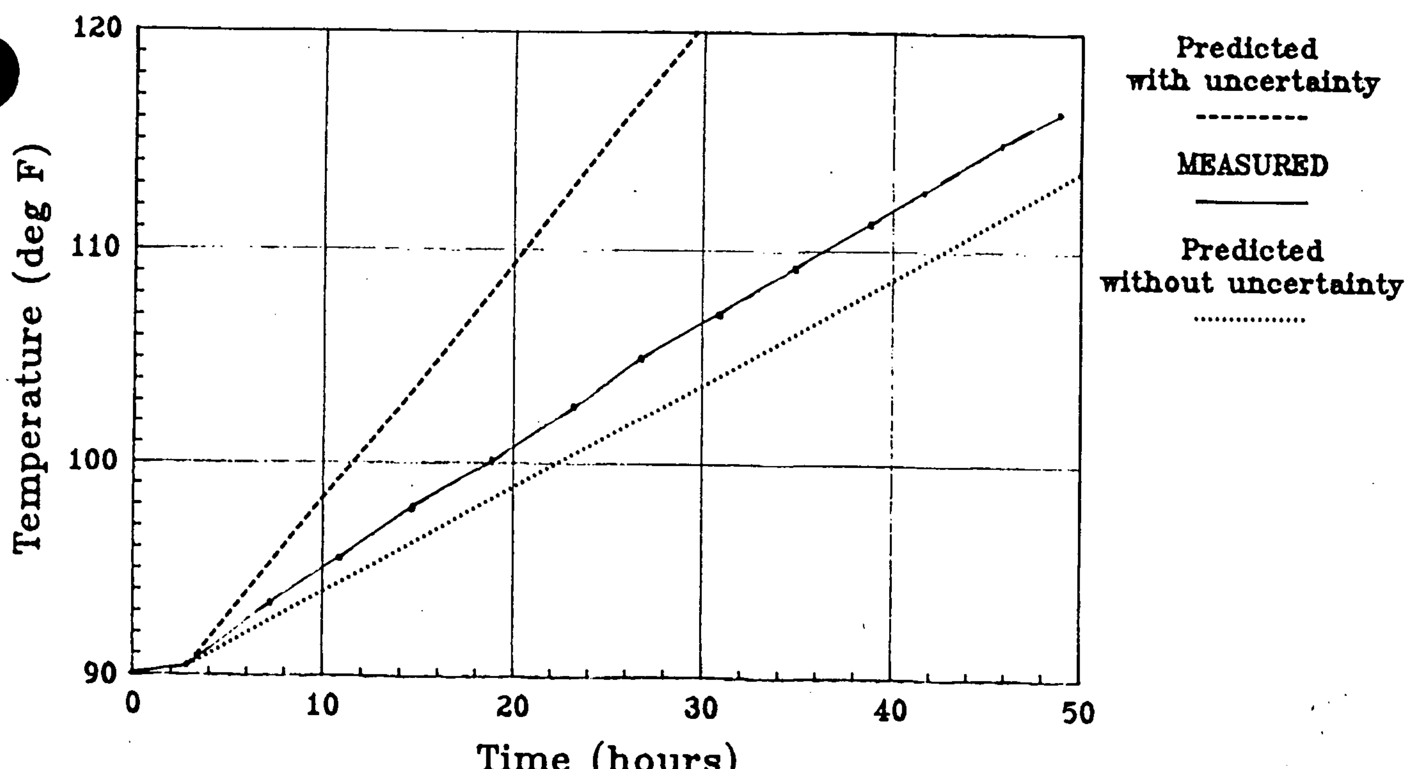
New York Power Authority			
CALCULATION NO. IP3-CALC-SFP-02065		REVISION 0	
Project N/A		Page 13 of 13	
Title Verification of SFP T/H Analyses		Date Nov 12 ,1996	
Preliminary ____	Prepared by F. Gumble	Date 11/15/96	
Final X	Checked by	Date	

Figure 1

(from Reference 7.8)

SPENT FUEL PIT TEMPERATURE VS. TIME

July 14 through July 16, 1994



Measured SFP temperatures are the average of 2 thermocouple readings. TCs were approx. 5 ft below SFP surface at locations AA-17 and T-12