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Additional 5 KWe Thermoelectric System Temperature
Transients

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ABSTRACT

Several additional system transients have been calculated for the 5 KWe TE system and are reported in this document. They include a startup transient with a reactivity rate of 0.005 ϵ /sec, several startup accidents, a step reactivity insertion at full power and a loss of electrical load. These data are intended for input to system design analyses and for possible use in the protected accident section of the safety report.

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I. PURPOSE

This report is intended to document additional transient data calculated for the 5 KWe TE system. The data are intended for input to design analyses and possible use in safety reports with protected accidents. The model and assumptions are as used in Reference 1.

II. RESULTS

Several 5 KWe TE system transients and protected accidents have been calculated to provide additional data using the model and assumptions reported in Reference 1. The transients are listed in Table 1 along with the figure numbers that correspond to the plotted results. Table 2 contains a list of parameters contained in the plots along with definitions. Figure 1 contains a system schematic diagram that shows the relative locations of computed temperatures.

In addition to the transients listed in Table 1, several cases were calculated to examine the sensitivity of results to variation of several system parameters. Transients were calculated to determine the sensitivity of the startup transient to the initial primary loop NaK flow rate. The results of that sensitivity analysis are listed in Table 3 for startup reactivity rates of 0.01 and 0.005 $\text{¢}/\text{sec}$. Initial startup flow rates of 2.5, 5.0, 10.0 and 20.0% were considered. An initial flow rate of 5% was considered to be the reference value. Therefore, the plotted results are shown for the 5% flow cases.

The sensitivity of the consequences of the protected startup accident to the scram reactivity rate was also determined. These results are

Table 1 - REACTOR TRANSIENTS

<u>Transient</u>	<u>Figures</u>
1. Startup Transient, 0.005 ϵ /sec, with 5% flow	2-9
2. Ramp From 1 to 100% Power at 0.025 ϵ /sec	10-17
3. 1.0 ϵ Step Reactivity Insertion at Full Power	18-25
4. Reactivity Insertion, 0.5 ϵ /sec, at Full Power with 1250°F Temp. Scram	26-33
5. Loss of Electrical Load	34-41
6. Startup Accident, 1.0 ϵ /sec, with 125% Power Scram	42-49
7. Startup Accident, 0.25 ϵ /sec, with 125% Power Scram	50-57

Table 2

LIST OF PARAMETERS FOUND IN THE PLOTTED RESULTS

<u>Parameter</u>	<u>Meaning</u>
N	Fraction of Rated Reactor Power
WNP	Fraction of Rated Primary NaK Flow
WNS	Fraction of Rated Secondary NaK Flow
TIP	Reactor Inlet Plenum Temperature ($^{\circ}\text{F}$)
TOP	Reactor Outlet Plenum Temperature ($^{\circ}\text{F}$)
TC10	Average Core NaK Outlet Temperature ($^{\circ}\text{F}$)
TC11	Reactor Coolant Temperature Rise ($^{\circ}\text{F}$)
TF3	Fuel Temperature at Center of Peak Rod ($^{\circ}\text{F}$)
TF8	Fuel Temperature at Center of Average Rod ($^{\circ}\text{F}$)
TF11	Average Fuel Temperature for Peak Rod ($^{\circ}\text{F}$)
TF12	Average Fuel Temperature for Average Rod ($^{\circ}\text{F}$)
TCP11	Average Temperature on Power Converter Primary Side ($^{\circ}\text{F}$)
TCP12	Average Temperature on Pump Converter Primary Side ($^{\circ}\text{F}$)
TCS11	Average Temperature on Power Converter Secondary Side ($^{\circ}\text{F}$)
TCS12	Average Temperature on Pump Converter Secondary Side ($^{\circ}\text{F}$)
TS4	Secondary NaK Temperature at Radiator Inlet ($^{\circ}\text{F}$)
TR5	Radiator NaK Outlet Temperature ($^{\circ}\text{R}$)
TR3	Radiator Temperature Center Node ($^{\circ}\text{R}$)
TR1	Radiator Temperature First Node ($^{\circ}\text{R}$)
PWR	Electrical Power Output (KW)
EFF	Power Converter Efficiency (%)
DTIP	Reactor Inlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTOP	Reactor Outlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTP4	Converter Primary Inlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTCP5	Power Converter Primary Outlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTCS1	Power Converter Secondary Outlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTS4	Radiator Inlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTR5	Radiator Outlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)
DTCP8	Pump Converter Primary Outlet Temperature Rate ($^{\circ}\text{F}/\text{sec}$)

Table 3

SENSITIVITY OF STARTUP TRANSIENTS
DURING THE FIRST POWER BURST TO INITIAL PRIMARY FLOW RATE

Initial Flow (%)	Peak Power Fraction	Max. Coolant Temp. Rise (°F)	Peak Inlet Temp. Rate (°F/sec)	Inlet Plenum Temp. Fast Ramp (°F)	Peak Fuel Temp. (°F)
------------------------	---------------------------	--	--	---	-------------------------------

STARTUP RATE = 0.01 ¢/sec

2.5	0.449	292	5.34	208	589
5.0	~ 0.47	250	3.68	~ 200	~ 529
10.0	0.535	190	2.01	177	469
20.0	0.582	106	0.67	171	398
30.0	~0.585	69			

STARTUP RATE = 0.005 ¢/sec

2.5	0.268	220	2.39	151	465
5.0	~ 0.29	184	1.56	~140	~ 418
10.0	0.333	129	0.70	128	370

Table 4

SENSITIVITY OF STARTUP ACCIDENT
WITH 5% PRIMARY FLOW AND 125% POWER SCRAM
TO THE SCRAM REACTIVITY RATE

Reactivity Rate (ϵ /sec)	Peak Power Fraction	Core Peak Coolant Temp. Rise ($^{\circ}$ F)	Peak Inlet Temp. Rate ($^{\circ}$ F/sec)	Peak Fuel Temp. ($^{\circ}$ F)
<u>Scram Rate = 10 ϵ/sec</u>				
1.0	2.85	63.8	0.10	208
0.5	1.70	41.1	0.06	169
<u>Scram Rate = 5.0 ϵ/sec</u>				
1.0	6.14	219	2.33	471
0.5	2.42	97.5	0.17	265
0.25	1.54	67.4	0.11	214
<u>Scram Rate = 2.5 ϵ/sec</u>				
1.0	13.0	549	23.7	1049
0.5	4.78	275	4.55	567
0.25	2.17	144	0.62	343

summarized in Table 4. The current reference scram reactivity rate is 5 $\text{¢}/\text{sec}$ which has been used in the calculation of the other protected accident transients. The data in Table 4 indicate the reference scram reactivity rate, 5 $\text{¢}/\text{sec}$, is adequate for startup accidents. Since the startup accidents tend to be more severe than the accidents at power, the same scram reactivity rate is also adequate for the other accidents considered.

The reference startup reactivity rate for automatic startup has not been selected yet. However, it probably lies between 0.005 and 0.025 $\text{¢}/\text{sec}$. The startup transient with a reactivity rate of 0.005 $\text{¢}/\text{sec}$ is shown in Figures 2 to 9. Startup transients with reactivity rates of 0.01 and 0.025 $\text{¢}/\text{sec}$ are contained in Reference 1. The actual selection will have to be based on design analyses and system requirements. A transient intended to represent a manual startup is shown in Figures 10 to 17. This transient is a reactivity ramp of 0.025 $\text{¢}/\text{sec}$ from critical at 1% power. Note, it is less severe than a corresponding startup from shutdown in Reference 1. In the case of the startup transient with a reactivity rate of 0.005 $\text{¢}/\text{sec}$, Figures 2 to 9 show the transient from 1% power. The time from 50 ¢ shutdown to 1% power represents an additional 12,260 seconds.

Figures 18 to 25 are intended to show the possible effects of a controller step at full power. The 1.0 cent magnitude of the step used is in the range of previously used reactivity steps on S8DR. For small reactivity steps in this range the results can be scaled to smaller or slightly larger steps if desired.

The calculated results for the equivalent of a rod withdrawal accident at full power with backup scram initiation is shown in Figures 26 to 33. The results are not particularly severe. However, the severity can be reduced by lowering the temperature scram set point from 1250°F upper plenum NaK temperature to a lower value.

Loss of electrical load is shown in Figures 34 to 41. The main effects of this accident initially are a reduction in overall heat transfer coefficient in the power converters and a slight additional amount of heat to be transferred. The strong inlet temperature coefficient of reactivity causes the reactor power to drop. Consequently, reactor outlet temperature drops following this accident and there is no need to scram.

Several additional startup accidents are shown in Figures 42 to 57. Reactivity rates of 1.0 and 0.25 $\text{\$/sec}$ were used. Reference 1 shows a startup accident with a reactivity rate of 0.5 $\text{\$/sec}$. These do not appear to be too severe. However, this document and Reference 1 are intended to document data to be used in design analyses. Those analyses should show what is acceptable and what is not.

III. METHOD OF ANALYSIS

The 5 KWe TE system transients reported in this document are based on using the system model contained in Reference 1 and appropriate input disturbances. Assumptions, heat capacities, power and other system parameters are exactly as in Reference 1.

IV. REFERENCES

1. F. Halfen, "5 KWe System Model and Transients,"
TI-652-510-001, 5-16-72

Figure 1

5 KWe SYSTEM SIMULATION

NOTE: PUMP CONVERTER LIKE PWR CONVERTER BUT NO'S 6 TO 8

Figure 2
Startup Transient, 0.005 c/sec, With 5% Flow

717087-42
051672 0001

Figure 3
Startup Transient, 0.005 c/sec, With 5% Flow

717087-42
051672 0002

COOLANT TEMPERATURES

Figure 4

Startup Transient, 0.005 g/sec, With 5% Flow

000000 PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

717087-42
051672 0003

Figure 5
Startup Transient, 0.005 g/sec, With 5% Flow

TE CONVERTER TEMPERATURES

717087-42
051672 0004

Figure 6

Startup Transient, 0.005 c/sec, With 5% Flow

000000 RADIATOR TEMPERATURES

717087-42
051672 0005

Figure 7
Startup Transient, 0.005 e/sec, With 5% Flow

TE MODULE POWER AND EFFICIENCY

717087-42
051672 0006

Figure 8

Startup Transient, 0.005 ϵ /sec, With 5% Flow

TEMPERATURE RATES

717087-42
051672 0007

Figure 9

Startup Transient, 0.005 ϵ /sec, With 5% Flow

000000 TEMPERATURE RATES

717087-42
051672 0008

Figure 10

Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

REACTOR POWER AND FLOWS

717087-45
051672 0001

Figure 11

Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

717087-45
051572 0002

Figure 12
Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

000000 PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

717087-45
051672 0003

Figure 13
Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

TE CONVERTER TEMPERATURES

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051672 0004

Figure 14
Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

000000 RADIATOR TEMPERATURES

717087-45
051672 0005

Figure 15

Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

TE MODULE POWER AND EFFICIENCY

717087-45
051672 0006

Figure 16
Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

TEMPERATURE RATES

717087-45
051672 0007

Figure 17
Ramp From 1.0 to 100% Power at 0.025 ϵ /sec

717097-45
051672 0008

Figure 18
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0017

Figure 19
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0018

Figure 20
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0019

000000 PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

Figure 21
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0020

Figure 22
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0021

Figure 23
1.0% Step Reactivity Insertion at Full Power

TE MODULE POWER AND EFFICIENCY

717087-46
051772 0022

Figure 24
1.0¢ Step Reactivity Insertion at Full Power

717087-46
051772 0023

Figure 25
1.0¢ Step Reactivity Insertion at Full Power

Figure 26

Reactivity Insertion, 0.5 ϵ /sec, at Full Power With 1250°F Seram

REACTOR POWER AND FLOWS

717087-34
051172 0001

Figure 27

Reactivity Insertion, 0.5 β /sec, at Full Power With 1250°F Temp Seram

717087-34
051172 0002

COOLANT TEMPERATURES

Figure 28

Reactivity Insertion, 0.5 β /sec, at Full Power With 1250°F Temp Seram

000000 PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

717087-34
051172 0003

Figure 29
Reactivity Insertion, 0.5 ϵ /sec, at Full Power With 1250°F Temp Scram

717087-34
051172 0004

TE CONVERTER TEMPERATURES

Figure 30

Reactivity Insertion, 0.5 ϵ /sec, at Full Power With 1250°F Temp Scram

717087-34
051172 0005

Figure 31

Reactivity Insertion, 0.5 ρ /sec, at Full Power With 1250°F Temp Scram

TE MODULE POWER AND EFFICIENCY

717087-34
051172 0006

Figure 32

Reactivity Insertion, 0.5 ϵ /sec, at Full Power With 1250°F Temp Scram

TEMPERATURE RATES

717087-34
051172 0007

Figure 33

Reactivity Insertion, 0.5 ϵ /sec, at Full Power With 1250°F Temp Scram

717087-34
051172 0008

TEMPERATURE RATES

Figure 34
Loss of Electrical Load

REACTOR POWER AND FLOWS

717087-34
051172 0009

Figure 35
Loss of Electrical Load

COOLANT TEMPERATURES

717087-34
051172 0010

Figure 36
Loss of Electrical Load

PEAK AND AVERAGE PHR ELEMENT FUEL TEMPERATURE

717087-34
051172 0011

Figure 37
Loss of Electrical Load

TE CONVERTER TEMPERATURES

717087-34
051172 0012

Figure 38
Loss of Electrical Load

717087-34
051172 0013

Figure 39
Loss of Electrical Load

TE MODULE POWER AND EFFICIENCY

717087-34
051172 0014

Figure 40
Loss of Electrical Load

717087-34
051172 0015

TEMPERATURE RATES

Figure 41
Loss of Electrical Load

TEMPERATURE RATES

717087-34
051172 0016

Figure 42
Startup Accident, 1.0 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0001

REACTOR POWER AND FLOWS

Figure 43
Startup Accident, 1.0 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0002

Figure 44
Startup Accident, 1.0 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0003

oooooo PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

Figure 45
Startup Accident, 1.0 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0004

TE CONVERTER TEMPERATURES

Figure 46

Startup Accident, 1.0 ϕ /sec, With 125% Power Scram (5 ϕ /sec)

000000 RADIATOR TEMPERATURES

717087-31
051072 0005

Figure 47

Startup Accident, 1.0 ϕ /sec, With 125% Power Scram (5 ϕ /sec)

TE MODULE POWER AND EFFICIENCY

717087-31-
051072 0006

Figure 48

Startup Accident, 1.0 ϕ /sec, With 125% Power Scram (5 ϕ /sec)

717087-31
051072 0007

Figure 49
Startup Accident, 1.0 ϕ /sec, With 125% Power Scram (5 ϕ /sec)

717087-31
051072 0008

Figure 50
Startup Accident, 0.25 ϵ /sec, With 125% Power Seram (5 ϵ /sec)

717087-31
051072 0009

Figure 51
Startup Accident, 0.25 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0010

Figure 52.

Startup Accident, 0.25 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

oooooo PEAK AND AVERAGE PWR ELEMENT FUEL TEMPERATURE

717087-31
051072 0011

Figure 53
Startup Accident, 0.25 ϵ /sec, With 125% Power Seram (5 ϵ /sec)

TE CONVERTER TEMPERATURES

717087-31
051072 0012

Figure 54
Startup Accident, 0.25 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

717087-31
051072 0013

000000 RADIATOR TEMPERATURES

Figure 55
Startup Accident, 0.25 ϵ /sec, With 125% Power Scram (5 ϵ /sec)

TE MODULE POWER AND EFFICIENCY

717087-31
051072 0014

Figure 56

Startup Accident, 0.25 ϵ /sec, With 125% Power Seram (5 ϵ /sec)

717087-31
051072 0015

Figure 57
Startup Accident, 0.25 ϵ /sec, With 125% Power Seram (5 ϵ /sec)

717087-31
051072 0016