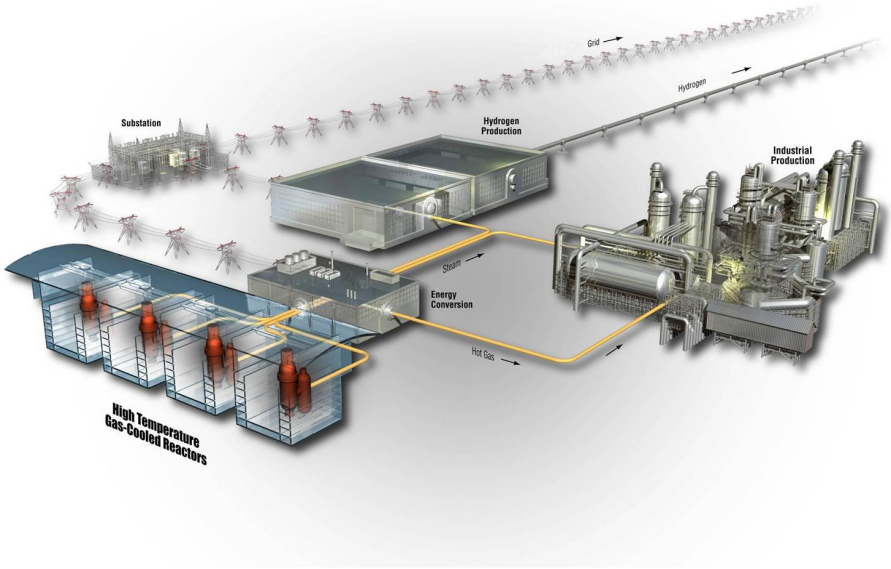
INL/EXT-11-23833
Revision 1

HTGR Cost Model Users' Manual

Anastasia M. Gandrik

January 2012



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January 2012

Idaho National Laboratory
Next Generation Nuclear Plant Project
Idaho Falls, Idaho 83415

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Next Generation Nuclear Plant Project

HTGR Cost Model
Users' Manual

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Revision 1

January 2012

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ABSTRACT

The High Temperature Gas-Cooled Reactor (HTGR) Cost Model was developed at the Idaho National Laboratory for the Next Generation Nuclear Plant Project. The HTGR Cost Model calculates an estimate of the capital costs, annual operating and maintenance costs, and decommissioning costs for an HTGR. The user can generate these costs for multiple reactor outlet temperatures; with and without power cycles, including either a Brayton or Rankine cycle; for the demonstration plant, first of a kind, or n^{th} of a kind project phases; for a single or four-pack configuration; and for a reactor size of 350 or 600 MWt.

This users' manual contains the mathematical models and operating instructions for the HTGR Cost Model. Instructions, screenshots, and examples are provided to guide the user through the HTGR Cost Model. This model was designed for users who are familiar with the HTGR design and Excel. Modification of the HTGR Cost Model should only be performed by users familiar with Excel and Visual Basic.

CONTENTS

ABSTRACT v

ACRONYMS x

1. INTRODUCTION 1

2. QUICK USERS' GUIDE 2

3. DETAILED WORKSHEET DESCRIPTIONS 4
   - 3.1 HTGR Cost Summary Worksheet 4
     - 3.1.1 Named Cells/Ranges 5
     - 3.1.2 Worksheet Formatting 5
     - 3.1.3 Worksheet Equations/IF Statements 5
     - 3.1.4 Worksheet Macros 7
   - 3.2 List Info Worksheet 8
     - 3.2.1 Named Cells/Ranges 9
     - 3.2.2 Worksheet Formatting 10
     - 3.2.3 Worksheet Equations/IF Statements 10
     - 3.2.4 Worksheet Macros 10
   - 3.3 HTGR Capital Cost Worksheet 11
     - 3.3.1 Preconstruction Costs 11
     - 3.3.2 Direct Costs 13
     - 3.3.3 Indirect Costs and Total Overnight Capital Costs 14
     - 3.3.4 Named Cells/Ranges 14
     - 3.3.5 Worksheet Formatting 14
     - 3.3.6 Worksheet Equations/IF Statements 15
     - 3.3.7 Worksheet Macros 17
   - 3.4 O&Ms Worksheet 17
     - 3.4.1 Named Cells/Ranges 18
     - 3.4.2 Worksheet Formatting 18
     - 3.4.3 Worksheet Equations/IF Statements 18
     - 3.4.4 Worksheet Macros 19
   - 3.5 Yearly Fuel Cost Worksheet 19
     - 3.5.1 Named Cells/Ranges 19
     - 3.5.2 Worksheet Formatting 19
     - 3.5.3 Worksheet Equations/IF Statements 20
     - 3.5.4 Worksheet Macros 21
   - 3.6 Decommissioning Worksheet 21
     - 3.6.1 Named Cells/Ranges 22
     - 3.6.2 Worksheet Formatting 22
     - 3.6.3 Worksheet Equations/IF Statements 22
     - 3.6.4 Worksheet Macros 22
   - 3.7 Full Results Worksheet 22
     - 3.7.1 Named Cells/Ranges 24
     - 3.7.2 Worksheet Formatting 24
     - 3.7.3 Worksheet Equations/IF Statements 24
     - 3.7.4 Worksheet Macros 24

3.8 Correlations Worksheet 30
3.8.1 Named Cells/Ranges 32
3.8.2 Worksheet Formatting 32
3.8.3 Worksheet Equations/IF Statements 32
3.8.4 Worksheet Macros 33

REFERENCES 33

FIGURES

Figure 1. HTGR Cost Model, quick users' guide screenshot. 3
Figure 2. HTGR Cost Summary worksheet screenshot. 6
Figure 3. UnHideSheets Macro 7
Figure 4. HideSheets Macro. 8
Figure 5. List Info worksheet screenshot. 9
Figure 6. Reactor input summary on the HTGR Capital Cost worksheet, screenshot. 11
Figure 7. Preconstruction costs on the HTGR Capital Cost worksheet, screenshot. 12
Figure 8. Direct costs on the HTGR Capital Cost worksheet, screenshot. 13
Figure 9. Indirect and total overnight costs on the HTGR Capital Cost worksheet, screenshot. 15
Figure 10. O&Ms worksheet screenshot. 18
Figure 11. Yearly Fuel Cost worksheet screenshot 20
Figure 12. Decommissioning worksheet screenshot. 22
Figure 13. Full Results worksheet, partial screenshot 23
Figure 14. FullResults Macro 24
Figure 15. Correlations worksheet screenshot. 31

TABLES

Table 1. HTGR Cost Model user inputs. 2
Table 2. HTGR Cost Model user inputs. 8

ACRONYMS

AACE	Association for the Advancement of Cost Engineering
CEPCI	chemical engineering plant cost index
DOE	Department of Energy
FOAK	first of a kind
HTGR	high temperature gas-cooled reactor
INL	Idaho National Laboratory
LWR	light water reactor
NGNP	Next Generation Nuclear Plant
NOAK	nth of a kind
O&M	operations and maintenance
ROT	reactor outlet temperature
SWU	separative work unit

HTGR Cost Model
Users' Manual

1. INTRODUCTION

The Next Generation Nuclear Plant (NGNP) Project is being conducted under U.S. Department of Energy (DOE) direction to meet a national strategic need identified in the 2005 *Energy Policy Act* to promote reliance on safe, clean, economic nuclear energy and to establish a greenhouse-gas-free technology for the production of hydrogen. The NGNP represents an integration of high-temperature reactor technology with advanced hydrogen, electricity, and process heat production capabilities, thereby meeting the mission need identified by DOE. The strategic goal of the NGNP Project is to broaden the environmental and economic benefits of nuclear energy in the U.S. economy by demonstrating its applicability to market sectors not being served by light water reactors. A high temperature gas-cooled reactor (HTGR) differs from a third generation light water reactor by using helium instead of water as the coolant, graphite instead of water as the moderator, and tristructural isotropic fuel instead of metal-clad fuel. With these features, an HTGR is capable of operating at higher temperatures, which offers a broader application to industrial processes and higher thermal efficiencies than are achievable with the lower operating temperatures of light water reactors.

The HTGR can be applied in many industrial applications as a substitute for burning of fossil fuels, including natural gas and coal, in addition to producing electricity. An objective of the NGNP Project is to evaluate the economics of heat and power production from an HTGR for incorporation into a variety of chemical processes, as well as for more traditional electricity production. However, in order to properly assess the economics of HTGR integration, it was first necessary to determine the capital costs, operating and maintenance (O&M) costs, and decommissioning costs of the HTGR. This was accomplished through the creation of the HTGR Cost Model which was used to generate the costs documented in TEV-1196, *Assessment of High Temperature Gas-Cooled Reactor (HTGR) Capital and Operating Costs* (Idaho National Laboratory [INL] 2011).

This users' manual contains the mathematical models and operating instructions for the HTGR Cost Model. Instructions, screenshots, and examples are provided to guide the user through the HTGR Cost Model. This model was designed for users who are familiar with the HTGR design and Excel. Modification of the HTGR Cost Model should only be performed by users familiar with Excel and Visual Basic. The bases and assumptions for the cost model are covered in TEV-1196 and will not be discussed in the associated users' manual; rather the users' manual will only discuss the model methodology.

The cost model was developed to estimate HTGR costs for a range of reactor outlet temperatures (ROT), 750°C to 950°C, in 50°C increments; with and without power cycles, including both Rankine and Brayton cycles; for single and four-pack reactor configurations; for both 350 MWt and 600 MWt power levels; for the NGNP, first of a kind (FOAK), and nth of a kind (NOAK) project phases. A four-pack reactor plant includes four reactor vessels with shared control facilities. The NGNP plant is the initial demonstration of the current HTGR design, a FOAK plant is the first commercial installation of the HTGR technology, while the NOAK plant is a mature commercial installation of the HTGR technology. O&M costs were developed from reactor vendor labor estimates and INL labor estimates, as described in TEV-1196 (INL 2011).

Capital cost estimates are based on estimates provided by Dominion Engineering, Inc. for the INL through a separate subcontract. This users' manual does not address Dominion's estimate, which is presented and discussed in TEV-1196 (INL 2011). The Association for the Advancement of Cost Engineering (AACE) International recognizes five classes of estimates. The level of project definition for

this study was determined to be an AACE International Class 4 estimate, which has a probable error of -30% and +50%, as described in TEV-1196 (INL 2011). A Class 4 estimate is associated with a feasibility study or top-down cost estimate and has one to fifteen percent of full project definition (AACE 2005).

2. QUICK USERS' GUIDE

The HTGR Cost Model (HTGR Cost Model.xlsm) can be used to quickly generate the capital, O&M, fuel, and decommissioning costs for a variety of HTGR configurations in 2009 dollars. After the Excel file is opened, the user is presented with the HTGR Cost Summary worksheet; next the user selects the desired configuration from the combo boxes labeled Reactor Inputs (cells D2 to D8); and the corresponding capital, O&M, fuel, and decommissioning costs are presented for the selected HTGR configuration (cells F12 to F41). All costs are calculated as described in TEV-1196 (INL 2011).

Table 1 outlines the reactor inputs available in the combo boxes and Figure 1 presents a screenshot of the HTGR Cost Summary worksheet for four-600 MWt 850°C ROT HTGRs with Rankine Power Cycles, for the NOAK project phase, and the vendor staffing plan. Advanced users can unhide the other worksheets used in the model, by clicking the Unhide Sheets button, if they wish to update, review, or change the underlying data. The Hide Sheet button hides the detailed worksheets. The detailed worksheet descriptions are presented in Section 3.

Table 1. HTGR Cost Model user inputs.

Reactor Size (MWt)	ROT (°C)	Project Phase	Number of Reactors	Power Cycle Present	Power Cycle Type	Staffing Plan
350	750	NGNP	1	Yes	Rankine	Vendor
600	800	FOAK	4	No	Brayton	INL Model
	850	NOAK				
	900					
	950					

	A	B	C	D	E	F
1	**Reactor Inputs:**					
2		Reactor Size (MWt):		600	Hide Sheets	
3		ROT (°C):		850		
4		Project Phase:		NOAK	Unhide Sheets	
5		Number of Reactors:		4		
6		Power Cycle Present:		Yes		
7		Power Cycle Type:		Rankine		
8		Staffing Plan:		Vendor		
9						
10	**Capital Cost Summary (Million 2009 $):**					
11		PRECONSTRUCTION COSTS:				
12			Land and Land Rights			10.00
13			Licensing and Application Costs			81.00
14		*TOTAL PRECONSTRUCTION COSTS*				*91.00*
15		DIRECT COSTS				
16			Selected Configuration Direct Cost Total			2052.42
17			Balance of Equipment Adder:			513.11
18		*TOTAL DIRECT COSTS:*				*2565.53*
19		INDIRECT COSTS:				
20			Total Design Costs:			20.00
21			Construction Services:			514.11
22			Home Office and Engineering Services:			413.66
23			Field Office and Engineering Services:			250.69
24			Owner's Costs:			295.75
25		*TOTAL INDIRECT COSTS:*				*1494.20*
26		*BASE CONSTRUCTION COST:*				*4150.73*
27		*PROJECT CONTINGENCY:*				*830.15*
28		*TOTAL OVERNIGHT COST:*				*4980.88*
29		*OVERNIGHT COST PER kWt ($/kWt):*				*2075.37*
30						
31	**Yearly O&M Summary (Million 2009 $):**					
32		*Total Yearly O&M Cost:*				*99.60*
33		*O&M Cost Per MWt-hr ($/MWt-hr)*				*4.74*
34						
35	**Fuel Cost Summary (Million 2009 $):**					
36		*Refueling Cost Per Core:*				*50.21*
37		*Total Average Yearly Fuel Cost:*				*133.88*
38		*Fuel Cost Per MWt-hr ($/MWt-hr)*				*6.37*
39						
40	**Decommissioning Cost Summary (Million 2009 $):**					
41		Total Decommissioning Costs:				491.47

HTGR Cost Summary

Figure 1. HTGR Cost Model, quick users' guide screenshot.

3. DETAILED WORKSHEET DESCRIPTIONS

The HTGR Cost Model (HTGR Cost Model.xlsm) is implemented in an Excel spreadsheet with Visual Basic Macros enabled; the model was developed in Excel 2007 for Windows operating systems (Excel 2007). However, the model has been successfully operated in other versions of Excel on various operating systems. Still, this users' manual assumes the user is running Excel 2007 for Windows and all screenshots are from this version. The following worksheets are included in the model:

- HTGR Cost Summary
- List Info
- HTGR Capital Cost
- O&Ms
- Yearly Fuel Cost
- Decommissioning
- Full Results
- Correlations

To ensure Macros are enabled click the 'Office Button' and select 'Excel Options'. Click the 'Trust Center' tab on the far left of the 'Excel Options' window, and click the 'Trust Center Settings' button. On the far left of the 'Trust Center Settings' window click 'Macro Settings' and ensure 'Enable all macros (not recommended; potentially dangerous code can run)' is selected. To edit Macros ensure that the 'Show Developer' tab in the 'Ribbon' is checked in the 'Popular' tab of the 'Excel Options' window, next click the 'Developer' tab in the 'Ribbon' and click the 'Macros' button. Select the Macro you wish to edit and click 'Edit'.

The following sections are arranged such that the approach for each worksheet is summarized, followed by a section which defines any named cells or ranges, a section explaining any special formatting, a section defining equations and IF statements contained in the worksheet, and finally a section listing Macros used in the worksheet. Special formatting may include cells highlighted a certain color identifying user inputs, etc. Equations and IF statements defined do not include every equation or function used in the workbook, rather complex equations are only specified, i.e. functions which use simple sums and averages are not necessarily defined, unless they include an IF statement or lookup function.

All screenshots are presented for an NOAK, four-pack of 600 MWt HTGRs with Rankine power cycles, for an ROT of 850°C, and the vendor staffing plan.

3.1 HTGR Cost Summary Worksheet

The HTGR Cost Summary worksheet is arranged such that the user selects the reactor inputs from several combo boxes. Based on these selections, the capital costs, yearly O&M costs, fuel costs, and decommissioning costs calculated in the workbook are summarized in the HTGR Cost Summary worksheet. Costs are reported in millions of U.S. dollars per the year specified by the user on the List Info worksheet, the default year is 2009. From the combo boxes the user specifies the following inputs:

- Reactor size
- ROT
- Project phase
- Number of reactors
- Power cycle present
- Power cycle type
- Staffing plan

After the selections are made, the capital cost summary is populated based on outputs from the HTGR Capital Cost worksheet, the yearly O&M cost summary is populated based on outputs from the O&Ms worksheet, the fuel cost summary is populated based on outputs from the Yearly Fuel Costs worksheet, and the decommissioning cost summary is populated based on outputs from the Decommissioning worksheet. A screenshot of the HTGR Cost Summary sheet is presented in Figure 2.

Advanced users can unhide the worksheets used in the model, by clicking the Unhide Sheets button, if they wish to update, review, or change the underlying data. The Hide Sheets button hides the detailed worksheets. The Unhide Sheets button is linked to the UnHideSheets Macro and the Hide Sheets button is linked to the HideSheets Macro.

3.1.1 Named Cells/Ranges

ResultsSummary refers to the cell range F12:F41.

3.1.2 Worksheet Formatting

No special formatting is used on the HTGR Cost Summary worksheet.

3.1.3 Worksheet Equations/IF Statements

The values in the combo boxes are populated based on the data contained in the List Info worksheet. To edit or add to the data in the combo boxes the user must right-click the combo box to be edited and select ‘Format Control’. Next, select the ‘Control’ tab, where the ‘Input range’ and ‘Cell link’ cell references are shown. Select the corresponding named cell range to be included from the List Info worksheet for the input range and the appropriate cell link on the List Info worksheet.

	A	B	C	D	E	F
1	**Reactor Inputs:**					
2		Reactor Size (MWt):		600	Hide Sheets	
3		ROT (°C):		850		
4		Project Phase:		NOAK	Unhide Sheets	
5		Number of Reactors:		4		
6		Power Cycle Present:		Yes		
7		Power Cycle Type:		Rankine		
8		Staffing Plan:		Vendor		
9						
10	**Capital Cost Summary (Million 2009 $):**					
11		PRECONSTRUCTION COSTS:				
12			Land and Land Rights			10.00
13			Licensing and Application Costs			81.00
14		*TOTAL PRECONSTRUCTION COSTS*				*91.00*
15		DIRECT COSTS				
16			Selected Configuration Direct Cost Total			2052.42
17			Balance of Equipment Adder:			513.11
18		*TOTAL DIRECT COSTS:*				*2565.53*
19		INDIRECT COSTS:				
20			Total Design Costs:			20.00
21			Construction Services:			514.11
22			Home Office and Engineering Services:			413.66
23			Field Office and Engineering Services:			250.69
24			Owner's Costs:			295.75
25		*TOTAL INDIRECT COSTS:*				*1494.20*
26		*BASE CONSTRUCTION COST:*				*4150.73*
27		*PROJECT CONTINGENCY:*				*830.15*
28		*TOTAL OVERNIGHT COST:*				*4980.88*
29		*OVERNIGHT COST PER kWt ($/kWt):*				*2075.37*
30						
31	**Yearly O&M Summary (Million 2009 $):**					
32		*Total Yearly O&M Cost:*				*99.60*
33		*O&M Cost Per MWt-hr ($/MWt-hr)*				*4.74*
34						
35	**Fuel Cost Summary (Million 2009 $):**					
36		*Refueling Cost Per Core:*				*50.21*
37		*Total Average Yearly Fuel Cost:*				*133.88*
38		*Fuel Cost Per MWt-hr ($/MWt-hr)*				*6.37*
39						
40	**Decommissioning Cost Summary (Million 2009 $):**					
41		Total Decommissioning Costs:				491.47

Figure 2. HTGR Cost Summary worksheet screenshot.

3.1.4 Worksheet Macros

The UnHideSheets Macro unhides the hidden sheets in the workbook when the user clicks the Unhide Sheets button, which by default includes the following worksheets:

- List Info
- HTGR Capital Cost
- O&Ms
- Yearly Fuel Cost
- Decommissioning
- Full Results
- Correlations

The UnHideSheets Macro is presented in Figure 3. The HideSheets Macro hides all sheets in the workbook, except the HTGR Cost Summary sheet, when the user clicks the Hide Sheets button. The HideSheets Macro is show in Figure 4.

```
Sub UnHideSheets()
'
' UnHideSheets Macro
'
' The following Macro selects the sheets that have been hidden in the
' workbook and unhides them when the user clicks the linked button.

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Selects the hidden sheets and makes them visible
    Sheets("List Info").Visible = True
    Sheets("HTGR Capital Cost").Visible = True
    Sheets("O&Ms").Visible = True
    Sheets("Yearly Fuel Cost").Visible = True
    Sheets("Decomissioning").Visible = True
    Sheets("Full Results").Visible = True
    Sheets("Correlations").Visible = True


    ' Selects the HTGR Cost Summary sheet
    Sheets("HTGR Cost Summary").Select

    ' Allows the screen to update
    Application.ScreenUpdating = True

End Sub
```

Figure 3. UnHideSheets Macro.

```
Sub HideSheets()
'
' HideSheets Macro
'
' The following Macro selects the sheets in the workbook, other than
' the HTGR Cost Summary sheet and hides them when the user clicks
' the linked button.

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Selects the sheets and hides them
    Sheets("List Info").Visible = False
    Sheets("HTGR Capital Cost").Visible = False
    Sheets("O&Ms").Visible = False
    Sheets("Yearly Fuel Cost").Visible = False
    Sheets("Decomissioning").Visible = False
    Sheets("Full Results").Visible = False
    Sheets("Correlations").Visible = False

    ' Selects the HTGR Cost Summary sheet
    Sheets("HTGR Cost Summary").Select

    ' Allows the screen to update
    Application.ScreenUpdating = True

End Sub
```

Figure 4. HideSheets Macro.

3.2 List Info Worksheet

The List Info worksheet provides the data which populates the combo boxes on the HTGR Cost Summary worksheet. Based on the value selected in the combo boxes on the HTGR Cost Summary worksheet, the appropriate cell link value is written to the cell for the corresponding reactor variable (row 8). Based on the cell link value, the value selected in the combo box is written to the cell for the corresponding reactor variable (row 10). The following table provides the user inputs and possible values used in the HTGR Cost Model:

Table 2. HTGR Cost Model user inputs.

Reactor Size (MWt)	ROT (°C)	Project Phase	Number of Reactors	Power Cycle Present	Power Cycle Type	Staffing Plan
350	750	NGNP	1	Yes	Rankine	Vendor
600	800	FOAK	4	No	Brayton	INL Model
	850	NOAK				
	900					
	950					

The analysis year, inflation rate, and analysis year Chemical Engineering Plant Cost Index (CEPCI) are also included on the List Info worksheet. All costs are scaled based on 2009 dollars, which has a corresponding CEPCI of 521.9. To adjust capital costs from 2009 dollars to a later year, the capital costs

are multiplied by the ratio of the CEPCIs. For instance, the CEPCI of 2010 is 550.8; therefore the 2009 base capital costs would be multiplied by 550.8/521.9 to adjust capital costs to 2010 dollars. An inflation rate of 3% is assumed to adjust O&M, fuel, and decommissioning costs to years other than 2009. To adjust costs from 2009 dollars the following equation is used:

$$Cost\ in\ 2009\ dollars \times (1 + 3\%)^{(Analysis\ Year - 2009)}$$

Figure 5 presents a screenshot of the List Info worksheet.

	A	B	C	D	E	F	G
1	**Reactor Size**	**ROT**	**Project Phase**	**Number of Reactors**	**Power Cycle Present**	**Power Cycle Type**	**Staffing Plan**
2	350	750	NGNP	1	Yes	Rankine	Vendor
3	600	800	FOAK	4	No	Brayton	INL Model
4		850	NOAK				
5		900					
6		950					
7	**Index from Drop-Down Selection**						
8	2	3	3	2	1	1	1
9	**Value Selected**						
10	600	850	NOAK	4	Yes	Rankine	Vendor
11							
12	**User Inputs for Cost Basis:**						
13	Analysis Year		2009				
14	Inflation Rate		3%				
15	Analysis Year CEPCI		521.9				

Figure 5. List Info worksheet screenshot.

3.2.1 Named Cells/Ranges

The following cells names have been assigned on the List Info worksheet:

- RSize – cell A10
- ROTSel – cell B10
- RPhase – cell C10
- Number – cell D10
- PCyc – cell E10
- CycChoice – cell F10
- Staff – cell G10
- CEPCIYEAR – cell C12
- IRT – cell C13
- CEPCI – cell C14

The following named ranges have been assigned on the List Info worksheet (used in the combo box input range on the HTGR Cost Summary worksheet):

- Reactor Size – range A2:A3
- ROT – range B2:B6
- Phase – range C2:C4
- ReactorQty – range D2:D3
- HeatorPower – range E2:E3
- PowerCycle – range F2:F3
- StaffPlan – range G2:G3
- RVariables – range A10:G10

3.2.2 Worksheet Formatting

Cells highlighted purple indicate user inputs, these include the cell for Analysis Year (C12), Inflation Rate (C13), and Analysis Year CEPCI (C14). Data validation limitations have been entered for the analysis year, such that the user must specify a whole number greater than or equal to 2009. Similarly, data validation limitations for the inflation rate have been entered such that the user must input a value between 1% and 5%. Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs.

To access the data validation information for a given cell, select the cell in question, select the 'Data' tab in the 'Ribbon', and click the 'Data Validation' button, next select the 'Data Validation' option from the drop down list. This brings up the 'Data Validation' window which includes the 'Validation criteria' in the 'Settings' tab.

3.2.3 Worksheet Equations/IF Statements

The following equations and IF statements are included in the List Info worksheet:

- D3=IF(RPhase="NGNP",1,4) – This equation sets the available number of reactors to 1 when the NGNP project phase is selected, as it was assumed the demonstration plant would only include a single reactor.
- F2=IF(PCyc="Yes","Rankine"," ") – This equation sets the power cycle type to Rankine when the power cycle present combo box is set to Yes.
- F3=IF(PCyc="Yes","Brayton"," ") – This equation sets the power cycle type to Brayton when the power cycle present combo box is set to Yes.
- A10 to G10=INDEX(array, index) – This equation sets the value selected in row 10 for the named ranges and the corresponding combo box index.

3.2.4 Worksheet Macros

No Macros are included in the List Info worksheet.

3.3 HTGR Capital Cost Worksheet

The HTGR Capital Cost worksheet calculates the total capital cost for the selected HTGR plant configuration, as well as includes the data used to calculate the capital costs. The results of the calculations are passed to the HTGR Cost Summary worksheet, see Section 3.1. Capital costs are the sum of preconstruction costs, direct costs, indirect costs, and project contingency. For a description of the references used to tabulate the data included in this worksheet refer to TEV-1196 (INL 2011). All costs are calculated in 2009 dollars. However, the model is developed such that the capital costs can be scaled from 2009 dollars using the CEPCI, as discussed in Section 3.2. Only the scaled values are passed to the HTGR Cost Summary worksheet. In the examples provided, the analysis year is assumed to be 2009; therefore, the scaled values are the same as the calculated values, i.e. 2009 dollars.

At the top of the HTGR Capital Cost worksheet the user inputs specified in the combo boxes on the HTGR Cost Summary worksheet are listed, as shown in Figure 6.

	A	B	C	D	E	F
1	**Reactor Input Summary:**					
2		Reactor Size (MWt):				600
3		ROT (°C):				850
4		Project Phase:				NOAK
5		Number of Reactors:				4
6		Power Cycle Present:				Yes
7		Power Cycle Type:				Rankine

Figure 6. Reactor input summary on the HTGR Capital Cost worksheet, screenshot.

3.3.1 Preconstruction Costs

Preconstruction costs are the sum of the land and land rights costs and licensing and application costs. A single reactor is assumed to occupy 50 acres of land, while a four-pack is assumed to occupy 100 acres, per TEV-1196 (INL 2011). Licensing and application costs are specified for the NGNP, FOAK, and NOAK project phases for single and four-pack configurations. Preconstruction costs were assumed to be consistent for both 350 MWt and 600 MWt reactor sizes (INL 2011). Figure 7 presents a screenshot of the preconstruction costs section of the HTGR Capital Cost worksheet. Conditional formatting is used to highlight which licensing and application cost should apply to the selected configuration, i.e. the cell is highlighted green and corresponds to the value in cell I24.

	A	B	C	D	E	F	G	H	I	J	K	L	M
9	**PRECONSTRUCTION COSTS:**												
10													
11		**Land and Land Rights (2009 $):**					100	Acres	**10.00**				
12		**Land and Land Rights (2009 $):**							**10.00**				
13													
14		**Licencing and Application Costs:**											
15							**Reactor Phase**		**NGNP**	**FOAK**		**NOAK**	
16			**Description**				**Number of Units**		**1**	**1**	**4**	**1**	**4**
17			Pre-Application						30.00	15.00	15.00	15.00	15.00
18			ESP and COLA Preparation						69.00	23.00	28.00	23.00	28.00
19			ESP and COLA Review by NRC						108.00	25.00	25.00	12.00	12.00
20			Support of Construction & Initial Operation						18.50	18.50	23.00	18.50	23.00
21			State and Local Permitting						3.00	3.00	3.00	3.00	3.00
22			**Total**						**228.50**	**84.50**	**94.00**	**71.50**	**81.00**
23													
24		***Selected Configuration Licensing Costs (2009 $):***							***81.00***				
25		***Selected Configuration Licensing Costs (2009 $):***							***81.00***				
26													
27	**TOTAL PRECONSTRUCTION COSTS (2009 $):**								**91.00**				
28	**TOTAL PRECONSTRUCTION COSTS (2009 $):**								**91.00**				

Figure 7. Preconstruction costs on the HTGR Capital Cost worksheet, screenshot.

3.3.2 Direct Costs

Direct costs are the sum of the individual estimates for the top capital cost items and the balance of equipment adder, assumed to be 25% of the sum of the individual estimates (INL 2011). The individual estimates are based on costs provided by Dominion Engineering, Inc. through a separate subcontract as documented in TEV-1196; cells highlighted in blue are scaled as described in the TEV (INL 2011). Figure 8 presents a screenshot of the direct costs section of the HTGR Capital Cost worksheet. Conditional formatting is used to highlight the sum of the individual estimates which should apply to the selected configuration, i.e. the cell is highlighted green, AE63, and corresponds to the value shown in cell I65. Conditional formatting is also used to hide the costs not associated with the selected power cycle, i.e. a Rankine cycle is selected for the example shown; hence, the rows corresponding to costs for the Brayton cycle are blank (rows 46, 47, 60, and 61).

30	DIRECT COSTS:																															
31																																
32		*Individual Estimates for Top Capital Cost Items:*																														
33																																
34					Reactor Phase			NGNP					FOAK					FOAK					NOAK					NOAK					
35					Number of Units			1					1					4					1					4					
36				Description		ROT		750	800	850	900	950	750	800	850	900	950	750	800	850	900	950	750	800	850	900	950	750	800	850	900	950
37				Reactor Building				163.67	170.49	177.60	185.00	192.70	141.81	150.86	160.49	170.73	181.63	402.73	428.44	455.79	484.88	515.83	88.95	90.77	92.62	94.51	96.44	252.62	257.78	263.04	268.40	273.88
38				Reactor Vessel				92.31	97.20	102.45	129.23	141.39	65.47	68.95	72.69	91.74	100.39	188.72	198.61	209.22	263.32	287.88	55.65	58.59	61.74	77.84	85.15	160.39	168.74	177.71	223.43	244.18
39				Reactor Initial Core				86.13	86.13	86.13	86.13	86.13	73.07	73.07	73.07	73.07	73.07	292.27	292.27	292.27	292.27	292.27	46.86	46.86	46.86	46.86	46.86	187.43	187.43	187.43	187.43	187.43
40				Reactor Metallic Internals				35.89	40.36	45.37	75.54	90.83	25.27	28.44	31.99	53.33	64.15	73.48	82.48	92.55	153.17	183.89	21.55	24.23	27.22	45.26	54.40	62.66	70.27	78.77	130.00	155.96
41			350 MWt Module	Reactor Graphite Internals				28.05	29.84	31.75	33.77	33.77	21.09	22.44	23.87	25.40	25.40	59.91	63.73	67.80	72.13	72.13	9.30	9.89	10.52	11.19	11.19	26.40	28.09	29.88	31.79	31.79
42				Reactor Cavity Cooling System				23.49	23.49	23.49	23.49	23.49	22.08	22.08	22.08	22.08	22.08	88.32	88.32	88.32	88.32	88.32	9.64	9.64	9.64	9.64	9.64	38.54	38.54	38.54	38.54	38.54
43				Core Refueling Equipment				73.53	73.53	73.53	73.53	73.53	69.12	69.12	69.12	69.12	69.12	196.30	196.30	196.30	196.30	196.30	42.50	42.50	42.50	42.50	42.50	120.69	120.69	120.69	120.69	120.69
44				Heat Rejection System				34.14	34.14	34.14	34.14	34.14	32.09	32.09	32.09	32.09	32.09	128.37	128.37	128.37	128.37	128.37	21.05	21.05	21.05	21.05	21.05	84.21	84.21	84.21	84.21	84.21
45				IHX				21.97	23.07	24.25	49.83	54.45	15.53	16.31	17.15	35.37	38.66	45.80	48.02	50.41	102.17	111.51	13.32	13.98	14.69	30.09	32.87	39.28	41.15	43.17	86.90	94.80
46				Power Conversion Vessel - Brayton																												
47				Turbomachinery - Brayton																												
48				Turbomachinery - Rankine				130.44	141.79	154.11	167.52	182.08	122.62	133.28	144.87	157.46	171.16	490.46	533.11	579.47	629.86	684.63	91.31	99.25	107.88	117.26	127.46	365.24	397.00	431.52	469.04	509.83
49				**Total**				**689.62**	**720.04**	**752.82**	**858.18**	**912.52**	**588.15**	**616.64**	**647.42**	**730.39**	**777.74**	**1966.36**	**2059.65**	**2160.49**	**2410.78**	**2561.13**	**400.11**	**416.74**	**434.72**	**496.19**	**527.55**	**1337.46**	**1393.90**	**1454.96**	**1640.43**	**1741.31**
50																																
51				Reactor Building				214.30	223.23	232.53	242.22	252.31	185.67	197.52	210.13	223.54	237.81	527.30	560.96	596.77	634.86	675.38	116.46	118.84	121.27	123.74	126.27	330.76	337.51	344.39	351.42	358.60
52				Reactor Vessel				133.65	140.74	148.35	187.17	204.79	94.80	99.84	105.26	132.87	145.40	273.13	287.46	302.84	381.24	416.84	80.56	84.82	89.39	112.72	123.32	232.09	244.20	257.19	323.45	353.53
53				Reactor Initial Core				133.11	133.11	133.11	133.11	133.11	112.92	112.92	112.92	112.92	112.92	451.69	451.69	451.69	451.69	451.69	72.41	72.41	72.41	72.41	72.41	289.66	289.66	289.66	289.66	289.66
54				Reactor Metallic Internals				37.66	42.37	47.63	79.31	95.36	35.78	40.27	45.29	75.51	90.83	104.01	116.76	131.01	216.87	260.38	30.51	34.30	38.54	64.09	77.03	88.69	99.46	111.51	184.05	220.82
55				Reactor Graphite Internals				28.05	29.84	31.75	33.77	33.77	26.37	28.05	29.84	31.75	31.75	74.89	79.67	84.75	90.16	90.16	16.27	17.31	18.41	19.59	19.59	46.20	49.15	52.29	55.63	55.63
56				Reactor Cavity Cooling System				30.75	30.75	30.75	30.75	30.75	28.91	28.91	28.91	28.91	28.91	115.63	115.63	115.63	115.63	115.63	12.62	12.62	12.62	12.62	12.62	50.46	50.46	50.46	50.46	50.46
57				Core Refueling Equipment				98.04	98.04	98.04	98.04	98.04	92.16	92.16	92.16	92.16	92.16	261.73	261.73	261.73	261.73	261.73	56.66	56.66	56.66	56.66	56.66	160.92	160.92	160.92	160.92	160.92
58				Heat Rejection System				44.70	44.70	44.70	44.70	44.70	42.02	42.02	42.02	42.02	42.02	168.07	168.07	168.07	168.07	168.07	39.98	39.98	39.98	39.98	39.98	159.93	159.93	159.93	159.93	159.93
59				IHX				31.09	32.65	34.32	70.56	77.10	21.98	23.09	24.28	50.08	54.74	64.80	67.95	71.33	144.64	157.87	18.84	19.78	20.79	42.60	46.53	55.56	58.23	61.08	123.02	134.20
60				Power Conversion Vessel - Brayton																												
61				Turbomachinery - Brayton																												
62				Turbomachinery - Rankine				170.79	185.64	201.78	219.33	238.40	160.54	174.50	189.68	206.17	224.10	642.17	698.01	758.70	824.68	896.39	119.55	129.95	141.25	153.53	166.88	478.21	519.79	564.99	614.12	667.52
63				**Total**				**922.14**	**961.07**	**1002.96**	**1138.95**	**1208.34**	**801.14**	**839.28**	**880.48**	**995.93**	**1060.64**	**2683.42**	**2807.93**	**2942.53**	**3289.58**	**3494.15**	**563.87**	**586.67**	**611.32**	**697.94**	**741.29**	**1892.48**	**1969.30**	**2052.42**	**2312.66**	**2451.26**
64																																
65		*Selected Configuration Direct Cost Total (2009 $):*						*2052.42*																								
66		*Selected Configuration Direct Cost Total (2009 $):*						*2052.42*																								
67																																
68		**Balance of Equipment Adder (2009 $):**				25%		**513.11**																								
69		**Balance of Equipment Adder (2009 $):**						**513.11**																								
70																																
71	**TOTAL DIRECT COSTS (2009 $):**							2565.53																								
72	**TOTAL DIRECT COSTS (2009 $):**							2565.53																								

Figure 8. Direct costs on the HTGR Capital Cost worksheet, screenshot.

3.3.3 Indirect Costs and Total Overnight Capital Costs

Indirect costs are the sum of design costs, construction services, home office and engineering services, field office and engineering services, and owner's costs. Design costs are the sum of conceptual design, preliminary design, final design, and research and development costs. The majority of design costs occur only for the NGNP project phase, only a fraction of the final design costs occur for the FOAK and NOAK project phases (INL 2011). Construction, home office and engineering services, field office and engineering services, and owner's costs are all assumed to be a fraction of the total direct costs: 20%, 16%, 10%, and 12%, respectively (INL 2011). The base construction costs are the sum of preconstruction, direct, and indirect costs. A project contingency of 20% is assumed for all project phases (INL 2011). The total overnight cost is the sum of the base construction costs and the project contingency. Figure 9 presents a screenshot of the indirect costs and total overnight capital costs sections of the HTGR Capital Cost worksheet.

3.3.4 Named Cells/Ranges

No named cells or ranges are included in the HTGR Capital Cost worksheet.

3.3.5 Worksheet Formatting

Cells highlighted blue indicate individual cost estimate data that was scaled from other known data values. Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs. Conditional formatting is used in row 22 which highlights the selected configuration licensing costs in green. Similarly, the selected configuration for the direct costs individual estimates (rows 29 and 63) is highlighted green according to the inputs specified by the user. Finally, conditional formatting is also used to hide the costs not associated with the selected power cycle configurations in the individual cost estimates (rows 46, 47, 48, 60, 61, and 62). To identify the conditional formatting used in any sheet, select the 'Home' tab on the 'Ribbon', select 'Conditional Formatting', and select 'Manage Rules' from the drop down list; this will list all conditional formatting on the given worksheet.

	A	B	C	D	E	F	G	H	I
74	**INDIRECT COSTS:**								
75									
76		***Design Costs (NGNP Only - Excluding Final Design):***							
77			Conceptual Design						0.00
78			Preliminary Design						0.00
79			Final Design						20.00
80			R&D						0.00
81		***Total Design Costs (2009 $):***							**20.00**
82		***Total Design Costs (2009 $):***							**20.00**
83									
84		**Construction Services (2009 $):**						20%	**514.11**
85		**Construction Services (2009 $):**							**514.11**
86									
87		**Home Office and Engineering Services (2009 $):**						16%	**413.66**
88		**Home Office and Engineering Services (2009 $):**							**413.66**
89									
90		**Field Office and Engineering Services (2009 $):**						10%	**250.69**
91		**Field Office and Engineering Services (2009 $):**							**250.69**
92									
93		**Owner's Costs (2009 $):**						12%	**295.75**
94		**Owner's Costs (2009 $):**							**295.75**
95									
96	**TOTAL INDIRECT COSTS (2009 $):**								**1494.20**
97	**TOTAL INDIRECT COSTS (2009 $):**								**1494.20**
98									
99	**BASE CONSTRUCTION COST (2009 $):**								**4150.73**
100	**BASE CONSTRUCTION COST (2009 $):**								**4150.73**
101									
102	**PROJECT CONTINGENCY (2009 $):**							20%	**830.15**
103	**PROJECT CONTINGENCY (2009 $):**								**830.15**
104									
105	**TOTAL OVERNIGHT COST (2009 $):**								**4980.88**
106	**OVERNIGHT COST PER kWt (2009 $):**								**2075.37**
107									
108	**TOTAL OVERNIGHT COST (2009 $):**								**4980.88**
109	**OVERNIGHT COST PER kWt (2009 $):**								**2075.37**

Figure 9. Indirect and total overnight costs on the HTGR Capital Cost worksheet, screenshot.

3.3.6 Worksheet Equations/IF Statements

In the preconstruction costs section of the HTGR Capital Cost worksheet, the following equation is used to set the acreage for the selected reactor configuration:

G11=IF(Number=1,50,IF(Number=4,100,))

Based on the above equation, if the user selects a single reactor cell G11 will display 50 acres, and if the user selects a four-pack configuration the cell will display 100 acres. Licensing and application costs are

also presented for multiple reactor configurations, as a result, an IF statement is used in cell I24 which selects the appropriate value from row 22 as follows:

```
I24=IF(RPhase="NGNP",I22,IF(RPhase="FOAK",IF(Number=1,J22,IF(Number=4,K22,)),
    IF(RPhase="NOAK",IF(Number=1,L22,IF(Number=4,M22,)))))
```

The above function sets the selected configuration licensing costs to the appropriate licensing and application costs based on the values selected by the user on the HTGR Cost Summary worksheet.

In the direct costs, individual estimates section, only FOAK cost data for a single reactor was provided in the Dominion estimate; as a result the FOAK four-pack data was scaled based on the relationship between the NOAK single and four-pack configurations (INL 2011). The following example is provided for calculating the reactor vessel cost for a four-pack of 600 MWt HTGRs, for a FOAK project phase, for an ROT of 850°C (cell T52). The following Excel function is entered:

```
T52=AD52/Y52*O52
```

where cell AD52 is the reactor vessel cost for an NOAK four-pack 600 MWt configuration at 850°C, cell Y52 is the reactor vessel cost for an NOAK single 600 MWt HTGR at 850°C, and cell O52 is the reactor vessel cost for an FOAK single 600 MWt HTGR at 850°C. Similar equations can be found for all FOAK four-pack costs for both 600 MWt and 350 MWt modules.

Item costs were also scaled to determine the costs for the NGNP project phase for all ROTs except 950°C, which was provided in the estimate from Dominion. Costs for the other ROTs were scaled based the average scaling factor for a single reactor for the FOAK and NOAK phases. For example, the reactor vessel cost for a single 600 MWt HTGR at 850°C ROT was calculated as follows:

```
K52=AVERAGE(P52/Q52,Z52/AA52)*L52
```

This equation multiples the scaled 900°C ROT NGNP cost by the average ratios for the 900°C and 850°C ROTs for the single FOAK and NOAK project phases.

The total costs for the individual estimates for top capital cost items are summed based on the power cycle selected by the user on the HTGR Cost Summary sheet. The following function is entered into cell AE63, the total cost for a NOAK, 600 MWt four-pack, for an ROT of 850°C:

```
AE63=SUM(AE51:AE59,IF(PCyc="yes",IF(CycChoice="Brayton",AE60:AE61,IF(CycChoice=
    "Rankine",AE62,))),)
```

This equation sums the individual item costs, excluding the power cycle components, and then depending upon if a power cycle is indicated by the user, the corresponding cycle costs, either Brayton or Rankine, selected by the user are added. The cycle selection also corresponds to the conditional formatting described in the section above, i.e. the example shown a Rankine cycle is selected; hence, the Brayton cycle parameters are hidden and not included in the summation.

Since the individual item direct costs are presented for multiple reactor configurations a lookup function is used in cell I65 which selects the appropriate value from either row 49 or 63:

```
I65=HLOOKUP(ROTSel,IF(RPhase="NGNP",I36:M63,IF(RPhase="FOAK",IF(Number=1,N36:
    R63,IF(Number=4,S36:W63,)),IF(RPhase="NOAK",IF(Number=1,X36:AB63,IF(Number=4,
    AC36:AG63,)))),IF(RSize=350,14,IF(RSize=600,28,)),TRUE)
```

The above function uses the built in HLOOKUP function in Excel (horizontal lookup, i.e. looking across rows in an array) to select the appropriate value corresponding to the selected ROT; corresponding to the array for a single NGNP configuration, a single or four-pack FOAK configuration, or single or four-pack

NOAK configuration; from either row 49 or 63 depending upon the reactor size selected [IF(RSize=350, 14,IF(RSize=600,28,)), tells the function to select a value from array row 14 or 28). In the example provided, the lookup function selects the value in cell AE63 based on the function above and the user inputs selected on the HTGR Cost summary worksheet, as the selected configuration direct cost total shown in cell I65.

IF statements used in the indirect cost section of the HTGR Capital Cost worksheet are limited to calculation of design costs, based on the selected project phase. The following equations are used for the corresponding design costs:

- Conceptual design – I77=IF(RPhase="NGNP",84,0)
- Preliminary design – I78=IF(RPhase="NGNP",182,0)
- Final design – I79=IF(RPhase="NGNP",296,20)
- R&D – I80=IF(RPhase="NGNP",452,0)

These equations set the design cost values for the NGNP project phase to the values described in TEV-1196, when the user sets the project phase to NGNP, otherwise all design costs are zero, except final design which has a cost of 20 (INL 2011).

The total overnight cost, presented in millions of dollars (cells I106 and I109), is converted to dollars per kWt using the following equation (only cell I106 is shown):

I106=I105*1000000/(RSize*1000*Number)

3.3.7 Worksheet Macros

No Macros are included in the HTGR Capital Cost worksheet.

3.4 O&Ms Worksheet

The O&Ms worksheet calculates O&M costs for the selected HTGR plant configuration. The results of the calculations are passed to the HTGR Cost Summary worksheet, see Section 3.1. O&M costs are the sum of payroll costs, various industry fees, insurance and taxes, material supplies services and upgrades, outage costs, and administration and general cost overhead (INL 2011). The worksheet includes the INL staffing estimate for a single and additional unit for both 600 MWt and 350 MWt plants, as outlined in TEV-1196 (INL 2011). A screenshot for the staffing plan is not included, as it identifies close to 200 positions and is prohibitively long, for the detailed staffing plans see TEV-1196 or the O&Ms worksheet. Only the total plant staffing level for the INL analysis is presented in the screenshot for the O&Ms worksheet. Additionally, the staffing levels identified in vendor estimates are presented; however, the breakdown by position is not included for the vendor estimate. Figure 10 presents a screenshot of the O&Ms worksheet. All O&M costs are presented in 2009 dollars; the inflation rate is used to adjust O&M costs to years other than 2009, as outlined in Section 3.2.

	A	B	C	D	E	F	G	H	I
1						600 MWt		350 MWt	
2						Single Unit	Additional Unit	Single Unit	Additional Unit
225	**TOTAL PLANT STAFF - INL Estimate**					**382**	**71**	**382**	**71**
226	**TOTAL PLANT STAFF - Vendor Estimate**					**165**	**25.3**	**165**	**25.3**
227									
228	**Payroll Estimate**								
229				Total Plant Staff from Vendor Estimate		165	25.3	165	25.3
230				Staff Salary	$63,400	10,461,000	1,606,133	10,461,000	1,606,133
231				Staff Overtime	7.5%	784,575	120,460	784,575	120,460
232				Staff Retirement and Benefits	38.5%	4,027,485	618,361	4,027,485	618,361
233				Staff Bonus and Incentives	8.0%	836,880	128,491	836,880	128,491
234				Staff Payroll Tax	7.7%	805,497	123,672	805,497	123,672
235	**Total Staff Payroll**					**16,915,437**	**2,597,118**	**16,915,437**	**2,597,118**
236	**Industry Fees:**								
237				NRC Fees		4,784,000	4,784,000	4,784,000	4,784,000
238				INPO Fees		706,344	176,586	706,344	176,586
239				NEI Fees		59,366	59,366	34,630	34,630
240	**Other Costs:**								
241				Insurance and Taxes		3,000,000	1,000,000	3,000,000	1,000,000
242				Material Supplies Services and Upgrades		5,000,000	5,000,000	3,000,000	3,000,000
243				Outage O&M		4,070,724	4,070,724	2,945,925	2,945,925
244				Administration and General Cost Overhead		3,000,000	3,000,000	3,000,000	3,000,000
245	**Total O&M (2009 $)**					**37,535,870**	**20,687,793**	**34,386,336**	**17,538,259**
246	**Total O&M (2009 $)**					**37,535,870**	**20,687,793**	**34,386,336**	**17,538,259**
247									
248	**Selected O&M Costs (Million 2009 $)**					**99.60**			
249	**Selected O&M Cost Per MWt-hr (2009 $)**					**4.74**	$/MWt-hr		

Figure 10. O&Ms worksheet screenshot.

3.4.1 Named Cells/Ranges

No named cells or ranges are included in the O&Ms worksheet.

3.4.2 Worksheet Formatting

Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs. Conditional formatting is used in rows 245 and 246, which highlights the costs used in the O&M calculations in green. To identify the conditional formatting used in any sheet, select the 'Home' tab on the 'Ribbon', select 'Conditional Formatting', and select 'Manage Rules' from the drop down list; this will list all conditional formatting on the given worksheet.

3.4.3 Worksheet Equations/IF Statements

In the O&Ms worksheet, the following equation is used to set the staffing estimate based on the user selection in the HTGR Cost Summary worksheet, cell F229 is used as the example:

F229=IF(Staff="Vendor",F226,IF(Staff="INL Model",F225,))

This equation sets the cell value (row 229) to either the INL or vendor staffing estimate (row 225 or 226, respectively) based on the value selected by the user. The selected O&M cost is calculated by the following equation in cell F248:

F248=(IF(RSize=600,F246,IF(RSize=350,H246,))+IF(Number=4,IF(RSize=600,(3*G246),
IF(RSize=350,(3*I246),))))/1000000

This equation selects either the 600 MWt or 350 MWt costs for the single reactor, then adds three times the appropriate additional unit costs if a four-pack is selected. Finally, the O&M cost per MWt-hr is calculated using the following equation:

F249=F248*1000000/(RSize*Number)/(365*24)

It is assumed that O&M costs are consistent for all project phases (INL 2011).

3.4.4 Worksheet Macros

No Macros are included in the O&Ms worksheet.

3.5 Yearly Fuel Cost Worksheet

The Yearly Fuel Cost worksheet calculates fuel costs for the selected HTGR plant configuration. The results of the calculations are passed to the HTGR Cost Summary worksheet, see Section 3.1. Fuel costs are the sum of uranium ore, uranium conversion, uranium enrichment, tails disposal, fuel fabrication, on-site spent fuel storage, and spent fuel disposition costs (INL 2011). The number of fuel blocks per reload is dependent upon the size and number of reactors in the selected configuration, as is the kilograms of heavy metals in the refueling blocks (INL 2011). The calculations for the amount of uranium, U_3O_8, and separative work units (SWU) are detailed in TEV-1196; however, they will also be summarized in this document (INL 2011). Figure 11 presents a screenshot of the Yearly Fuel Cost worksheet. All fuel costs are presented in 2009 dollars; the inflation rate is used to adjust fuel costs to years other than 2009, as outlined in Section 3.2.

3.5.1 Named Cells/Ranges

No named cells or ranges are included in the Yearly Fuel Cost worksheet.

3.5.2 Worksheet Formatting

Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs.

	A	B	C	D
1	**Description**	**Value**		
2	Fuel Blocks in Reload	2040		
3	Uranium Loading	4.4		
4	Enrichment	15%		
5	Fuel Cycle Length, months	18		
6	Reload Blocks per Year	0.66667		
7	Uranium in Tailings	0.20%		
8	U235 Percentage	0.72%		
9	Heavy Metals in Refueling Blocks, kg	9048		
10	Uranium Product per Year, kg	5984		
11	Uranium Feed per Year, kg	171634		
12	Uranium in U3O8	85%		
13	U3O8 Required per Year, kg	202403		
14	Uranium Tailings per Year, kg	165650		
15	SWU	197881		
16				
17	**Item**	**Unit Cost**		**Yearly Cost - $**
18	Uranium Ore	106	$ per kg U3O8	21,472,961
19	Uranium Conversion	11	$ per kg Uranium Feed	1,820,866
20	Uranium Enrichment	122	$ per SWU	24,142,134
21	Tails Disposal	11	$ per kg Uranium Tailings	1,757,382
22	NGNP Fuel Fab Cost	10,609	$ per kg Uranium Product	63,484,256
23	On-Site Spent Fuel Storage	223	$ per kg Heavy Metals	1,343,863
24	Spent Fuel Disposition	3,293	$ per kg Heavy Metals	19,861,446
25	**Total (2009 $)**			**133,882,908**
26	**Refueling Cost Per Core, for Full 18 Month Fuel Cycle (2009 $)**			**50,206,091**
27	**Total (2009 $)**			**133,882,908**
28	**Total (Million 2009 $)**			**133.88**
29	**Refueling Cost Per Core, for Full 18 Month Fuel Cycle (2009 $)**			**50,206,091**
30	**Refueling Cost Per Core, for Full 18 Month Fuel Cycle (Million 2009 $)**			**50.21**
31	**Fuel Cost Per MWt-hr (2009 $/MWt-hr)**			**6.37**

Figure 11. Yearly Fuel Cost worksheet screenshot.

3.5.3 Worksheet Equations/IF Statements

Data and specific references for the equations described in this section are presented in TEV-1196; please refer to that document for detailed information on the following calculations (INL 2011). In the Yearly Fuel Cost worksheet, the following equation is used to calculate the number of fuel blocks in each fuel reloading:

B2=510*RSize/600*Number

The mass of heavy metals, in the refueling blocks, is calculated as follows:

B9=(1748+514)*RSize/600*Number

The mass of uranium fed per year is next calculated based on the following equation (see page 40 of INL 2011):

B11=B10*(B4-B7)/(B8-B7)

The amount of uranium tailings per year is then calculated (see page 40 of INL 2011):

B14=B10*(B4-B8)/(B8-B7)

Finally, the SWUs are calculated (see page 40 of INL 2011):

B15=B10*(1-2*B4)*LN((1-B4)/B4)+B14*(1-2*B7)*LN((1-B7)/B7)-B11*(1-2*B8)*
LN((1-B8)/B8)

The above calculations provide the fuel requirements to calculate the yearly costs that make up the total annual refueling costs and the refueling cost per core. The majority of costs are consistent for all project phases, excluding fuel fabrication costs, for which costs are higher for the NGNP and FOAK project phases. The fuel fabrication unit cost is defined as follows:

B22=IF(OR(RPhase="NGNP",RPhase="FOAK"),25000,IF(RPhase="NOAK",10000,))*
(1+IRT)^(2009-2007)

The fuel fabrication cost is based on 2007 values; thus, the costs are adjusted to 2009 values using the inflation rate specified in the List Info worksheet. Yearly costs (column D) are calculated by multiplying the unit cost by the annual yearly requirement (column B). The total cost is the sum of all the yearly costs, and the cost per core is calculated as follows:

B26=D25/Number/B6

Finally, the fuel cost per MWt-hr is calculated using the following equation:

B31=D28*1000000/(RSize*Number)/(365*24)

3.5.4 Worksheet Macros

No Macros are included in the Yearly Fuel Cost worksheet.

3.6 Decommissioning Worksheet

The Decommissioning worksheet calculates decommissioning costs for the selected HTGR plant configuration. The results of the calculations are passed to the HTGR Cost Summary worksheet, see Section 3.1. Decommissioning costs were estimated based on the methodology presented in NUREG-1307, Rev. 14. As this document is for estimation of decommissioning costs for large light water reactors (LWRs), the decommissioning costs were converted to a dollar per MWt basis in order to estimate the costs for decommissioning the HTGR (INL 2011). Figure 12 presents a screenshot of the Decommissioning worksheet. All decommissioning costs are presented in 2009 dollars; the inflation rate is used to adjust fuel costs to years other than 2009, as outlined in Section 3.2.

	A	B	C	D	E	F
1		PWR	BWR	Average		
2	C_{1986}	105	135	120		
3	E	2.139	2.181	2.10		
4						
5		Northeast	South	Midwest	West	Average
6	L	2.41	2.21	2.29	2.29	2.23
7						
8		Direct Disposal		Direct Disposal with Vendors		Average
9		PWR	BWR	PWR	BWR	
10	B	27.292	24.356	12.28	12.54	18.543
11						
12	Calculated Decommissioning Cost:			696.25		
13	MWt:			3,400		
14						
15	$/MWt (2009 $)			204,780		
16	$/MWt (2009 $)			204,780		
17	Total Decommissioning Cost (2009 $)			491.47		

Figure 12. Decommissioning worksheet screenshot.

3.6.1 Named Cells/Ranges

No named cells or ranges are included in the Decommissioning worksheet.

3.6.2 Worksheet Formatting

Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs.

3.6.3 Worksheet Equations/IF Statements

The decommissioning cost for an average light water reactor, as specified in NUREG-1307, was calculated using the following equation (see page 41 of INL 2011):

D12=D2*(0.65*F6+0.13*D3+0.22*F10)

The dollar per MWt for decommissioning is calculated based on a 3,400 MWt LWR. This average cost per MWt is used to calculate the total decommissioning cost as follows:

D17=D16*RSize*Number/1000000

3.6.4 Worksheet Macros

No Macros are included in the Decommissioning worksheet.

3.7 Full Results Worksheet

The Full Results worksheet tabulates the results summarized on the HTGR Cost Summary worksheet for all possible configuration iterations, excluding the staffing plan, which is set equal to the current user selection. To populate the tables, click the Populate Tables for Selected Staffing Plan button. This button

is linked to the FullResults Macro. A partial screenshot of the Full Results worksheet is shown in Figure 13. Note, all reactor sizes and phases are included on this sheet, not just the NGNP project phase as shown in the partial screenshot.

1		Populate Tables for Selected Staffing Plan		Staffing Plan Selected:			Vendor		
2									
3									
4		**Reactor Power Size**		600	600	600	600	600	
5		**Number of Reactors**		1	1	1	1	1	
6		**Reactor Outlet Temperature**		750	800	850	900	950	
7		**Power Cycle Present**		No	No	No	No	No	
8		**Power Cycle Type**							
9		**Reactor Phase**		NGNP	NGNP	NGNP	NGNP	NGNP	
10									
11		**Capital Cost Summary (Million 2009 $):**							
12		PRECONSTRUCTION COSTS:							
13		Land and Land Rights:		5.00	5.00	5.00	5.00	5.00	
14		Licencing and Application Costs:		228.50	228.50	228.50	228.50	228.50	
15		TOTAL PRECONSTRUCTION COSTS:		233.50	233.50	233.50	233.50	233.50	
16		DIRECT COSTS:							
17		Selected Configuration Direct Cost Total:		751.35	775.43	801.18	919.62	969.93	
18		BOP Adders:		187.84	193.86	200.29	229.91	242.48	
19		TOTAL DIRECT COSTS:		939.19	969.28	1001.47	1149.53	1212.42	
20		INDIRECT COSTS:							
21		Total Design Costs:		1014.00	1014.00	1014.00	1014.00	1014.00	
22		Construction Services:		188.21	194.24	200.69	230.36	242.96	
23		Home Office and Engineering Services:		151.43	156.28	161.47	185.35	195.49	
24		Field Office and Engineering Services:		91.77	94.71	97.86	112.32	118.47	
25		Owner's Costs:		108.27	111.74	115.45	132.52	139.76	
26		TOTAL INDIRECT COSTS:		1553.68	1570.97	1589.46	1674.54	1710.68	
27		BASE CONSTRUCTION COST:		2726.37	2773.75	2824.43	3057.57	3156.60	
28		PROJECT CONTINGENCY:		545.27	554.75	564.89	611.51	631.32	
29		**TOTAL OVERNIGHT COST:**		**3271.65**	**3328.50**	**3389.32**	**3669.09**	**3787.92**	
30		*OVERNIGHT COST PER kWt:*		*5452.74*	*5547.50*	*5648.87*	*6115.15*	*6313.19*	
31									
32		**Yearly O&M Summary (Million 2009 $):**							
33		**Total Yearly O&M Cost:**		**37.54**	**37.54**	**37.54**	**37.54**	**37.54**	
34		*O&M Cost Per MWt-hr*		*7.14*	*7.14*	*7.14*	*7.14*	*7.14*	
35									
36		**Fuel Cost Summary (Million 2009 $):**							
37		**Refueling Cost per Core:**		**85.92**	**85.92**	**85.92**	**85.92**	**85.92**	
38		**Average Yearly Fuel Cost:**		**57.28**	**57.28**	**57.28**	**57.28**	**57.28**	
39		*Fuel Cost Per MWt-hr*		*10.90*	*10.90*	*10.90*	*10.90*	*10.90*	
40									
41		**Decommissioning Cost Summary (Million 2009 $):**							
42		**Total Decommissioning Costs:**		**122.87**	**122.87**	**122.87**	**122.87**	**122.87**	

NGNP Project Phase

Figure 13. Full Results worksheet, partial screenshot.

3.7.1 Named Cells/Ranges

No named cells or ranges are included in the Full Results worksheet.

3.7.2 Worksheet Formatting

No special formatting is used on the Full Results worksheet.

3.7.3 Worksheet Equations/IF Statements

No equations or IF statements are included in the Full Results worksheet.

3.7.4 Worksheet Macros

The FullResults Macro compiles the full results for the user selected staffing plan into several tables, when the user clicks the Populate Tables for Selected Staffing Plan button. The FullResults Macro is presented in Figure 14. Note this Macro is several pages long.

```
Sub FullResults()
'
' FullResults Macro
'
' The following Macro creates tables of all iterations for the use
' selected staffing plan.

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Clears previous cell contents
    Sheets("Full Results").Select
    Columns("F:BM").Select
    Selection.ClearContents

    ' Writes the selected staffing plan to the sheet
    Range("F1").Value = "Staffing Plan Selected:"
    Range("I1").Value = Sheets("List Info").Range("Staff").Value

    ' Selects the List Info sheet and copies the current RVariables
    ' entries and pastes the values to row 17.
    Sheets("List Info").Select
    Range("RVariables").Copy Destination:=Cells(17, 1)

    ' Initializes the count variables for each project phase
    NGNP = 0
    FOAK = 0
    NOAK = 0

    ' Dimensions the array for the power cycle choice and
    ' initializes i which is used to iterate through the cycle
    ' choices
    Dim CycleChoice(0 To 2) As String
    i = 0
```

Figure 14. FullResults Macro.

```
' Sets the values for the array
CycleChoice(0) = "Brayton"
CycleChoice(1) = "Rankine"
CycleChoice(2) = " "

' Dimensions the array for generating heat or power and
' initializes j which is used to iterate through the choices
Dim PowerCycle(0 To 1) As String
j = 0

' Sets the values for the array
PowerCycle(0) = "No"
PowerCycle(1) = "Yes"

' Dimensions the array for the reactor size and initializes
' k which is used to iterate through the choices
Dim ReactorSize(0 To 1) As String
k = 0

' Sets the values for the array
ReactorSize(0) = 600
ReactorSize(1) = 350

' Dimensions the array for the number of reactors and
' initializes l which is used to iterate through the choices
Dim ReactorNumber(0 To 1) As String
l = 0

' Sets the values for the array
ReactorNumber(0) = 1
ReactorNumber(1) = 4

' Dimensions the array for the reactor phase and initializes
' m which is used to iterate through the choices
Dim ReactorPhase(0 To 2) As String
m = 0

' Sets the values for the array
ReactorPhase(0) = "NGNP"
ReactorPhase(1) = "FOAK"
ReactorPhase(2) = "NOAK"

' Dimensions the array for the ROT and initializes
' n which is used to iterate through the choices
Dim ReactorTemp(0 To 4) As String
n = 0
```

Figure 14. FullResults Macro. (continued)

```
' Sets the values for the array
ReactorTemp(0) = 750
ReactorTemp(1) = 800
ReactorTemp(2) = 850
ReactorTemp(3) = 900
ReactorTemp(4) = 950

' Iterates through reactor sizes
Do Until k = 2

    ' Sets value in the List Info sheet to array value
    Sheets("List Info").Select
    Range("RSize").Value = ReactorSize(k)

    ' Cycle through reactor phases
    Do Until m = 3

        ' Sets value in the List Info sheet to array value
        Sheets("List Info").Select
        Range("RPhase").Value = ReactorPhase(m)

        ' If the project phase is NGNP
        If m = 0 Then

            ' Sets the number of modules to one
            l = 0

            ' Sets value in the List Info sheet to array value
            Sheets("List Info").Select
            Range("Number").Value = ReactorNumber(l)

            ' Goes to the set power cycle subroutine
            GoSub SetPowerCycle

        ' If the project phase is FOAK or NOAK
        Else

            ' Cycles through the number of modules
            Do Until l = 2

                ' Sets value in the List Info sheet to array value
                Sheets("List Info").Select
                Range("Number").Value = ReactorNumber(l)

                ' Goes to the set power cycle subroutine
                GoSub SetPowerCycle

                ' Iterates to the next value of l
                l = l + 1

            ' Reactor number loop
            Loop
```

Figure 14. FullResults Macro. (continued)

```
                ' Reinitializes l
                l = 0

            End If

            ' Iterates to the next value of m
            m = m + 1

        ' Project phase loop
        Loop

        ' Reinitializes m
        m = 0

        ' Iterates to the next value of k
        k = k + 1

    ' Reactor size loop
    Loop

    ' Reinitializes k
    k = 0

    ' Copies the original functions back to row 10
    Sheets("List Info").Select
    Range("A17:G17").Copy Destination:=Range("A10")

    ' Clears the placeholders
    Range("A17:G17").Clear

    Sheets("Full Results").Select

    ' Allows the screen to update
    Application.ScreenUpdating = True

Exit Sub

' SetPowerCycle Subroutine
SetPowerCycle:

' Cycles through having or not having power cycles
Do Until j = 2

    ' Sets value in the List Info sheet to array value
    Sheets("List Info").Select
    Range("PCyc").Value = PowerCycle(j)

    ' If no power cycle is selected
    If j = 0 Then

        ' Sets the power cycle choice to " "
        i = 2
```

Figure 14. FullResults Macro. (continued)

```
        ' Sets value in the List Info sheet to array value
        Sheets("List Info").Select
        Range("CycChoice").Value = CycleChoice(i)

        ' Cycles through reactor outlet temperatures
        Do Until n = 5

            ' Sets value in the List Info sheet to array value
            Sheets("List Info").Select
             Range("ROTSel").Value = ReactorTemp(n)

            ' Runs the subroutine for writing values to the sheet
            GoSub SetValues

            ' Adds one to the count
            If m = 0 Then
                NGNP = NGNP + 1
            ElseIf m = 1 Then
                FOAK = FOAK + 1
            ElseIf m = 2 Then
                NOAK = NOAK + 1
            End If

            ' Iterates to the next value of n
            n = n + 1

        ' ROT loop
        Loop

        ' Reinitializes n
        n = 0

        ' Reinitializes i
        i = 0

    ' Else if a power cycle is selected
    Else

        ' Cycles the types of power cycles
        Do Until i = 2

            ' Sets value in the List Info sheet to array value
            Sheets("List Info").Select
            Range("CycChoice").Value = CycleChoice(i)

            ' Cycles through reactor outlet temperatures
            Do Until n = 5

                ' Sets value in the List Info sheet to array value
                Sheets("List Info").Select
                 Range("ROTSel").Value = ReactorTemp(n)
```

Figure 14. FullResults Macro. (continued)

```
                ' Runs the subroutine for writing values to the sheet
                GoSub SetValues

                ' Adds one to the count
                If m = 0 Then
                    NGNP = NGNP + 1
                ElseIf m = 1 Then
                    FOAK = FOAK + 1
                ElseIf m = 2 Then
                    NOAK = NOAK + 1
                End If

                ' Iterates to the next value of n
                n = n + 1

            ' ROT loop
            Loop

            ' Reinitializes n
            n = 0

            ' Iterates to the next value of i
            i = i + 1

        ' Power cycle loop
        Loop

        ' Reinitializes i
        i = 0

    End If

    ' Iterates to the next value of j
    j = j + 1

' Heat or power loop
Loop

' Reinitializes j
j = 0

Return

' SetValues subroutine
SetValues:

    ' Sets the value for Factor based on count values
    Factor = 6 + (1 - m) * (2 - m) / 2 * NGNP + m * (2 - m) * _
        FOAK + m / 2 * (m - 1) * NOAK
```

Figure 14. FullResults Macro. (continued)

```
    ' Writes the configuration to the sheet
    Sheets("Full Results").Select
    Cells(4 + 40 * m, Factor).Value = ReactorSize(k)
    Cells(5 + 40 * m, Factor).Value = ReactorNumber(l)
    Cells(6 + 40 * m, Factor).Value = ReactorTemp(n)
    Cells(7 + 40 * m, Factor).Value = PowerCycle(j)
    Cells(8 + 40 * m, Factor).Value = CycleChoice(i)
    Cells(9 + 40 * m, Factor).Value = ReactorPhase(m)

    ' Copies the value from the HTGR Cost Summary sheet and
    ' pastes values only
    Sheets("Full Results").Range(Cells(13 + 40 * m, Factor), _
        Cells(42 + 40 * m, Factor)) = Sheets("HTGR Cost Summary"). _
        Range("ResultsSummary").Value
    Range(Cells(4 + 40 * m, Factor), Cells(42 + 40 * m, Factor)) _
        = Range(Cells(4 + 40 * m, Factor), Cells(42 + 40 * m, _
        Factor)).Value

Return

End Sub
```

Figure 14. FullResults Macro. (continued)

3.8 Correlations Worksheet

The Correlations worksheet is used to develop relationships for the HTGR and power cycle costs based on the ROT, thermal rating, power cycle rating, number of modules, and project phase. These correlations were developed in order to scale the costs for project variations not included in HTGR Cost Model. For example, these correlations can be used to estimate the cost of six HTGR modules at an ROT of 775°C for an NOAK HTGR plant. Separate correlations are developed for the HTGR cost without power cycles (i.e. for heat production only), the Brayton cycle cost, and the Rankine cycle cost. The correlations are based on the direct costs, less the adders, which can be added to the correlations to account for the balance of equipment costs, indirect costs, preconstruction costs, and project contingency as described in TEV-1196 (INL 2011).

The totals for the HTGR less power cycle (rows 4 and14), the Brayton cycle (rows 7 and 17), and the Rankine cycle (rows 10 and 20) are determined based on the summation of the corresponding individual item costs on the HTGR Capital Cost worksheet. Based on this information, along with the assumed cycle efficiencies (rows 25 and 28), correlations were developed as described in TEV-1196 (INL 2011). The correlations are then used to predict the various direct costs (rows 5, 8, 11, 15, 18, 21) and the percent error between the model prediction and actual value is also calculated (rows 6, 9, 12, 16, 19, 22). Figure 15 presents a screenshot of the Correlations worksheet. Charts comparing the correlations and predicted values are also included on this sheet; however, the screenshot does not include these charts.

		Reactor Phase		NGNP					FOAK					FOAK					NOAK					NOAK				
		Number of Units		1					1					4					1					4				
	Description		ROT	750	800	850	900	950	750	800	850	900	950	750	800	850	900	950	750	800	850	900	950	750	800	850	900	950
	Total Less Power Cycle			559.17	578.25	598.71	690.67	730.44	465.54	483.37	502.55	572.93	606.58	1475.90	1526.54	1581.02	1780.93	1876.50	308.80	317.49	326.84	378.93	400.09	972.22	996.90	1023.44	1171.39	1231.48
	Model Prediction			543.25	559.00	574.76	665.87	702.56	459.41	472.73	486.05	563.10	594.13	1446.72	1488.67	1530.63	1773.26	1870.98	308.96	317.92	326.88	378.69	399.56	972.94	1001.15	1029.37	1192.54	1258.26
	% Error			2.85	3.33	4.00	3.59	3.82	1.32	2.20	3.28	1.72	2.05	1.98	2.48	3.19	0.43	0.29	0.05	0.13	0.01	0.06	0.13	0.07	0.43	0.58	1.81	2.17
350 MWt	Total Brayton Cycle			279.81	301.83	325.71	367.45	400.13	247.17	267.03	288.59	323.23	351.86	933.87	1010.29	1093.25	1215.29	1322.31	118.10	126.97	136.59	156.52	170.56	425.85	458.79	494.50	560.25	610.06
350 MWt	Model Prediction			277.70	299.28	320.86	369.07	402.24	244.63	263.64	282.64	325.11	354.32	875.18	943.19	1011.20	1163.12	1267.64	117.93	127.10	136.26	156.73	170.82	421.92	454.70	487.49	560.73	611.12
350 MWt	% Error			0.75	0.84	1.49	0.44	0.53	1.03	1.27	2.06	0.58	0.70	6.28	6.64	7.51	4.29	4.13	0.14	0.10	0.24	0.14	0.15	0.92	0.89	1.42	0.09	0.17
	Total Rankine Cycle			130.44	141.79	154.11	167.52	182.08	122.62	133.28	144.87	157.46	171.16	490.46	533.11	579.47	629.86	684.63	91.31	99.25	107.88	117.26	127.46	365.24	397.00	431.52	469.04	509.83
	Model Prediction			129.39	142.29	155.19	168.09	180.99	121.62	133.75	145.88	158.00	170.13	486.49	535.00	583.51	632.01	680.52	90.57	99.60	108.63	117.66	126.69	362.28	398.40	434.53	470.65	506.77
	% Error			0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60
	Total Less Power Cycle			751.35	775.43	801.18	919.62	969.93	640.60	664.78	690.80	789.76	836.54	2041.26	2109.92	2183.83	2464.90	2597.76	444.31	456.72	470.08	544.41	574.41	1414.27	1449.51	1487.43	1698.54	1783.74
	Model Prediction			780.97	803.62	826.27	957.25	1010.00	660.44	679.60	698.75	809.51	854.12	2079.81	2140.12	2200.43	2549.25	2689.72	444.16	457.04	469.92	544.41	574.41	1398.70	1439.26	1479.82	1714.40	1808.88
	% Error			3.94	3.64	3.13	4.09	4.13	3.10	2.23	1.15	2.50	2.10	1.89	1.43	0.76	3.42	3.54	0.04	0.07	0.03	0.00	0.00	1.10	0.71	0.51	0.93	1.41
600 MWt	Total Brayton Cycle			384.11	414.15	446.73	505.16	550.16	337.97	364.98	394.29	442.52	481.77	1271.85	1375.48	1487.98	1656.76	1802.81	163.52	175.70	188.90	217.09	236.60	586.13	631.14	679.95	772.29	841.06
600 MWt	Model Prediction			384.65	414.54	444.43	511.20	557.13	338.83	365.16	391.49	450.31	490.77	1212.21	1306.41	1400.61	1611.04	1755.80	163.35	176.04	188.73	217.09	236.60	584.39	629.81	675.22	776.67	846.46
600 MWt	% Error			0.14	0.09	0.51	1.20	1.27	0.25	0.05	0.71	1.76	1.87	4.69	5.02	5.87	2.76	2.61	0.10	0.19	0.09	0.00	0.00	0.30	0.21	0.70	0.57	0.64
	Total Rankine Cycle			170.79	185.64	201.78	219.33	238.40	160.54	174.50	189.68	206.17	224.10	642.17	698.01	758.70	824.68	896.39	119.55	129.95	141.25	153.53	166.88	478.21	519.79	564.99	614.12	667.52
	Model Prediction			169.41	186.30	203.19	220.08	236.97	159.24	175.12	191.00	206.88	222.75	636.97	700.48	763.99	827.50	891.01	118.58	130.41	142.23	154.06	165.88	474.34	521.63	568.93	616.22	663.52
	% Error			0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60	0.81	0.35	0.70	0.34	0.60
				750	800	850	900	950																					
Brayton	% Efficiency			46.8	47.7	48.5	49.2	49.9																					
Brayton	Power (MWe) - 350 MWt			163.8	166.95	169.75	172.2	174.65																					
Brayton	Power (MWe) - 600 MWt			280.8	286.2	291	295.2	299.4																					
Rankine	Efficiency			44.5	45.3	46.1	46.8	47.5																					
Rankine	Power (MWe) - 350 MWt			155.75	158.55	161.35	163.8	166.25																					
Rankine	Power (MWe) - 600 MWt			267	271.8	276.6	280.8	285																					

			ROT			Reactor #		HTGR Size - Base 600		FOAK Phase		NGNP Phase	
		T Range	T≤850	850<T<900	T>900								
HTGR Less Power Cycle		Slope	0.2576	1.48667	0.6	Exponent	0.8275	Exponent	0.6734	Multiplier	1.487	Multiplier	1.7583
		Int.	250.95	-793.598	4.4148								
		T Range	T≤850	850<T<900	T>900								
Brayton Cycle		Slope	0.2539	0.56373	0.3901	Exponent	0.9195	Exponent	0.6044	Multiplier	2.0743	Multiplier	2.3548
		Int.	-27.06	-290.269	-134.03								
		T Range		All T's									
Rankine Cycle		Slope		0.23648		Exponent	1	Exponent	0.5	Multiplier	1.3429	Multiplier	1.4286
		Int.		-58.7751									

Figure 15. Correlations worksheet screenshot.

3.8.1 Named Cells/Ranges

No named cells or ranges are included in the Correlations worksheet.

3.8.2 Worksheet Formatting

Cells highlighted pink include IF statements, other Excel functions, or equations dependent upon user inputs.

3.8.3 Worksheet Equations/IF Statements

All ROT correlations were developed using the costs for a single 600 MWt unit for an NOAK project phase. The ROT correlation is developed using the SLOPE and INTERCEPT Excel functions. Both the HTGR and Brayton cycle correlations are linear step functions due to materials changed (INL 2011). The following equation is used to calculate the slope for ROTs less than 850°C for the HTGR with no power cycle:

D34=SLOPE(S14:U14,S3:U3)

where S14:U14 are the known y-values, and S3:U3 are the known x-values. The following equation is used to calculate the intercept:

D35=INTERCEPT(S14:U14,S3:U3)

Similar equations are used for the remaining HTGR ROT ranges and for the Brayton and Rankine cycle ROT correlations. An exponential function is used in the correlation for the number of units. The exponent was determined by averaging the exponents for all ROTs for the single and four-pack NOAK costs. The following equation is used to set the exponent for the HTGR with no power cycle:

H34=AVERAGE(LN(X14/S14)/LN(4),LN(Y14/T14)/LN(4),LN(Z14/U14)/LN(4),LN(AA14/V14)/LN(4),LN(AB14/W14)/LN(4))

Again, similar equations are used for the Brayton and Rankine cycles. The correlation for reactor size is also in the form of an exponential function. The exponent was determined by averaging the exponents for all ROTs for the single 600 MWt and 350 MWt NOAK costs, 600 MWt is the basis. The following equation is used to set the exponent for the HTGR with no power cycle:

J34=AVERAGE(LN(S14/S4)/LN(600/350),LN(T14/T4)/LN(600/350),LN(U14/U4)/LN(600/350),LN(V14/V4)/LN(600/350),LN(W14/W4)/LN(600/350))

Similar equations are used for the Brayton and Rankine cycles; however the ratio of the power cycle sizes are used (rows 26, 27, 29, and 30) instead of the thermal rating ratio. It should be noted that the gross heat input to the power cycle could also be used in place of the power cycle size.

Finally, multipliers for the FOAK and NGNP plants were determined by averaging the multipliers for each ROT for the single 600 MWt and 350 MWt configurations, with the NOAK plant as the basis, i.e. a multiplier of one. The equation for the FOAK correlation for the HTGR with no power cycle is provided as an example:

L34=AVERAGE(AVERAGE((I14/S14),(J14/T14),(K14/U14),(L14/V14),(M14/W14)),AVERAGE((I4/S4),(J4/T4),(K4/U4),(L4/V4),(M4/W4)))

Both 600 MWt and 350 MWt plants were used to determine the reactor phase multipliers in order to minimize the percent error for a variety or reactor sizes.

The correlations were then used to predict costs for the HTGR, Brayton cycle, and Rankine cycle. The calculation for a 350 MWt NGNP HTGR with no power cycle and an ROT of 750°C (cell D5) is provided as the example:

```
D5=$N$34*((350/600)^$J$34)*($D$2^$H$34)*IF(D$3<=850,$D$34*D$3+$D$35,IF(AND(
  D$3>850,D$3<=900),$E$34*D$3+$E$35,IF(D$3>900,$F$34*D$3+$F$35,)))
```

For detailed descriptions of the correlations developed in the HTGR Cost Model see pages 22 through 29 of TEV-1196 (INL 2011).

3.8.4 Worksheet Macros

No Macros are included in the Correlations worksheet.

REFERENCES

AACE, 2005, *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*, AACE International Recommended Practice No. 18R-97.

INL, 2011, "Assessment of High Temperature Gas-Cooled (HTGR) Capital and Operating Costs," Idaho National Laboratory, TEV-1196, Rev. 1, January 05, 2012.

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