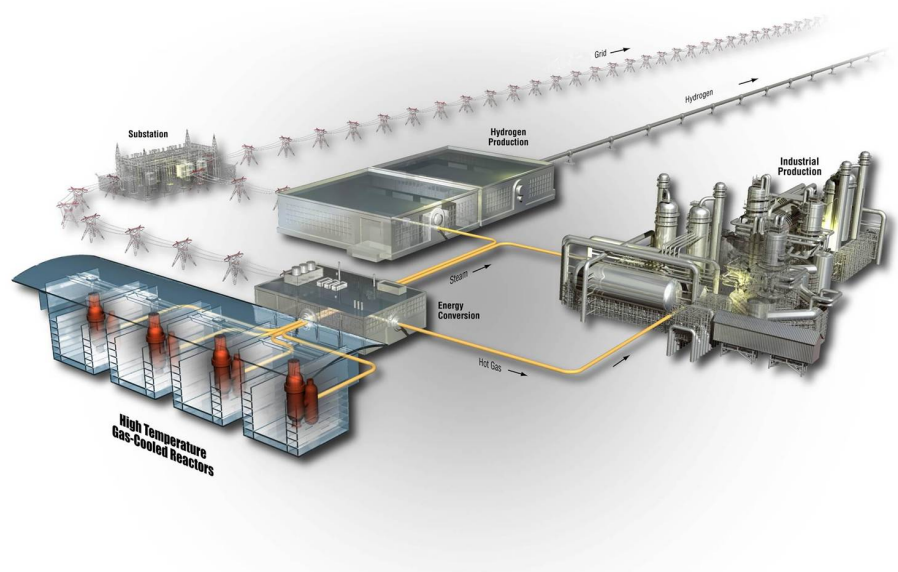# HTGR Application Economic Model Users' Manual

Anastasia M. Gandrik

January 2012

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Idaho National
Laboratory

HTGR Application Economic Model
Users' Manual

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

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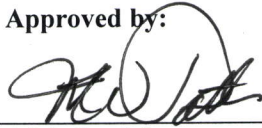
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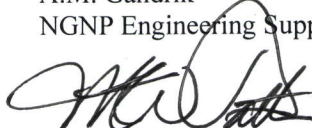
HTGR Application Economic Model
Users' Manual

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ABSTRACT

The High Temperature Gas-Cooled Reactor (HTGR) Application Economic Model was developed at the Idaho National Laboratory for the Next Generation Nuclear Plant Project. The HTGR Application Economic Model calculates either the required selling price of power and/or heat for a given internal rate of return (IRR) or the IRR for power and/or heat being sold at the market price. The user can generate these economic results for a range of 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 up to 16 reactor modules; and for module ratings of 200, 350, or 600 MWt.

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

CONTENTS

FIGURES

TABLES

x

ACRONYMS

AACE	Association for the Advancement of Cost Engineering
ATCF	after tax cash flow
BOE	balance of equipment
BTCF	before tax cash flow
CEPCI	chemical engineering plant cost index
DOE	Department of Energy
DSCR	debt service coverage ratio
EIA	Energy Information Administration
FOAK	first of a kind
GIF	GEN-IV International Forum
HTGR	high temperature gas-cooled reactor
IHX	intermediate heat exchanger
INL	Idaho National Laboratory
IRR	internal rate of return
LWR	light water reactor
MACRS	modified accelerated cost recovery system
NEI	Nuclear Energy Institute
NHSS	nuclear heat supply system
NIBT	net income before taxes
NGNP	Next Generation Nuclear Plant
NOAK	nth of a kind
NPV	net present value
NRC	Nuclear Regulatory Commission
O&M	operations and maintenance
PCS	power conversion system
PV	present value
ROT	reactor outlet temperature
TCI	total capital investment

$a(Module)$	multiplier for capital fraction equation
$b(Module)$	exponent for capital fraction equation
C_k	capital expenditures
c_months	total number of months in the current modules construction period

d_k depreciation

E_k cash outflows

i' IRR discount rate

k year

month   current month in reactor construction period

Number   total number of reactor modules

R_k revenues

t tax rate

T_k income taxes

HTGR Application Economic 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 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 industrial processes, as well as for more traditional electricity production. The focus of this users' manual is the economics of power and/or heat production.

This users' manual contains the mathematical models and operating instructions for the HTGR Application Economic Model, specifically for power and/or heat production. Instructions, screenshots, and examples are provided to guide the user through the HTGR Application Economic Model. This model was designed for users who are familiar with the HTGR design, Excel, and engineering economics. Modification of the HTGR Application Economic Model should only be performed by users familiar with the HTGR technology and its applications, Excel, and Visual Basic. Development of the HTGR capital cost bases, operating and maintenance (O&M) costs, fuel costs, and decommissioning costs used in the economic model are covered in TEV-1196, "Assessment of High Temperature Gas-Cooled Reactor (HTGR) Capital and Operating Costs," and will not be discussed in the associated users' manual (INL 2012a). The costs presented are for a prismatic block reactor configuration; however, the costs should also be adequate for estimation of pebble bed configurations (INL 2012a).

The HTGR Application Economic Model was developed to estimate the economic feasibility of HTGR operation for power and/or heat production for the following range of conditions:

- Reactor outlet temperatures (ROT) from 600°C to 1000°C

- With and without power conversion systems, including both Rankine and Brayton power cycles, including the option for co-generation of steam and electricity

- Up to 16 reactor modules

- 200, 350, and 600 MWt power levels

- For the NGNP demonstration plant, first of a kind (FOAK), and nth of a kind (NOAK) project phases. 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.

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 2012a). 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. ECONOMIC MODELING OVERVIEW

The economic viability of the HTGR for power and/or heat generation is assessed using standard economic evaluation methods, specifically the internal rate of return (IRR). The total capital investment (TCI), based on the total equipment costs; annual revenues; and annual manufacturing costs are estimated in the model for the user defined HTGR. The present worth of the annual cash flows (after taxes) is calculated by the model for the specified configuration. The following sections describe the methodology used to calculate the capital costs, annual revenues, annual manufacturing costs, and the economic indicators. The implementation of these calculations into the Excel workbook is described in Section 3.

2.1 Capital Cost Estimation

Separate capital cost correlations were developed in TEV-1196 for the nuclear heat supply system (NHSS) and for the power conversion systems (PCS) (INL 2012a). The correlation results are in millions of 2009 dollars. The user specifies the design of the plant indicating the net thermal rating for each NHSS module (*Net Thermal Rating Per Unit* in MWt), the total number of reactor modules (*Number*), the ROT, and whether the plant includes a PCS, which can be either a Brayton or Rankine power cycle. The following correlation is then used to calculate the installed capital costs for the HTGR NHSS:

$$
\begin{aligned}
Cost(ROT) &= 0.258 \times ROT + 250.952 & ROT \leq 850 \\
&= 1.487 \times ROT - 793.598 & 850 < ROT \leq 900 \\
&= 0.600 \times ROT + 4.415 & ROT > 900
\end{aligned}
$$

$$
HTGR\ Cost = Cost(ROT) \times Number^{0.927} \times \left(\frac{Net\ Thermal\ Rating\ Per\ Unit}{600\ MWt}\right)^{0.673} \\
\times (Phase\ Multiplier)
$$

$$
\begin{aligned}
Phase\ Multiplier &= 1 & Phase = NOAK \\
&= 1.486 & Phase = FOAK \\
&= 1.758 & Phase = NGNP
\end{aligned}
$$

If a Brayton cycle is specified by the user, the model calculates the gross power produced for each Brayton cycle (*Gross Power Per B_Unit* in MWe) along with the number[1] of Brayton cycles (*B_Number)*. The installed capital cost correlation for the Brayton cycle is similar to the correlation for the HTGR NHSS:

$$
\begin{aligned}
Cost(ROT) &= 0.254 \times ROT - 27.058 & ROT \leq 850 \\
&= 0.564 \times ROT - 290.269 & 850 < ROT \leq 900 \\
&= 0.390 \times ROT - 134.030 & ROT > 900
\end{aligned}
$$

---

[1] The number of Brayton cycles calculated by the model can be overridden by the user.

$$Brayton\ Cost = Cost(ROT) \times B\_Number^{0.920} \times \left(\frac{Gross\ Power\ Per\ B\_Unit}{301.4\ MWe}\right)^{0.604}$$
$$\times (Phase\ Multiplier)$$

$$
\begin{aligned}
Phase\ Multiplier &= 1 & Phase &= NOAK \\
&= 2.074 & Phase &= FOAK \\
&= 2.354 & Phase &= NGNP
\end{aligned}
$$

If a Rankine cycle is specified by the user, the model calculates the gross power produced for each Rankine cycle (*Gross Power Per R_Unit* in MWe) along with the number[2] of Rankine cycles *R_Number)*. The following correlation is used to calculate the installed capital costs for the Rankine cycle:

$$Cost(ROT) = 0.236 \times ROT - 58.775 \qquad\qquad ROT \leq 850$$

$$Rankine\ Cost = Cost(ROT) \times R\_Number \times \left(\frac{Gross\ Power\ Per\ R\_Unit}{287.6\ MWe}\right)^{0.5}$$
$$\times (Phase\ Multiplier)$$

$$
\begin{aligned}
Phase\ Multiplier &= 1 & Phase &= NOAK \\
&= 1.343 & Phase &= FOAK \\
&= 1.429 & Phase &= NGNP
\end{aligned}
$$

Preconstruction costs, balance of equipment (BOE) costs, indirect costs, and project contingencies are added in accordance with the costs outlined in Sections 2.1 through 2.5 of TEV-1196 (INL 2012a). The capital costs presented in TEV-1196 are updated from 2009 to current year dollars[3] using the Chemical Engineering Plant Cost Index (CEPCI) shown in Table 1.

Table 1. CEPCI Data.

Year	CEPCI
2009	521.9
2010	550.8

2.2   Estimation of Revenues

Yearly revenues are estimated based on the current market price of electricity selling to the grid, $59.28/MWe-hr[4], or to an industrial end user, $67.90/MWe-hr (Energy Information Administration [EIA] 2011a). When heat is sold from the HTGR to an end user, the market selling price is assumed to be related to the industrial electricity price and a power generation efficiency of 43%, which results in a market heat price of $29.20/MWt-hr.

Revenues are also calculated to determine the necessary selling prices of power and/or heat to achieve a specific rate of return, which is specified by the user. If only power is generated, the model iterates on the required electricity selling price, similarly if only heat is generated the model iterates on the heat selling price. If both electricity and heat are generated the heat price is related to the electricity price, which is iterated on by the model, based on the following equation:

---

[2]   The number of Rankine cycles calculated by the model can be overridden by the user.

[3]   The most recent CEPCI available is 2010, which has a value of 550.8

[4]   60% of $98.80/MWe-hr, 40% of costs are for transmission, distribution, and other costs not associated with power generation (EIA 2011b)

$$Heat\ Price = Electricity\ Price * Power\ Generation\ Efficiency$$

The model also converts the heat price from $/MWt-hr to $/MMBTU. If the user specifies the secondary steam flow to the process the model also calculates for selling price of steam in $/lb.

2.3   Estimation of Manufacturing Costs

Manufacturing costs for the nuclear plant are based on information presented in TEV-1196 (INL 2012a). HTGR manufacturing costs include O&M costs, fuel costs, and decommissioning costs.

If the user specifies a heat only configuration where the reactor would supply only heat and generate no power; the power required for the primary helium circulators is assumed to be purchased from the grid. The price assumed for purchasing electricity is based on the average industrial electricity purchase price.

The O&M, fuel, and decommissioning costs are based on the total thermal rating of the plant (INL 2012a). Therefore, these costs are unchanged for a given plant rating regardless of if the reactor is producing heat or power for export. O&M and decommissioning costs are presented on an annual basis, fuel costs are presented as the total refueling cost per core. Currently, O&M, fuel, and decommissioning costs are not a function of ROT as they are expected to be independent of the ROT (INL 2012a).

The decommissioning fund payment is calculated using the decommissioning cost in dollars per MWt based on NUREG-1307 as developed in TEV-1196 (Nuclear Regulatory Commission [NRC] 2010). That per MWt cost is multiplied by the total reactor power level to determine the total decommissioning cost and then inflated to the year decommissioning will occur; assumed to be initiated at the end of the economic life. It has been assumed that the decommissioning fund would be funded through annual sinking fund payments as opposed to a single upfront payment. The sinking fund payment is calculated based on the estimated decommissioning cost and a discount rate of 2% plus the assumed inflation rate, per 10 CFR 50.75 (NRC 2012).

2.4   Economic Calculations

The following sections describe the methodology behind the economic calculations used in the HTGR Application Economic Model.

2.4.1   Cash Flow

The IRR and the net present value (NPV) for the specified configuration is calculated based on the annual after tax cash flows (ATCF). The ATCF is calculated based on the annual capital expenditures (C_k), revenues (R_k); cash outflows (E_k); sum of all noncash, or book costs such as depreciation (d_k); net income before taxes (NIBT); the effective income tax rate (t); and the income taxes (T_k), for each year (k). The taxable income is the revenue minus the sum of all cash outflows and noncash costs. Therefore the NIBT and the income taxes per year are defined as follows (Sullivan 2003):

$$NIBT = R_k - E_k - d_k$$

$$T_k = t \times NIBT$$

Depreciation is calculated using a standard Modified Accelerated Cost Recovery System (MACRS) depreciation method with a property class of 15 years, the property class life for an electric utility nuclear production plant. Depreciation is calculated based on the TCI for each reactor module, with the first charge occurring the year the corresponding HTGR comes online, i.e. when initial revenues are generated. Table 2 presents the recovery rates for a 15-year property class (Perry 2008).

Table 2. MACRS depreciation.

Year	Recovery Rate	Year	Recovery Rate
1	0.05	9	0.0591
2	0.095	10	0.059
3	0.0855	11	0.0591
4	0.077	12	0.059
5	0.0693	13	0.0591
6	0.0623	14	0.059
7	0.059	15	0.0591
8	0.059	16	0.0295

The ATCF is the sum of the before tax cash flow (BTCF) minus the income taxes owed. Note that the expenditures for capital are not taxed but are included in the BTCF each year there is a capital expenditure; this includes the equity capital and the debt principle payment.

The BTCF is defined as follows (Sullivan 2003):

$$BTCF_k = R_k - E_k - C_k$$

The ATCF can then be defined as:

$$ATCF_k = BTCF_k - T_k$$

2.4.1.1 Capital Cash Flows during Construction

Capital cash flow fractions for the HTGR during construction are calculated for each year of construction based on two separate correlations. First, the percentage of capital assigned to each module is calculated based on an exponential correlation (INL 2012a):

$$ModFrac(Module) = a(Module) \times (Number - (Module - 1))^{b(Module)}$$

where *Number* is the total number of reactor modules. The multiplier, *a(Module)*, is defined by the following equation:

$$a(Module) = 0.908 \times Module^{-1.172} \qquad Module > 1$$
$$= 1 \qquad Module = 1$$

while the exponent for the correlation, *b(Module)*, is defined as follows:

$$b(Module) = 0.102 \times \ln(Module + 0.963) - 0.402$$

The monthly fractional breakdown for each module's capital cost is calculated by applying a generic standard cumulative distribution, the s-curve distribution, as recommended by the Gen-IV International Forum ([GIF] 2007). The capital breakdown per month is calculated as follows:

$$ConstFrac(month) = 0.5 \times \left(\sin\left(\frac{-\pi}{2} + \frac{\pi \times month}{c\_months} \right) + 1 \right) - \sum_{n=1}^{n=month-1} ConstFrac(n)$$

where *month* is the current month in the module's construction period and *c_months* is the total number of months in the module's construction period. The capital fraction for each year is calculated by summing the capital fractions for the corresponding months. The yearly capital fractions are then multiplied by the module fraction to determine the overall yearly capital fraction breakdown per module. The total yearly

capital cost is the sum of the yearly capital fractions for all modules times the total cost of the application. An inflation factor input by the user is applied for each year of construction.

2.4.1.2   Reactor Refueling Cash Flows

Reactor refueling charges occur the years refuelings are scheduled. The occurrences are determined based on the total number of reactor modules, when the modules come online, and the specified period between refuelings.

2.4.2   Internal Rate of Return

The IRR method is the most widely used rate of return method for performing engineering economic analyses. This method solves for the discount rate that equates the equivalent worth of an alternative's cash inflows to the equivalent worth of cash outflows (after tax cash flow), i.e., the discount rate at which the NPV is zero. The resulting discount rate is the IRR (i'). For the project to be economically viable, the calculated IRR must be greater than the desired minimum annual rate of return (Sullivan 2003). The NPV is defined by the following expression:

$$NPV(i') = \sum_{k=0}^{N} ATCF_k (1 + i')^{-k} = 0$$

The present value (PV) of a cash flow is defined as follows:

$$PV(i') = ATCF_k (1 + i')^{-k}$$

2.4.3   Debt Service Coverage Ratio

The debt service coverage ratio is a measure of the security of the project financing based on the earnings before interest, taxation, and depreciation and the debt interest and principal payments. The yearly debt service coverage ratio (DSCR) is defined as follows:

$$DSCR_k = \frac{R_k - E_k}{Prinicpal_k + Interest_k}$$

2.4.4   Discounted Payback Period

The discounted payback period is calculated to determine at which year the sum of the ATCFs become positive. This indicates the year at which the project has paid back all initial investments.

3.   DETAILED WORKSHEET DESCRIPTIONS

The HTGR Application Economic Model (HTGR Economic 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:

- **Project Inputs** – The user specifies the HTGR configuration (i.e. module rating, number of modules, application electricity and heat demands, etc.) and other factors affecting the economic calculations (i.e. economic life, interest rates, debt ratio, financing terms, etc.) on this worksheet.

- **HTGR Project Fractions** – Based on the data in the Project Inputs worksheet, the HTGR Project Fractions worksheet calculates the yearly construction and operation fractions for the HTGR module(s) per the specified project period.

- **HTGR Cost Basis** – The capital, O&M, fuel, and decommissioning costs are calculated on the HTGR Cost Basis worksheet based on the correlations provided in the previous section and the costs outlined in TEV-1196 (INL 2012a).

- **Commodity Prices** – Market prices for electricity and heat are specified on the Commodity Prices worksheet along with the MACRS depreciation schedule.

- **Economic Inputs** – The outputs from the HTGR Cost Basis and Commodity Prices worksheets are used to populate the Economic Inputs worksheet, where the TCI, annual O&M costs, fuel costs per core, and annual revenues are calculated for the specified HTGR configuration.

- **IRR Analysis** – The values from the Economic Inputs worksheet are used in conjunction with the values calculated on the HTGR Project Fractions worksheet to populate the IRR Analysis worksheet, which calculates the annual cash flows for the project. The IRR Analysis worksheet allows the user to select if the worksheet calculates the commodity price required to achieve a given IRR or calculate the IRR selling power and/or heat at the market price.

- **List Info** – The List Info worksheet provides the data which populates the combo boxes on the Project Inputs and IRR Analysis worksheets. In general this sheet is hidden and must be unhidden[5] for access to the data which populates the combo boxes.

- **Results Summary** – The Results Summary worksheet uses a Macro to populate a table solving for both the IRR at the market price and product price to achieve a given IRR for variations in the TCI.

- **Sensitivity Analysis** – The Sensitivity Analysis worksheet uses a Macro to perform a sensitivity analysis on the user specified economic inputs, the result of which is a tornado diagram.

The HTGR Application Economic Model must have both Macros[6] and iterative calculations[7] enabled. 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

---

[5]   To unhide a worksheet, click the 'Home' tab in the 'Ribbon' and click the 'Format' button. Under 'Visibility', click 'Hide & Unhide', and then click 'Unhide Sheet'. In the Unhide sheet box, double-click the name of the hidden sheet to display.

[6]   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'.

[7]   To ensure iterative calculations are enabled click the 'Office Button' and select 'Excel Options'. Click the 'Formulas' tab on the far left of the 'Excel Options' window, and ensure that the box next to 'Enable iterative calculation' is checked. For the worksheet to function efficiently the 'Maximum Iterations' should be set to '5000' and the 'Maximum Change' should be '0.0001'.

function used in the workbook, rather complex equations are only specified, i.e. functions which use simple sums and averages are not defined, unless they include an IF statement or lookup function.

The HTGR Application Economic Model is password protected, to keep the user from inadvertently altering or deleting equations entered into cells, excluding the specified areas for user input, as well as editing the Macros. However, if the user wishes to modify these equations, the individual worksheets can be unprotected[8] by entering the worksheet password – '███████████'. The Macros can also be unprotected[9] using this password. It should be noted, that if any equations or Macros are altered, the iterative calculations used in the workbook may no longer function as designed. Therefore, if the user elects to unprotect any worksheet, they should proceed with caution and the results may not be accurate.

All user inputs identified in the following sections are limited using data validation[10]. Cells which do not include user inputs or combo boxes have been locked and cannot be altered when the worksheet is protected. If the user elects to remove any data validation limitations the results generated by the model may not be accurate.

3.1   Project Inputs Worksheet

The Project Inputs worksheet is arranged into several sections where the user provides the general project inputs, economic assumptions, and HTGR specifications used in the economic analyses. Some fields include combo boxes which restricts the user to a list of selections, which are defined on the List Info sheet. All user inputs, excluding combo boxes, are limited using data validation.

3.1.1   General Project Inputs

A screenshot of the general project inputs section of the Project Inputs worksheet is shown in Figure 1. The following list identifies the cells which make up the general project inputs section. A brief description of the input is included for each cell as well as if the cell is a user input or a calculated value. Additionally, if the cell is a user input, the assumed default value and any data validation criteria are included in the description.

	A	B	C
1	General Project Inputs		
2	Project Start Year	2013	
3	Project Base Year	2010	
4	Project Base Year CEPCI	550.8	
5	Construction Factor for Alternate Location	1	
6	State/Provincial Tax	6	%
7	Federal Tax	35	%
8	Total Tax Rate	38.9	%
9	Inflation Rate - Commodities	3	%
10	Inflation Rate - Analysis	3	%

Figure 1. General project inputs section of the Project Inputs worksheet, screenshot.

---

[8]   To unprotect a worksheet, click the 'Review' tab on the 'Ribbon', next click the 'Unprotect Sheet' button. A box will prompt the user to enter the password, which is '████████████', and then the user clicks the 'OK' button. The worksheet is now unprotected. To re-enable worksheet protection, click the 'Protect Sheet' button on the 'Review' tab of the Ribbon and enter the worksheet password when prompted.

[9]   To access Macros, click the 'Developer' tab on the 'Ribbon', next click the 'Visual Basic' button. In the Visual Basic window, click 'VBAProject (HTGR Economic Model.xlsm)' project and enter the password, '████████████'.

[10]   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.

- **Project Start Year** – Cell B2 – *User Input* – Currently, the model assumes that the project begins construction one year from the current year. However, any year greater than one year plus the current year can be entered.

- **Project Base Year** – Cell B3 – *User Input* – The year which corresponds to the CEPCI entered in cell B4, which is the most recent annual CEPCI available, currently 2010. This year is the year that all costs are adjusted to for the IRR Analysis worksheet. Any whole number greater than or equal to 2009 can be entered in this cell.

- **Project Base Year CEPCI** – Cell B4 – *User Input* – The CEPCI which corresponds to the project base year entered in cell B3. To adjust capital costs to dollars corresponding to the project base year from earlier years, the capital costs are multiplied by the ratio of the CEPCIs. For instance, the CEPCI of 2010 is 550.8; therefore the HTGR capital costs, which are in 2009 dollars, would be multiplied by 550.8/521.9 to adjust to 2010 dollars. Any value greater than zero can be entered in this cell.

- **Construction Factor for Alternate Location** – Cell B5 – *User Input* – The construction costs for the HTGR were developed assuming construction on the U.S. Gulf Coast. The construction factor would be used to adjust construction costs for an alternate location. The factor can be determined using the RS Means index, or a similar source. This adder is directly applied to the HTGR capital costs. The value entered must be greater than zero.

- **State/Provincial Tax** – Cell B6 – *User Input* – State income taxes are in most cases less than federal taxes and are often within the range of six to 12 percent of taxable income. A baseline value of six percent is assumed; however, a value greater than or equal to zero must be specified.

- **Federal Tax** – Cell B7 – *User Input* – The U.S. federal corporate tax is a graduated tax structure. However, the HTGR generally has taxable income greater than $18,333,333 per year; hence a flat rate of 35 percent is assumed. The tax rate has an allowable range of 15 to 39 percent to account for applications outside of the U.S. and/or changes to the U.S. federal tax rates.

- **Total Tax Rate** – Cell B8 – *Calculated* – The total tax rate is calculated using the user specified state tax and federal tax as follows:

$$Total\ Tax\ Rate = State\ Rate + Federal\ Rate \times (1 - State\ Rate)$$

- **Inflation Rate – Commodities** – Cell B9 – *User Input* – A commodity price inflation rate of three percent is assumed in order to adjust commodity prices to the project base year. This cell has an allowable range of zero to five percent. For example, to adjust costs from 2009 dollars to the project base year (*CEPCI Year*) the following equation is used throughout the model:

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

- **Inflation Rate – Analysis** – Cell B10 – *User Input* – The analysis inflation rate is also assumed to be three percent. This rate is used to adjust capital costs, revenues, fuel costs, and operating costs for the cash flow analysis. This cell has an allowable range of zero to five percent.

3.1.2 HTGR Economic Assumptions

The HTGR economic assumptions section includes the user inputs necessary to perform the economic analysis. A screenshot of the section is shown in Figure 2. The following list identifies the cells which make up the economic assumptions section. A brief description of the input is included for each cell as well as if the cell is a user input or a calculated value. Additionally, if the cell is a user input data validation criteria are included in the description.

	A	B	C
11	**HTGR Economic Assumptions**		
12	Economic Life	30	yr
13	Module Life	60	yr
14	Debt Financing	50	%
15	Equity Financing	50	%
16	Interest Rate During Construction	8	%
17	Interest Rate on Debt	8	%
18	Repayment Term	15	yr
19	IRR	12	%
20	HTGR Availability	90	%

Figure 2. HTGR economic assumptions section of the Project Inputs worksheet, screenshot.

- **Economic Life** – Cell B12 – *User Input* – The economic recovery period for each reactor module. A whole number between 10 and 60 must be entered.

- **Module Life** – Cell B13 – *User Input* – The operating lifetime for each rector module. A whole number between 40 and 80 must be entered.

- **Debt Financing** – Cell B14 – *User Input* – The fraction of the total capital investment that is financed. The value entered must be between zero and 100 percent.

- **Equity Financing** – Cell B15 – *Calculated* – The percentage of the total capital investment that is financed by the equity holder(s). This cell is set equal to 100 minus the value specified for the debt financing percentage.

- **Interest Rate During Construction** – Cell B16 – *User Input* – The interest rate for interest accrued on debt during construction, i.e. capitalized interest. The rate entered should be between two and 15 percent. The model currently assumes this interest rate is equal to the general interest rate for the loan, cell B17.

- **Interest Rate on Debt** – Cell B17 – *User Input* – The interest rate on the portion of the TCI financed. The rate entered should be between two and 15 percent.

- **Repayment Term** – Cell B18 – *User Input* – The loan repayment term. This value should be between ten and 30 years, unless the economic life is less than 30 years, then the upper limit is the length of the economic life.

- **IRR** – Cell B19 – *User Input* – The internal rate of return for the project. The value entered should be between zero and 25 percent. The value must be greater than the interest rate on debt specified (B17).

- **HTGR Availability** – Cell B20 – *User Input* – The overall availability, on-stream factor, or capacity factor, i.e. the ratio of the actual output versus the potential output. The value

entered must be between zero and 100. A baseline value of 90 is assumed based on light water reactor performance and internal analysis of expected HTGR performance.

3.1.3   HTGR Specifications

The HTGR specifications section includes the specifications for the HTGR configuration utilized in the economic analysis. A screenshot of the HTGR specifications section of the Project Inputs worksheet is shown in Figure 3. Several specifications are set using combo boxes, including the reactor project phase, staffing plan, and the reactor module rating. The data which populates the combo boxes is included in the List Info worksheet. The following list identifies the cells which make up the HTGR specifications section. A brief description of the input is included for each cell as well as if the cell is a user input or a calculated value. Additionally, if the cell is a user input data validation criteria are included in the description.

	A	B	C	D
21	**HTGR Specifications**			
22	Reactor Phase	NOAK ▼		
23	Staffing Plan	Vendor ▼		
24	Reactor Outlet Temperature	750	°C	
25	Reactor Module Rating	600 ▼	MWt	
26	Number of Reactors	4		
27	Plant Thermal Rating	2,400	MWt	
28	Heat Generated in Primary Circulators	82.3	MWt	
29	Gross Heat Available for Heat and Power Generation	2,482.3	MWt	
30	Heat Required by Process	0.0	MWt	
31	Steam Flow to the Process	0.0	lb/hr	
32	Heat Available for Power Generation	2,482.3		
33	Gross Model Brayton Cycle Efficiency (TEV-988, function of ROT)	38.7	%	
34	Gross Model Rankine Cycle Efficiency (TEV-988)	45	%	
35	Gross Brayton Cycle Efficiency (value used in model)	0	%	
36	Gross Rankine Cycle Efficiency (value used in model)	45	%	
37	Gross Power Produced	1,117.0	MWe	
38	HTGR House Load (primary circulator power requirement)	82.3	MWe	
39	Net Power Produced, Gross Power Less HTGR House Loads	1,034.8	MWe	
40	Reactor Power Required by Process	0.0	MWe	
41	Net Power Available for Export	1,034.8	MWe	
42	Calculated Net Power Cycle Efficiency	43.1	%	
43	Net Power Cycle Efficiency Used in Economic Calculations	43	%	
44	Reactor Site Preparation	6	months	
45	Reactor Construction Period - Assuming All Equal	36	months	
46	Reactor Construction Staggering	6	months	
47	Refueling Period	18	months	
48	Startup Time	12	months	
49	Operating Cost - Multiplier	1.2		
50	Revenues - Fraction	0.65		Check Value
51	Years in Decommissioning Fund	62	years	62
52	Decommissioning Year	2078		
53	Sinking Fund Rate of Return	5	%	
54	-Δ TCI %, HTGR	30	%	
55	+Δ TCI %, HTGR	50	%	

Figure 3. HTGR specifications section of the Project Inputs worksheet, screenshot.

- **Reactor Phase** – Cell B22 – *User Input Combo Box* – The user can select the desired project phase for the economic analysis using the combo box. Selections include NGNP, FOAK, and NOAK project phases. The NGNP plant is the initial demonstration of the HTGR technology, a FOAK plant is the first full commercial installation of the HTGR technology, while the NOAK plant is a mature commercial installation of the HTGR technology.

- **Staffing Plan** – Cell B23 – *User Input Combo Box* – The user can select the desired staffing estimate used in the economic analysis using the combo box. Selections include vendor or INL staffing plans. The vendor and INL staffing plants are described in TEV-1196 (INL 2012a). The user can override these staffing estimates on the HTGR Cost Basis worksheet.

- **ROT** – Cell B24 – *User Input* – Reactor outlet temperature specification. The value can be between 600°C and 1000°C.

- **Reactor Module Rating** – Cell B25 – *User Input Combo Box* – The user can select the reactor module thermal rating from the combo box. The user can chose from 200, 350, or 600 MWt ratings.

- **Number of Reactors** – Cell B26 – *User Input* – The number of reactor modules. The value entered can be a whole number between one and 16.

- **Plant Thermal Rating** – Cell B27 – *Calculated* – This value is equal to the number of reactor modules times the reactor module rating.

- **Heat Generated in Primary Circulators** – Cell B28 – *Calculated* – This value is equal to the power requirement for the primary circulator, cell B38. The model assumes an isentropic compressor, where the work required for compression is equal to the enthalpy difference across the compressor.

- **Gross Heat Available for Heat and Power Generation** – Cell B29 – *Calculated* – The gross heat generated and transferred from the NHSS, which is equal to the reactor thermal rating plus the heat generated in the primary circulator.

- **Heat Required by Process** – Cell B30 – *User Input* – The amount of heat exported to the process, if applicable. The value entered must be greater than or equal to zero and less than or equal to the gross heat available from the HTGR. If only heat is supplied by the HTGR to the process this cell value should be set equal to cell B29.

- **Steam Flow to the Process** – Cell B31 – *User Input* – The flowrate of steam, if applicable, exported to the process, in lb/hr. Used to calculate the $/lb cost in the project economics. Not a necessary input value; however, a value greater than or equal to zero must be specified.

- **Heat Available for Power Generation** – Cell B32 – *Calculated* – The amount of heat used to generate electric power. This value equals the gross heat generated minus the amount of heat sent to the process.

- **Gross Model Brayton Cycle Efficiency** – Cell B33 – *Calculated[11]* – The correlation entered in this cell, which is a function of ROT, is based on data presented in TEV-988, "Sensitivity of HTGR Heat and Power Production to Reactor Outlet Temperature, Economic Analysis" (INL 2011). The gross efficiency is used to calculate the power produced in a Brayton cycle,

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[11] For reference only, see Cell B35 for the value used in the model.

less loads lost within the power cycle. It does not include power losses from the primary circulator.

- **Gross Model Rankine Cycle Efficiency** – Cell B34 – *Calculated[12]* – The value entered in this cell is based on data presented in TEV-988, and is valid for all ROTs (INL 2011). The gross efficiency is used to calculate the power produced in a Rankine cycle, less loads lost within the power cycle. It does not include power losses from the primary circulator.

- **Gross Brayton Cycle Efficiency** – Cell B35 – *User Input* – The efficiency used to calculate the power produced in the Brayton cycle, less loads lost within the cycle, in the economic model. For a Brayton cycle generating only electricity set the value equal to cell B33; otherwise, enter zero if a Brayton cycle is not part of the HTGR configuration. Only a single type of power cycle can be specified at a time. For heat generation only, both Brayton and Rankine cycle efficiencies should be set equal to zero.

  For a co-generation cycle, the Goal Seek[13] function can be used to iterate this cell value to the required efficiency, after all heat and power requirements to the process have been specified, such that the power available for export is equal to a known value. The value entered must be between zero and 100.

- **Gross Rankine Cycle Efficiency** – Cell B36 – *User Input* – The efficiency used to calculate the power produced in the Rankine cycle, less loads lost within the cycle, in the economic model. For a Rankine cycle generating only electricity set the value equal to cell B34; otherwise, enter zero if a Rankine cycle is not part of the HTGR configuration. Only a single power cycle can be specified at a time. For heat generation only, both Brayton and Rankine cycle efficiencies should be set equal to zero.

  For a co-generation cycle, the Goal Seek function can be used to iterate this cell to the required efficiency, after all heat and power requirements to the process have been specified, such that the power available for export is equal to a known value. The value entered must be between zero and 100.

- **Gross Power Produced** – Cell B37 – *Calculated* – This value is equal to the heat available for electric power generation times the selected power cycle efficiency (cell B35 or B36); the value is referenced from the calculated value on the HTGR Cost Basis worksheet.

- **HTGR House Load** – Cell B38 – *Calculated* – The correlation used determines the power requirement for the primary circulator as a function of the ROT and the thermal rating of the plant. The basis for the calculation is a 600 MWt HTGR per TEV-988 (INL 2011). An isentropic compressor is assumed, with 80% isentropic efficiency.

- **Net Power Produced** – Cell B39 – *Calculated* – The total amount of power generated by the HTGR. The value is equal to the gross power production less the house loads. If no power is produced, i.e. only heat is generated with no power cycle, the value is negative.

- **Reactor Power Required by Process** – Cell B40 – *User Input* – The amount of power exported to the process. The value entered must be greater than or equal to zero and less than or equal to the net power produced by the HTGR, if power is exported.

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[12] For reference only, see Cell B36 the value used in the model.

[13] To access the Goal Seek function click the 'Data' tab on the 'Ribbon' and select the 'What If Analysis' button, select 'Goal Seek' from the drop down.

- **Net Power Available for Export** – Cell B41 – *Calculated* – The amount of power exported to the grid. This value is equal to the net power produced less the power exported to the process. If no power is produced, i.e. only heat is generated with no power cycle, the value is negative.

- **Calculated Net Power Cycle Efficiency** – Cell B42 – *Calculated* –The net power cycle efficiency is calculated based on the portion of the reactor thermal rating used for power generation and the net power produced by the HTGR. If no power is produced or power is imported from the grid, the value is equal to zero.

- **Net Power Cycle Efficiency Used for Economic Calculations** – Cell B43 – *User Input* – The power cycle efficiency used to relate the power and heat prices in the economic calculations. Assumed to be 43 percent; however, if a different value is entered, the value must be greater than zero and less than or equal to the overall net cycle efficiency (B42) or 43 percent.

- **Reactor Site Preparation** – Cell B44 – *User Input* – The number of months of site preparation prior to construction of the first reactor module. This value can be between zero and 18 months, whole numbers only.

- **Reactor Construction Period** – Cell B45 – *User Input* – The number of months for individual module construction. This value can be overwritten for each individual module on the HTGR Project Fractions sheet. The value entered should be a whole number between 12 and 72 months.

- **Reactor Construction Staggering** – Cell B46 – *User Input* – The number of months between startup of each reactor module. The value entered dictates when the construction of each module begins. This value must be a whole number between zero and 18 months.

- **Refueling Period** – Cell B47 – *User Input* – The number of months between refuelings for each reactor module. The value entered must be a whole number between six and 24. A default value of 18 months is assumed.

- **Startup Time** – Cell B48 – *User Input* – The number of months, for each module, during which operating costs and revenues are multiplied by the fractions/multipliers specified in cells B49 and B50. . This value can be overwritten for each individual module on the HTGR Project Fractions sheet. The value entered can be between zero and 36 months, whole numbers only

- **Operating Cost Multiplier during Startup** – Cell B49 – *User Input* – It is assumed operating costs are higher during the specified startup period. This value can be overwritten for each individual module on the HTGR Project Fractions sheet. The operating cost multiplier entered must be between one and three.

- **Revenues Fraction during Startup** – Cell B50 – *User Input* – It is assumed annual revenues are lower during the specified startup period. This value can be overwritten for each individual module on the HTGR Project Fractions sheet. The revenue fraction entered must be between zero and one.

- **Years in Decommissioning Fund** – Cell B51 – *Calculated* – The number of payments made to the decommissioning fund, based on the module life. It is assumed that a payment is made each year there is revenue. A check value is shown in cell D51.

- **Decommissioning Year** – Cell B52 – *Calculated* – The year that decommissioning begins. This is the year after the last revenue is received for the last reactor module.

- **Sinking Fund Rate of Return** – Cell B53 – *Calculated* – The sinking fund rate of return is assumed to be 2% plus the analysis inflation rate per the NRC (2012).

- **Lower Bound for TCI Change** – Cell B54 – *User Input* – The lower bound on the TCI range. Currently a -30% change in the TCI is assumed based on an AACE Class 4 estimate (-30% to +50% TCI). A range of 15 to 50 percent is accepted.

- **Upper Bound for TCI Change** – Cell B55 – *User Input* – The upper bound on the TCI range. Currently a +50% change in the TCI is assumed based on an AACE Class 4 estimate (-30% to +50% TCI). A range of 15 to 50 percent is accepted.

3.1.4   Named Cells/Ranges

The following cell names have been assigned in the Project Inputs worksheet:

- CYEAR – cell B2

- CEPCIYEAR – cell B3

- CEPCI – cell B4

- CA – cell B5

- STax – cell B6

- FTax – cell B7

- TTax – cell B8

- IRT_C – cell B9

- IRT_A – cell B10

- ELN – cell B12

- MLN – cell B13

- DebtN – cell B14

- EquityN – cell B15

- RDebtN_Con – cell B16

- RDebtN – cell B17

- RTermN – cell B18

- IRRN – cell B19

- HTGR_A – cell B20

- ROT – cell B24

- Number – cell B26

- HTGR_TR – cell B27

- PCirc_Heat – cell B28

- HTGR_GR_Heat – cell B29

- CP_Heat – cell B30

- Heat_Flow – cell B31

- PG_Heat – cell B32

- HTGRBEFF – cell B35

- HTGRREFF – cell B36

- Gross_PWR – cell B37

- HTGR_HL – cell B38

- Net_PWR – cell B39

- CP_PWR – cell B40

- Grid_PWR – cell B41

- HTGRGEFF – cell B43

- SitePrep – cell B44

- CPN – cell B45

- StaggerN – cell B46

- Refuel – cell B47

- STN – cell B48

- STOCN – cell B49

- STRVN – cell B50

- Decon_Yrs – cell B51

- Decon_Yr – cell B52

- Rate_Decon – cell B53

- MTCIHTGR – cell B54

- PTCIHTGR – cell B55

3.1.5 Worksheet Formatting

Cells highlighted purple indicate user inputs. Light blue cells indicate user inputs which are also manipulated by Macros within the model, specifically the Macros on the Results Summary and Sensitivity Analysis worksheets. Data validation limitations have been entered for all user inputs. All other cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.1.6 Worksheet Equations/IF Statements

The majority of the equations used in the Project Inputs worksheet are simple functions and therefore are not included in the following list. However, the following complex equations, which require explanation, are included on the Project Inputs worksheet:

- B42=IF(PG_Heat=0,0,(Net_PWR+HTGR_HL*CP_Heat/HTGR_GR_Heat)/(PG_Heat/ HTGR_GR_Heat*HTGR_TR)*100) – This equation sets the net power cycle efficiency equal to zero if only heat is being generated in the plant, otherwise, the net power cycle efficiency is equal to the net power generated plus the circulator power associated with process heat generation, divided by the portion of the reactor thermal rating used for power generation.

- B51=MLN+ROUNDUP(MCE_TN/12,0)-ROUNDDOWN(MCE_1N/12,0) – This equation calculates the number of years in the decommissioning fund by adding the specified module plant life to the difference between the last year of construction and first full year of construction.

- D51=COUNTIF(HTGR Project Fractions'!R427:R516,">0")+MLN-ELN – This function counts the number of positive operating fractions on the HTGR Project Fractions worksheet plus the difference between the module plant life and the economic life, this corresponds to the total number of years the reactor operates, during which decommissioning fund payments should be made. This value should equal the value in cell B51.

- B52=Decon_Yrs+ROUNDDOWN(MCE_1N/12,0)+CYEAR – This equation sets the year decommissioning occurs equal to the number of years of decommissioning fund payments plus the last full year of construction for the first reactor module plus the year construction begins.

3.1.7 Worksheet Macros

No Macros are included in the Project Inputs worksheet.

3.2 HTGR Project Fractions

The HTGR Project Fractions worksheet calculates the construction periods, construction period fractions, revenue fractions, operating cost fractions, reactor refueling occurrences, depreciation fractions, debt interest payments, debt principal payments, and the capitalized interest for all reactor modules. This information is calculated based on the HTGR specifications on the Project Inputs sheet. However, the user can override certain specifications and calculations, including the reactor construction period, the month construction ends, the startup period and associated cost/revenue multipliers/fractions, and the construction capital fraction for each reactor module. The HTGR Project Fractions worksheet is over 850 rows; therefore, screenshots will be presented for each segment of the worksheet. All calculations are documented in detail in Section 3.2.9. User inputs are limited using the data validation tool.

3.2.1   Module Construction Schedule

The worksheet first calculates the construction period for each reactor module based on the user input specified on the Project Inputs worksheet, if the user wishes to enter different construction periods for each module, they can do so in row 5, which acts as an override to the values calculated in row 4. Data validation limitations have been set in row 5 such that the construction period entered must be a whole number between 12 and 72 months. In addition, the specified period must be less than or equal to the month construction ends, row 11. The construction period used in the model, row 6, uses the value calculated by the model unless the user override is entered. Based on the value calculated in row 6 and the month construction ends, row 11, the month and year construction starts is calculated for each module, rows 7 and 8, respectively.

Next, the month construction ends is calculated in row 9, which is based on the month construction ends for the first reactor, assuming construction begins in month one for the first module, and the staggering period entered on the Project Inputs sheet plus the month construction ends for all remaining modules. Like the construction period, the user can override the month construction ends for each module in row 10. Data validation limitations have again been set for the user overrides, such that the value entered must a be a whole number greater than or equal to the construction period for the first reactor module and greater than or equal to the month construction ends for the previous reactor module. The month construction ends used in the model, row 11, uses the value calculated by the model unless the user override is entered. The model then calculates the year construction ends, the first year of operations, and the number of months in the first year of operations for each reactor module.

The startup period for each module in displayed in row 15, this value can be overridden for each module in row 16. Data validation limits have been set in row 16 such that the value entered must be a whole number between 0 and 36 months. The startup period used in the model, row 17, uses the value calculated by the model unless the user override is entered. The fractions used to adjust the revenues during the startup period are displayed for each module in row 18. Again, a user override can be set for each module in row 19, which is limited to a value between zero and one. Similarly, the multipliers used to adjust the operating costs during the startup period are presented in row 21. The user override for the module multipliers are in row 22, inputs are limited to values between one and three. The values used in the model, row 20 for the revenue fractions and row 23 for the operating cost multipliers, use the values calculated by the model unless user overrides are entered. Figure 4 presents a screenshot of the module construction period and initial operations section for the HTGR Project Fractions worksheet.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
Const. Period	42	36	36	36	0	0	0	0	0	0	0	0	0	0	0	0	
User Override																	
Const. Period Used	42	36	36	36	0	0	0	0	0	0	0	0	0	0	0	0	
Month Const. Starts	1	13	19	25	0	0	0	0	0	0	0	0	0	0	0	0	
Year Const. Starts	1	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	
Mo. Const Ends	42	48	54	60	0	0	0	0	0	0	0	0	0	0	0	0	
User Override																	
Const. End Used	42	48	54	60	0	0	0	0	0	0	0	0	0	0	0	0	60
Year Const. Ends	4	4	5	5	0	0	0	0	0	0	0	0	0	0	0	0	
1st Year of Ops.	4	5	5	6	0	0	0	0	0	0	0	0	0	0	0	0	
# Mos. in 1st Op. Yr.	6	12	6	12	0	0	0	0	0	0	0	0	0	0	0	0	
Startup Period	12	12	12	12	0	0	0	0	0	0	0	0	0	0	0	0	
User Override																	
Startup Period Used	12	12	12	12	0	0	0	0	0	0	0	0	0	0	0	0	
Revenues Fraction	0.65	0.65	0.65	0.65	0	0	0	0	0	0	0	0	0	0	0	0	
User Override																	
Rev. Fraction Used	0.65	0.65	0.65	0.65	0	0	0	0	0	0	0	0	0	0	0	0	
Op. Cost Multiplier	1.2	1.2	1.2	1.2	0	0	0	0	0	0	0	0	0	0	0	0	
User Override																	
Op. Cost Mult. Used	1.2	1.2	1.2	1.2	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 4. Module construction period and initial operations section of the HTGR Project Fractions worksheet, screenshot.

3.2.2 Module Capital Cost Fractions

The exponent, multiplier, and the resulting module construction fractions are calculated for each active module in rows 24, 25, and 26. These fractions represent the portion of the capital cost associated with each reactor module as described in Section 2.4.1.1. The capital fraction calculated can be overridden in row 27. Data validation limitations have been set in row 27 such that the fraction entered must be between zero and one and conditional formatting is used to highlight the row in red until the fractions specified in the override row sum to one. The fraction used in the model, row 28, uses the value calculated by the model unless the user override is entered. The monthly expenditure for each module during construction is calculated using the s-curve distribution in rows 29 to 390; these rows are hidden by default as the s-curve distribution is calculated for 360 months of construction. However, the rows can be unhidden and rehidden using the buttons at the top of the worksheet, which are linked to Macros. Figure 5 presents a screenshot of the module construction fractions and a portion of the s-curve distribution calculations.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
Exponent	-0.738277411	-0.398294143	-0.32942923	-0.288691241	-0.259658812	-0.237085312	-0.218613466	-0.202979442	-0.1894263	-0.177464619	-0.166759617	-0.157072167	-0.148225506	-0.14008527	-0.132546937	-0.125527589	
Multiplier	1	0.402975547	0.250553075	0.178842832	0.137687021	0.111196875	0.092817731	0.079371463	0.069137493	0.06110628	0.054647918	0.049349804	0.044930809	0.041193035	0.037993289	0.035225505	
Module Fraction	0.359345912	0.260162138	0.199402986	0.181088964	0	0	0	0	0	0	0	0	0	0	0	0	1
User Override																	0
Module Frac. Used	0.359345912	0.260162138	0.199402986	0.181088964	0	0	0	0	0	0	0	0	0	0	0	0	1
Month							MONTH S-CURVE DISTRIBUTION										
1	0.001398101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000349525
2	0.004186485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001046621
3	0.006951457	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001737864
4	0.009677553	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002419388
5	0.012349529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003087382
6	0.01495244	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00373811
7	0.017471732	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004367933
8	0.019893315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004973329
9	0.022203646	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005550911
10	0.024389805	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006097451
11	0.026439567	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006609892
12	0.028341468	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007085367
13	0.030084872	0.001902651	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007996881
14	0.031660029	0.005693473	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.009338375
15	0.03305813	0.009440963	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.010624773
16	0.034271357	0.013116603	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01184699
17	0.035292925	0.016692417	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012996335
18	0.03611712	0.020141192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.014064578
19	0.036739334	0.02343668	0.001902651	0	0	0	0	0	0	0	0	0	0	0	0	0	0.015519666
20	0.037156086	0.026553801	0.005693473	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01735084
21	0.037365047	0.029468831	0.009440963	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01906871
22	0.037365047	0.032159586	0.013116603	0	0	0	0	0	0	0	0	0	0	0	0	0	0.020660309
23	0.037156086	0.034605587	0.016692417	0	0	0	0	0	0	0	0	0	0	0	0	0	0.022113522
24	0.036739334	0.036788218	0.020141192	0	0	0	0	0	0	0	0	0	0	0	0	0	0.023417186
25	0.03611712	0.038690869	0.02343668	0.001902651	0	0	0	0	0	0	0	0	0	0	0	0	0.02503683
26	0.035292925	0.040299059	0.026553801	0.005693473	0	0	0	0	0	0	0	0	0	0	0	0	0.026959814
27	0.034271357	0.041600549	0.029468831	0.009440963	0	0	0	0	0	0	0	0	0	0	0	0	0.028695425
28	0.03305813	0.042585434	0.032159586	0.013116603	0	0	0	0	0	0	0	0	0	0	0	0	0.030229938
29	0.031660029	0.043246217	0.034605587	0.016692417	0	0	0	0	0	0	0	0	0	0	0	0	0.031551063
30	0.030084872	0.043577871	0.036788218	0.020141192	0	0	0	0	0	0	0	0	0	0	0	0	0.032648038
31	0.028341468	0.043577871	0.038690869	0.02343668	0	0	0	0	0	0	0	0	0	0	0	0	0.033511722
32	0.026439567	0.043246217	0.040299059	0.026553801	0	0	0	0	0	0	0	0	0	0	0	0	0.034134661
33	0.024389805	0.042585434	0.041600549	0.029468831	0	0	0	0	0	0	0	0	0	0	0	0	0.034511155
34	0.022203646	0.041600549	0.042585434	0.032159586	0	0	0	0	0	0	0	0	0	0	0	0	0.034637304
35	0.019893315	0.040299059	0.043246217	0.034605587	0	0	0	0	0	0	0	0	0	0	0	0	0.034511045
36	0.017471732	0.038690869	0.043577871	0.036788218	0	0	0	0	0	0	0	0	0	0	0	0	0.034132173
37	0.01495244	0.036788218	0.043577871	0.038690869	0	0	0	0	0	0	0	0	0	0	0	0	0.03350235
38	0.012349529	0.034605587	0.043246217	0.040299059	0	0	0	0	0	0	0	0	0	0	0	0	0.032625098
39	0.009677553	0.032159586	0.042585434	0.041600549	0	0	0	0	0	0	0	0	0	0	0	0	0.03150578
40	0.006951457	0.029468831	0.041600549	0.042585434	0	0	0	0	0	0	0	0	0	0	0	0	0.030151568
41	0.004186485	0.026553801	0.040299059	0.043246217	0	0	0	0	0	0	0	0	0	0	0	0	0.028571391
42	0.001398101	0.02343668	0.038690869	0.043577871	0	0	0	0	0	0	0	0	0	0	0	0	0.02677588
43	0	0.020141192	0.036788218	0.043577871	0	0	0	0	0	0	0	0	0	0	0	0	0.02512682

Figure 5. Module construction fractions and s-curve distribution on the HTGR Project Fractions worksheet, screenshot.

The fraction of the TCI expended each year for each module (rows 392 to 421) is calculated by multiplying the sum of the monthly s-curve distributions corresponding to the analysis year, rows 30 to 390, by the construction module fraction in row 28. The results of which are the annual construction fractions for each module, the sum of the annual construction fractions, row 422, should equal the module fraction calculated in row 28. The sum for all modules, column R, should equal one. A screenshot of the calculated annual construction fractions for each module is presented in Figure 6. The fractions calculated in column R are used to partition TCI to the corresponding analysis year for calculation of the annual project cash flows on the IRR Analysis worksheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
391	Analysis Year	CONSTRUCTION FRACTIONS																
392	1	0.0676487	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0676487
393	2	0.15200525	0.065040534	0.013357467	0	0	0	0	0	0	0	0	0	0	0	0	0	0.230403251
394	3	0.121898746	0.130081069	0.086344026	0.045272241	0	0	0	0	0	0	0	0	0	0	0	0	0.383596081
395	4	0.017793216	0.065040534	0.086344026	0.090544482	0	0	0	0	0	0	0	0	0	0	0	0	0.259722259
396	5	0	0	0.013357467	0.045272241	0	0	0	0	0	0	0	0	0	0	0	0	0.058629708
397	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
398	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
399	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
401	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
402	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
403	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
404	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
406	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
407	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
408	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
409	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
410	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
411	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
412	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
413	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
414	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
415	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
416	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
417	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
418	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
419	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
420	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
421	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
422	Total	0.359345912	0.260162138	0.199402986	0.181088964	0	0	0	0	0	0	0	0	0	0	0	0	1

Figure 6. Annual construction fractions section of the HTGR Project Fractions worksheet, screenshot.

3.2.3   Module Revenue and Operating Cost Fractions

Next, the revenue and operating cost fractions are calculated for each analysis year for each reactor module. Revenue fractions, rows 424 to 513, are based on the economic life specified on the Project Inputs worksheet and the startup time and revenue fraction multipliers, rows 17 and 20, respectively. The operating cost fractions, rows 516 to 605, are based on the economic life, the startup time (row 17), and the operating cost multipliers (row 23). The yearly averages of the fractions, which are calculated in column R by summing the fractions and dividing by the number of modules for each year, are applied to the annual revenues and operating costs calculated on the Economic Inputs worksheet to calculate the annual project cash flows on the IRR Analysis worksheet. Up to 90 analysis years are included for the revenue and operating cost fraction calculations, a portion of the rows corresponding to analysis years 46 to 79 are hidden to allow the screenshots to fit on a single page. A check value is calculated in column S for the sum of the revenue and operating cost fractions to allow the user to ensure the algorithm is calculating the appropriate value; however, the check value is not included in the screenshot. Figure 7 presents screenshot of the revenue fractions and Figure 8 presents the screenshot of the operating cost fractions.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
423	Analysis Year									REVENUE FRACTIONS								
424	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
425	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
426	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
427	4	0.325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08125
428	5	0.825	0.65	0.325	0	0	0	0	0	0	0	0	0	0	0	0	0	0.45
429	6	1	1	0.825	0.65	0	0	0	0	0	0	0	0	0	0	0	0	0.86875
430	7	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
431	8	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
432	9	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
433	10	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
434	11	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
435	12	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
436	13	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
437	14	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
438	15	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
439	16	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
440	17	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
441	18	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
442	19	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
443	20	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
444	21	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
445	22	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
446	23	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
447	24	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
448	25	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
449	26	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
450	27	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
451	28	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
452	29	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
453	30	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
454	31	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
455	32	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
456	33	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
457	34	0.5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.875
458	35	0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0.375
459	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
460	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
461	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
462	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
463	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
464	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
465	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
466	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
467	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
468	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
503	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
504	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
505	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
506	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
507	84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
508	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
509	86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
510	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
511	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
512	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
513	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
514	Total	29.65	29.65	29.65	29.65	0	0	0	0	0	0	0	0	0	0	0	0	29.65

Figure 7. Annual revenue fractions section of the HTGR Project Fractions worksheet, screenshot.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
515	Analysis Year	OPERATING COSTS FRACTIONS																
516	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
517	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
518	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
519	4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15
520	5	1.1	1.2	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.725
521	6	1	1	1.1	1.2	0	0	0	0	0	0	0	0	0	0	0	0	1.075
522	7	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
523	8	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
524	9	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
525	10	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
526	11	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
527	12	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
528	13	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
529	14	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
530	15	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
531	16	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
532	17	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
533	18	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
534	19	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
535	20	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
536	21	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
537	22	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
538	23	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
539	24	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
540	25	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
541	26	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
542	27	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
543	28	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
544	29	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
545	30	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
546	31	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
547	32	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
548	33	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
549	34	0.5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.875
550	35	0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0.375
551	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
552	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
553	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
554	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
555	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
556	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
557	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
558	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
559	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
560	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
595	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
596	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
597	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
598	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
599	84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
601	86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
602	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
603	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
604	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
605	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
606	Total	30.2	30.2	30.2	30.2	0	0	0	0	0	0	0	0	0	0	0	0	30.2

Figure 8. Annual operating cost fractions section of the HTGR Project Fractions worksheet, screenshot.

3.2.4   Module Refueling Occurrences

Reactor refueling occurrences for each module (rows 608 to 697) are calculated based on the economic life and the refueling period specified on the Project Inputs worksheet. The worksheet identifies the number of refueling occurrences that occur in each analysis year for each reactor

module in column R. Check values are also calculated in column S for the individual and total refueling occurrences; however, the check values are not presented in the following screenshot. Figure 9 presents the screenshot of the refueling occurrences; analysis years 46 to 79 are hidden.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
607	Analysis Year									REFUELING OCCURENCES								
608	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
609	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
610	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
611	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
612	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
613	6	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
614	7	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
615	8	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
616	9	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
617	10	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
618	11	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
619	12	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
620	13	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
621	14	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
622	15	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
623	16	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
624	17	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
625	18	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
626	19	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
627	20	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
628	21	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
629	22	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
630	23	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
631	24	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
632	25	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
633	26	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
634	27	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
635	28	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
636	29	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
637	30	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
638	31	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
639	32	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
640	33	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
641	34	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
642	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
643	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
644	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
645	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
646	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
647	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
648	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
649	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
650	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
651	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
652	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
687	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
688	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
689	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
690	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
691	84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
692	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
693	86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
694	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
695	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
696	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
697	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
698	Total	19	19	19	19	0	0	0	0	0	0	0	0	0	0	0	0	76

Figure 9. Annual refueling occurrences section of the HTGR Project Fractions worksheet, screenshot.

3.2.5   Module Depreciation Fractions

The annual depreciation fractions are calculated for each reactor module in rows 700 to 749. Deprecation is assumed to begin the first year of module operation for each module. The yearly fraction is set by multiplying corresponding depreciation fraction, from the Commodity Prices worksheet, by the module construction factor, row 28. The sum of the annual depreciation fractions, row 750, should equal the module fraction, row 28. Figure 10 presents a screenshot of the depreciation section. The sum for all modules, column R, should equal one. The fractions calculated in column R are used to set the depreciation deduction for calculation of the annual project cash flows on the IRR Analysis worksheet.

	A Analysis Year	B	C	D	E	F	G	H	I	J DEPRECIATION FRACTIONS	K	L	M	N	O	P	Q	R
700	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
701	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
702	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
703	4	0.017967296	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.017967296
704	5	0.034137862	0.013008107	0.009970149	0	0	0	0	0	0	0	0	0	0	0	0	0	0.057116118
705	6	0.030724075	0.024715403	0.018943284	0.009054448	0	0	0	0	0	0	0	0	0	0	0	0	0.08343721
706	7	0.027669635	0.022243863	0.017048955	0.017203452	0	0	0	0	0	0	0	0	0	0	0	0	0.084165905
707	8	0.024902672	0.020032485	0.01535403	0.015483106	0	0	0	0	0	0	0	0	0	0	0	0	0.075772293
708	9	0.02238725	0.018029236	0.013818627	0.01394385	0	0	0	0	0	0	0	0	0	0	0	0	0.068178964
709	10	0.021201409	0.016208101	0.012422806	0.012549465	0	0	0	0	0	0	0	0	0	0	0	0	0.062381781
710	11	0.021201409	0.015349566	0.011764776	0.011281842	0	0	0	0	0	0	0	0	0	0	0	0	0.059597594
711	12	0.021237343	0.015349566	0.011764776	0.010684249	0	0	0	0	0	0	0	0	0	0	0	0	0.059035935
712	13	0.021201409	0.015375582	0.011784716	0.010684249	0	0	0	0	0	0	0	0	0	0	0	0	0.059045957
713	14	0.021237343	0.015349566	0.011764776	0.010702358	0	0	0	0	0	0	0	0	0	0	0	0	0.059054043
714	15	0.021201409	0.015375582	0.011784716	0.010684249	0	0	0	0	0	0	0	0	0	0	0	0	0.059045957
715	16	0.021237343	0.015349566	0.011764776	0.010702358	0	0	0	0	0	0	0	0	0	0	0	0	0.059054043
716	17	0.021201409	0.015375582	0.011784716	0.010684249	0	0	0	0	0	0	0	0	0	0	0	0	0.059045957
717	18	0.021237343	0.015349566	0.011764776	0.010702358	0	0	0	0	0	0	0	0	0	0	0	0	0.059054043
718	19	0.010600704	0.015375582	0.011784716	0.010684249	0	0	0	0	0	0	0	0	0	0	0	0	0.048445252
719	20	0	0.007674783	0.005882388	0.010702358	0	0	0	0	0	0	0	0	0	0	0	0	0.024259529
720	21	0	0	0	0.005342124	0	0	0	0	0	0	0	0	0	0	0	0	0.005342124
721	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
722	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
723	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
724	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
725	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
726	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
727	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
728	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
729	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
730	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
731	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
732	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
733	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
734	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
735	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
736	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
737	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
738	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
739	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
740	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
741	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
742	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
743	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
744	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
745	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
746	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
747	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
748	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
749	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
750	Total	0.359345912	0.260162138	0.199402986	0.181088964	0	0	0	0	0	0	0	0	0	0	0	0	1

Figure 10. Depreciation section of the HTGR Project Fractions worksheet, screenshot.

3.2.6   Module Debt Payments

Debt principal payments are calculated for each reactor module in rows 752 to 801, shown in Figure 11. Loan payments are assumed to begin the first year of module operations. The calculations are based on the percent of capital financed, loan term, and interest rate specified on the Project Inputs sheet. The sum of the payments, calculated in column R, is used to set the debt principal payments on the IRR Analysis worksheet. A check value is calculated in column S for the sum of the debt principal payments which allows the user to ensure the algorithm is calculating the appropriate value; however, the check value is not included in the screenshot.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
751	Analysis Year									DEBT PRINCIPAL PAYMENT								
752	1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
753	2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
754	3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
755	4	-$20,284,325	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,284,325
756	5	-$43,077,256	-$29,968,519	-$11,255,881	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$84,301,656
757	6	-$46,652,647	-$32,455,891	-$23,903,802	-$20,859,946	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$123,872,285
758	7	-$50,524,793	-$35,149,714	-$25,887,805	-$22,591,311	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$134,153,624
759	8	-$54,718,326	-$38,067,123	-$28,036,481	-$24,466,379	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$145,288,309
760	9	-$59,259,920	-$41,226,676	-$30,363,495	-$26,497,076	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$157,347,167
761	10	-$64,178,464	-$44,648,469	-$32,883,650	-$28,696,320	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$170,406,904
762	11	-$69,505,245	-$48,354,270	-$35,612,976	-$31,078,101	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$184,550,593
763	12	-$75,274,146	-$52,367,651	-$38,568,836	-$33,657,568	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$199,868,201
764	13	-$81,521,863	-$56,714,140	-$41,770,030	-$36,451,129	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$216,457,163
765	14	-$88,288,138	-$61,421,386	-$45,236,922	-$39,476,555	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$234,423,001
766	15	-$95,616,010	-$66,519,331	-$48,991,564	-$42,753,090	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$253,879,994
767	16	-$103,552,091	-$72,040,402	-$53,057,840	-$46,301,575	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$274,951,909
768	17	-$112,146,864	-$78,019,720	-$57,461,615	-$50,144,583	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$297,772,781
769	18	-$121,454,998	-$84,495,318	-$62,230,900	-$54,306,558	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$322,487,775
770	19	-$64,457,033	-$91,508,388	-$67,396,034	-$58,813,976	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$282,175,432
771	20	$0	$0	-$35,767,556	-$63,695,507	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$99,463,063
772	21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
773	22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
774	23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
775	24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
776	25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
777	26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
778	27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
779	28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
780	29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
781	30	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
782	31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
783	32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
784	33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
785	34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
786	35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
787	36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
788	37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
789	38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
790	39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
791	40	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
792	41	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
793	42	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
794	43	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
795	44	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
796	45	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
797	46	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
798	47	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
799	48	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
800	49	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
801	50	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
802	Total	-$1,150,512,120	-$832,957,000	-$638,425,387	-$579,789,673	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$3,201,684,180

Figure 11. Debt principal payment section of the HTGR Project Fractions worksheet, screenshot.

Debt interest payments are similarly calculated for each reactor module in rows 804 to 853, shown in Figure 12. The sum of the payments, calculated in column R, is used to set the debt interest payments on the IRR Analysis worksheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
803	Analysis Year									DEBT INTEREST PAYMENT								
804	1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
805	2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
806	3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
807	4	-$45,685,033	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$45,685,033
808	5	-$88,861,461	-$65,553,532	-$25,350,872	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$179,765,865
809	6	-$85,286,070	-$63,066,160	-$49,309,705	-$45,629,319	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$243,291,254
810	7	-$81,413,923	-$60,372,337	-$47,325,701	-$43,897,954	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$233,009,915
811	8	-$77,220,391	-$57,454,928	-$45,177,026	-$42,022,886	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$221,875,231
812	9	-$72,678,796	-$54,295,375	-$42,850,012	-$39,992,189	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$209,816,373
813	10	-$67,760,252	-$50,873,582	-$40,329,857	-$37,792,945	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$196,756,635
814	11	-$62,433,471	-$47,167,781	-$37,600,530	-$35,411,164	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$182,612,947
815	12	-$56,664,570	-$43,154,400	-$34,644,670	-$32,831,697	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$167,295,338
816	13	-$50,416,853	-$38,807,911	-$31,443,476	-$30,038,136	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$150,706,376
817	14	-$43,650,579	-$34,100,665	-$27,976,584	-$27,012,710	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$132,740,538
818	15	-$36,322,707	-$29,002,721	-$24,221,942	-$23,736,176	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$113,283,545
819	16	-$28,386,625	-$23,481,649	-$20,155,666	-$20,187,690	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$92,211,631
820	17	-$19,791,853	-$17,502,331	-$15,751,892	-$16,344,682	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$69,390,758
821	18	-$10,483,718	-$11,026,733	-$10,982,606	-$12,182,707	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$44,675,764
822	19	-$1,512,325	-$4,013,663	-$5,817,472	-$7,675,289	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$19,018,749
823	20	$0	$0	-$839,197	-$2,793,758	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$3,632,955
824	21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
825	22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
826	23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
827	24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
828	25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
829	26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
830	27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
831	28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
832	29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
833	30	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
834	31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
835	32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
836	33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
837	34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
838	35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
839	36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
840	37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
841	38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
842	39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
843	40	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
844	41	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
845	42	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
846	43	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
847	44	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
848	45	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
849	46	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
850	47	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
851	48	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
852	49	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
853	50	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
854	Total	-$828,568,630	-$599,873,768	-$459,777,206	-$417,549,304	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$2,305,768,908

Figure 12. Debt interest payment section of the HTGR Project Fractions worksheet, screenshot.

Finally, the capitalized interest, which is the interest accumulated on debt during construction, is calculated for each module in rows 856 to 885. These calculations are based on the construction period for each module and the interest rate on debt during construction specified on the Project Inputs worksheet. It is assumed that funds are borrowed on a monthly basis; hence interest is accrued monthly for each module. The interest on debt is lumped with the amount of capital financed in determining the total debt interest and principal payments. Figure 13 presents a

screenshot of the capitalized interest section of the HTGR Project Fractions worksheet. The sum for all modules, column R, is used in the annual cash flow analysis on the IRR Analysis worksheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2	Reactor #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
3	Active	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
855	Analysis Year									CAPITALIZED INTEREST								
856	1	-$6,641,104	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$6,641,104
857	2	-$30,071,404	-$6,576,611	-$605,750	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$37,253,765
858	3	-$62,709,406	-$28,013,593	-$11,903,912	-$4,715,060	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$107,341,971
859	4	-$83,530,403	-$52,430,592	-$32,074,638	-$19,994,321	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$188,029,955
860	5	$0	$0	-$45,448,836	-$37,070,458	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$82,519,295
861	6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
862	7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
863	8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
864	9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
865	10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
866	11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
867	12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
868	13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
869	14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
870	15	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
871	16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
872	17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
873	18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
874	19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
875	20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
876	21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
877	22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
878	23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
879	24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
880	25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
881	26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
882	27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
883	28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
884	29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
885	30	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
886	Total	-$182,952,318	-$87,020,796	-$90,033,137	-$61,779,840	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$421,786,090

Figure 13. Capitalized interest section of the HTGR Project Fractions worksheet, screenshot.

3.2.7 Named Cells/Ranges

The following cells names have been assigned on the HTGR Project Fractions worksheet:

- MCE_1N – cell B11

- MCE_TN – cell R11

3.2.8 Worksheet Formatting

Cells highlighted purple indicate user inputs. Data validation limitations have been entered for all user inputs. All other cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

Conditional formatting[14] is used in row 33, which highlights the row red if the sum of the values entered for the user override for the capital breakdown fractions do not sum to one.

3.2.9 Worksheet Equations/IF Statements

Several complex equations and IF statements are utilized in the HTGR Project Fractions worksheet, the following sections summarize these functions.

3.2.9.1 Module Construction Schedule

A simple IF statement is used in row three to display if the listed reactor module is active based on the user input for the number of reactor modules on the Project Inputs worksheet. The equation for cell B3 is used as the example:

B3=IF(B2<=Number,TRUE,FALSE)

If the reactor module is active, the corresponding cell in row three displays TRUE, otherwise the cell reads FALSE. Next, another IF statement is used in row four, displaying the construction period for the active modules:

B4=IF(B3=TRUE,IF(B2=1,CPN+SitePrep,CPN),0)

This equation sets the construction period equal to the value specified on the Project Inputs worksheet, plus the preconstruction period for the first reactor module, if the corresponding value in row three is active, i.e. TRUE; otherwise the construction period is zero. Row six calculates the construction period used by the model for each module, cell B6 is used as the example:

B6=IF(B3=TRUE,IF(ISBLANK(B5)=TRUE,B4,B5),0)

Based on the above equation, if the corresponding cell in row three is active the construction period used will equal the value entered in the user override, row five, if no value is entered in the user override then the construction period calculated by the model is used, row four. The value calculated in row six is used along with the month construction ends, row 11, to calculate the month construction starts, row seven, cell B7 is shown in the example:

B7=IF(B3=TRUE,B11-B6+1,0)

---

[14] 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.

Again, if the corresponding value in row three is active, then the month construction starts is equal to the month construction ends (row 11) minus the construction period used in the model (row 6) plus one. The value calculated in row seven is used to then calculate the year construction begins for each module:

B8=ROUNDUP(B7/12,0)

The month construction ends for each module, row nine, is calculated using the following equation:

B9=IF(B3=TRUE,IF(B2>1,A11+StaggerN,B6),0)

This calculates the month construction ends if the corresponding cell in row three is active for each module. For the first module the month construction ends is equal to the construction period for that module, row 6. For all other modules, the month construction ends is equal to the end of the previous construction period used in the model, row 11, plus the reactor construction staggering period. Like the construction period, the user can override the month construction ends as described previously. The month used in the model, row 11, is calculated using an equation similar to the equation used for row 6.

The calculation for the year construction ends for each module is calculated based on the calculation for the first year of operations, row 13, and the number of months in the first year of operations, row 14:

B12=IF(B14<12,B13,B13-1)

The value in row 12 is equal to the first year of operations, if the number of months in the first year of operations is less than 12; otherwise, the value is equal to the first year of operations minus one. The first year of operations, row 13, is calculated as follows:

B13=IF(B3=TRUE,ROUNDDOWN(B11/12,0)+1,0)

This equation divides the month construction ends for each module (row 11) by 12, and rounds the resulting value down to the next nearest integer, then adds one, if the corresponding cell in row three is active. The number of months in the first year of operations is then calculated as follows:

B14=IF(B3=TRUE,B13*12-B11,0)

The startup period, revenues fraction, and operating cost multiplier are calculated in rows 15, 18, and 21, respectively, using the following equations:

B15=IF(B3=TRUE,STN,0)

B18=IF(B3=TRUE,STRVN,0)

B21=IF(B3=TRUE,STOCN,0)

These equations set the values equal to the cells specified on the Project Inputs worksheet, if the corresponding cell in row three is active for each module. Like the construction period and the month construction ends, the user can override the startup period, revenues fraction, and operating cost multiplier as described previously. The values used in the model (rows 17, 20, and 23), are calculated using an equation similar to the equation used for row 6.

3.2.9.2   Module Capital Cost Fractions

The equations for the reactor module fraction calculations were previously presented in Section 2.4.1.1. Row 24 calculates the exponent used for each module, cell B24 is used as the example:

B24=0.102*LN(B2+-0.963)-0.402

The multiplier for each module is calculated in row 25:

> B25=IF(B2=1,1,0.908*B2^-1.172)

This equation sets the multiplier equal to one if the module number, row 2, is equal to one; otherwise, the exponential correlation is used to calculate the multiplier for the given module. The exponent and multiplier are then used to calculate the fractional breakdown for each module, row 26, cell B26 is used as the example:

> B26=IF(Number=B$2,(1-SUMIF($B$2:$Q$2,"<"&B$2,$B26:$Q26)),IF(Number<B$2,0,
>   B$25*(Number-(B$2-1))^B$24))

This equation calculates the fraction for the number of reactor modules specified by the user such that if the module fraction being calculated is equal to the number of modules specified by the user, the fraction is equal to one minus the sum of all fractions for modules less than the number specified, this ensures that the fractions add to one. Otherwise, the module fraction is equal to the multiplier, row 24, times the number of modules less the current module minus one raised to the exponent calculated in row 25. Like the construction period and the month construction ends, the user can override the module fractions as previously discussed. The fraction used in the model, row 28, is calculated using an equation similar to the equations used for rows six and 11. If a user override is specified for the module fractions, the fractions must sum to one.

The following calculations are made in rows 30 to 389; these rows are normally hidden on the worksheet. To view these calculations, click the 'Unhide Rows – Capital Fractions Detail' button, which runs a short Macro described in the next section. The hidden section calculates the fraction of construction capital expended for each module per month using the monthly s-curve distribution, previously described in Section 2.4.1.1. It is necessary to calculate the monthly distribution, rather than the yearly distribution, as the construction period can be specified in monthly increments. As such, up to 360 months of construction, or 30 years, can be accommodated in the model. Rows 30 to 389 include the following function, cell B30 is used in the example:

> B30=IF(AND($A30<=B$11,$A30>=B$7),

> *If the current month (column A) is between the month construction starts and the month construction ends:*

> > 0.5*(SIN(-PI()/2+PI()*($A30-(B$7-1))/B$6)+1)-IF($A30=1,0,SUM(B29:B$30)),0)

> *Then, the cell value is equal to the cumulative s-curve distribution function[15] minus the sum of all previous distribution values if the month (column A) is greater than one, if the month is equal to one zero is subtracted. Otherwise, the cell is equal to zero.*

Column R sums the monthly distributions calculated for each module and divides the sum by the number of modules specified; this value is the overall monthly capital distribution for all modules. Row 390 serves as a check for the distribution calculation. The sum of rows 30 to 389 should equal one for all active modules as should the total monthly capital distribution, column R.

The annual capital construction fractions, rows 392 to 421, are calculated using the following formula, cell B392 is used in the example:

> B392=B$28*SUMIFS(B$30:B$389,$A$30:$A$389,">="&(1+($A392-1)*12),$A$30:$A$389,
>   "<="&$A392*12)

---

[15] $Cumulative\ S\text{-}Curve\ Distribution = 0.5 \times \left(\sin\left(-\frac{\pi}{2} + \frac{\pi \times month}{c\_months} \right) + 1 \right)$

The annual fraction is equal to the module capital fraction used in the model, row 28, times the sum of the months from the s-curve distribution calculated which correspond to the analogous analysis year in column A. For the example shown, the function SUMIFS sums the values in column B for rows 30 to 389, when the values in column A for rows 30 to 389 are between 1 and 12 months, i.e. the first year of construction. Column R sums the annual distributions for all modules; this value is the overall annual capital construction distribution. Row 422 sums the annual distributions for the modules which should equal the fractions in row 28. The sum of column R for rows 392 to 421 should equal one.

3.2.9.3   Module Revenue and Operating Cost Fractions

The annual revenue fractions for each module are calculated in rows 424 to 513. A complex IF statement is used for this function, cell B424 is used in the following calculation example:

B424=IF(B$3=TRUE,

If the reactor module is present then following function is calculated:

IF($A424=B$13,

If the year in column A is equal to the first year of operations for the module, as shown in row 13, then:

IF(B$14<=B$17,B$20*B$14/12,(B$17*B$20+B$14-B$17)/12),

If the number of months during the first year of operations, row 14, is less than or equal to the number of months in the startup period, row 17, then the value is equal to the startup revenue multiplier, row 20, times the number of months in the first year of operations, row 14, divided by 12. Otherwise, the value is equal to the startup time period, row 17, times the revenue multiplier, row 20, plus the number of months in the first year of operations, row 14, less the number of months in the startup period, row 17, all divided by 12.

IF(AND($A424>B$13,$A424<ELN+B$13),

Otherwise, if the year in column A is greater than the first year of operations, row 13, and less than the economic life (ELN) specified by the user plus the first year of operations, then:

IF((B$17-B$14)/12>=$A424-B$13,B$20,

If the startup period, row 17, less the number of months in the first year of operations, row 14, divided by twelve is greater than or equal to the current year less the first year of operations, row 13, then the value is equal to the startup revenue multiplier calculated in row 20.

IF(AND((B$17-B$14)/12<$A424-B$13,(B$17-B$14)/12+1>=$A424-B$13),

Otherwise if the startup period, row 17, less the number of months in the first year of operations, row 14, divided by twelve is less than the current year less the first year of operations, row 13, and the startup period, row 17, less the number of months in the first year of operations, row 14, divided by twelve plus one is greater than or equal to the current year less the first year of operations, row 13, then:

MOD(B$17-B$14,12)/12*B$20+(1-MOD(B$17-B$14,12)/12),1)),

> *The revenue fraction is equal to the fraction of the startup time remaining, calculated using the MOD function, times the startup multiplier plus the number of months remaining in the current year divided by 12. This allows the revenue fraction to be calculated for startup periods lasting multiple years. Otherwise, the value is equal to one, i.e. full revenues when the startup period is complete.*

IF($A424=ELN+B$13,(12-B$14)/12,0)),0)

> *Finally, if the current year is equal to the economic life specified by the user plus the first year of operations, row 13, then the value is equal to 12 minus the number of partial months in the first year of operations, row 14, divided by twelve. Otherwise if the number of years is greater than the economic life plus the first year of operations the value is zero, i.e. the plant is no longer operating.*

Column R sums the revenue fractions for all modules and divides by the number of modules. Row 514 sums the annual revenue fractions which should equal the check value provided in cell S514:

S514=ELN-(AVERAGEIFS(B17:Q17,B3:Q3,TRUE)/12)+(B17*B20+C17*C20+D17*D20
+E17*E20+F17*F20+G17*G20+H17*H20+I17*I20+J17*J20+K17*K20+L17*L20+
M17*M20+N17*N20+O17*O20+P17*P20+Q17*Q20)/(Number*12)

The operating cost fractions for each module are calculated in rows 516 to 605. A complex IF statement is used for this function, cell B516 is used in the following calculation example:

B516=IF(B$3=TRUE,IF($A424=B$13,IF(B$14<=B$17,B$23*B$14/12,(B$17*B$23+B$14-
B$17)/12),IF(AND($A424>B$13,$A424<ELN+B$13),IF((B$17-B$14)/12>=$A424-
B$13,B$23,IF(AND((B$17-B$14)/12<$A424-B$13,(B$17-B$14)/12+1>=$A424-B$13)
,MOD(B$17-B$14,12)/12*B$23+(1-MOD(B$17-B$14,12)/12),1)),IF($A424=ELN+B$13
,(12-B$14)/12,0))),0)

The IF statement description is not provided as this equation is the exact equation used for the revenue fractions calculation, except the operating cost multiplier, row 21, is used instead of the revenues multiplier, row 18. Again, Column R sums the operating cost fractions for all modules and divides by the number of modules. Row 606 sums the annual operating cost fractions which should equal the check value provided in cell S606:

S606=ELN-(AVERAGEIFS(B17:Q17,B3:Q3,TRUE)/12)+(B17*B23+C17*C23+D17*D23+
E17*E23+F17*F23+G17*G23+H17*H23+I17*I23+J17*J23+K17*K23+L17*L23+
M17*M23+N17*N23+O17*O23+P17*P23+Q17*Q23)/(Number*12)

3.2.9.4   Module Refueling Occurrences

The number of yearly refueling occurrences for each module is calculated in rows 608 to 697. A complex IF statement is used for this function, cell B608 is used in the following calculation example:

B608=IF(B$3=TRUE,

> *If the reactor module is present then following function is calculated:*

IF(AND($A608*12-B$11>=Refuel,$A608*12-B$11<ELN*12-Refuel),
ROUNDDOWN(($A608*12-B$11)/Refuel,0)-ROUNDDOWN(($A607*12-B$11)/Refuel,0),

> *If the current year, column A, times 12 less the months of construction used in the model, row 11, is greater than or equal to the months between refuelings (Refuel) and less than the economic life (ELN), converted to months, less the months between refuelings, then the value*

is equal to the number of refuelings in the current year less the number of refuelings in the previous year.

IF(AND($A608*12-B$11<=ELN*12,$A608*12-B$11>=ELN*12-Refuel),(ELN*12-Refuel)/Refuel-SUM(B607:B$608),0)),0)

Otherwise, if the current year times 12 less the number of months of construction used in the model is less than or equal to the economic life times 12 and greater than or equal to the economic life times twelve less the refueling period (this represents the last refueling occurrence for the plant), then the fraction of refuelings performed for the remainder of the economic life is calculated by taking the total number of refuelings for the economic life minus the total refuelings performed for all previous years. Otherwise, the value is zero.

Column R sums the refueling occurrences for all modules. Row 698 sums the individual module refuelings which should equal the check value provided in cell S697:

S697=(ELN*12-Refuel)/Refuel

The sum for all modules, cell R698, should equal the check value provided in cell S698, which is equal to the value calculated in cell S697 times the number of modules.

3.2.9.5   Module Depreciation Fractions

The depreciation fractions are calculated in rows 700 to 749. A complex, but much shorter, IF statement is used for this function, cell B700 is used in the following calculation example:

B700=IF(B$3=TRUE,IF(AND($A700>=B$13,$A700<16+B$13),B$28*VLOOKUP(1+$A700-B$13,'Commodity Prices'!$F$2:$G$22,2),0),0)

If the reactor module is present then, if the current year is greater than or equal to first year of operations, row 13, and less than 16 plus the first year of operations then the depreciation fraction is equal to the module construction fraction in row 28 times the depreciation fraction specified on the Commodity Prices worksheet, which is set using the VLOOKUP function. Column R sums the depreciation fractions for all modules. Row 750 sums the individual module depreciation fractions, which should equal the module fraction in row 28, and the total module fractions are calculated in column R, which should sum to one.

3.2.9.6   Module Debt Payments

The debt principal payment for each module is calculated in rows 752 to 801. A complex IF statement is used for this function, cell B752 is used in the following calculation example:

B752=IF(B$3=TRUE,

If the reactor module is present then following function is calculated:

IF(OR($A752*12<=B$11,$A752*12-B$11>=(RTermN+1)*12),0,

If the current year from column A, converted to months, is less than or equal to the month construction ends, row 11, or the current year, converted to months, less the months of construction, row 11, is greater than or equal to the number of years in the loan term (RTermN) plus one, converted to months, then the value is zero.

CUMPRINC(RDebtN/100/12,RTermN*12,B$28*(-SUM(DebtCapital,DebtInterest)),

Otherwise the debt principal payment is calculated using the built in Excel function CUMPRINC, which uses the following syntax: CUMPRINC(rate,nper,pv,start period,end period,type). The rate (RDebtN) and term (RTermN) use the values entered on the Project Inputs worksheet converted to their equivalent monthly values, and the present value is equal to the sum of the debt capital and debt interest on the IRR Analysis worksheet times the capital fraction for the first module, row 28.

IF($A752=B$13,1,IF($A752=B$13+1,B$14+1,($A752-B$13-1)*12+B$14+1)),

The start period is equal to one if the current year is equal to the first year of operations, row 13. If the current year is equal to the second year of operations, then the start period is equal to the number of months in the first year of operations, row 14, plus one; otherwise, the start period is equal to the current year minus the first year of operations minus one, converted to months, plus the number of months in the first year of operations plus one.

IF($A752*12-B$11<=RTermN*12,$A752*12-B$11,RTermN*12),0)),0)

If current year times twelve less the month construction ends, row 11, is less than the number of months in the loan term (RTermnN), then the end period is equal the current year times 12 less the month construction ends, otherwise the end period is the number of months in the loan term, i.e. the last year of the loan.

Column R sums the debt principal payments for all modules. Row 802 sums the individual module payments, the sum of which, cell R802, should equal the check value provided in cell S802, which is the sum of the debt capital and debt interest ranges on the IRR Analysis worksheet:

The debt interest payment for each module is calculated in rows 804 to 852. A complex IF statement is used for this function, cell B804 is used in the following calculation example:

B804=IF(B$3=TRUE,IF(OR($A804*12<=B$11,$A804*12-B$11>=(RTermN+1)*12),0,
CUMIPMT(RDebtN/100/12,RTermN*12,B$28*(-SUM(DebtCapital,DebtInterest))),
IF($A804=B$13,1,IF($A804=B$13+1,B$14+1,($A804-B$13-1)*12+B$14+1)),
IF($A804*12-B$11<=RTermN*12,$A804*12-B$11,RTermN*12),0)),0)

The IF statement description is not provided for this equation as it is the exact equation used for the debt principal calculation, except the CUMIPMT function, is used instead of the CUMPRINC function. Again, Column R sums the individual module interest payments for all modules.

Finally, the capitalized interest, or the interest on debt during construction, is calculated for each module in rows 856 to 885. Another complex IF statement is used for this function, cell B856 is used in the following calculation example:

B856=IF(AND($A856>=B$8,$A856<=B$12),

If the current year in column A is greater than or equal to the year construction starts, row 8, and less than or equal to the year construction ends, row 12, then the cell value is equal to the sum of the following values:

-FV(RDebtN_Con/100/12,

The negative of the value calculated using the built in Excel function FV, which calculates the future value of the annual debt financed where the loan is assumed to be amortized in equal monthly increments, the following syntax is used: FV(rate,nper,pmt,pv,type). The rate is

specified by the interest on debt during construction (RDebtN_Con) entered on the Project Inputs worksheet, converted to its equivalent monthly value.

IF($A856=B$8,$A856*12-B$7+1,IF($A856<B$12,12,IF($A856=B$12,12-IF(B$14<12,B$14,0),0))),

The number of periods, i.e. the number of months during which money is being lent for the corresponding analysis year is calculated as follows. If the analysis year equals the year construction begins, then the number of periods is equal to the analysis year times 12 less the month construction starts, row 7, plus one month. If the analysis year is less than the year construction ends, then the number of periods is equal to 12, i.e. a full year. Finally, if the analysis year is equal to the year construction ends, then the number of periods is equal to 12 less the number of months in the first year of operations, row 14, if that value is less than 12, if the number of months is equal to 12 the period is equal to 12. Otherwise, the period is equal to zero.

('IRR Analysis'!$D27*B392/$R392)/IF($A856=B$8,$A856*12-B$7+1,IF($A856<B$12,12,IF($A856=B$12,12-IF(B$14<12,B$14,0),0))),0)

The payment, which since we are calculating the amount of interest accumulated during construction, is assumed to equal the corresponding debt capital value on the IRR Analysis sheet multiplied by the yearly construction fraction for the current module divided by the overall annual construction fraction (column R) divided by the number of periods for the current year, which was described in the paragraph above. The present value is set equal to zero since the calculation is for the amount of interest accumulated during construction.

-'IRR Analysis'!$D27*B392/$R392

The corresponding loan amount financed for the analysis year is subtracted from the future value of the loan with interest, to determine the interest accumulated during construction.

+IF($A856>1,SUMIF($A$856:$A$885,"<"&$A856,B$856:B$885)+SUMIF($A$856:$A$885,"<"&$A856,DebtCapital)*SUMIF($A$856:$A$885,"<"&$A856,B$392:B$421)/IF(SUMIF($A$856:$A$885,"<"&$A856,$R$392:$R$421)>0,SUMIF($A$856:$A$885,"<"&$A856,$R$392:$R$421),1),0)*RDebtN_Con/100,0)

Next, if the analysis year is greater than one, the previous annual sums for interest accumulated on the debt during construction are added to the previous annual sums for the capital financed for the current module, times the interest rate on debt during construction. This adds the interest on the interest accumulated for the previous years and interest on the capital financed during the previous years. Otherwise, if the annual year is outside the range specified in the equation, the interest on debt is equal to zero.

3.2.10 Worksheet Macros

The UnhideCellsHTGRFractions Macro unhides the hidden rows 29 to 390 on the HTGR Project Fractions worksheet when the user clicks the 'Unhide Rows – Capital Fractions Detail' button. The UnhideCellsHTGRFractions Macro is presented in Figure 14.

```
Sub UnhideCellsHTGRFractions()

' UnhideCellsHTGRFractions Macro

    ' Shows the hidden rows on the HTGR Project Fractions Sheet
    Sheets("HTGR Project Fractions").Select
    Rows("29:390").Select
    Selection.EntireRow.Hidden = False

End Sub
```

Figure 14. UnhideCellsHTGRFractions Macro.

The HideCellsHTGRFractions Macro hides rows 29 to 390 on the HTGR Project Fractions worksheet, when the user clicks the 'Hide Rows – Capital Fractions Detail' button. The HideCellsHTGRFractions Macro is show in Figure 15.

```
Sub HideCellsHTGRFractions()

' HideCellsHTGRFractions Macro

    ' Hides the rows on the HTGR Project Fractions Sheet
    Sheets("HTGR Project Fractions").Select
    Rows("29:390").Select
    Selection.EntireRow.Hidden = True

End Sub
```

Figure 15. HideCellsHTGRFractions Macro.

3.3   HTGR Cost Basis

The HTGR Cost Basis worksheet is arranged into several sections where the capital cost, operating and maintenance cost, fuel cost, and decommissioning cost are calculated based on the user inputs specified on the Project Inputs worksheet along with correlations developed for the reactor capital and operating costs in TEV-1196 (INL 2012a). The only user inputs available on the HTGR Cost Basis worksheet are the user overrides for the number of power cycles and staffing levels for the single and additional reactor unit, the inputs of which are limited using the data validation tool.

3.3.1   Capital Costs

Capital cost correlations are used to develop the HTGR capital cost according to the equations presented in Section 2.1, which are based on the correlations presented in TEV-1196 (INL 2012a). These correlations can be easily changed if the underlying data presented in TEV-1196 is updated. The data for the correlations is pasted from the HTGR Cost Model, which is documented in the "HTGR Cost Model Users' Manual," INL/EXT-11-23833, (INL 2012b). The relationship for the ROT is a linear correlation, while the number of units and HTGR and power cycle size are exponential correlations; multipliers are used to adjust the baseline NOAK costs to either FOAK or NGNP costs. Figure 16 presents the factors used in the HTGR and power cycle correlations on the HTGR Cost Basis worksheet. In general these rows are hidden; however, they can be unhidden by clicking the 'Unhide Rows – HTGR Capital Cost Correlations' button which is linked to a Macro. The rows can be redhidden by clicking the 'Hide Rows – HTGR Capital Cost Correlation' button, also linked to a Macro.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Capital Cost Correlations			ROT			Reactor #		HTGR/Power Cycle Size		FOAK		NGNP	
2			T Range	T≤850	850<T<900	T>900			Base 600					
3		HTGR Less Power Cycle	Slope	0.2576	1.4867	0.6000	Exponent	0.8275	Exponent	0.6734	Multiplier	1.4870	Multiplier	1.7583
4			Int.	250.9524	-793.5981	4.4148								
5			T Range	T≤850	850<T<900	T>900			Base 280.8					
6		Brayton Cycle	Slope	0.2539	0.5637	0.3901	Exponent	0.9195	Exponent	0.6044	Multiplier	2.0743	Multiplier	2.3548
7			Int.	-27.0585	-290.2688	-134.0303								
8			T Range		All T's				Base 267					
9		Rankine Cycle	Slope		0.2365		Exponent	1	Exponent	0.5	Multiplier	1.3429	Multiplier	1.4286
10			Int.		-58.7751									

Figure 16. Capital cost correlations section of the HTGR Cost Basis worksheet, screenshot.

Using the factors presented above, the capital costs are developed based on the correlations presented in Section 2.1. First, the user inputs selected on the project inputs sheet are presented. Then the capital cost is calculated for the HTGR NHSS, the Brayton cycle, and the Rankine cycle. The power cycle cost is calculated based on the gross power produced, rather than the net power, which is the basis outlined in TEV-1196. Hence, the basis for the Brayton cycle is 301.4 MWe and the basis for the Rankine cycle is 287.6 MWe[16]. The power cycle size bases are also used to determine the number of power cycle units required. However, the user can override the number of power cycles used in the model in row 24.

Preconstruction costs are the sum of the land and land rights costs and licensing and application costs. All preconstruction costs are accounted for in the HTGR portion of the plant. Direct costs are the sum of the estimate for the top capital cost items, determined using the capital cost correlations, and the BOE adder, assumed to be 25% of the top capital cost items (INL 2012a).

---

[16]   20.6 MWe is added to the net power basis to account for the HTGR house loads at 750°C ROT:

Brayton: 280.8 MWe + 20.6 MWe = 301.4 MWe

Rankine: 267 + MWe + 20.6 MWe = 287.6 MWe

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 2012a). 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 2012a). 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 2012a). The total overnight cost is the sum of the base construction costs and the project contingency. Costs are presented in 2009 dollars and converted to dollars for the project base year using the CEPCI. Figure 17 presents the capital cost section of the HTGR Cost Basis worksheet.

	A	B	C	D	E	F	G	H
12	Assumptions from Project Inputs Sheet						Unhide Rows - HTGR Capital Cost Correlations	
13		ROT	750	°C				
14		Reactor Phase	NOAK				Hide Rows - HTGR Capital Cost Correlations	
15		Reactor Module Rating	600					
16		Staffing Plan	Vendor					
17		Refueling Period	18	months				
18								
19	Reactor Capital Cost				HTGR	Power Cycles		Total
20						Brayton	Rankine	
21	Plant Inputs							
22		HTGR Thermal Rating/Gross Power (MWt, MWe)			2,400	0.0	1,117.0	
23		Number of Units			4	0	4	
24		User Override (Power Cycles Only)						
25		Number of Units Used			4	0	4	
26		Capacity per Unit (MWt, MWe)			600	0.0	279.3	
27	Preconstruction Costs							
28		Land and Land Rights			$10.00			$10.00
29		Licensing Costs			$81.00			$81.00
30	Total Preconstruction Costs				$91.00			$91.00
31	Direct Costs							
32		Direct Cost Total from Correlations			$1,398.70	$0.00	$467.40	$1,866.10
33		Balance of Equipment Costs		25%	$349.67	$0.00	$116.85	$466.53
34	Total Direct Costs				$1,748.37	$0.00	$584.25	$2,332.63
35	Indirect Costs							
36		Design Costs			$20.00			$20.00
37		Construction Services		20%	$350.36	$0.00	$117.08	$467.44
38		Home Office & Engineering Services		16%	$281.90	$0.00	$94.20	$376.11
39		Field Office & Engineering Services		10%	$170.84	$0.00	$57.09	$227.93
40		Owner's Costs		12%	$201.55	$0.00	$67.35	$268.90
41	Total Indirect Costs				$1,024.65	$0.00	$335.72	$1,360.37
42	Base Construction Cost				$2,864.02	$0.00	$919.98	$3,784.00
43	Project Contingency			20%	$572.80	$0.00	$184.00	$756.80
44	Total Construction Cost ($1,000,000 - 2009 Basis)				$3,436.83	$0.00	$1,103.97	$4,540.80
45		$/kWt						$1,892.00
46		$/kWe						$4,388.29
47	Total Construction Cost ($1,000,000 - 2010 Basis)				$3,627.14	$0.00	$1,165.11	$4,792.25
48		$/kWt						$1,996.77
49		$/kWe						$4,631.29

Figure 17. Capital costs section of the HTGR Cost Basis worksheet, screenshot.

3.3.2   O&M Cost

The O&M cost is 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 2012a). The worksheet includes the vendor and INL staffing estimates for a single and the additional HTGR modules, staffing levels are assumed to be independent of the module rating. The vendor or INL staffing plan is selected by the user on the Project Inputs worksheet. Additionally, the user can override the vendor or INL staffing levels with a staffing estimate for the single and additional reactor unit. Data validation limitations have been set for the user overrides, such that the value entered must be greater than the vendor staffing levels, which are assumed to represent the minimum staffing level required for the plant. References for values included in the O&M cost section can be found in TEV-1196 (INL 2012a). Figure 18 presents a screenshot of the O&M cost section of the HTGR Cost Basis worksheet. The O&M cost is presented in 2009 dollars; the commodity price inflation rate is used to adjust the O&M cost to the project base year, 2010 in the following example, which is used in the economic analysis.

	A	B	C	D	E	F	G	H
51	Reactor O&M Cost						Single Unit	Additional Unit
52								
53	Staffing - User Override (Number of Employees)							
54	Staffing - Vendor or INL Plans (Number of Employees)						165.0	25.3
55	Staff Salary					$63,400	$10,461,000	$1,606,133
56	Staff Adders					61.7%	$6,454,437	$990,984
57	*Total Staff Payroll*						*$16,915,437*	*$2,597,118*
58	NRC Fees						$4,784,000	$4,784,000
59	INPO Fees						$706,344	$176,586
60	NEI Fees						$59,366	$59,366
61	Insurance and Taxes						$3,000,000	$1,000,000
62	Material Supplies Services and Upgrades						$5,000,000	$5,000,000
63	Outage O&M						$4,070,724	$4,070,724
64	Administration and General Cost Overhead						$3,000,000	$3,000,000
65	*Total O&M*						*$37,535,870*	*$20,687,793*
66	**Total O&M For Given Configuration ($1,000,000 - 2009 Basis)**							$99.60
67	$/MWt-h							$4.73
68	$/MWe-h							$10.98
69	**Total O&M For Given Configuration ($1,000,000 - 2010 Basis)**							$102.59
70	$/MWt-h							$4.88
71	$/MWe-h							$11.31
72								

Figure 18. O&M cost section of the HTGR Cost Basis worksheet, screenshot.

3.3.3   Fuel Cost

The reactor fuel cost section of the HTGR Cost Basis worksheet calculates fuel costs for the replacement reactor core for the selected HTGR plant configuration. 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, as document in TEV-1196 (INL 2012a). The cost per core for the NGNP, FOAK, and NOAK project phases were taken from the HTGR Cost Model for a 600 MWt HTGR, all other module ratings are scaled linearly with respect to the module rating specified by the user on the Project Inputs worksheet. In addition to the fuel cost per core, the average yearly fuel cost is calculated for the specified configuration. Figure 19 presents a screenshot of the fuel cost section of the HTGR Cost Basis worksheet. The fuel cost is presented in 2009 dollars; the commodity price inflation rate is used to adjust the fuel cost to the project base year, 2010, which is used in the economic analysis.

	A	B	C	D	E	F	G	H
73	Reactor Fuel Cost							
74	Fuel Cost per Core ($1,000,000 - 2009 Basis)							$50.21
75	Average Yearly Fuel Cost ($1,000,000 - 2009 Basis)							$133.88
76	$/MWt-h							$6.36
77	$/Mwe-h							$14.76
78	Fuel Cost per Core ($1,000,000 - 2010 Basis)							$51.71
79	Average Yearly Fuel Cost ($1,000,000 - 2010 Basis)							$137.90
80	$/MWt-h							$6.55
81	$/Mwe-h							$15.20

Figure 19. Fuel cost section of the HTGR Cost Basis worksheet, screenshot.

3.3.4   Decommissioning Cost

The decommissioning cost for the selected HTGR plant configuration is calculated based on the cost per MWt developed in TEV-1196 which is based on the methodology presented in NUREG-1307, Rev. 14 (INL 2012a). The 2009 cost from TEV-1196 is adjusted to the project base year using the commodity price inflation rate. The total decommissioning cost is then adjusted to the decommissioning year calculated on the Project Inputs worksheet using the analysis inflation rate also specified on the Project Inputs worksheet. Based on the future value, the annual sinking fund payment is calculated which is dependent on the sinking fund rate of return, specified on the Project Inputs worksheet. Figure 20 presents a screenshot of the decommissioning cost section of the HTGR Cost Basis worksheet.

	A	B	C	D	E	F	G	H
83	Decommissioning Cost							
84	Decommissioning Cost ($/MWt - 2009 Basis)							$204,779.78
85	Total Decommissioning Cost ($1,000,000 - 2009 Basis)							$491.47
86	Total Decommissioning Cost ($1,000,000 - 2010 Basis)							$506.22
87	Future Value Decomissioning Cost ($1,000,000 - 2078 Basis)							$3,778.04
88	Yearly Sinking Fund Payment ($1,000,000/year)							$9.64
89	Check							$3,778.04

Figure 20. Decommissioning cost section of the HTGR Cost Basis worksheet, screenshot.

3.3.5   Named Cells/Ranges

The following cells names have been assigned on the HTGR Cost Basis worksheet:

- HTGRCost – cell E47

- BraytonCost – cell F47

- RankineCost – cell G47

- OpMt – cell H70

- CoreCost – cell H78

- DeconPmt – cell H88

3.3.6   Worksheet Formatting

Cells highlighted purple indicate user inputs. Data validation limitations have been entered for all user inputs. All other cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.3.7 Worksheet Equations/IF Statements

There are several complex equations and IF statements used on the HTGR Cost Basis worksheet, which will be detailed in this section. However, there are also several simple functions used within the worksheet which will not be described in detail. These functions include simple sums, references from other worksheets, and simple multiplication and division. For instance, balance of equipment costs, certain indirect costs, project contingency, staff salary, and staff adders are all simple multiplication functions, for which the multiplication factor is listed in the column to the left of the calculated columns. The development of these factors is described in detail in TEV-1196 and will not be described further in this users' manual (INL 2012a).

3.3.7.1 Capital Costs

In the reactor capital cost section the thermal rating, number of units, and capacity per unit for the HTGR are referenced from the Project Inputs worksheet. The corresponding plant inputs are calculated for the power cycle options. First, the gross power is calculated using the amount of heat available for power generation and the specified efficiency from the Project Inputs sheet. The following examples show the calculations for the Brayton and Rankine cycle thermal ratings:

F22=(PG_Heat)*HTGRBEFF/100

G22=(PG_Heat)*HTGRREFF/100

Next, the number of units for the power cycles are determined using the ROUND function in Excel along with the gross power cycle size bases for the Brayton cycle, 301.4 MWe, and the Rankine cycle, 287.6 MWe. The number of units is calculated in row 23 for the Brayton and Rankine cycle, respectively:

F23=IF(AND(F22>0,ROUND(F22/(280.8+20.6),0)=0),1,ROUND(F22/(280.8+20.6),0))

G23=IF(AND(G22>0,ROUND(G22/(267+20.6),0)=0),1,ROUND(G22/(267+20.6),0))

These equations set the number of units equal to one if the power cycle size is significantly smaller than the basis; otherwise the number of units is determined using the ROUND function. The user can override the value calculated in row 23 in row 24 for the Brayton and Rankine cycles. The value entered must be a whole number between 1 and 20. If a value is entered in row 24, the value used in the model, row 25, reflects the user override as described in the previous sections. The capacity per unit, row 26, is then calculated for each cycle as follows:

F26=IF(F22=0,0,F22/F25)

G26=IF(G22=0,0,G22/G25)

This equation sets the capacity per unit equal to zero if the gross power is zero, otherwise the function would return a divide by zero error.

The land and land rights costs are calculated using the following function:

E28=(50+(50/3)*(E23-1))/10

This function is developed based on the cost per acre and the number of acres required per unit as described in TEV-1196 (INL 2012a). The licensing costs are also calculated based on information documented in TEV-1196, such that:

E29=IF(RPhase="NGNP",IF(E23=1,228.5,248),IF(RPhase="FOAK",IF(E23=1,84.5,94),
    IF(RPhase="NOAK",IF(E23=1,71.5,81))))

This equation sets the licensing costs equal to the values indentified in TEV-1196 for the appropriate reactor phases. It is assumed that the four-pack costs in TEV-1196 are valid for all multiple module configurations. Furthermore, TEV-1196 did not include a multiple module option for the NGNP project phase; hence the trends identified for the four-pack FOAK and NOAK configurations were adjusted for multiple module NGNP configurations.

The direct costs for the HTGR and power cycles are then calculated using the equations outlined in Section 2.1. The following function is used to calculate the HTGR cost:

E32=(E26/600)^J3*E23^H3*IF(ROT<=850,D3*ROT+D4,IF(AND(ROT>850,ROT<=900),E3*
ROT+E4,IF(ROT>900,F3*ROT+F4,)))*IF(RPhase="FOAK",L3,IF(RPhase="NGNP",N3,
IF(RPhase="NOAK",1,)))

The Brayon cycle cost is similarly calculated using the following equation:

F32=(F26/(280.8+20.6))^J6*F25^H6*IF(ROT<=850,D6*ROT+D7,IF(AND(ROT>850,ROT<=
900),E6*ROT+E7,IF(ROT>900,F6*ROT+F7,)))*IF(RPhase="FOAK",L6,IF(RPhase=
"NGNP",N6,IF(RPhase="NOAK",1,)))

Finally, the Rankine cycle cost is calculated:

G32=IF(G22=0,0,(G26/(267+20.6))^J9*G25^H9*(E9*ROT+E10)*IF(RPhase="FOAK",L9,
IF(RPhase="NGNP",N9,IF(RPhase="NOAK",1,))))

The design costs are calculated based on information documented in TEV-1196:

E36=IF(RPhase="NGNP",1014,20)

The majority of design costs only occur for the NGNP project phase, furthermore, design costs are consistent for single and multiple module configurations (INL 2012a).

The total construction cost per kWt is calculated based on the thermal rating of the plant, defined on the Project Inputs sheet:

H45=H42/HTGR_TR*1000

While the cost per kWe is calculated based on the net power produced, also defined on the Project Inputs sheet:

H46=H42/Net_PWR*1000

Finally, the construction cost is adjusted to the project base year using the CEPCI specified on the Project Inputs sheet. The capital costs are also adjusted for alternate locations using the construction adder, specified on the Project Inputs sheet. The HTGR cost is used in the following example:

E47=E42*(CEPCI/521.9)*CA

Similar functions are used for cells H48 and H49 as presented for cells H45 and H46.

3.3.7.2   O&M Costs

The staffing levels are calculated based on the selection made on the Project Inputs sheet; however, if a user override is entered in row 51, the override is automatically used:

G54=IF(ISNUMBER(G53)=TRUE,G53,IF(Staffing="INL",382,IF(Staffing="Vendor",165,)))

H54=IF(ISNUMBER(H53)=TRUE,H53,IF(Staffing="INL",71,IF(Staffing="Vendor",25+1/3,)))

Nuclear Energy Institute (NEI) fees are a function of the HTGR capacity per unit in cell E26 (INL 2012a):

G60=251.1*0.33*E26*(1+IRT_C/100)^(2009-2003)

The baseline value is from 2003; therefore, it is inflated to 2009 dollars using the commodity price inflation rate specified on the Project Inputs sheet. The same formula is used for the additional unit as for the single unit. Materials supplies services and upgrades are calculated in a similar manner:

G62=5000000*(E26/600)^0.947734582824931

The exponential factor was determined to fit the data for the 600 MWt and 350 MWt module ratings documented in TEV-1196 (INL 2012a). Next, the outage costs are calculated, which are also a function of the module rating:

G63=(E26/(1200/0.33))^0.6*12000000

Finally, the total O&M cost in 2009 dollars is calculated for the specified configuration, as a function of the number of modules:

H66=(G65+(E23-1)*H65)/1000000

The O&M cost per MWt-hr is calculated based on the thermal rating of the plant, defined on the Project Inputs sheet:

H67=H66/HTGR_TR/365.25/24*1000000

While the cost per MWe-hr is calculated based on the net power produced, also defined on the Project Inputs sheet:

H68=H66/Net_PWR/365.25/24*1000000

The O&M cost is adjusted to the project base year using the year specified on the Project Inputs sheet along with the commodity price inflation rate:

H69=H66*(1+IRT_C/100)^(CEPCIYEAR-2009)

Similar functions are used for cells H70 and H71 as presented for cells H67 and H68.

3.3.7.3   Fuel Cost

The fuel cost per core is calculated based on the core costs presented in TEV-1196 (INL 2012a):

H74=IF(RPhase="NOAK",50.2060905399957,85.9159845399957)*E26/600

The average yearly fuel cost is then calculated based on the specified refueling period:

H75=H74*12/Refuel*E23

The fuel cost per MWt-hr is calculated based on the thermal rating of the plant, defined on the Project Inputs sheet:

H76=H75*1000000/HTGR_TR/365.25/24

While the cost per MWe-hr is calculated based on the net power produced, also defined on the Project Inputs sheet:

$$H77=H75*1000000/Net\_PWR/365.25/24$$

The fuel cost is adjusted to the project base year using the year specified on the Project Inputs sheet along with the commodity price inflation rate:

$$H78=H74*(1+IRT\_C/100)\wedge(CEPCIYEAR-2009)$$

Similar functions are used for cells H79, H80, and H81 as presented for cells H75, H76, and H77.

3.3.7.4   Decommissioning Costs

The total decommissioning cost in 2009 dollars is calculated based on the cost per MWt calculated in TEV-1196 (INL 2012a):

$$H85=H84*E22/1000000$$

The cost is then inflated to the project base year using the commodity price inflation rate specified on the Project Inputs sheet:

$$H86=H85*(1+IRT\_C/100)\wedge(CEPCIYEAR-2009)$$

The future value of decommissioning for the decommissioning year calculated on the Project Inputs sheet is calculated using the analysis inflation rate specified on the Project Inputs sheet:

$$H87=H86*(1+IRT\_A/100)\wedge(Decon\_Yr-CEPCIYEAR)$$

The decommissioning fund payment is then calculated using the built in PMT function in Excel, along with the decommissioning rate and the number of years the fund payment is made, both calculated on the Project Inputs sheet, along with the future value calculated in cell H87:

$$H88=PMT(Rate\_Decon/100,Decon\_Yrs,0,-H87)$$

The FV Excel function is used to ensure that the payment calculated yields the appropriate decommissioning cost calculated in cell H87:

$$H89=-FV(Rate\_Decon/100,Decon\_Yrs,DeconPMT)$$

3.3.8   Worksheet Macros

The UnhideCellsHTGRCostBasis Macro unhides the hidden rows on the HTGR Cost Basis worksheet when the user clicks the 'Unhide Rows – Capital Cost Correlations' button, which includes rows 1 to 11. The UnhideCellsHTGRCostBasis Macro is presented in Figure 21.

The HideCellsHTGRCostBasis Macro hides rows 1 to 11 on the HTGR Cost Basis worksheet, when the user clicks the 'Hide Rows – Capital Cost Correlations' button. The HideCellsHTGRFCostBasis Macro is show in Figure 22.

```
Sub UnhideCellsHTGRCostBasis()

' UnhideCellsHTGRCostBasis Macro

    ' Shows the hidden rows on the HTGR Cost Basis Sheet
    Sheets("HTGR Cost Basis").Select
    Rows("1:11").Select
    Selection.EntireRow.Hidden = False

End Sub
```

Figure 21. UnhideCellsHTGRCostBasis Macro.

```
Sub HideCellsHTGRCostBasis()

' HideCellsHTGRCostBasis Macro

    ' Hides the rows on the HTGR Cost Basis Sheet
    Sheets("HTGR Cost Basis").Select
    Rows("1:11").Select
    Selection.EntireRow.Hidden = True

End Sub
```

Figure 22. HideCellsHTGRCostBasis Macro.

3.4   Commodity Prices Worksheet

A screenshot of the Commodity Prices worksheet is shown in Figure 23. The following list identifies the cells which make up the Commodity Prices worksheet. A brief description is included for each cell as well as if the cell is a user input or a calculated value. If the cell is a user input, any data validation criteria are included in the description.

- **Average Retail Electricity Price** – Cell B2 – *User Input* – The average electricity purchase price corresponding to the project base year specified by the user on the Project Inputs worksheet. If the project base year is updated the average electricity price for the corresponding year should be entered by the user. Any value greater than or equal to 40 can be entered in this cell.

- **Generation Percentage of Electricity Price** – Cell B3 – *User Input* – The percentage of the average retail electricity price associated with power generation, used to calculate the average grid electricity sale price. Any value between 40 and 70 can be entered. 60% is the current value based on 2010 electricity prices (EIA 2011b).

- **Cost of Electricity Transmission and Distribution** – Cell B4 – *Calculated* – The average cost of electricity transmission and distribution. This value is deducted from the average retail electricity price to determine the grid electricity price.

- **Grid Electricity Price** – Cell B5 – *Calculated* – The grid electricity sale price is assumed to be equal to the retail electricity price less the cost of transmission and distribution.

- **Industrial Electricity Price** – Cell B6 – *User Input* – The industrial electricity purchase/sale price corresponding to the project base year specified by the user on the Project Inputs worksheet. If the project base year is updated the industrial electricity price for the

corresponding year should be entered by the user. Any value greater than or equal to 20 can be entered in this cell.

- **HTGR Heat Price** – Cell B7 – *Calculated* – The HTGR heat price is calculated based on the general HTGR power generation efficiency specified on the Project Inputs worksheet and the industrial electricity purchase/sale price.

- **CO_2 Emission Offset Credit** – Cell B8 – *User Input* – The CO_2 emission offset credit is the equivalent of a cap and trade system, where CO_2 avoided would be treated as a revenue stream. The avoidance allowance is based on offsetting power produced using natural gas. A value greater than or equal to zero dollars per ton must be specified.

- **Depreciation Fractions** – Cells G2 to G22 – The yearly depreciation fractions corresponding to a 15 year MACRS property class, up to a 20 year property class can be specified.

	A	B	C	D	E	F	G
1	Commodity Market Prices	Price		Source		Depreciation Fractions	
2	Average Retail Electricity Price	$98.80	/MWe-hr	(EIA 2011a)		1	0.05
3	Generation % of Electricity Price	60	%	(EIA 2011b)		2	0.095
4	Cost of Electricity Trans. & Dist.	$39.52	/MWe-hr			3	0.0855
5	Grid Electricity Price	$59.28	/MWe-hr			4	0.077
6	Industrial Electricity Price	$67.90	/MWe-hr	(EIA 2011a)		5	0.0693
7	HTGR Heat Price	$29.20	/MWt-hr			6	0.0623
8	CO₂ Emission Offset Credit	$0.00	/ton			7	0.059
9						8	0.059
10						9	0.0591
11						10	0.059
12						11	0.0591
13						12	0.059
14						13	0.0591
15						14	0.059
16						15	0.0591
17						16	0.0295
18						17	0
19						18	0
20						19	0
21						20	0
22						21	0

Figure 23. Commodity Prices worksheet screenshot.

3.4.1   Named Cells/Ranges

The following cell names have been assigned on the Commodity Prices worksheet:

- GenPer – cell B3

- Transm – cell B4

- CarbonTax – cell B8

3.4.2   Worksheet Formatting

Cells highlighted purple indicate user inputs. In addition, light blue cells indicate user inputs which are also manipulated by Macros within the model, specifically the Macros on the Results Summary and

Sensitivity Analysis worksheets. Data validation limitations have been entered for all user inputs. All other cells in the workbook have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.4.3 Worksheet Equations/IF Statements

Only a single complex equation is entered on the Commodity Prices worksheet, which is used to calculate the HTGR market heat purchase/sale price, cell B6:

- B6=B5*HTGRGEFF/100 – This equation calculates the HTGR heat purchase and/or sale price, based on the general HTGR efficiency specified on the project inputs sheet.

3.4.4 Worksheet Macros

No Macros are included in the Commodity Prices worksheet.

3.5 Economic Inputs Worksheet

The Economic Inputs worksheet consolidates the data generated in other worksheets into values required to complete the economic evaluation on the IRR Analysis worksheet. A screenshot of the Economic Inputs worksheet is shown in Figure 24.

	A	B	C	D	E
1	Total Capital Investment				
2		Installed Cost	Engineering Fee	Contingency	Total Cost
3	HTGR(s)	$3,627,142,047	Inc.	Inc.	$3,627,142,047
4	Power Cycle	$1,165,105,905	Inc.	Inc.	$1,165,105,905
5	TCI				$4,792,247,952
6	TCI +% Change TCI				$7,188,371,928
7	TCI -% Change TCI				$3,354,573,566
8					
9	O&M Costs HTGR		Amount	Daily Cost	Annual Cost
10	O&M Nuclear	2,400	MWt	$280,869	$92,328,504
11	Electricity	0	MWe	$0	$0
12	O&M Costs HTGR				$92,328,504
13					
14	Fuel Costs HTGR				
15					Total Cost
16	Cost Per Core				$51,712,273
17					
18	Decommissioning Cost				
19					Annual Cost
20	Fund Payment				$9,640,912
21					
22	Revenues HTGR		Amount	Daily Revenue	Annual Revenue
23	Heat to Process	0	MWt	$0	$0
24	Power to Process	0	MWe	$0	$0
25	Power to Grid	1,035	MWe	$2,422,670	$796,392,300
26	CO$_2$ Avoidance Income	10,215	ton/day	$0	$0
27	Annual Revenue				$796,392,300

Figure 24. Economic Inputs worksheet screenshot.

The TCI is calculated by summing the HTGR and power cycle capital costs calculated on the HTGR Cost Basis worksheet. As noted previously, the engineering fees and contingencies are included in these costs and are not added in this worksheet. Next, the TCI at the lower and upper TCI boundaries specified on the Project Inputs sheet are calculated.

O&M costs are then calculated. The base O&M cost is referenced from the HTGR Cost Basis worksheet, while the electricity costs are calculated for heat only operations (i.e. if the plant does not generate electricity), where the house loads are assumed to be purchased from the grid at the industrial electricity price specified on the Commodity Prices sheet. Fuel costs per core and the annual decommissioning fund payment are referenced from the HTGR Cost Basis worksheet.

Annual revenue is calculated for the electricity and/or heat generated, which are either sold to an industrial process and/or to the grid. In addition, CO_2 avoidance income is calculated using the CO_2 emission offset credit specified on the Commodity Prices worksheet. The CO_2 avoidance is calculated based on substituting the HTGR for a natural gas combine cycle unit, where 117 pounds of CO_2 is emitted per MMBTU of natural gas input and 7.05 MMBTU of natural gas is required per MWe-hr generated (EIA 2010).

3.5.1   Named Cells/Ranges

No named cells or ranges are included in the Economic Inputs worksheet.

3.5.2   Worksheet Formatting

No special formatting has been used on the Economic Inputs worksheet. All cells on the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.5.3   Worksheet Equations/IF Statements

Several of the equations entered on the Economic Inputs worksheet are simple equations and, therefore, do not include detailed descriptions. The following equation is used to calculate the daily cost for nuclear O&M costs:

D10=B10*OpMt*24

Where OpMt is the O&M cost per MWt-hr calculated on the HTGR Cost Basis worksheet. The calculated daily cost is then used to calculate the annual O&M cost, using the availability for the plant (HTGR_A):

E10=D10*365.25*HTGR_A/100

A similar formula is used to calculate all annual costs and revenues, where the daily amount is multiplied by 365.25 days per year then multiplied by the HTGR availability; this will be the only example provided.

The following equation is used to calculate the electricity requirement, when only heat is generated by the HTGR:

B11=-IF(Grid_PWR<0,Grid_PWR,0)

This equation sets the amount equal to the negative value of the amount of power exported to the grid, if the amount exported is negative, i.e. power is being purchased from the grid. The daily cost is then calculated using the industrial price of electricity on the Commodity Prices worksheet:

D11=B11*'Commodity Prices'!B4*24

Daily revenues for heat are calculated as follows:

D23=B23*IF(ISNUMBER(HeatPrice)=FALSE,0,HeatPrice)*24

This formula multiplies the amount of heat sold to the process times the heat price calculated on the IRR Analysis worksheet, if that price is a number; otherwise, the value is multiplied by zero. The heat price calculated on the IRR Analysis worksheet automatically iterates between the market price and the price required to match the specified IRR per the users' selection on the IRR Analysis worksheet. Similar formulas are used to calculate the daily revenues for power to the process and power to the grid; however, the process electricity price and grid electricity price, also solved for on the IRR Analysis sheet, are used. The amount of power sold to the grid is specified on the Economic Inputs sheet using the following IF statement:

B25=IF(Grid_PWR>0,Grid_PWR,0)

Similar to the specification for the amount of power required from the electric grid, this formula only lists the power sold to the grid when the value is greater than zero.

The amount of CO_2 avoided is calculated using the following formula:

B26=HTGR_TR*HTGRGEFF/100*7.05*117/2000*24

This formula sets the equivalent amount of CO_2 emitted from a similar sized natural gas combined cycle power plant, where the thermal requirement of natural gas is set to equal the thermal rating of the HTGR. The daily revenue is calculated by multiplying the daily amount avoided by the CO_2 offset emission credit specified on the Commodity Prices worksheet:

D26=B26*CarbonTax

3.5.4   Worksheet Macros

No Macros are included in the Economic Inputs worksheet.

3.6   IRR Analysis Worksheet

The IRR Analysis worksheet calculates the IRR for the project using data supplied from the other worksheets described in the preceding sections. There are two fundamental options applied in this worksheet. The IRR can be calculated for given prices of the commodities generated by the project or the prices of the commodities can be adjusted to achieve a given IRR supplied by the user. The commodities generated by the project can be electricity and/or process heat. If electricity is generated it can be sold to the process and/or to the electrical grid. Figure 25 provides a screenshot of the cells in the worksheet that summarize the key inputs and the outputs for the IRR calculations. It should be noted that this example only includes selling electricity to the grid; hence the prices for power and heat to the process are all N/A. The worksheet includes an option to toggle displaying the average retail electricity price, which is based on the electricity price to the grid plus the average cost of transmission and distribution calculated on the Commodity Prices sheet. In general the grid price should be used for economic assessments; however, if only the average retail price is available for cost comparisons the user can display the price by clicking the 'Toggle Retail Electricity Price' button. By default, this value is not displayed.

	A	B	C	D	E
1	Iteration Factor		500,000,000		
2	**Economic Modeling Results**				
3	HTGR IRR		12	%	
5	Electricity Price to Grid		$97.55	/MWe-hr	Toggle Retail Electricity Price
6	Electricity Price to Process		N/A	/MWe-hr	
7	Heat Price to Process		N/A	/MWt-hr	
8	Heat Price to Process		N/A	/MMBTU	
9	Steam Price to Process		N/A	/1000-lb	
10	NPV Check		$0.00		
11	Avg. Debt Service Coverage Ratio		2.70		
12	Payback Period		13	years	
13	**Project Selections**				
14	Grid Power Sales Option		Price to Match IRR ▼		
15	Process Power Sales Option		▼		
16	Process Heat Sales Option		▼		
17	TCI Variation		TCI ▼		
18	**Economic Inputs**				
19	TCI		$4,792,247,952		
20	O&M Costs		$92,328,504	/year	
21	Decommissioning Fund Payment		$9,640,912	/year	
22	Fuel Cost per Core		$51,712,273	/core	
23	Revenues		$796,392,300	/year	

Figure 25. IRR Analysis worksheet screenshot, section one.

The following describes each of the values in these cells.

- **Iteration Factor** – Cell C1 – *User Input* – The calculations performed on the IRR Analysis sheet are iterative, and determine either the product price to achieve a given IRR or the IRR for given product prices. This factor is used in the iterative calculations. If this value is too small, the worksheet will not converge on a solution, if this value is too large the worksheet will take extremely long to converge on the solution. For this model a value 500,000,000 has been specified. Care should be taken when manipulating this factor as it can cause instability in the model. The value for this factor is restricted to be between 10,000,000 and 10,000,000,000.

- **Economic Modeling Results** – Cells C3 to C12 – All values are calculated by the model:

  - **HTGR IRR** – Cell C3 –The calculated IRR for the project. If the user selects 'Market Price' for all of the applicable Project Selection combo boxes, the model iterates on the IRR value until the NPV is equal to zero. If the user selects 'Price to Match IRR' for one of the applicable Project Selection combo boxes, the model sets the IRR value to the value specified on the Project Inputs worksheet.

  - **Average Retail Electricity Price** – Cell C4 – *Hidden* – This is the equivalent average retail electricity price for all end use sectors. This value is calculated based on the electricity price to the grid and the average cost of transmission and distribution. This value is displayed by clicking the 'Toggle Retail Electricity Price' button. In general the grid price should be used for economic assessments; however, if only the average retail price is available for cost comparisons the user can display the average retail value.

  - **Electricity Price to Grid** – Cell C5 – The calculated electricity price to the grid for the project. If the user selects 'Market Price' for the applicable Project Selection combo box,

51

the model sets this value equal to the market price specified on the Commodity Prices worksheet; otherwise, the model iterates on this value until the NPV is equal to zero. If no power is exported to the grid, the value reads N/A.

- **Electricity Price to Process** – Cell C6 – The calculated electricity price to the process for the project. If the user selects 'Market Price' for the applicable Project Selection combo box, the model sets this value equal to the market price specified on the Commodity Prices worksheet. If the combo boxes for the grid power sales and the process power sales are both set equal to 'Price to Match IRR' this value is set equal to the grid price in cell C5; otherwise, the model iterates on this value until the NPV is equal to zero. If no power is exported to the grid, the value reads N/A.

- **Heat Price to Process** – Cells C7 and C8 – The calculated heat price to the process for the project. If the user selects 'Market Price' for the applicable Project Selection combo box, the model sets this value equal to the market price specified on the Commodity Prices worksheet. If the combo boxes for the grid power sales, the process power sales, and/or the process heat sales are set equal to 'Price to Match IRR' this value is calculated using either the grid or process electricity price and the efficiency specified on the Project Inputs worksheet; otherwise, the model iterates on this value until the NPV is equal to zero. If no power is exported to the grid, the value reads N/A. Cell C7 is the value iterated/set by the model and has the units $/MWt-hr. Cell C8 is calculated based on the value in cell C7 and has the units $/MMBTU.

- **Steam Price to Process** – Cell C9 – The price of steam to the process. This value is calculated if the user sets the steam flow in cell B30 on the project inputs sheet. The value is calculated based on the heat price calculated in cell C7. If a steam price is not specified by the user, the value reads N/A.

- **NPV Check** – Cell C10 – Check value for the NPV, equals zero if the model has converged.

- **Average Debt Service Coverage Ratio** – Cell C11

- **Payback Period** – Cell C12 – The year in which the cumulative ATCFs becomes positive.

- **Project Selections** – Cells C14 to C17 – All values are user inputs set using combo boxes.

  - **Grid Power Sales Option** – Cell C14 – Allows the user to select if power is sold to the grid at the market price or if the price is set to achieve a given IRR. If no power is exported to the grid the combo box is empty.

  - **Process Power Sales Option** – Cell C15 – Allows the user to select if power is sold to the process at the market price or if the price is set to achieve a given IRR. If no power is exported to the process the combo box is empty.

  - **Process Heat Sales Option** – Cell C16 – Allows the user to select if heat is sold to the process at the market price or if the price is set to achieve a given IRR. If no heat is exported to the process the combo box is empty.

  - **TCI Variation** – Cell C17 – Permits the calculations to be performed at the nominal, low, and high values of the TCI.

- **Economic Inputs** – Cells C19 to C23 – Include the TCI, O&M costs, decommissioning fund payment, fuel cost per core, and annual revenues calculated on the Economic Inputs worksheet.

The IRR is calculated using a discounted cash flow analysis; (i.e., setting the IRR to a value which results in a NPV of zero). A screenshot of the elements of this analysis is shown in Figure 26, the model is built to accommodate up to 90 years of analysis, a portion of the rows corresponding to analysis years 46 to 79 are hidden to allow the screenshot to fit on a single page. The following list discusses each element of cash flow analysis calculations:

- **Year** – Column A – The actual year corresponding to the analysis year.

- **Analysis Year** – Column B

- **Inflation Factor** – Column C – Inflation factor for the current year, calculated based on the analysis inflation rate specified on the Project Inputs worksheet.

- **Debt Capital** – Column D – Debt capital expenditure for the current year, based on the capital fraction calculated on the HTGR Project Fractions worksheet, the debt ratio specified on the Project Inputs worksheet, and the TCI. The expenditure is increased by the inflation factor in column C. These values are negative cash flows.

- **Equity Capital** – Column E – Equity capital expenditure for the current year, based on the capital fraction calculated on the HTGR Project Fractions worksheet, the equity ratio specified on the Project Inputs worksheet, and the TCI. The expenditure is increased by the inflation factor in column C. These values are negative cash flows.

- **Capitalized Interest** – Column F – Interest accumulated on debt during construction, referenced from the HTGR Project Fractions worksheet. These values are negative cash flows.

- **Debt Interest Payment** – Column G– Debt interest payment, referenced from the HTGR Project Fractions worksheet. These values are negative cash flows.

- **Debt Principal Payment** – Column H – Debt principal payment, referenced from the HTGR Project Fractions worksheet. These values are negative cash flows.

- **Debt Service Coverage Ratio** – Column I – DSCR calculated based on the equation presented in Section 2.4.3.

- **Revenues** – Column J – Annual revenues, based on the revenue fractions calculated on the HTGR Project Fractions worksheet and the annual revenue, cell C23 (RevHTGR). The expenditure is increased by the inflation factor in column C.

- **Operating Costs** – Column K – Sum of the annual operating costs, based on the operating cost fractions calculated on the HTGR Project Fractions worksheet and the annual operating costs (cell C20 – OMHTGR), and the refueling costs, based on the refueling occurrences calculated on the HTGR Project Fractions worksheet and the fuel cost per core (cell C22 – HTGRFuel). The expenditures are increased by the inflation factor in column C. These values are negative cash flows.

24 Annual Cash Flow Analysis

	Year	Analysis Year	Inflation Factor	Debt Capital	Equity Capital	Capitalized Interest	Debt Interest Payment	Debt Principal Payment	Debt Service Coverage Ratio	Revenues	Operating Costs	D&D Fund Payment	Depreciation	Taxable Income	Taxable Inc. w/ Carryover Loss	Taxes	After Tax Income	After Tax Cash Flow	PV of ATCF @ IRR
26	2013	1	1.093	-$177,125,225	-$177,125,225	-$6,641,104	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0		-$177,125,225	-$158,147,522
27	2014	2	1.126	-$621,365,000	-$621,365,000	-$37,253,765	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0		-$621,365,000	-$495,348,374
28	2015	3	1.159	-$1,065,539,541	-$1,065,539,541	-$107,341,971	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0		-$1,065,539,541	-$758,429,998
29	2016	4	1.194	-$743,090,663	-$743,090,663	-$188,029,955	-$45,685,033	-$20,284,325	0.92	$77,263,392	-$16,536,759	-$9,640,912	-$107,472,857	-$102,072,169	-$102,072,169	$0	$5,400,688	-$757,974,300	-$481,706,371
30	2017	5	1.230	-$172,777,662	-$172,777,662	-$82,519,295	-$179,765,865	-$84,301,656	1.12	$440,757,934	-$145,925,073	-$9,640,912	-$341,644,758	-$236,430,673	-$338,290,842	$0	$105,426,084	-$151,653,233	-$86,052,117
31	2018	6	1.267	$0	$0	$0	-$243,291,254	-$123,872,285	1.69	$876,434,909	-$256,746,031	-$9,640,912	-$499,086,539	-$132,329,826	-$470,620,668	$0	$366,756,712	$242,884,427	$123,052,810
32	2019	7	1.305	$0	$0	$0	-$233,009,915	-$134,153,624	1.95	$1,039,111,317	-$322,886,118	-$9,640,912	-$503,445,285	-$29,870,913	-$500,491,581	$0	$473,574,372	$339,420,748	$153,536,709
33	2020	8	1.344	$0	$0	$0	-$221,875,231	-$145,288,309	2.01	$1,070,284,656	-$332,572,701	-$9,640,912	-$453,238,202	$52,957,610	-$447,533,971	$0	$506,195,812	$360,907,504	$145,764,488
34	2021	9	1.384	$0	$0	$0	-$209,816,373	-$157,347,167	2.26	$1,102,393,196	-$270,968,002	-$9,640,912	-$407,818,080	$204,149,829	-$243,384,142	$0	$611,967,909	$454,620,743	$163,940,797
35	2022	10	1.426	$0	$0	$0	-$196,756,635	-$170,406,904	2.13	$1,135,464,992	-$352,826,379	-$9,640,912	-$373,141,757	$203,099,309	-$40,284,833	$0	$576,241,066	$405,834,162	$130,667,739
36	2023	11	1.469	$0	$0	$0	-$182,612,947	-$184,550,593	2.20	$1,169,528,941	-$363,411,170	-$9,640,912	-$356,487,909	$257,376,004	$217,091,171	-$84,448,465	$529,415,448	$344,864,855	$99,140,405
37	2024	12	1.513	$0	$0	$0	-$167,295,338	-$199,868,201	2.47	$1,204,614,810	-$296,094,052	-$9,640,912	-$353,128,300	$378,456,208	$378,456,208	-$147,219,465	$584,365,043	$384,496,842	$98,690,763
38	2025	13	1.558	$0	$0	$0	-$150,706,376	-$216,457,163	2.33	$1,240,753,254	-$385,542,910	-$9,640,912	-$353,188,247	$341,674,809	$341,674,809	-$132,911,501	$561,951,555	$345,494,392	$79,178,397
39	2026	14	1.605	$0	$0	$0	-$132,740,538	-$234,423,001	2.40	$1,277,975,851	-$397,109,198	-$9,640,912	-$353,236,620	$385,248,584	$385,248,584	-$149,861,699	$588,623,504	$354,200,504	$72,476,441
40	2027	15	1.653	$0	$0	$0	-$113,283,545	-$253,879,994	2.70	$1,316,315,127	-$323,549,965	-$9,640,912	-$353,188,247	$516,652,458	$516,652,458	-$200,977,806	$668,862,899	$414,982,905	$75,815,825
41	2028	16	1.702	$0	$0	$0	-$92,211,631	-$274,951,909	2.55	$1,355,804,581	-$421,293,148	-$9,640,912	-$353,236,620	$479,422,271	$479,422,271	-$186,495,263	$646,163,627	$371,211,719	$60,552,672
42	2029	17	1.754	$0	$0	$0	-$69,390,758	-$297,772,781	2.62	$1,396,478,718	-$433,931,942	-$9,640,912	-$353,236,620	$530,326,860	$530,326,860	-$206,297,148	$677,217,958	$379,445,177	$55,264,043
43	2030	18	1.806	$0	$0	$0	-$44,675,764	-$322,487,775	2.95	$1,438,373,080	-$353,551,783	-$9,640,912	-$353,236,620	$677,268,002	$677,268,002	-$263,457,253	$767,047,369	$444,559,593	$57,810,347
44	2031	19	1.860	$0	$0	$0	-$19,018,749	-$282,175,432	3.39	$1,481,524,272	-$460,358,398	-$9,640,912	-$289,779,261	$702,726,953	$702,726,953	-$273,360,785	$719,145,429	$436,969,997	$50,735,178
45	2032	20	1.916	$0	$0	$0	-$3,632,955	-$99,463,063	10.20	$1,525,970,000	-$474,169,150	-$9,640,912	-$145,110,368	$893,416,615	$893,416,615	-$347,539,063	$690,987,920	$591,524,858	$61,321,468
46	2033	21	1.974	$0	$0	$0	$0	$0	0.00	$1,571,749,100	-$386,335,579	-$9,640,912	-$31,954,357	$1,143,818,253	$1,143,818,253	-$444,945,300	$730,827,309	$730,827,309	$67,645,092
47	2034	22	2.033	$0	$0	$0	$0	$0	0.00	$1,618,901,573	-$503,046,051	-$9,640,912	$0	$1,106,214,611	$1,106,214,611	-$430,317,484	$675,897,127	$675,897,127	$55,857,835
48	2035	23	2.094	$0	$0	$0	$0	$0	0.00	$1,667,468,621	-$518,137,432	-$9,640,912	$0	$1,139,690,277	$1,139,690,277	-$443,339,518	$696,350,759	$696,350,759	$51,382,299
49	2036	24	2.157	$0	$0	$0	$0	$0	0.00	$1,717,492,679	-$422,159,318	-$9,640,912	$0	$1,285,692,449	$1,285,692,449	-$500,134,363	$785,558,086	$785,558,086	$51,754,219
50	2037	25	2.221	$0	$0	$0	$0	$0	0.00	$1,769,017,460	-$549,692,002	-$9,640,912	$0	$1,209,684,546	$1,209,684,546	-$470,567,288	$739,117,258	$739,117,258	$43,477,321
51	2038	26	2.288	$0	$0	$0	$0	$0	0.00	$1,822,087,983	-$566,182,762	-$9,640,912	$0	$1,246,264,310	$1,246,264,310	-$484,796,816	$761,467,493	$761,467,493	$39,992,889
52	2039	27	2.357	$0	$0	$0	$0	$0	0.00	$1,876,750,623	-$461,304,886	-$9,640,912	$0	$1,405,804,826	$1,405,804,826	-$546,858,077	$858,946,749	$858,946,749	$40,279,088
53	2040	28	2.427	$0	$0	$0	$0	$0	0.00	$1,933,053,142	-$600,663,292	-$9,640,912	$0	$1,322,748,938	$1,322,748,938	-$514,549,337	$808,199,601	$808,199,601	$33,838,725
54	2041	29	2.500	$0	$0	$0	$0	$0	0.00	$1,991,044,736	-$618,683,191	-$9,640,912	$0	$1,362,720,633	$1,362,720,633	-$530,098,326	$832,622,307	$832,622,307	$31,126,148
55	2042	30	2.575	$0	$0	$0	$0	$0	0.00	$2,050,776,078	-$504,080,304	-$9,640,912	$0	$1,537,054,863	$1,537,054,863	-$597,914,342	$939,140,521	$939,140,521	$31,346,561
56	2043	31	2.652	$0	$0	$0	$0	$0	0.00	$2,112,299,360	-$656,360,997	-$9,640,912	$0	$1,446,297,451	$1,446,297,451	-$562,609,709	$883,687,743	$883,687,743	$26,335,413
57	2044	32	2.732	$0	$0	$0	$0	$0	0.00	$2,175,668,341	-$676,051,827	-$9,640,912	$0	$1,489,975,602	$1,489,975,602	-$579,600,509	$910,375,093	$910,375,093	$24,223,876
58	2045	33	2.814	$0	$0	$0	$0	$0	0.00	$2,240,938,391	-$550,822,158	-$9,640,912	$0	$1,680,475,322	$1,680,475,322	-$653,704,900	$1,026,770,422	$1,026,770,422	$24,393,752
59	2046	34	2.898	$0	$0	$0	$0	$0	0.00	$2,019,645,725	-$384,021,049	-$9,640,912	$0	$1,625,983,764	$1,625,983,764	-$632,507,684	$993,476,080	$993,476,080	$21,073,887
60	2047	35	2.985	$0	$0	$0	$0	$0	0.00	$891,529,327	-$103,358,067	-$9,640,912	$0	$778,530,349	$778,530,349	-$302,848,306	$475,682,043	$475,682,043	$9,009,195
61	2048	36	3.075	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
62	2049	37	3.167	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
63	2050	38	3.262	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
64	2051	39	3.360	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
65	2052	40	3.461	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
66	2053	41	3.565	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
67	2054	42	3.671	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
68	2055	43	3.782	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
69	2056	44	3.895	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
70	2057	45	4.012	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
105	2092	80	11.289	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
106	2093	81	11.628	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
107	2094	82	11.976	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
108	2095	83	12.336	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
109	2096	84	12.706	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
110	2097	85	13.087	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
111	2098	86	13.480	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
112	2099	87	13.884	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
113	2100	88	14.300	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
114	2101	89	14.729	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
115	2102	90	15.171	$0	$0	$0	$0	$0	0.00	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
116																	NPV @ IRR	$0
117																	Check Value	$0

Figure 26. IRR Analysis worksheet screenshot, second section.

- **Decommissioning Fund Payment** – Column L – Yearly decommissioning fund payments, cell C21 (DCFP). These values are negative cash flows.

- **Depreciation** – Column M – Depreciation deduction based on the fractions calculated on the HTGR Project Fractions worksheet and the total debt capital, equity capital, and capitalized interest costs in columns D, E, and F. These values are negative cash flows.

- **Taxable Income –** Column N – Annual taxable income, equal to revenues less operating costs, less depreciation, less debt interest payments.

- **Taxable Income with Carryover Losses** – Column O – Carries over the negative taxable income until the cumulative taxable income is positive.

- **Taxes** – Column P– Annual taxes paid based on the taxable income with carryover losses. These values are negative cash flows.

- **After Tax Income** – Column Q – Revenues less operating costs, less debt interest payment, less taxes.

- **After Tax Cash Flow –** Column R – After tax income less the equity capital and the debt principal payment.

- **Present Value of the ATCF at the IRR** – Column S – The present value of the ATCFs, the sum of which should equal zero. Used as a check to ensure the calculations are functioning correctly and the model has converged.

3.6.1   Named Cells/Ranges

The following cells names have been assigned on the IRR Analysis worksheet:

- Iteration – cell C1

- IRRValue – cell C3

- RetailPrice – cell C4

- GridElecPrice – cell C5

- ProcElecPrice – cell C6

- HeatPrice – cell C7

- HeatPrice_MMBTU – cell C8

- HeatPrice_LB – cell C9

- TCIHTGR – cell C19

- OMHTGR – cell C20

- DCFP – cell C21

- HTGRFuel – cell C22

- RevHTGR – cell C23

- NPV – cell Q116

The following named ranges have been assigned on the IRR Analysis worksheet:

- DebtCapital – cells D26:D115

- DebtInterest – cell F26:F115

3.6.2 Worksheet Formatting

Cells highlighted purple indicate user inputs. Cells highlighted in pink indicate cells where automatic iterations occur. Data validation limitations have been entered for all user inputs. All other cells in the workbook have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3. If the pink cells flash between #VALUE and 0, simply change the product selling option from 'Price to Match IRR' to 'Market Price', if this does not solve the problem the user has altered an equation which was previously protected and should reload the original model.

3.6.3 Worksheet Equations/IF Statements

Several of the equations entered on the IRR Analysis worksheet are simple equations and, therefore, do not require explanation. The following IF statement is used to calculate/set the IRR value:

C3=IF(OR(PPP="Price to Match IRR",GPP="Price to Match IRR",HPP="Price to Match IRR"),IRRN,

If any of the sales options (cells C14 to C16) are set to 'Price to Match IRR' the IRR value is set to the IRR specified on the Project Inputs worksheet.

IF(HTGRFuel*12/Refuel*Number+DCFP+OMHTGR>=RevHTGR,"N/A",

Otherwise, if the operating costs are greater than the project revenues, the IRR value is set to N/A as operating costs cannot exceed revenues for a viable project.

IF(ISNUMBER(IRRValue)=FALSE,0,

If the current value of the IRR is not a number, the current value is reset to zero.

IF(NPV<>0,IRRValue+NPV/Iteration,IRRValue))))

Finally, if the NPV is not equal to zero, the current NPV is divided by the iteration value in cell B1 and added to the current IRR value. Otherwise, the iteration stops at the current IRR value. This iterates the IRR by an increasingly smaller fraction as the NPV approaches zero, until the NPV is equal to zero.

The average electricity market price is then calculated based on the current grid price and the average cost of transmission and distribution, specified on the Commodity Prices worksheet:

C4=IF(ISNUMBER(GridElecPrice)=TRUE,GridElecPrice+Transm,"N/A")

This equation sets the average electricity price equal to the grid electricity price plus the average price of transmission and distribution (Transm), otherwise, N/A is displayed; this indicates that electricity is not being supplied to the general market. The electricity price to the grid is calculated/set using the following IF statement:

C5=IF(Grid_PWR<=0,"N/A",

If power exported to the grid (Grid_PWR) is less than or equal to zero, the value is listed as N/A.

IF(GPP="Market Price",'Commodity Prices'!B5,

Otherwise, if the user selects the grid power sales option (GPP) to match the market price using the combo box, the value is set equal to the grid price on the Commodity Prices worksheet.

IF(ISNUMBER(GridElecPrice)=FALSE,60,

Otherwise, if the user selects 'Price to Match IRR' in the grid power sales combo box and the current grid price is not a number; the value is reset to 60.

IF(NPV<>0,GridElecPrice-NPV/Iteration,GridElecPrice))))

Finally, if the NPV is not equal to zero, the current NPV is divided by the iteration value in cell B1 and subtracted from the current grid electricity price. Otherwise, the iteration stops at the current grid electricity price. This iterates the grid electricity price by an increasingly smaller fraction as the NPV approaches zero, until the NPV is equal to zero.

A similar iterative formula is used to calculate/set the electricity price to an external process:

C6=IF(CP_PWR=0,"N/A",

If no power is exported to the process, the value is listed as N/A.

IF(PPP="Market Price",'Commodity Prices'!B6,

Otherwise, if the user selects the process power sales option to match the market price using the combo box, the value is set equal to the industrial electricity price on the Commodity Prices worksheet.

IF(GPP="Price to Match IRR",GridElecPrice,

Next, if the grid power combo box has been set to the price to match the IRR, the process electricity price is set equal to the grid electricity price. This is necessary, as only one value can be iterated on at a time in the model.

IF(ISNUMBER(ProcElecPrice)=FALSE,60,

Otherwise, if the user selects 'Price to Match IRR' in the process power sales combo box and the current process power price is not a number; the value is reset to 60.

IF(NPV<>0,ProcElecPrice-NPV/Iteration,ProcElecPrice)))))

Finally, if the NPV is not equal to zero, the current NPV is divided by the iteration value in cell B1 and subtracted from the current process electricity price. Otherwise, if the NPV is equal to zero the iteration stops at the current process electricity price. This iterates the process electricity price by an increasingly smaller fraction as the NPV approaches zero, until the NPV is equal to zero.

A similar iterative formula is used to calculate/set the heat price to an external process:

C7=IF(CP_Heat=0,"N/A",

If no heat is exported to the process, the value is listed as N/A.

IF(HPP="Market Price",'Commodity Prices'!B7,

Otherwise, if the user selects the process heat sales option to match the market price using the combo box, the value is set equal to the market heat price on the Commodity Prices worksheet.

IF(PPP="Price to Match IRR",ProcElecPrice*HTGRGEFF/100,IF(GPP="Price to Match IRR",GridElecPrice*HTGRGEFF/100,

Otherwise, if the process power purchase price is set equal the price required to match the IRR, the process heat price is equal to the process electricity price times the general HTGR efficiency. Otherwise, if the grid electricity price is equal to the price required to match the IRR, the process heat prices is equal to the grid electricity price times the general HTGR efficiency. This is necessary, as only one value can be iterated on at a time in the model.

IF(ISNUMBER(HeatPrice)=FALSE,60,

Otherwise, if the user selects 'Price to Match IRR' in the process heat sales combo box and the current process heat price is not a number; the value is reset to 60.

IF(NPV<>0,HeatPrice-NPV/Iteration,HeatPrice))))))

Finally, if the NPV is not equal to zero, the current NPV is divided by the iteration value in cell B1 and subtracted from the current process heat price. Otherwise, if the NPV is equal to zero the iteration stops at the current process heat price. This iterates the process heat price by an increasingly smaller fraction as the NPV approaches zero, until the NPV is equal to zero.

The process heat price solved for in cell B7 has units of $/MWt-hr. It was determined that the heat price should also be presented in units of $/MMBTU and $/1000-lb. The following equations are used to convert the heat price calculated in $/MWt-hr to these units:

C8=IF(CP_Heat=0,"N/A",HeatPrice*0.2930711)

C9=IF(ISNUMBER(NPV)=FALSE,"N/A",NPV)

The average debt service coverage ratio is calculated using the following formula:

C11=AVERAGEIF(I26:I115,"<>0")

This calculates the average of the debt service coverage ratios for all values not equal to zero. The final iterative calculation is performed for the payback period calculation:

C12=IF(SUM(R26:R115)<0,"N/A",IF(ISNUMBER(C12)=FALSE,1,IF(C12>90,1,

If the sum of the after tax cash flows is less than zero, the value is equal to N/A. Otherwise, if the current value of the payback period is not a number, the value is reset to zero. If the current value of the payback period is greater than 90, then the value is reset to one.

IF(SUM(INDIRECT(CELL("address",R26)&":"&ADDRESS(CELL("row",R26)+C12-1, CELL("col",R26))))<=0,C12+1,

Otherwise, if the sum of the ATCF for the first analysis year to the analysis year corresponding to the payback period calculated is less than or equal to zero, one is added to the current payback period.

IF(AND(SUM(INDIRECT("R27:"&ADDRESS(CELL("row",R26)+C12-2,CELL("col",
R26))))<0,SUM(INDIRECT("R27:"&ADDRESS(CELL ("row",R26)+C12-1,CELL("col",
R26))))>=0),C12,C12-1)))))

If the sum of the ATCFs from the first analysis year to the current payback period less one is less than zero and the sum of the ATCFS from the first analysis year to the current payback period is greater than or equal to zero, the value is equal to the current payback period. Otherwise, the payback period is equal to the current value minus one.

The following equations are used to calculate the values associated with the cash flow analysis. All examples are shown for row 26, analysis year one:

- C26=(1+IRT_A/100)^(A26-CEPCIYEAR) – This equation sets the annual inflation factor based on the analysis inflation rate and the project base year (CEPCIYEAR) specified on the Commodity Prices worksheet and the actual year corresponding to the analysis year.

- D26=-IF(B26>30,0,TCIHTGR*DebtN/100*'HTGR Project Fractions'!R392)*C26 – This equation sets the debt capital for the analysis year equal to the negative of the total capital investment times the debt ratio, from the Project Inputs worksheet, times the corresponding capital fraction from the HTGR Project Fractions worksheet, times the corresponding inflation factor, if the analysis year is less than or equal to 30; otherwise, the value is zero.

- E26=-IF(B26>30,0,TCIHTGR*EquityN/100*'HTGR Project Fractions'!R392)*C26 – This equation sets the equity capital for the analysis year equal to the negative of the total capital investment times the equity ratio, from the Project Inputs worksheet, times the corresponding capital fraction from the HTGR Project Fractions worksheet, times the corresponding inflation factor, if the analysis year is less than or equal to 30; otherwise, the value is zero.

- F26=IF(B26<=30,'HTGR Project Fractions'!R856,0) – This equation sets the capitalized interest for the current analysis year equal to the corresponding value calculated on the HTGR Project Fractions worksheet, if the analysis year is less than or equal to 30; otherwise, the value is zero.

- G26=IF(ISNUMBER('HTGR Project Fractions'!R804)=TRUE,IF(B26<=50,'HTGR Project Fractions'!R804,0),0) – This equation sets the debt interest payment equal to the corresponding value on the HTGR Project Fractions worksheet, if the value calculated is a number and the analysis year is less than 50; otherwise, the value is zero.

- H26=IF(ISNUMBER('HTGR Project Fractions'!R752)=TRUE,IF(B26<=50,'HTGR Project Fractions'!R752,0),0) – This equation sets the debt principal payment equal to the corresponding value on the HTGR Project Fractions worksheet, if the value calculated is a number and the analysis year is less than 50; otherwise, the value is zero.

- I26=IF(G26<0,SUM(J26:K26)/-SUM(G26:H26),0) – This sets the debt service coverage ratio equal to the sum of the revenues and operating costs divided by debt principal and interest payments, if a payment is being made; otherwise, the values is zero.

- J26=RevHTGR*'HTGR Project Fractions'!R424*C26 – This equation sets the revenue equal to the annual revenue times the corresponding revenue fraction calculated on the HTGR Project Fractions worksheet times the corresponding inflation factor.

- K26=(-OMHTGR*'HTGR Project Fractions'!R516-HTGRFuel*'HTGR Project Fractions'!R608)*C26 – The operating costs are equal to the negative of the operating and

maintenance costs times the corresponding operating cost fraction calculated on the HTGR Project Fractions worksheet less the refueling cost per core times the corresponding refueling occurrence calculated on the HTGR Project Fractions worksheet, times the corresponding inflation factor.

- L26=-IF('HTGR Project Fractions'!R424>0,1,0)*DCFP – The decommissioning fund payment is equal to the negative decommissioning fund payment, if the revenue fraction calculated on the HTGR Project Fractions worksheet is greater than zero.

- M26=IF(B26<=50,SUM($D$26:$F$115)*'HTGR Project Fractions'!R700,0) – The depreciation deduction is equal to the depreciation fraction calculated on the HTGR Project Fractions sheet, corresponding to the analysis year, times the sum of the debt and equity capital outlays plus the capitalized interest if the analysis year is less than or equal to 50; otherwise, the value is zero.

- N26=SUM(J26,K26,G26,M26,L26) – The taxable income is equal to the sum of the debt interest payment, revenue, operating cost, and depreciation deduction.

- O26=IF(ISNUMBER(O26)=TRUE,IF(N26=0,0,IF(O25<=0,O25+N26,N26)),0) – This equation sets the taxable income with carryover losses equal to zero if the taxable income, column N, is equal to zero, otherwise if the previous taxable income with carryover losses is less than or equal to zero, the value is set equal to the previous taxable income with carryover loss plus the current taxable income. Otherwise the value is set equal to the current taxable income. This carries over and accumulates all negative taxable incomes until the sum is positive.

- P26=IF(O26<0,0,-O26*TTax/100) – This equation calculates the taxes paid using the total tax rate from the Project Inputs worksheet and the taxable income with carryover loss. If taxable income with carryover loss is less than zero, no tax is withheld.

- Q26=SUM(J26,K26,G26,P26,L26) – The after tax income equals the sum of the debt interest payment, revenues, operating costs, and taxes.

- R26=SUM(E26,H26,Q26) – The after tax cash flow is equal to the sum of the after tax income plus the debt principal payment and equity capital expenditures.

- S26=R26/(1+IRRValue/100)^(B26) – Calculates the present value of the ATCF at the IRR.

Finally, the sum of the ATCFs are evaluated using the NPV Excel function and the IRR calculated/set by the worksheet:

Q116=NPV(IRRValue/100,R26:R115)

This value should equal zero as a result of the iterative calculation described previously. A check value of the calculation is calculated in cell Q117 by summing the values calculated in column S, the present value of the ATCFs.

3.6.4   Worksheet Macros

The ToggleRetailPrice Macro unhides toggles displaying the estimated retail electricity price when the user clicks the 'Toggle Retail Electricity Price' button. The ToggleRetailPrice Macro is presented in Figure 27.

```
Sub ToggleRetailPrice()

' ToggleRetailPrice Macro

    ' Toggles between showing and hiding the retail
    ' electricity price on the IRR Analysis Sheet
    Sheets("IRR Analysis").Select
    Rows("4").Select

    ' If the row is hidden then the row is unhidden
    If Rows("4").Hidden = True Then
        Selection.EntireRow.Hidden = False
    ' Otherwise if the row is shown it's hidden
    Else
        Selection.EntireRow.Hidden = True
    End If

End Sub
```

Figure 27. ToggleRetailPrice Macro.

3.7   List Info Worksheet

The List Info worksheet provides the data which populates the combo boxes on the Project Inputs and IRR Analysis worksheets. In general this worksheet is hidden and must be unhidden for the user to access. Based on the value selected in the combo boxes[17], the appropriate cell link value is written to the cell for the corresponding reactor variable (row 6). Based on the cell link value, the value selected in the combo box is written to the cell for the corresponding variable (row 8). The following table provides the user inputs and possible values currently provided in the HTGR Application Economic Model:

Table 3. HTGR Application Economic Model user inputs for combo boxes.

Grid Power Selling Option	Process Power Selling Option	Process Heat Selling Option	Reactor Module Rating	TCI	Project Phase	Staffing Plan
Market Price	Market Price	Market Price	200	TCI	NGNP	INL
Price to Match IRR	Price to Match IRR	Price to Match IRR	350	Low TCI	FOAK	Vendor
			600	High TCI	NOAK	

Product selling options are only shown if power and/or heat are being supplied to the grid or process. For instance, in the example shown, power is only being sold to the grid; hence the process power and heat selling options appear blank. Figure 28 presents a screenshot of the List Info worksheet.

---

[17]   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	G
1	Grid Power Selling Option	Process Power Selling Option	Process Heat Selling Option	Base Reactor Size	TCI	Project Phase	Staffing Plan
2	Market Price			200	TCI	NGNP	INL
3	Price to Match IRR			350	Low TCI	FOAK	Vendor
4				600	High TCI	NOAK	
5	Index from Drop-Down Selection						
6	2	2	1	3	1	3	2
7	Value Selected						
8	Price to Match IRR			600	TCI	NOAK	Vendor

Figure 28. List Info worksheet screenshot.

3.7.1   Named Cells/Ranges

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

- GridElec1 – cell A2

- GridElec2 – cell A3

- ProcElec1 – cell B2

- ProcElec2 – cell B3

- ProcHeat1 – cell C2

- ProcHeat2 – cell C3

- RSize1 – cell D2

- RSize2 – cell D3

- RSize3 – cell D4

- Phase1 – cell F2

- Phase2 – cell F3

- Phase3 – cell F4

- Staffing1 – cell G2

- Staffing2 – cell G3

- GPP – cell A8

- PPP – cell B8

- HPP – cell C8

- RSize – cell D8

- TCI_Selection – cell E8

- RPhase – cell F8

- Staffing – cell G8

The following named range has been assigned on the List Info worksheet:

- VariablesEcon – range B8:G8

3.7.2   Worksheet Formatting

No special formatting has been used on the List Info worksheet. All cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.7.3   Worksheet Equations/IF Statements

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

- A2=IF(Grid_PWR>0,"Market Price","") – This equation sets the grid power selling option to Market Price when power is being sold to the grid.

- A3=IF(Grid_PWR>0,"Price to Match IRR","") – This equation sets the grid power selling option to Price to Match IRR when power is being sold to the grid.

- B2=IF(CP_PWR>0,"Market Price","") – This equation sets the process power selling option to Market Price when power is being sold to an external process.

- B3=IF(CP_PWR>0,"Price to Match IRR","") – This equation sets the process power selling option to Price to Match IRR when power is being sold to an external process.

- C2=IF(CP_Heat>0,"Market Price","") – This equation sets the process heat selling option to Market Price when heat is sold to an external process.

- C3=IF(CP_Heat>0,"Price to Match IRR","") – This equation sets the process heat selling option to Price to Match IRR when heat is sold to an external process.

- A8 to G8=INDEX(array, index) – This equation sets the value selected in row 8 for the named ranges and the corresponding combo box index.

3.7.4   Worksheet Macros

No Macros are included in the List Info worksheet.

3.8   Results Summary Worksheet

The Results Summary worksheet presents the results of a parametric analysis for the project in which the IRR is calculated for product market prices and specified product prices are calculated to achieve a given IRR varying the TCI over the range set on the Project Inputs worksheet. In addition, the effect of a carbon offset credit on the product price is assessed. To execute the calculations and repopulate the worksheet click the 'Run Economic Calculations' button. This button is linked to the Economics Macro. A screenshot of the Results Summary worksheet is shown in Figure 29. The parametric analysis includes the option to display the average retail electricity price, which is based on the electricity price to the grid plus the average cost of transmission and distribution calculated on the Commodity Prices sheet. In general the grid price should be used for economic assessments; however, if only the average retail price is available for cost comparisons the user can display the price by selecting the option to display the value in the user form. By default, this value is not displayed.

		-% Δ TCI		TCI		+% Δ TCI	
		IRR	Price	IRR	Price	IRR	Price
	Capital (HTGR)	$3,354,573,566		$4,792,247,952		$7,188,371,928	
Market Price	Grid Elec. Price ($/MWe-hr)	6.8	$59.28	3.6	$59.28	0.9	$59.28
	Process Elec Price ($/MWt-hr)	6.8	N/A	3.6	N/A	0.9	N/A
	Process Heat Price ($/MWt-hr)	6.8	N/A	3.6	N/A	0.9	N/A
	Process Heat Price ($/MMBTU)	6.8	N/A	3.6	N/A	0.9	N/A
	Proc. Steam Price ($/1000-lb)	6.8	N/A	3.6	N/A	0.9	N/A
	Capital (HTGR)	$3,354,573,566		$4,792,247,952		$7,188,371,928	
Price @ IRR	Grid Elec. Price ($/MWe-hr)	12.0	$77.10	12.0	$97.55	12.0	$131.64
	Process Elec Price ($/MWt-hr)	12.0	N/A	12.0	N/A	12.0	N/A
	Process Heat Price ($/MWt-hr)	12.0	N/A	12.0	N/A	12.0	N/A
	Process Heat Price ($/MMBTU)	12.0	N/A	12.0	N/A	12.0	N/A
	Proc. Steam Price ($/1000-lb)	12.0	N/A	12.0	N/A	12.0	N/A

Carb. Tax	-% Δ TCI	TCI	+% Δ TCI	-% Δ TCI	TCI	+% Δ TCI	-% Δ TCI	TCI	+% Δ TCI	-% Δ TCI	TCI	+% Δ TCI	-% Δ TCI	TCI	+% Δ TCI
($/ton)	Grid Elec. Price ($/MWe-hr)			Process Elec Price ($/MWt-hr)			Process Heat Price ($/MWt-hr)			Process Heat Price ($/MMBTU)			Proc. Steam Price ($/1000-lb)		
$0	$77.10	$97.55	$131.64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
$50	$56.54	$76.99	$111.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
$100	$35.97	$56.42	$90.51	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
$150	$15.40	$35.86	$69.94	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
$200	-$5.16	$15.29	$49.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure 29. Results Summary worksheet screenshot.

64

3.8.1 Named Cells/Ranges

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

3.8.2 Worksheet Formatting

No special formatting is used on the Results Summary worksheet, this worksheet is not protected. All cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.8.3 Worksheet Equations/IF Statements

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

3.8.4 Worksheet Macros

The Economics Macro compiles the economics results, when the user clicks the 'Run Economic Calculations' button. The user enters the economic inputs in a user form which is called by the Macro; the initial values are copied from the current values on the Project Inputs worksheet. The EconomicInput_UF user form code is presented in Figure 30, a screenshot is presented in Figure 31. The Economics Macro is presented in Figure 32. The user form and Macro codes are several pages long.

```
Private Sub CancelButton_Click()

    ' Cancels the macro and hides the form
    CancelMacro = True
    EconomicInput_UF.Hide

End Sub

Private Sub ContinueButton_Click()

    ' Ensures that the term of the loan is less than the plant life
    If LoanTermN_Entry > PlantLifeN_Entry Then

        ' Message box for user
        Response = MsgBox("Please ensure the loan term is less" & _
        " than the plant life.", vbOKOnly)
    Else

        ' Ensures that at least one product is set to price to match IRR
        If GridElecN_Entry.Value = "Price to Match IRR" Or _
        ProcElecN_Entry.Value = "Price to Match IRR" Or _
        ProcHeatN_Entry.Value = "Price to Match IRR" Then

            ' Writes the values specified in the form
            IRRN_Value = IRRN_Entry
            DebtRatioN_Value = DebtRatioN_Entry
            DebtIntN_Value = DebtIntN_Entry
            DebtIntConN_Value = DebtIntConN_Entry
            LoanTermN_Value = LoanTermN_Entry
            ConstructionN_Value = ConstructionN_Entry
```

Figure 30. EconomicInput_UF user form code.

```
                PlantLifeN_Value = PlantLifeN_Entry
                RefuelingPeriodN_Value = RefuelingPeriodN_Entry
                ProjectPhaseN_Value = ProjectPhaseN_Entry
                StaffingPlanN_Value = StaffingPlanN_Entry
                BaseReactorSizeN_Value = BaseReactorSizeN_Entry
                GridElecN_Value = GridElecN_Entry
                ProcElecN_Value = ProcElecN_Entry
                ProcHeatN_Value = ProcHeatN_Entry
                CTI = CarbonTax_Entry
                RetailPriceDisplay = RetailPrice

                ' Continues the macro and hides the form
                CancelMacro = False
                EconomicInput_UF.Hide

            Else

                ' Message box for user
                Response = MsgBox("Specify at least one product to iterate" & _
                " the product price on for the analysis.", vbOKOnly)

            End If

        End If

End Sub


Private Sub CarbonTax_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If CarbonTax_Entry <= 100 And CarbonTax_Entry >= 10 Then

    Else

        ' Resets the value to the initial value
        CarbonTax_Entry.Value = 50
        ' Message box for user
        Response = MsgBox("Enter a value between 10 and 100.", vbOKOnly)

    End If
End Sub


Private Sub DebtIntN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If DebtIntN_Entry <= 15 And DebtIntN_Entry >= 2 Then

    Else

        ' Resets the value to the initial value
        DebtIntN_Entry.Value = Range("RDEBTN").Value
```

Figure 30. EconomicInput_UF user form code. (continued)

```vba
            ' Message box for user
            Response = MsgBox("Enter a value between 2 and 15.", vbOKOnly)

        End If

End Sub

Private Sub DebtIntConN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If DebtIntConN_Entry <= 15 And DebtIntConN_Entry >= 2 Then

    Else

        ' Resets the value to the initial value
        DebtIntConN_Entry.Value = Range("RDEBTN_CON").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 2 and 15.", vbOKOnly)

    End If

End Sub

Private Sub ConstructionN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If ConstructionN_Entry <= 72 And ConstructionN_Entry >= 12 Then

    Else

        ' Resets the value to the initial value
        ConstructionN_Entry.Value = Range("CPN").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 12 and 72.", vbOKOnly)

    End If

End Sub

Private Sub DebtRatioN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If DebtRatioN_Entry / 100 <= 1 And DebtRatioN_Entry >= 0 Then

    Else

        ' Resets the value to the initial value
        DebtRatioN_Entry.Value = Range("DEBTN").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 0 and 100.", vbOKOnly)

    End If
```

Figure 30. EconomicInput_UF user form code. (continued)

67

```vba
End Sub

Private Sub IRRN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If IRRN_Entry <= 25 And IRRN_Entry >= 0 Then

    Else

        ' Resets the value to the initial value
        IRRN_Entry.Value = Range("IRRN").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 0 and 25.", vbOKOnly)

    End If

End Sub

Private Sub LoanTermN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If LoanTermN_Entry <= 30 And LoanTermN_Entry >= 10 Then

    Else

        ' Resets the value to the initial value
        LoanTermN_Entry.Value = Range("RTERMN").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 10 and 30.", vbOKOnly)

    End If

End Sub

Private Sub PlantLifeN_Entry_AfterUpdate()

    ' Ensures the value entered is within the proper range
    If PlantLifeN_Entry <= 60 And PlantLifeN_Entry >= 10 Then

    Else

        ' Resets the value to the initial value
        PlantLifeN_Entry.Value = Range("ELN").Value
        ' Message box for user
        Response = MsgBox("Enter a value between 10 and 60.", vbOKOnly)

    End If

End Sub

Private Sub RefuelingPeriodN_Entry_AfterUpdate()
```

Figure 30. EconomicInput_UF user form code. (continued)

```
        ' Ensures the value entered is within the proper range
        If RefuelingPeriodN_Entry <= 24 And RefuelingPeriodN_Entry >= 6 Then

        Else

            ' Resets the value to the initial value
            RefuelingPeriodN_Entry.Value = Range("Refuel").Value
            ' Message box for user
            Response = MsgBox("Enter a value between 6 and 24.", vbOKOnly)

        End If

    End Sub

    Private Sub UserForm_Initialize()

        ' Sets the project phases in the ComboBox
        ProjectPhaseN_Entry.AddItem Range("Phase1").Value
        ProjectPhaseN_Entry.AddItem Range("Phase2").Value
        ProjectPhaseN_Entry.AddItem Range("Phase3").Value

        ' Sets the project phase set on the List Info Worksheet
        ProjectPhaseN_Entry.Value = Range("RPhase").Value

        ' Sets the reactor size in the ComboBox
        BaseReactorSizeN_Entry.AddItem Range("RSize1").Value
        BaseReactorSizeN_Entry.AddItem Range("RSize2").Value
        BaseReactorSizeN_Entry.AddItem Range("RSize3").Value

        ' Sets the reactor size to the value on the List Info Worksheet
        BaseReactorSizeN_Entry.Value = Range("RSize").Value

        ' Sets the staffing plant in the ComboBox
        StaffingPlanN_Entry.AddItem Range("Staffing1").Value
        StaffingPlanN_Entry.AddItem Range("Staffing2").Value

        ' Sets the staffing plan to the value selected in the model
        StaffingPlanN_Entry.Value = Range("Staffing").Value

        ' Sets the grid electricity price options in the ComboBox
        GridElecN_Entry.AddItem Range("GridElec1").Value
        GridElecN_Entry.AddItem Range("GridElec2").Value

        ' Sets the grid electricity price based on the List Info Worksheet
        GridElecN_Entry.Value = Range("GPP").Value

        ' Sets the process electricity price options in the ComboBox
        ProcElecN_Entry.AddItem Range("ProcElec1").Value
        ProcElecN_Entry.AddItem Range("ProcElec2").Value

        ' Sets the process electricity price based on the List Info Worksheet
        ProcElecN_Entry.Value = Range("PPP").Value
```

Figure 30. EconomicInput_UF user form code. (continued)

```vba
' Sets the process heat price options in the ComboBox
ProcHeatN_Entry.AddItem Range("ProcHeat1").Value
ProcHeatN_Entry.AddItem Range("ProcHeat2").Value

' Sets the process price based on the List Info Worksheet
ProcHeatN_Entry.Value = Range("HPP").Value

'Writes the values from the Project Inputs sheet to the user form
IRRN_Entry.Value = Range("IRRN").Value
DebtRatioN_Entry.Value = Range("DEBTN").Value
DebtIntN_Entry.Value = Range("RDEBTN").Value
LoanTermN_Entry.Value = Range("RTERMN").Value
ConstructionN_Entry.Value = Range("CPN").Value
DebtIntConN_Entry.Value = Range("RDEBTN_CON").Value
PlantLifeN_Entry.Value = Range("ELN").Value
RefuelingPeriodN_Entry.Value = Range("Refuel").Value

' Locks the retail price option if no grid power is produced
If Range("Grid_PWR").Value <= 0 Then
    RetailPrice.Enabled = False
Else
    RetailPrice.Enabled = True
End If

End Sub
```

Figure 30. EconomicInput_UF user form code. (continued)

Figure 31. EconomicInput_UF user form screenshot.

```vba
' Declare public variables
Public CancelMacro
Public CTI
Public RetailPriceDisplay
' Nuclear Process
Public IRRN_Value
Public DebtRatioN_Value
Public DebtIntN_Value
Public DebtIntConN_Value
Public LoanTermN_Value
Public ConstructionN_Value
Public PlantLifeN_Value
Public RefuelingPeriodN_Value
Public ProjectPhaseN_Value
Public StaffingPlanN_Value
Public BaseReactorSizeN_Value
Public GridElecN_Value
Public ProcElecN_Value
Public ProcHeatN_Value


Sub Economics()

    ' Economics Macro
    ' Macro developed by Anastasia Gandrik
    ' Idaho National Laboratory
    ' NGNP Project

    ' This macro runs the economic calculator, calculating the IRR for
    ' selling power and/or heat. In addition, the price of the main product
    ' is computed, such that the IRR is equal to a user specified IRR%.

    ' Clears the clipboard
    Application.CutCopyMode = False

    ' Sets the model password
    NGNPPass = "▮▮▮▮▮▮▮▮▮▮"

    ' Sets initial value of all variables to zero
    i = 0        ' Carbon tax variation
    j = 0        ' TCI variation
    l = 1        ' Selling heat/electricity at market price or at IRR

    ' Message box for user
    Response = MsgBox("Run Macro for the economic calculations?", vbYesNo)

    ' Begin calculations for economic analysis
    If Response = vbYes Then

        ' Message box for user
        Response = MsgBox("Please wait for the calculations to complete." & _
        " A message box will prompt you when calculations are complete, " & _
        " please click OK.", vbOKOnly)
```

Figure 32. Economics Macro.

```vba
' Brings up user form for economic entries
EconomicInput_UF.Show

' Quits the user form, so entries are reset to baseline values
Unload EconomicInput_UF

' If the user indicates to continue calculations
If CancelMacro = False Then

    ' Selects the summary sheet and unprotects it
    Sheets("Results Summary").Unprotect Password:=NGNPPass
    Sheets("Results Summary").Select

    ' Brings up user form showing calculations in progress
    CalcProg_UF.Show

    ' Unloads the user form
    Unload CalcProg_UF

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Copies the values set in the drop down boxes, so that they are
    ' preserved after the economic analysis is run
    Sheets("List Info").Unprotect Password:=NGNPPass
    Sheets("List Info").Visible = True
    Sheets("List Info").Select
    Range("VariablesEcon").Copy Destination:=Cells(10, 1)

    ' Writes the economic inputs from the user form to the project
    ' inputs sheet
    Sheets("Project Inputs").Select
    Range("IRRN").Value = IRRN_Value
    Range("DEBTN").Value = DebtRatioN_Value
    Range("RDEBTN").Value = DebtIntN_Value
    Range("RDEBTN_Con").Value = DebtIntConN_Value
    Range("RTERMN").Value = LoanTermN_Value
    Range("CPN").Value = ConstructionN_Value
    Range("ELN").Value = PlantLifeN_Value
    Range("Refuel").Value = RefuelingPeriodN_Value

    ' Writes the economic inputs from the user form to the list
    ' info sheet
    Sheets("List Info").Select
    Range("RPhase").Value = ProjectPhaseN_Value
    Range("Staffing").Value = StaffingPlanN_Value
    Range("RSize").Value = BaseReactorSizeN_Value
    Range("GPP").Value = GridElecN_Value
    Range("PPP").Value = ProcElecN_Value
    Range("HPP").Value = ProcHeatN_Value

    ' Loops though market price for price at the IRR
    Do Until l = -1
```

Figure 32. Economics Macro. (continued)

```
        ' Loops through TCIs
        Do Until j = 3

            ' Set TCI subroutine
            GoSub SetTCI

            ' Only performs carbon tax @IRR calculations
            If l = 1 Then

                ' Loops through the carbon tax cases
                Do Until i = 4

                    ' Runs the carbon tax subroutine
                    GoSub CarbonTax

                    ' Iterates to the next value of i (carbon tax)
                    i = i + 1

                ' Carbon tax loop
                Loop

                ' Reinitializes i
                i = 0

                ' Resets the carbon tax to zero
                Sheets("Commodity Prices").Select
                Range("CarbonTax").Value = 0

            Else
            End If

            ' Runs the economic analysis subroutine
            GoSub EconomicAnalysis

            ' Iterates to the next value of j (TCI)
            j = j + 1

        ' TCI loop
        Loop

        ' Reinitializes j
        j = 0

        ' Iterates to the next value of l (@market price or IRR)
        l = l - 1

    ' Product price loop
    Loop

    ' Reinitializes l
    l = 1
```

Figure 32. Economics Macro. (continued)

```vba
' Pastes the economic variables to their original location
Sheets("List Info").Select
Range("A10:G10").Copy Destination:=Range("A8")
Range("A10:G10").Clear

' Selects the summary sheet
Sheets("Results Summary").Select

' Shows the retail electricity price if the user indicates to
If RetailPriceDisplay = True Then
    Rows("6").Hidden = False
    Rows("13").Hidden = False
    Columns("J:L").Hidden = False
Else
    Rows("6").Hidden = True
    Rows("13").Hidden = True
    Columns("J:L").Hidden = True
End If

' Hides the List Info sheet
Sheets("List Info").Visible = False
Sheets("List Info").Protect Password:=NGNPPass

' Protects the Results summary sheet
Sheets("Results Summary").Protect Password:=NGNPPass

' Allows the screen to update again
Application.ScreenUpdating = True

' Message box for user
Response = MsgBox("Calculations Complete, please click OK" & _
"", vbOKOnly)

' Message box for to copy current results
Response2 = MsgBox("Would you like to save a copy of the" & _
" model results?", vbYesNo)

' If the user wants to copy the previous results
If Response2 = vbYes Then

    ' Subroutine for copying previous results
    GoSub CopyResults

Else
End If

Else

    ' Message box for user
    Response = MsgBox("Exiting Macro.", vbOKOnly)

End If
```

Figure 32. Economics Macro. (continued)

```vba
    Else

        ' Message box for user
        Response = MsgBox("Exiting Macro...", vbOKOnly)

    End If

    ' Clears the clipboard
    Application.CutCopyMode = False

Exit Sub

' Subroutine for calculations for carbon tax cases
CarbonTax:

    'Writes the value of the carbon tax to the sheet
    Sheets("Commodity Prices").Select
    Range("CarbonTax").Value = CTI * (i + 1)

    ' Solves for the HTGR product price and copies it to the summary sheet
    Sheets("Results Summary").Select
    Cells((15 + i), 9).Value = CTI * (i + 1)
    Cells((15 + i), (10 + j)).Value = Range("RetailPrice").Value
    Cells((15 + i), (13 + j)).Value = Range("GridElecPrice").Value
    Cells((15 + i), (16 + j)).Value = Range("ProcElecPrice").Value
    Cells((15 + i), (19 + j)).Value = Range("HeatPrice").Value
    Cells((15 + i), (22 + j)).Value = Range("HeatPrice_MMBTU").Value
    Cells((15 + i), (25 + j)).Value = Range("HeatPrice_LB").Value

Return

' Subroutine for the economic analysis calculations
EconomicAnalysis:

    ' For the market price iteration
    If l = 0 Then

        ' Writes the selector for heat/power purchased @IRR or market price
        Sheets("List Info").Select
        If Range("GPP").Value = "" Then
        Else
            Range("GPP").Value = "Market Price"
        End If

        If Range("PPP").Value = "" Then
        Else
            Range("PPP").Value = "Market Price"
        End If

        If Range("HPP").Value = "" Then
        Else
            Range("HPP").Value = "Market Price"
        End If
```

Figure 32. Economics Macro. (continued)

```
    Else

    End If

    ' Writes the IRR & product price to the summary sheet
    Sheets("Results Summary").Select
    Cells((6 + 7 * 1), (3 + 2 * j)).Value = Range("IRRValue").Value
    Cells((6 + 7 * 1), (4 + 2 * j)).Value = Range("RetailPrice").Value
    Cells((7 + 7 * 1), (4 + 2 * j)).Value = Range("GridElecPrice").Value
    Cells((8 + 7 * 1), (4 + 2 * j)).Value = Range("ProcElecPrice").Value
    Cells((9 + 7 * 1), (4 + 2 * j)).Value = Range("HeatPrice").Value
    Cells((10 + 7 * 1), (4 + 2 * j)).Value = Range("HeatPrice_MMBTU").Value
    Cells((11 + 7 * 1), (4 + 2 * j)).Value = Range("HeatPrice_LB").Value

Return

' Sets the TCI
SetTCI:

    ' Sets the TCI Value
    Sheets("List Info").Select
    If j = 0 Then
        Range("TCI_Selection").Value = "Low TCI"
    ElseIf j = 1 Then
        Range("TCI_Selection").Value = "TCI"
    Else
        Range("TCI_Selection").Value = "High TCI"
    End If

Return

' Copies the previous model results to the end of the workbook
CopyResults:

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Determines the number of sheets in the workbook
    SheetNums = ActiveWorkbook.Sheets.Count

    ' Initializes count variables
    CountSheet = 1
    SavedResults = 0

    ' Checks if a saved results sheet exists for numbering
    Do Until CountSheet = SheetNums + 1
        SheetName = ActiveWorkbook.Sheets(CountSheet).Name
        If InStr(SheetName, "Saved Results") = 0 Then
        Else
            SavedResults = SavedResults + 1
        End If
```

Figure 32. Economics Macro. (continued)

```vba
' Progresses to the next sheet
CountSheet = CountSheet + 1

Loop

' Reinitializes the count
CountSheet = 1

' Copies the results from the previous run to the end of the workbook
Sheets("Results Summary").Select
Sheets("Results Summary").Copy _
After:=ActiveWorkbook.Sheets(ActiveWorkbook.Sheets.Count)

' Names the results summary sheet
SavedResults = SavedResults + 1
NewSheetName = "Saved Results " & SavedResults
ActiveSheet.Name = NewSheetName

' Removes the button to run the macro
ActiveSheet.Unprotect Password:=NGNPPass
ActiveSheet.Shapes("Button 1").Select
Selection.Cut

' Deletes the first two rows
Rows("1:2").Delete

' Selects and pastes the information from the Project Inputs sheet to
' the new summary sheet
Sheets("Project Inputs").Range("A1:C200").Copy
Sheets(NewSheetName).Range("AC1").Select
Selection.PasteSpecial (xlPasteValuesAndNumberFormats)
Selection.PasteSpecial (xlFormats)

' Sizes the cells appropriately, so the text is viewable
Columns("AC:AE").EntireColumn.AutoFit

' Selects all the cells on the sheet, copies, and pastes the values
Range("A1:Z200") = Range("A1:Z200").Value

' Clears the cell shading
Columns("AC:AE").Select
With Selection.Interior
    .Pattern = xlNone
End With

' Protects the saved results sheet
ActiveSheet.Protect Password:=NGNPPass

' Clears the clipboard
Application.CutCopyMode = False
Sheets("Results Summary").Select
```

Figure 32. Economics Macro. (continued)

```
    ' Allows the screen to update again
    Application.ScreenUpdating = True


Return


' Ends the subroutine
End Sub
```

Figure 32. Economics Macro. (continued)

3.9   Sensitivity Analysis Worksheet

The Sensitivity Analysis worksheet assesses the impact of varying key analysis parameters over specified ranges, while holding all other parameters at baseline values, on the required product selling prices to achieve a given IRR. The results of the analyses are presented in tornado diagrams; each product price is presented in a separate chart. A tornado chart is useful in that it shows the influence of varying each variable over a specific range on the required prices. It also depicts the relative importance of variables by arranging the results for each variable in descending order of influence. To run the sensitivity analysis and repopulate the worksheet, click the 'Run Sensitivity Analysis' button. This button is linked to the Sensitivity Macro. The tornado diagram for the electricity price to the grid is presented in Figure 33. A screenshot of the Sensitivity Analysis worksheet is shown in Figure 34.

The sensitivity analysis includes the option to display the average retail electricity price, which is based on the electricity price to the grid plus the average cost of transmission and distribution calculated on the Commodity Prices sheet. In general the grid price should be used for economic assessments; however, if only the average retail price is available for cost comparisons the user can display the price by selecting the option to display the value in the user form. By default, this value is not displayed.
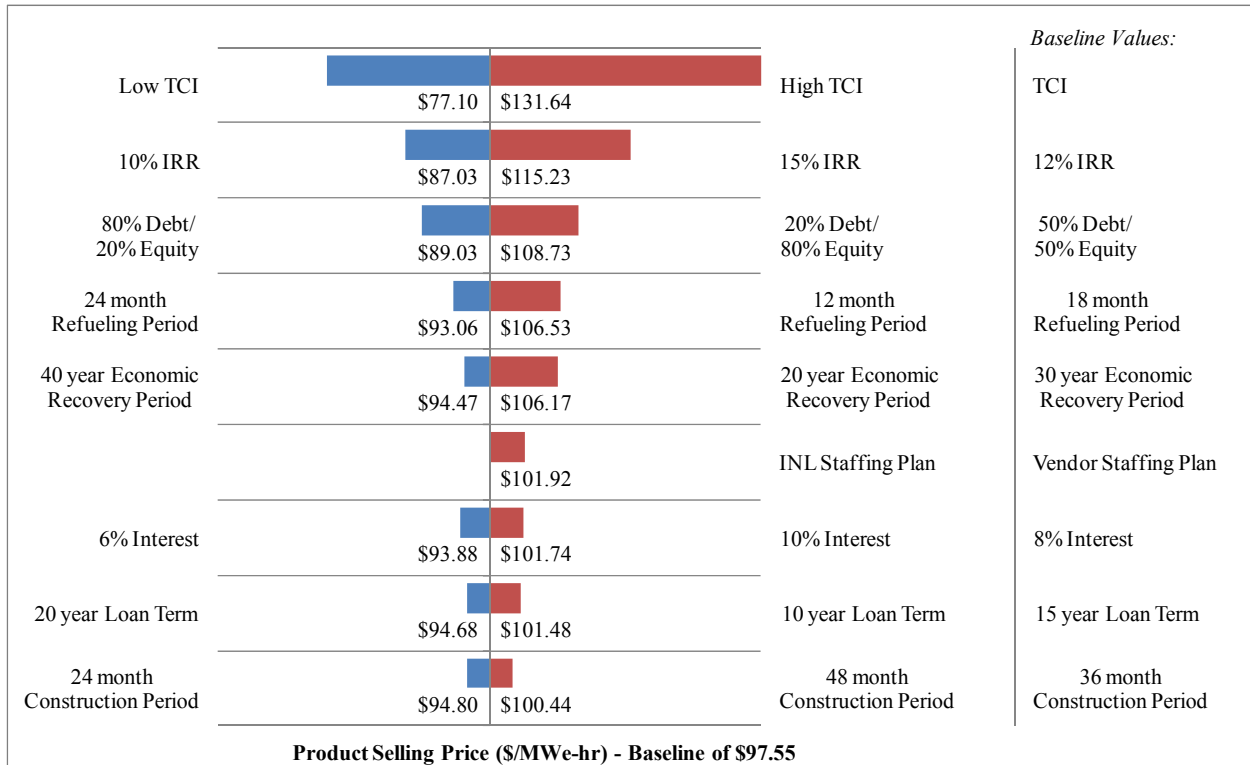
Figure 33. Grid electricity price tornado diagram.

79

Run Sensitivity Analysis

Electricity Price to Grid / Electricity Price to Process / Heat Price to Process

			Electricity Price to Grid $/MWe-hr							Electricity Price to Process $/MWe-hr							Heat Price to Process $/MWt-hr						
A	B	C	Lower Bound	Upper Bound	Neg. Lower	Lower %Δ	Upper %Δ	Δ Lower	Δ Upper	Lower Bound	Upper Bound	Neg. Lower	Lower %Δ	Upper %Δ	Δ Lower	Δ Upper	Lower Bound	Upper Bound	Neg. Lower	Lower %Δ	Upper %Δ	Δ Lower	Δ Upper
Baseline			$97.55							N/A							N/A						
24 month Construction Period	36 month Construction Period	48 month Construction Period	$94.80	$100.44	-$94.80	-3%	3%	-2.75	2.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20 year Loan Term	15 year Loan Term	10 year Loan Term	$94.68	$101.48	-$94.68	-3%	4%	-2.87	3.93	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6% Interest	8% Interest	10% Interest	$93.88	$101.74	-$93.88	-4%	4%	-3.67	4.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Vendor Staffing Plan	INL Staffing Plan		$101.92			4%		4.37		N/A			N/A		N/A		N/A			N/A		N/A
40 year Economic Recovery Period	30 year Economic Recovery Period	20 year Economic Recovery Period	$94.47	$106.17	-$94.47	-3%	9%	-3.08	8.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24 month Refueling Period	18 month Refueling Period	12 month Refueling Period	$93.06	$106.53	-$93.06	-5%	9%	-4.49	8.98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
80% Debt/ 20% Equity	50% Debt/ 50% Equity	20% Debt/ 80% Equity	$89.03	$108.73	-$89.03	-9%	11%	-8.52	11.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10% IRR	12% IRR	15% IRR	$87.03	$115.23	-$87.03	-11%	18%	-10.5	17.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Low TCI	TCI	High TCI	$77.10	$131.64	-$77.10	-21%	35%	-20.5	34.09	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Run Sensitivity Analysis

Heat Price to Process / Steam Price to Process

			Heat Price to Process $/MMBTU							Steam Price to Process $/1000-lb						
A	B	C	Lower Bound	Upper Bound	Neg. Lower	Lower %Δ	Upper %Δ	Δ Lower	Δ Upper	Lower Bound	Upper Bound	Neg. Lower	Lower %Δ	Upper %Δ	Δ Lower	Δ Upper
Baseline			N/A							N/A						
24 month Construction Period	36 month Construction Period	48 month Construction Period	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20 year Loan Term	15 year Loan Term	10 year Loan Term	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6% Interest	8% Interest	10% Interest	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Vendor Staffing Plan	INL Staffing Plan		N/A			N/A		N/A		N/A			N/A		N/A
40 year Economic Recovery Period	30 year Economic Recovery Period	20 year Economic Recovery Period	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24 month Refueling Period	18 month Refueling Period	12 month Refueling Period	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
80% Debt/ 20% Equity	50% Debt/ 50% Equity	20% Debt/ 80% Equity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10% IRR	12% IRR	15% IRR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Low TCI	TCI	High TCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure 34. Sensitivity Analysis worksheet screenshot.

3.9.1   Named Cells/Ranges

No named cells or ranges are included in the Sensitivity Analysis worksheet.

3.9.2   Worksheet Formatting

No special formatting is used on the Sensitivity Analysis worksheet, this worksheet is not protected. All cells in the worksheet have been locked. In order to access the locked cells the worksheet must be unprotected using the password identified in Section 3.

3.9.3   Worksheet Equations/IF Statements

The following IF statements are included in the Sensitivity Analysis worksheet:

O4=IF(L4="N/A","N/A",IF(ISBLANK(L4)=TRUE,"",Q4/L$3))

Q4=IF(L4="N/A","N/A",IF(ISBLANK(L4)=TRUE,"",-ABS(L$3-L4)))

These equations calculate variations in the lower bound grid electricity price calculated in the analysis from the baseline value. The first equation calculates the lower boundary percentage change; the second calculates the absolute value of the difference in the lower bound price and the baseline price. If the calculated value is blank or N/A the cell displays that value. The upper bound calculations (P4, R4) are similar.

3.9.4   Worksheet Macros

The Sensitivity Macro compiles the sensitivity analysis results when the user clicks the 'Run Sensitivity Analysis' button. The user can enter the upper and lower bounds for the economic inputs in a user form which is called by the Macro; the baseline values are copied from the current values on the Project Inputs worksheet. The SensitivityInput_UF user form code is presented in Figure 35, a screenshot is presented in Figure 36. The Sensitivity Macro is presented in Figure 37. The user form and Macro codes are several pages long.

```
Private Sub CancelButton_Click()

    ' Cancels the macro and hides the form
    CancelMacro2 = True
    SensitivityInput_UF.Hide

End Sub

Private Sub ContinueButton_Click()

    ' Ensures that at least one products price is set to match the IRR
    If GridElecS_Entry.Value = "Price to Match IRR" Or _
    ProcElecS_Entry.Value = "Price to Match IRR" Or _
    ProcHeatS_Entry.Value = "Price to Match IRR" Then

        ' Writes values specified in the form
        IRRS_Value(0) = IRRS_LL
        IRRS_Value(1) = IRRS_BL
        IRRS_Value(2) = IRRS_UL
```

Figure 35. SensitivityInput_UF user form code.

```
            DebtRatioS_Value(0) = DebtRatioS_LL
            DebtRatioS_Value(1) = DebtRatioS_BL
            DebtRatioS_Value(2) = DebtRatioS_UL
            DebtIntS_Value(0) = DebtIntS_LL
            DebtIntS_Value(1) = DebtIntS_BL
            DebtIntS_Value(2) = DebtIntS_UL
            LoanTermS_Value(0) = LoanTermS_LL
            LoanTermS_Value(1) = LoanTermS_BL
            LoanTermS_Value(2) = LoanTermS_UL
            ConstructionS_Value(0) = ConstructionS_LL
            ConstructionS_Value(1) = ConstructionS_BL
            ConstructionS_Value(2) = ConstructionS_UL
            StaffingS_Value(1) = StaffingS_BL
            StaffingS_Value(2) = StaffingS_UL
            PlantLifeS_Value(0) = PlantLifeS_LL
            PlantLifeS_Value(1) = PlantLifeS_BL
            PlantLifeS_Value(2) = PlantLifeS_UL
            TCIS_Value(0) = TCIS_LL
            TCIS_Value(1) = TCIS_BL
            TCIS_Value(2) = TCIS_UL
            RefuelingS_Value(0) = RefuelingS_LL
            RefuelingS_Value(1) = RefuelingS_BL
            RefuelingS_Value(2) = RefuelingS_UL
            ProjectPhaseS_Value = ProjectPhase
            RSizeS_Value = ReactorSize
            GridElecS_Value = GridElecS_Entry
            ProcElecS_Value = ProcElecS_Entry
            ProcHeatS_Value = ProcHeatS_Entry
            RetailPriceDisplay2 = RetailPrice

            ' Continues the macro and hides the form
            CancelMacro2 = False
            SensitivityInput_UF.Hide

        Else

            ' Message box for user
            Response = MsgBox("Specify at least one product to iterate" & _
            " the product price on for the analysis.", vbOKOnly)

        End If

End Sub
```

```
Private Sub IRRS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' less than the baseline value
    If IRRS_LL < 0 Or IRRS_LL >= IRRS_BL Then

        ' Resets the value to the initial value
        IRRS_LL = 10
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vba
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 0" & _
            " which is less than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub IRRS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' greater than the baseline value
    If IRRS_UL > 25 Or IRRS_UL <= IRRS_BL Then

        ' Resets the value to the initial value
        IRRS_UL = 15
        ' Message box for user
        Response = MsgBox("Enter a value less than or equal to 25" & _
            " which is greater than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub DebtRatioS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' greater than the baseline value
    If DebtRatioS_LL > 100 Or DebtRatioS_LL / 10 <= DebtRatioS_BL / 10 Then

        ' Resets the value to the initial value
        DebtRatioS_LL = 80
        ' Message box for user
        Response = MsgBox("Enter a value less than or equal to 100" & _
            " which is greater than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub DebtRatioS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' less than the baseline value
    If DebtRatioS_UL < 0 Or DebtRatioS_UL >= DebtRatioS_BL Then

        ' Resets the value to the initial value
        DebtRatioS_UL = 20
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vba
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 0" & _
            " which is less than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub DebtIntS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' less than the baseline value
    If DebtIntS_LL < 2 Or DebtIntS_LL >= DebtIntS_BL Then

        ' Resets the value to the initial value
        DebtIntS_LL = 6
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 2" & _
            " which is less than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub DebtIntS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' greater than the baseline value
    If DebtIntS_UL > 15 Or DebtIntS_UL / 10 <= DebtIntS_BL / 10 Then

        ' Resets the value to the initial value
        DebtIntS_UL = 10
        ' Message box for user
        Response = MsgBox("Enter a value less than or equal to 15" & _
            " which is greater than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub ConstructionS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' less than the baseline value
    If ConstructionS_LL < 12 Or ConstructionS_LL >= ConstructionS_BL Then

        ' Resets the value to the initial value
        ConstructionS_LL = 24
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vba
            ' Message box for user
            Response = MsgBox("Enter a value greater than or equal to 12" & _
               " which is less than the baseline.", vbOKOnly)

        Else
        End If

End Sub


Private Sub ConstructionS_UL_AfterUpdate()

        ' Ensures the upper limit is within data validation limits and
        ' greater than the baseline value
        If ConstructionS_UL > 72 Or ConstructionS_UL <= ConstructionS_BL Then

            ' Resets the value to the initial value
            ConstructionS_UL = 48
            ' Message box for user
            Response = MsgBox("Enter a value less than or equal to 72" & _
                " which is greater than the baseline.", vbOKOnly)

        Else
        End If

End Sub


Private Sub LoanTermS_LL_AfterUpdate()

        ' Ensures the lower limit is within data validation limits and
        ' greater than the baseline value
        If LoanTermS_LL > 30 Or LoanTermS_LL <= LoanTermS_BL Then

            ' Resets the value to the initial value
            LoanTermS_LL = 20
            ' Message box for user
            Response = MsgBox("Enter a value less than or equal to 30" & _
                " which is greater than the baseline.", vbOKOnly)

        ' Ensures the value entered is less than or equal to the economic
        ' recovery period baseline
        ElseIf LoanTermS_LL > PlantLifeS_BL Then

            ' Resets the value to the initial value
            LoanTermS_LL = 20
            ' Message box for user
            Response = MsgBox("Enter a value less than or equal to the" & _
                "baseline economic recovery period.", vbOKOnly)

        End If

End Sub
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vb
Private Sub LoanTermS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' less than the baseline value
    If LoanTermS_UL < 10 Or LoanTermS_UL >= LoanTermS_BL Then

        ' Resets the value to the initial value
        LoanTermS_UL = 10
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 10" & _
          " which is less than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub PlantLifeS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' greater than the baseline value
    If PlantLifeS_LL > 60 Or PlantLifeS_LL <= PlantLifeS_BL Then

        ' Resets the value to the initial value
        PlantLifeS_LL = 40
        ' Message box for user
        Response = MsgBox("Enter a value less than or equal to 60" & _
            " which is greater than the baseline.", vbOKOnly)

    Else
    End If

End Sub

Private Sub PlantLifeS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' less than the baseline value
    If PlantLifeS_UL < 10 Or PlantLifeS_UL >= PlantLifeS_BL Then

        ' Resets the value to the initial value
        PlantLifeS_UL = 20
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 10" & _
          " which is less than the baseline.", vbOKOnly)

    ' Ensures the value is greater than or equal to the loan term
    ' baseline
    ElseIf PlantLifeS_UL < LoanTermS_BL Then

        ' Resets the value to the initial value
        PlantLifeS_UL = 20
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vba
                ' Message box for user
                Response = MsgBox("Enter a value greater than or equal to the" & _
                " loan term baseline.", vbOKOnly)

        End If

End Sub


Private Sub RefuelingS_LL_AfterUpdate()

    ' Ensures the lower limit is within data validation limits and
    ' greater than the baseline value
    If RefuelingS_LL > 24 Or RefuelingS_LL <= RefuelingS_BL Then

        ' Resets the value to the initial value
        RefuelingS_LL = 24
        ' Message box for user
        Response = MsgBox("Enter a value less than or equal to 24" & _
            " which is greater than the baseline.", vbOKOnly)

    Else
    End If

End Sub


Private Sub RefuelingS_UL_AfterUpdate()

    ' Ensures the upper limit is within data validation limits and
    ' less than the baseline value
    If RefuelingS_UL < 6 Or RefuelingS_UL / 10 >= RefuelingS_BL / 10 Then

        ' Resets the value to the initial value
        RefuelingS_UL = 12
        ' Message box for user
        Response = MsgBox("Enter a value greater than or equal to 6" & _
          " which is less than the baseline.", vbOKOnly)

    Else
    End If

End Sub


Private Sub UserForm_Initialize()

    ' Sets the project phases in the ComboBox
    ProjectPhase.AddItem Range("Phase1").Value
    ProjectPhase.AddItem Range("Phase2").Value
    ProjectPhase.AddItem Range("Phase3").Value

    ' Sets the project phase to the value selected in the model
    ProjectPhase.Value = Range("RPhase").Value
```

Figure 35. SensitivityInput_UF user form code. (continued)

```vba
    ' Sets the reactor size in the ComboBox
    ReactorSize.AddItem Range("RSize1").Value
    ReactorSize.AddItem Range("RSize2").Value
    ReactorSize.AddItem Range("RSize3").Value

    ' Sets the reactor size to the value selected in the model
    ReactorSize.Value = Range("RSize").Value

    ' Sets the grid electricity price options in the ComboBox
    GridElecS_Entry.AddItem Range("GridElec1").Value
    GridElecS_Entry.AddItem Range("GridElec2").Value

    ' Sets the grid electricity price based on the List Info Worksheet
    GridElecS_Entry.Value = Range("GPP").Value

    ' Sets the process electricity price options in the ComboBox
    ProcElecS_Entry.AddItem Range("ProcElec1").Value
    ProcElecS_Entry.AddItem Range("ProcElec2").Value

    ' Sets the process electricity price based on the List Info Worksheet
    ProcElecS_Entry.Value = Range("PPP").Value

    ' Sets the process heat price options in the ComboBox
    ProcHeatS_Entry.AddItem Range("ProcHeat1").Value
    ProcHeatS_Entry.AddItem Range("ProcHeat2").Value

    ' Sets the process price based on the List Info Worksheet
    ProcHeatS_Entry.Value = Range("HPP").Value

    'Writes the values from the Project Inputs sheet to the user form
    IRRS_BL.Value = Range("IRRN").Value
    DebtRatioS_BL.Value = Range("DEBTN").Value
    DebtIntS_BL.Value = Range("RDEBTN").Value
    LoanTermS_BL.Value = Range("RTERMN").Value
    ConstructionS_BL.Value = Range("CPN").Value
    PlantLifeS_BL.Value = Range("ELN").Value
    RefuelingS_BL.Value = Range("Refuel").Value

    ' Locks the retail price option if no grid power is produced
    If Range("Grid_PWR").Value <= 0 Then
        RetailPrice.Enabled = False
    Else
        RetailPrice.Enabled = True
    End If

End Sub
```

Figure 35. SensitivityInput_UF user form code. (continued)

Figure 36. SensitivityInput_UF user form screenshot.

```
' Declare public variables
Public CancelMacro2
Public RetailPriceDisplay2
' Nuclear Process
Public IRRS_Value(2)
Public DebtRatioS_Value(2)
Public DebtIntS_Value(2)
Public LoanTermS_Value(2)
Public ConstructionS_Value(2)
Public StaffingS_Value(2)
Public PlantLifeS_Value(2)
Public TCIS_Value(2)
Public RefuelingS_Value(2)
Public ProjectPhaseS_Value
Public RSizeS_Value
Public GridElecS_Value
Public ProcElecS_Value
Public ProcHeatS_Value


Sub Sensitivity()

    ' Sensitivity Analysis Macro
    ' Macro developed by Anastasia Gandrik
    ' Idaho National Laboratory
    ' NGNP Project

    ' This macro runs the sensitivity analysis, calculating the required
    ' selling price of heat and/or power for the HTGR.

    ' Clears the clipboard
    Application.CutCopyMode = False

    ' Sets the model password
    NGNPPass = "██████████"

    ' Sets initial value of all variables to zero
    i = 0        ' Sensitivity variation

    ' Message box for user
    Response = MsgBox("Run Macro for the sensitivity analysis?", vbYesNo)

    ' Begin calculations for sensitivity analysis
    If Response = vbYes Then

        ' Message box for user
        Response = MsgBox("Please wait for the calculations to complete." & _
        " A message box will prompt you when calculations are complete, " & _
        " please click OK.", vbOKOnly)

        ' Brings up user form for economic entries
        SensitivityInput_UF.Show
```

Figure 37. Sensitivity Macro.

```
' Quits the user form, so entries are reset to baseline values
Unload SensitivityInput_UF

' If the user indicates to continue calculations
If CancelMacro2 = False Then

    ' Brings up user form showing calculations in progress
    CalcProg_UF.Show

    ' Unloads the user form
    Unload CalcProg_UF

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Clears the previous sensitivity analysis results
    Sheets("Sensitivity Analysis").Unprotect Password:=NGNPPass
    Sheets("Sensitivity Analysis").Select
    Range("E3:AN3,A4:C12,E4:G12,L4:N12,S4:U12").ClearContents
    Range("Z4:AB12,AG4:AI12,AN4:AP12").ClearContents

    ' Copies the values set in the drop down boxes, so that they
    ' are preserved after the sensitivity analysis is run
    Sheets("List Info").Unprotect Password:=NGNPPass
    Sheets("List Info").Visible = True
    Sheets("List Info").Select
    Range("VariablesEcon").Copy Destination:=Cells(10, 1)

    ' Sets the reactor base size, the generation option, and the
    ' project phase based on the input to the user form
    Range("RSize").Value = RSizeS_Value
    Range("RPhase").Value = ProjectPhaseS_Value
    Range("GPP").Value = GridElecS_Value
    Range("PPP").Value = ProcElecS_Value
    Range("HPP").Value = ProcHeatS_Value

    ' Runs the baseline value subroutine to set the baseline values
    GoSub SetBaselineValues

    'Writes the baseline values to the sensitivity analysis sheet
    Sheets("Sensitivity Analysis").Select
    Range("B4").Value = IRRS_Value(1) & "% IRR"
    Range("B5").Value = DebtRatioS_Value(1) & "% Debt/" & _
        Chr(10) & (100 - DebtRatioS_Value(1)) & "% Equity"
    Range("B6").Value = DebtIntS_Value(1) & "% Interest"
    Range("B7").Value = LoanTermS_Value(1) & " year Loan Term"
    Range("B8").Value = ConstructionS_Value(1) & _
        " month" & Chr(10) & "Construction Period"
    Range("B9").Value = StaffingS_Value(1) & " Staffing Plan"
    Range("B10").Value = PlantLifeS_Value(1) & _
        " year Economic" & Chr(10) & "Recovery Period"
    Range("B11").Value = TCIS_Value(1)
```

Figure 37. Sensitivity Macro. (continued)

```vba
Range("B12").Value = RefuelingS_Value(1) & _
    " month" & Chr(10) & "Refueling Period"

' Writes the baseline product selling price to the sheet
Range("E3").Value = Range("RetailPrice").Value
Range("L3").Value = Range("GridElecPrice").Value
Range("S3").Value = Range("ProcElecPrice").Value
Range("Z3").Value = Range("HeatPrice").Value
Range("AG3").Value = Range("HeatPrice_MMBTU").Value
Range("AN3").Value = Range("HeatPrice_LB").Value

' Iterates through the sensitivity analysis
Do Until i > 2

    ' Performs sensitivity for the IRR and writes the value
    ' to the sheet
    GoSub SetBaselineValues
    Range("IRRN").Value = IRRS_Value(i)
    Sheets("Sensitivity Analysis").Select
    Cells(4, 1 + 2 * i / 2).Value = IRRS_Value(i) & "% IRR"
    Cells(4, 5 + i / 2).Value = Range("RetailPrice").Value
    Cells(4, 12 + i / 2).Value = Range("GridElecPrice").Value
    Cells(4, 19 + i / 2).Value = Range("ProcElecPrice").Value
    Cells(4, 26 + i / 2).Value = Range("HeatPrice").Value
    Cells(4, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
    Cells(4, 40 + i / 2).Value = Range("HeatPrice_LB").Value

    ' Performs sensitivity for the debt to equity ratio
    GoSub SetBaselineValues
    Range("DEBTN").Value = DebtRatioS_Value(i)
    Sheets("Sensitivity Analysis").Select
    Cells(5, 1 + 2 * i / 2).Value = DebtRatioS_Value(i) & _
        "% Debt/" & Chr(10) & (100 - DebtRatioS_Value(i)) & _
        "% Equity"
    Cells(5, 5 + i / 2).Value = Range("RetailPrice").Value
    Cells(5, 12 + i / 2).Value = Range("GridElecPrice").Value
    Cells(5, 19 + i / 2).Value = Range("ProcElecPrice").Value
    Cells(5, 26 + i / 2).Value = Range("HeatPrice").Value
    Cells(5, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
    Cells(5, 40 + i / 2).Value = Range("HeatPrice_LB").Value

    ' Performs sensitivity for the loan interest rate
    GoSub SetBaselineValues
    Range("RDEBTN_CON").Value = DebtIntS_Value(i)
    Range("RDEBTN").Value = DebtIntS_Value(i)
    Sheets("Sensitivity Analysis").Select
    Cells(6, 1 + 2 * i / 2).Value = DebtIntS_Value(i) & _
        "% Interest"
    Cells(6, 5 + i / 2).Value = Range("RetailPrice").Value
    Cells(6, 12 + i / 2).Value = Range("GridElecPrice").Value
    Cells(6, 19 + i / 2).Value = Range("ProcElecPrice").Value
    Cells(6, 26 + i / 2).Value = Range("HeatPrice").Value
```

Figure 37. Sensitivity Macro. (continued)

```vb
Cells(6, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
Cells(6, 40 + i / 2).Value = Range("HeatPrice_LB").Value

' Performs sensitivity for the loan term
GoSub SetBaselineValues
Range("RTERMN").Value = LoanTermS_Value(i)
Sheets("Sensitivity Analysis").Select
Cells(7, 1 + 2 * i / 2).Value = LoanTermS_Value(i) & _
    " year Loan Term"
Cells(7, 5 + i / 2).Value = Range("RetailPrice").Value
Cells(7, 12 + i / 2).Value = Range("GridElecPrice").Value
Cells(7, 19 + i / 2).Value = Range("ProcElecPrice").Value
Cells(7, 26 + i / 2).Value = Range("HeatPrice").Value
Cells(7, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
Cells(7, 40 + i / 2).Value = Range("HeatPrice_LB").Value

' Performs sensitivity for the reactor construction period
GoSub SetBaselineValues
Range("CPN").Value = ConstructionS_Value(i)
Sheets("Sensitivity Analysis").Select
Cells(8, 1 + 2 * i / 2).Value = ConstructionS_Value(i) & _
    " month" & Chr(10) & "Construction Period"
Cells(8, 5 + i / 2).Value = Range("RetailPrice").Value
Cells(8, 12 + i / 2).Value = Range("GridElecPrice").Value
Cells(8, 19 + i / 2).Value = Range("ProcElecPrice").Value
Cells(8, 26 + i / 2).Value = Range("HeatPrice").Value
Cells(8, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
Cells(8, 40 + i / 2).Value = Range("HeatPrice_LB").Value

' Performs sensitivity for the staffing level
If i = 2 Then
    GoSub SetBaselineValues
    Range("Staffing").Value = StaffingS_Value(i)
    Sheets("Sensitivity Analysis").Select
    Cells(9, 1 + 2 * i / 2).Value = StaffingS_Value(i) & _
        " Staffing Plan"
    Cells(9, 5 + i / 2).Value = Range("RetailPrice").Value
    Cells(9, 12 + i / 2).Value = Range("GridElecPrice").Value
    Cells(9, 19 + i / 2).Value = Range("ProcElecPrice").Value
    Cells(9, 26 + i / 2).Value = Range("HeatPrice").Value
    Cells(9, 33 + i / 2).Value = Range("HeatPrice_MMBTU"). _
        Value
    Cells(9, 40 + i / 2).Value = Range("HeatPrice_LB").Value
End If

' Performs sensitivity for the economic recovery period
GoSub SetBaselineValues
Range("ELN").Value = PlantLifeS_Value(i)
Sheets("Sensitivity Analysis").Select
Cells(10, 1 + 2 * i / 2).Value = PlantLifeS_Value(i) & _
    " year Economic" & Chr(10) & "Recovery Period"
Cells(10, 5 + i / 2).Value = Range("RetailPrice").Value
```

Figure 37. Sensitivity Macro. (continued)

```vba
        Cells(10, 12 + i / 2).Value = Range("GridElecPrice").Value
        Cells(10, 19 + i / 2).Value = Range("ProcElecPrice").Value
        Cells(10, 26 + i / 2).Value = Range("HeatPrice").Value
        Cells(10, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
        Cells(10, 40 + i / 2).Value = Range("HeatPrice_LB").Value

        ' Performs sensitivity for the reactor TCI
        GoSub SetBaselineValues
        Range("TCI_Selection").Value = TCIS_Value(i)
        Sheets("Sensitivity Analysis").Select
        Cells(11, 1 + 2 * i / 2).Value = TCIS_Value(i)
        Cells(11, 5 + i / 2).Value = Range("RetailPrice").Value
        Cells(11, 12 + i / 2).Value = Range("GridElecPrice").Value
        Cells(11, 19 + i / 2).Value = Range("ProcElecPrice").Value
        Cells(11, 26 + i / 2).Value = Range("HeatPrice").Value
        Cells(11, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
        Cells(11, 40 + i / 2).Value = Range("HeatPrice_LB").Value

        ' Performs sensitivity for the refueling period
        GoSub SetBaselineValues
        Range("Refuel").Value = RefuelingS_Value(i)
        Sheets("Sensitivity Analysis").Select
        Cells(12, 1 + 2 * i / 2).Value = RefuelingS_Value(i) & _
            " month" & Chr(10) & "Refueling Period"
        Cells(12, 5 + i / 2).Value = Range("RetailPrice").Value
        Cells(12, 12 + i / 2).Value = Range("GridElecPrice").Value
        Cells(12, 19 + i / 2).Value = Range("ProcElecPrice").Value
        Cells(12, 26 + i / 2).Value = Range("HeatPrice").Value
        Cells(12, 33 + i / 2).Value = Range("HeatPrice_MMBTU").Value
        Cells(12, 40 + i / 2).Value = Range("HeatPrice_LB").Value

        ' Iterates to the next value of i
        i = i + 2

    Loop
    i = 0

    ' Runs the baseline value subroutine
    GoSub SetBaselineValues

    ' Pastes the economic variables to their original location
    Sheets("List Info").Select
    Range("A10:G10").Copy Destination:=Range("A8")
    Range("A10:G10").Clear

    ' Selects the sensitivity analysis sheet
    Sheets("Sensitivity Analysis").Select

    ' Initializes count variables
    k = 0
    j = 1
```

Figure 37. Sensitivity Macro. (continued)

```
' Loops through the product prices
Do Until j > 6

    ' Loops through the economic variables
    Do Until k > 8

        ' Sets the negative lower value, this was necessary
        ' as entering an equation in this column created a zero
        ' value on the data label, even if the cell is blank
        If Cells(k + 4, 7 * j - 2).Value = "" Then
            Cells(k + 4, 7 * j).Value = ""
        ElseIf Cells(k + 4, 7 * j - 2).Value = "N/A" Then
            Cells(k + 4, 7 * j).Value = "N/A"
        Else
            Cells(k + 4, 7 * j).Value = _
                -Cells(k + 4, 7 * j - 2).Value
        End If

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

    Loop

    ' Reinitializes k
    k = 0

    ' Determines the minimum value of the lower bound
    MinVal = Application.WorksheetFunction.Min _
        (Range(Cells(4, 7 * j + 3), Cells(12, 7 * j + 3)))
    MinVal = Abs(MinVal)

    ' Determines the maximum value of the upper bound
    MaxVal = Application.WorksheetFunction.Max _
        (Range(Cells(4, 7 * j + 4), Cells(12, 7 * j + 4)))
    MaxVal = Abs(MaxVal)

    ' Sets the scaling value for each product chart
    ScaleV = Application.WorksheetFunction.Max(MinVal, MaxVal)

    ' Determines the corresponding chart name
    ChartNumber = 48 + (j - 1) * 6
    ChartName = "Chart " & ChartNumber

    ' Sets the range for the chart based on the scaling value
    ActiveSheet.ChartObjects(ChartName).Activate
    ActiveChart.Axes(xlValue, xlSecondary).MinimumScale = -ScaleV
    ActiveChart.Axes(xlValue, xlSecondary).MaximumScale = ScaleV
    ActiveChart.Axes(xlValue).MinimumScale = -ScaleV
    ActiveChart.Axes(xlValue).MaximumScale = ScaleV

    ' Determines the corresponding textbox name
    TextBoxNumber = 46 + (j - 1) * 6
```

Figure 37. Sensitivity Macro. (continued)

95

```vba
        TextBoxName = "TextBox " & TextBoxNumber

        ' Writes the appropriate baseline price to the textbox text
        If j < 4 Then
            TextboxText = "Product Selling Price ($/MWe-hr) -" & _
                " Baseline of $" & Cells(3, 7 * j - 2)
        ElseIf j = 4 Then
            TextboxText = "Product Selling Price ($/MWt-hr) -" & _
                " Baseline of $" & Cells(3, 7 * j - 2).Value
        ElseIf j = 5 Then
            TextboxText = "Product Selling Price ($/MMBTU) -" & _
                " Baseline of $" & Cells(3, 7 * j - 2).Value
        ElseIf j = 6 Then
            TextboxText = "Product Selling Price ($/1000-lb) -" & _
                " Baseline of $" & Cells(3, 7 * j - 2).Value
        End If

        ' Sets the text in the text box
        Worksheets("Sensitivity Analysis").Shapes(TextBoxName).Select
        Selection.Characters.Text = TextboxText

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

    Loop

    ' Reinitializes j
    j = 1

    ' Determines which range to sort
    If GridElecS_Value = "Price to Match IRR" Then
        SortRange = "M4:M12"
    ElseIf ProcElecS_Value = "Price to Match IRR" Then
        SortRange = "T4:T12"
    ElseIf ProcHeatS_Value = "Price to Match IRR" Then
        SortRange = "AA4:AA12"
    End If

    ' Sorts by the appropriate range
    Range("A4:AT12").Select
    ActiveWorkbook.Worksheets("Sensitivity Analysis").Sort. _
        SortFields.Clear
    ActiveWorkbook.Worksheets("Sensitivity Analysis").Sort. _
        SortFields.Add Key:=Range(SortRange), SortOn:= _
        xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
    With ActiveWorkbook.Worksheets("Sensitivity Analysis").Sort
        .SetRange Range("A4:AT12")
        .Header = xlGuess
        .MatchCase = False
        .Orientation = xlTopToBottom
        .SortMethod = xlPinYin
        .Apply
    End With
```

Figure 37. Sensitivity Macro. (continued)

```vba
        ' Shows the retail electricity price if the user indicates to
        If RetailPriceDisplay2 = True Then
            Columns("E:K").Hidden = False
        Else
            Columns("E:K").Hidden = True
            Worksheets("Sensitivity Analysis").Shapes("TextBox 46").Select
            Selection.Characters.Text = ""
        End If

        ' Hides the List Info sheet
        Sheets("List Info").Visible = False
        Sheets("List Info").Protect Password:=NGNPPass

        ' Protects the Results summary sheet
        Sheets("Sensitivity Analysis").Protect Password:=NGNPPass

        ' Allows the screen to update again
        Application.ScreenUpdating = True

        ' Message box for user
        Response = MsgBox("Calculations Complete, please click OK" & _
        "", vbOKOnly)

        ' Message box for to copy current results
        Response2 = MsgBox("Would you like to save a copy of the" & _
        " model results?", vbYesNo)
        ' If the user wants to copy the previous results
        If Response2 = vbYes Then

            ' Subroutine for copying previous results
            GoSub CopyResults

        Else
        End If

    Else

        ' Message box for user
        Response = MsgBox("Exiting Macro...", vbOKOnly)

    End If

Else

    ' Message box for user
    Response = MsgBox("Exiting Macro...", vbOKOnly)

End If

' Clears the clipboard
Application.CutCopyMode = False
```

Figure 37. Sensitivity Macro. (continued)

```vb
Exit Sub

' Sets the baseline values specified in the sensitivity user form
SetBaselineValues:

    ' Selects the Project Inputs sheet
    Sheets("Project Inputs").Select

    ' Specifies the baseline values on the Project Inputs sheet
    Range("IRRN").Value = IRRS_Value(1)
    Range("DEBTN").Value = DebtRatioS_Value(1)
    Range("RDEBTN_CON").Value = DebtIntS_Value(1)
    Range("RDEBTN").Value = DebtIntS_Value(1)
    Range("RTERMN").Value = LoanTermS_Value(1)
    Range("CPN").Value = ConstructionS_Value(1)
    Range("ELN").Value = PlantLifeS_Value(1)
    Range("Refuel").Value = RefuelingS_Value(1)

    ' Selects the List Info sheet
    Sheets("List Info").Select

    ' Specifies the baseline values on the List Info sheet
    Range("Staffing").Value = StaffingS_Value(1)
    Range("TCI_Selection").Value = TCIS_Value(1)

Return

' Copies the previous model results to the end of the workbook
CopyResults:

    ' Stops the screen from updating
    Application.ScreenUpdating = False

    ' Determines the number of sheets in the workbook
    SheetNums = ActiveWorkbook.Sheets.Count

    ' Initializes count variables
    CountSheet = 1
    SavedResults = 0

    ' Checks if a saved results sheet exists for numbering
    Do Until CountSheet = SheetNums + 1
        SheetName = ActiveWorkbook.Sheets(CountSheet).Name
        If InStr(SheetName, "Saved Sensitivity") = 0 Then
        Else
            SavedResults = SavedResults + 1
        End If

    ' Progresses to the next sheet
    CountSheet = CountSheet + 1

    Loop
```

Figure 37. Sensitivity Macro. (continued)

```vb
' Reinitializes the count
CountSheet = 1

' Copies the results from the previous run to the end of the workbook
Sheets("Sensitivity Analysis").Select
Sheets("Sensitivity Analysis").Copy _
After:=ActiveWorkbook.Sheets(ActiveWorkbook.Sheets.Count)

' Names the sensitivity results summary sheet
SavedResults = SavedResults + 1
NewSheetName = "Saved Sensitivity " & SavedResults
ActiveSheet.Name = NewSheetName

' Removes the button to run the macro
ActiveSheet.Unprotect Password:=NGNPPass
ActiveSheet.Shapes("Button 1").Select
Selection.Cut

' Clears the clipboard
Application.CutCopyMode = False

' Selects all the cells on the sheet, copies, and pastes the values
Range("A1:Z200") = Range("A1:Z200").Value

' Protects the saved results sheet
ActiveSheet.Protect Password:=NGNPPass

' Allows the screen to update again
Application.ScreenUpdating = True

Return

End Sub
```

Figure 37. Sensitivity Macro. (continued)

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