NGNP-NHS TI-RISK
Revision 0

May 2008

Metallic Component Schedule Risk and Cost Uncertainty Assessment

APPROVALS

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BACKGROUND INTELLECTUAL PROPERTY CONTENT

Section	Title	Description
NONE		NONE

REVISION HISTORY

RECORD OF CHANGES

Revision No.	Revision Made by	Description	Date
A	P. L. Rittenhouse Technology Insights	Final Draft	30 April 2008
0	S. A. Caspersson Westinghouse Electric Company	Final Report	21 May 2008

DOCUMENT TRACEABILITY

Created to Support the Following Document(s)	Document Number	Revision
NONE	NONE	

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ACRONYMS

Acronym	Definition
COP	Core Outlet Pipe
CTF	Component Test Facility
DPP	Demonstration Power Plant
FOAK	First-of-a-Kind
IDC	Interest During Construction
IHX	Intermediate Heat Exchanger
LWR	Light Water Reactor
NGNP	Next Generation Nuclear Plant
NHSS	Nuclear Heat Supply System
PBMR	Pebble Bed Modular Reactor
PCDR	Pre-conceptual Design Report
PHTS	Primary Heat Transport System
RIT	Reactor Inlet Temperature
ROT	Reactor Outlet Temperature
RPV	Reactor Pressure Vessel
V&V	Verification and Validation

SUMMARY AND CONCLUSIONS

This report addresses how key operating parameters and the associated component materials influence both schedule and cost risks for selected metallic components of the PBMR NGNP. Specifically, the components considered in this evaluation are the Intermediate Heat Exchanger (IHX), the vessel containing the IHX, the Reactor Pressure Vessel (RPV), and the Core Outlet Pipe (COP). The key operating parameters considered included the Reactor Outlet Temperature (ROT), the Reactor Inlet Temperature (RIT), the primary system pressure, and the power level.

Schedule Risk

The component schedules developed were compared with a target date for initial plant operation of the end of CY2018. A start date at the beginning of FY2009 for the design and development of all components was assumed without funding, resource, or programmatic constraints.

It was determined that the IHX and its vessel were limiting in terms of schedule for those components evaluated and that the ROT was the key design parameter. Only in the case where the ROT is <760°C can the 2018 initial plant operation date be met with a reasonably high degree of confidence (80%). For ROTs of 900°C and 950°C, the probability of meeting the 2018 date is 20%, and 10%, respectively. Also, initial operation of the 950°C design at lower reactor outlet temperatures was found to have no significant influence on schedule.

The RPV is the next most limiting component in terms of meeting schedule. It meets the 2018 schedule, with probabilities of 88% and 37%, respectively, depending on whether the location is a coastal site or the INL site.

The ROT is the key design parameter for the COP schedule. However, for all cases (<760°C to 950°C) the initial plant operation date is met with 100% probability for this component.

Cost Risk

The IHX and its vessel have high uncertainties in their costs and the cost is highly dependent on and increases with the ROT from <760°C to 950°C. A significant portion of the costs for the 900°C and 950°C systems is associated with the need for periodic replacements of the highest temperature sections of the Ni-base Alloy 617 IHX due to uncertainties in the component lifetime. There is relatively little impact on total cost brought about by operating initially at lower temperatures for those cases where the system is designed for an ROT of 950°C.

The PBMR RPV is a high cost component designed and fabricated using SA-508/SA-533 low-alloy steels, such as employed for the LWR. The uncertainty in its overall cost is, however, very low.

The COP is a relatively low cost component with a risk profile equivalent to that for the IHX. Cost does increase with ROT, but initial operation of the 950°C design at lower temperatures has no effect.

INTRODUCTION

Key reactor operating parameters in conjunction with materials selected for major components of the NGNP Nuclear Heat Supply System (NHSS) have the potential to challenge project cost and schedule requirements and the ability to commercialize NGNP technology. Among the key operating parameters are: (1) Reactor Outlet Temperature (ROT); (2) Reactor Inlet Temperature (RIT); (3) primary system helium pressure and (4) core power level. Related to these parameters, materials-related challenges are a function of the temperatures and configuration of components subjected to high temperatures, including the COP and the Intermediate Heat Exchanger (IHX). Final design selections relative to these parameters will be influenced in no small part by the impact of these selections on overall schedule and cost and their uncertainties.

OBJECTIVES AND SCOPE

The first specific objective of the task addressed in this report is to evaluate and describe how selections made for key operating parameters (temperatures, pressures, etc.) and selected components (RPV, COP, and IHX) influence the schedule for achieving initial operation of the NGNP and the uncertainties in this schedule. This is then compared with a desired 2018 date for initial plant operation. The second specific objective addresses cost and cost uncertainties as functions of these same operating parameters and materials for the same specific set of components, namely the RPV, IHX and COP.

ORGANIZATION OF THE REPORT

The first section of this report briefly describes the assumptions and ground rules that have been made relative to systems, resources, and dates for NGNP operation and for IHX replacements. The report next describes the approaches that have been taken relative to predicting the readiness of major components (IHX, IHX vessel, RPV, and COP) for meeting the schedule for NGNP operation. This is followed by discussion of cost-specific assumptions adopted for estimation of life-cycle costs for the components noted above.

The next section of the report discusses in detail the schedule contributors for each of the major components noted above and how these interact to influence the overall schedule and its uncertainty. The final major section of the report addresses overall life-cycle costs of selected components, including costs for periodic replacement of the high-temperature portion of the IHX and its vessel. Also included are the total development costs for all the metallic components that were addressed. Observations, conclusions and a summary are provided for both the schedule and cost assessments.

1 EVALUATION ASSUMPTIONS

The first assumptions made for this study are that there are no funding, resource or programmatic limitations on the NGNP project beginning at the start of FY2009 (October 1, 2008), and that the target for initial power operation is the end of CY2018. This assumption was made to focus the evaluation on technical aspects of schedule and cost uncertainty for the selected components. Also, consideration of schedules and costs is limited to the intermediate heat exchanger (IHX), IHX vessel, reactor pressure vessel (RPV), and core outlet pipe (COP) metallic components. For each component, schedule and cost are evaluated for operation at nominally 750°C, 900°C and 950°C. These temperatures are characteristic of HTGRs used for electric generation, as well as process steam and cogeneration, steam methane reforming and HyS applications, respectively. Consideration of the two higher temperature options also addresses the potential replacement of IHX sections. The schedule risk assessment addresses both a coastal site and the INL site.

It is also assumed that the PBMR NGNP reference is of the design described in the PCDR and that the design options addressed are based on the range of PBMR PHP designs and take advantage of the engineering and development efforts associated with the PBMR Demonstration Power Plant (DPP) Project. Specific to costs, the RPV and the COP are not considered first-of-a-kind (FOAK) because of their similarity to the same components for the DPP. However, the IHX and its vessel are FOAK. All costs are given in 2008 dollars with no interest during construction (IDC) included; replacement costs, which include the capital costs of replacement components, removal and replacement costs, and costs of lost electric power generation, are discounted back to a 2018 startup. Development costs include those for design, materials qualification, testing and FOAK, but exclude those for the Component Test Facility (CTF). Fully burdened labor is assumed as $300K per year in 2008 dollars.

The scope of the present study does not encompass the many other system, component, and licensing issues associated with the NGNP. These, however, will likely have significant impacts on the overall NGNP schedule and overall NGNP cost. The only allowance that was made for the contributions to schedule from other SSCs was the assumption that each evaluated component was required to be on site and ready for installation at some fixed time prior to plant startup: 30 months prior to startup for the RPV, and 27 months prior to startup for the IHX and its vessel and the COP. When the component was not ready at these specified times, it was considered to not be successfully supporting the 2018 startup schedule.

2 STUDY APPROACH

2.1 Schedule Risk Approach

There are sixteen steps involved in the assessment of schedules and risks associated with missing the target date for NGNP operation for the IHX, IHX vessel, RPV and COP. These are as described below.

1. The design operating parameters (temperatures, pressures and reactor power) and materials applicable to each component were determined and selected. These are detailed in Section 3 for each component.
2. A case to be evaluated for schedule risk for each component was selected for each of the design operating parameters/materials.
3. Contributors to the overall schedule (e.g., design and development and long lead orders) were identified.
4. The consensus of a group of experts was then used to estimate and characterize schedule (e.g. in which sequence should the parts of the schedule be completed and which parts can be done in parallel). For each part of the schedule, the experts arrived at a consensus on the best estimate of the schedule duration and the uncertainty for the first schedule-contributing factor for the first design operating parameter case.
5. Similarly, estimates of schedule durations in terms of best estimates and uncertainties about these estimates were then made for subsequent cases for the first schedule contributor.
6. Next, schedule durations were estimated for the first and subsequent cases based on the second schedule contributor.
7. For the second schedule contributor it was necessary to determine whether it is in series, parallel, or partially in parallel with the first schedule contributor. (The same is true for each subsequent schedule contributor and its predecessor.) If the schedule contributors are partially in parallel, it is necessary to estimate the overlap (the time its start lags the start of a previous contributor's initiation) or un-overlap (the time its completion extends beyond a previous contributor's completion). This involved the creation of criteria for when each schedule contributor could be started, and which tasks had to be completed to begin the subsequent tasks.
8. A Gant Chart with duration estimates for all schedule contributors for each case was then constructed and the structure of the chart was agreed upon by the panel of experts. An example Gant chart for the RPV schedule is shown in Figure 2-1.

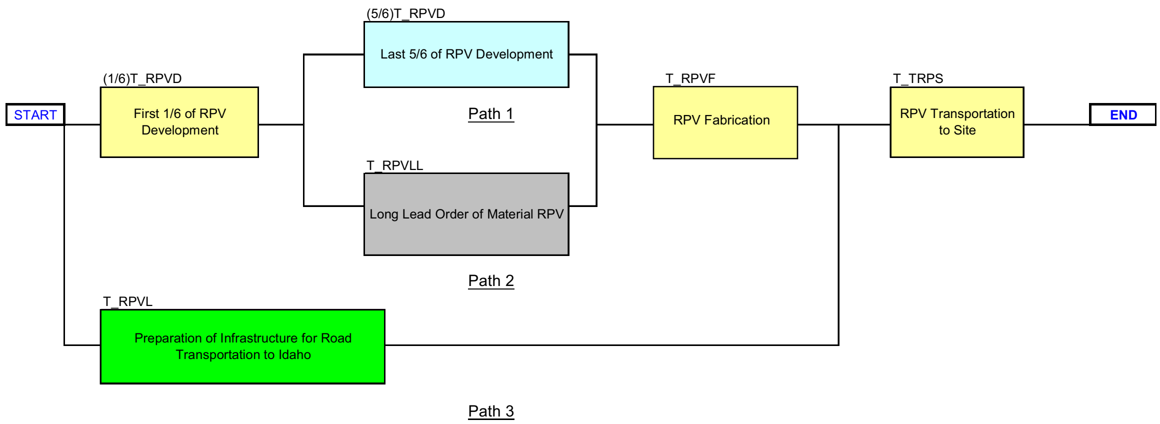

Figure 2-1 Gant Chart for RPV Schedule

9. Cell equations were used to define the total schedule by summing the schedule duration for tasks in series and determining the maximum duration for tasks in parallel. In the event that a given parallel task could not start until a certain fraction of a parallel task was completed, the task was broken into parts so that the part in series and the part in parallel could be resolved. For example the RPV Gant Chart in Figure 2-1 was represented by the following Excel cell equation:

   RPV Schedule Duration=SUM(MAX(SUM((1/6)*T_RPVD,
   MAX((5/6)*T_RPVD,T_RPVLL),T_RPVF),T_RPVL),T_RPVS)

10. Input distributions were assigned to represent the best estimate, upper bound, and lower bound schedules defined by the expert panel for each task and subtask defined in the Gant Chart for each component. In general, triangular distributions were used in which the 5%tile was assigned to the lower bound, the 95%tile was assigned to the upper bound, and the best estimate was assigned to the most likely or peak value of the triangular distribution. An example triangle distribution for the RPV design development schedule is shown in Figure 2-2. This approach is based on the following considerations:

    a. The triangular distribution is a finite distribution and, in practice, there are practical considerations that lead to finite schedules.
    b. Skewed distributions can be easily accommodated using the triangle model
    c. Upper and lower bounds were set at the 95%tile and 5%tile because experts are reluctant to give certain input on 100%tiles and 0%tiles
    d. When input distributions are propagated via Monte Carlo, the results tend to be rather insensitive to the assumed shape of the input distribution.

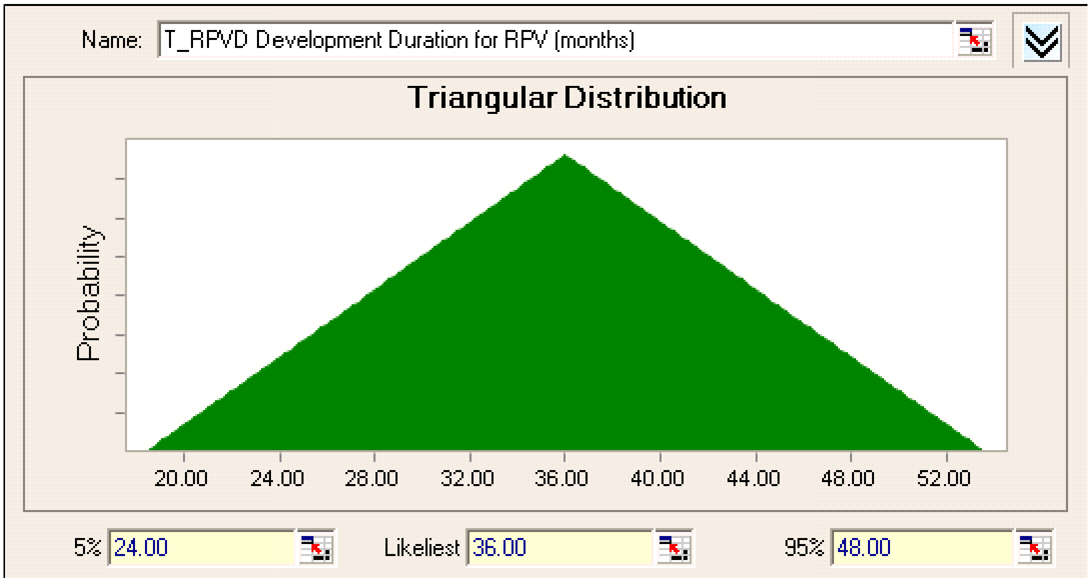

Figure 2-2 Triangle Distribution for RPV Design Development Schedule

11. In the event that the experts assigned one set of estimates for two or more reactor outlet temperature cases, the resulting input distributions were assumed to be fully correlated as there is only one state of the knowledge about the parameters and the expert input was that the schedule parameter was not dependent on the reactor temperature values in question.
12. Separate Gant charts were constructed for the RPV, the COP and for the integrated schedule for the IHX and IHX vessels.
13. In order to make a realistic estimate of the required schedule for each component, it is necessary to establish and agree on the time at which each component needs to be on site to meet the schedule for operation at the end of CY2018. The RPV was assumed to be required to be onsite and ready for installation 30 months prior to the end of CY2018. The IHX and COP were assumed to be required to be on site 27 months prior to the end of CY2018.
14. Finally, the schedule contributors were combined statistically utilizing Monte Carlo uncertainty propagation routines to determine the uncertainty probability distribution on the overall schedule as well as on each parallel path through the Gant Chart.
15. By comparing the parameters and percentiles of the schedule uncertainty distribution to the project schedule requirements, the margins to the target startup date and the probability that the target date is exceeded were quantified.
16. The expert panel was then asked to review the results of the Monte Carlo analysis to confirm that the statistical analysis of the Gant Chart and the input uncertainty distributions that were assigned to each schedule contributor was a satisfactory evaluation of the results of expert elicitation. After several iterations, the analysis was refined and a consensus was reached that the statistical analysis was in alignment with the expert inputs to the evaluation.

The input distributions that were developed for the schedule uncertainty analysis are listed in Table 2-1.

Table 2-1 Input Distributions for Schedule Uncertainty Analysis

Gant Chart	Schedule Parameter Variable Name	Definition	Best Estimate	5%tile	Most Likely	95%tile	Dist. Type
RPV	T_RPVD	RPV Design Development	36	24	36	48	Triangular
	T_RPVLL	RPV Long Lead Order	36	24	36	42	Triangular
	T_RPVF	RPV Fabrication	42	36	42	48	Triangular
	T_RPVS	RPV Transport to Site	6	4.75	6	10.5	Triangular
	T_RPVL	RPV Transport Logistics	60	Treated as fixed value			
COP	T_HDD1	COP Design Development Case COP-1	6	3	6	9	Triangular
	T_HDD2	COP Design Development Case COP -2	6	3	6	12	Triangular
	T_HDD345	COP Design Development Case COP -3, -4, -5	9	6	9	15	Triangular
	T_HDLL	COP Long Lead Order	51	48	51	54	Triangular
	T_HDF	COP Fabrication	20	18	20	26	Triangular
	T_HDS	COP Transport to Site	2	1	2	3	Triangular
IHX + IHX Vessel	T_D1	IHX Design Development –Case IHX-1	36	30	36	48	Triangular
	T_D2	IHX Design Development –Case IHX -2	48	42	48	63	Triangular
	T_D3	IHX Design Development –Case IHX -3, -4, -5	48	45	48	66	Triangular
	T_CC	IHX Code Case Development	12	6	12	18	Triangular
	T_S	IHX Supplier Readiness	6	3	6	9	Triangular
	T_LL	IHX Long Lead Order	15	12	15	18	Triangular
	T_F	IHX Fabrication	24	21	24	30	Triangular
	T_TIHXV	IHX Transport to Site	2	1	2	3	Triangular
	T_VDB	IHX Vessel Development –Case IV-B	36	30	36	48	Triangular
	T_VDA	IHX Vessel Development –Case IV-A	48	42	48	64	Triangular
	T_VLL	IHX Vessel Long Lead Order	30	24	30	42	Triangular
	T_VF	IHX Vessel Fabrication	24	18	24	30	Triangular
	T_TVS	IHX Vessel Transport to Site	2	1	2	3	Triangular
	T_AC	Onsite assembly IHX and IHX Vessel	6	4	6	8	Triangular

2.2 Cost Uncertainty Analysis Approach

The approach to assessment of cost and its uncertainty involved the following steps:

1. The ranges of design and materials parameters applicable to each component were determined. This is identical to what was done in the schedule risk assessment.
2. The second step, as was done in the schedule risk assessment, was to select a case for each of the operating parameters.
3. Next, the contributors to overall cost were determined.
4. Expert consensus was then used to estimate costs and to characterize uncertainties, as explained in detail in the following steps.
5. A cost model was developed in the form of Microsoft Excel equations for the IHX and IHX vessel, the RPV and the COP. The cost model included the following elements:
    a. Development Cost, which was further analyzed by the following categories:
        i. Design Codes and Standards Labor Costs
        ii. Materials Qualification Labor Costs
        iii. Testing and V&V Labor Costs
        iv. Capital and Non-labor Development Costs
    b. Capital Costs of Components
    c. Replacement Costs for IHX A and IHX A Vessel
        i. Capital Costs for Replacement Components
        ii. Loss of Opportunity Power Generation Costs
6. The labor costs under Item 5a were developed from input uncertainty distributions for the labor person-months and a fixed hourly labor rate (See Table 2-3 below). Capital and non-labor costs under Item 5a-iv were developed from input uncertainty distributions.
7. The capital costs of each component were developed from input distributions that were initially normalized against an assumed $ per kWt value (See Table 2-3 below) and then converted to $millions for a fixed thermal power capacity for each component, based on a reactor power of 510MWt.
8. Replacement costs for the high temperature IHX (IHX A) and associated vessel were estimated by first establishing the uncertainty on the number of replacements to be expected in the 60-year lifetime of the plant. The expert panel provided an input uncertainty distribution on the expected lifetime of the component prior to replacement. Then an algorithm was developed to convert this variable component lifetime to an equivalent lifetime that would produce an integral number of components equal to the minimum number of components that would be needed to support 60-years of licensed NGNP plant operation. This integral number of lifetimes was then used to calculate the expected date of each replacement outage, whose duration was also described by an input uncertainty distribution.

Discounting was accomplished by calculating an equivalent number of replacements using the following formulas:

$$ENR_{RPC} = \sum_{j}^{N} \frac{1}{(1+DR)^{T_j}} \qquad (1)$$

$$ENR_{CCR} = \sum_{j}^{N} \frac{1}{(1+DR)^{T_j - 1}} \qquad (2)$$

Where:

ENR_{RPC} = Equivalent number of replacements for discounted replacement power cost

ENR_{CCR} = Equivalent number of replacements for discounted capital replacement cost

DR = annual discount rate

N = number of replacements over the plant lifetime

T_j = time in years from Oct 1, 2008 for the jth outage for IHX replacement

9. The replacement costs were discounted to 2008 dollars using a fixed discount rate of 10% per year. The discount time clock was adjusted forward by 1 year, as shown in Equation (2), to indicate an assumed 1-year period in advance of the replacement outage for ordering the new IHX components. So, for example, if an outage was selected for year 2030, the replacement power costs were calculated by discounting from 2030 to 2008 but the capital costs for the replacement were discounted from 2029 to 2008. The replacement power costs were based on a variable outage duration, expressed by an input uncertainty distribution and then converted to 2008 dollars using an assumed replacement energy cost discounted to 2008 dollars. The replacement capital costs were based on an assumed fraction of the initial capital costs to represent a learning curve and another factor to indicate additional costs of tearing out and removing the radioactively contaminated IHX and vessel, discounted from 1 year prior to the outage to 2008 at a fixed 10% per year discount rate.
10. For Case IHX-1 (ROT<760°C) it was assumed that the initial IHX will last for the lifetime of the plant with no uncertainty assigned. For cases IHX-2 and IHX-5 that are operated for 60 years at constant ROTs of 900°C and 950°C, respectively, mapping of variable component lifetimes to fixed lifetimes was made using the following Table 2-2:

Table 2-2 Variable and Fixed Replacement Lifetimes for Cases IHX-2 and IHX-5

Variable IHX interval Range described by input uncertainty (years)		Discrete Replacement Interval	
Lower	Upper	No. Replacements in 60 year lifetime	Reference Interval (years)
30	>30	1	30.00
20	30	2	20.00
15	20	3	15.00
12	15	4	12.00
10	12	5	10.00
8.6	10	6	8.57
7.5	8.6	7	7.50
6.7	7.5	8	6.67
6	6.7	9	6.00
5.45	6	10	5.45
5	5.45	11	5.00

11. For Case IHX-3, with an initial ROT of < 760°C and a final ROT of 950°C it was assumed that the first replacement outage would be delayed by a fixed 5 year period operating at the lower temperature. This reduces the period available for random replacement outages to 55 years so the model for mapping variable component lifetime to an integral number of replacement outages is given in Table 2-3.
12. For Case IHX-4, with an initial ROT of 900°C and a final ROT of 950°C it was assumed that the first replacement outage would be delayed by a fixed 3 year period operating at the lower temperature. This reduces the period available for random replacement outages to 57 years so the model for mapping variable component lifetime to an integral number of replacement outages is given by Table 2-4.

Table 2-3 Variable and Fixed Replacement Lifetimes for Case IHX-3

Variable IHX interval Range described by input uncertainty (years)		Discrete Replacement Interval	
Lower	Upper	No. Replacements in last 55 years	Reference Interval (years)[Note 1]
27.50	>27.5	1	27.50
18.33	27.50	2	18.33
13.75	18.33	3	13.75
11.00	13.75	4	11.00
9.17	11.00	5	9.17
7.86	9.17	6	7.86
6.88	7.86	7	6.88
6.11	6.88	8	6.11
5.50	6.11	9	5.50
5.00	5.50	10	5.00
4.58	5.00	11	4.58

[1] The first replacement interval begins in operating year 6

Table 2-4 Variable and Fixed Replacement Lifetimes for Case IHX-4

Variable IHX interval Range described by input uncertainty (years)		Discrete Replacement Interval	
Lower	Upper	No. Replacements in last 57 years	Reference Interval (years) [Note 1]
28.50	>28.50	1	28.50
19.00	28.50	2	19.00
14.25	19.00	3	14.25
11.40	14.25	4	11.40
9.50	11.40	5	9.50
8.14	9.50	6	8.14
7.13	8.14	7	7.13
6.33	7.13	8	6.33
5.70	6.33	9	5.70
5.18	5.70	10	5.18
4.75	5.18	11	4.75

[1] The first replacement interval begins in operating year 4

13. Input distributions were assigned to represent the best estimate, upper bound, and lower bound replacement schedules defined by the expert panel for each task and subtask defined in the Gant Chart for each component. In general, triangular distributions were used in which the 5%tile was assigned to the lower bound, the 95%tile was assigned to the upper bound, and the best estimate was assigned to the most likely or peak value of the triangular distribution. An example triangle distribution for the expected component lifetime for IHX A case IHX-2 is shown in Figure 2-3. This approach is based on the following considerations:

    a. The triangular distribution is a finite distribution and in practice there are practical considerations that lead to finite schedules.
    b. Skewed distributions can be easily accommodated using the triangle model
    c. Upper and lower bounds were set at the 95%tile and 5%tile because experts are reluctant to give certain input on 100%tiles and 0%tiles
    d. When input distributions are propagated via Monte Carlo, the results tend to be rather insensitive to the assumed shape of the input distribution.

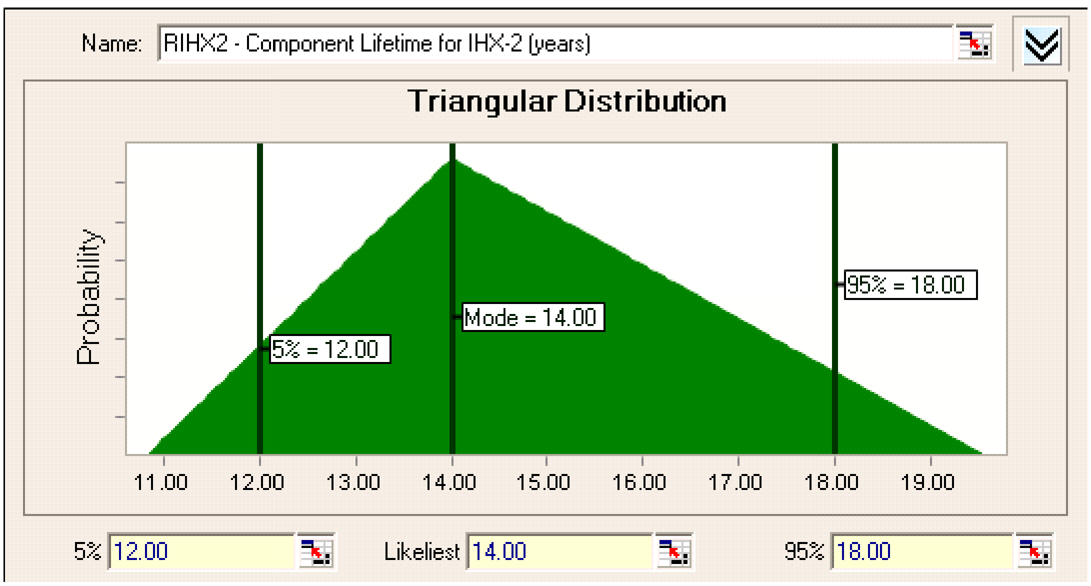

Figure 2-3 Triangle Distribution for Expected IHX A Lifetime for Case IHX-2

14. In the event that the experts assigned one set of estimates for two or more reactor outlet temperature cases, the resulting input distributions were assumed to be fully correlated as there is only one state of the knowledge about the parameters and the expert input was that the schedule parameter was not dependent on the reactor temperature values in question.

15. The input distributions and fixed constants used for the component cost models are shown in Tables 2-5 and 2-6, respectively.

Table 2-5 Input Distributions for Cost Uncertainty Analysis

Cost Model Parameter Variable Name	Definition	Best Estimate	5%tile	Most Likely	95%tile	Dist. Type
DCSIH1	Design, Codes Standards Cost-IHX-1 ($M)	2.58	2.19	2.58	3.44	Triangular
DCSIH2345	Design, Codes Standards Cost-IHX-2, -3, -4, and -5 ($M)	3.45	2.93	3.45	5.75	Triangular
DCSIV1	Design, Codes Standards Cost-IV-1 ($M)	1.20	0.60	1.20	1.50	Triangular
DCSIV23	Design, Codes Standards Cost-IV-2, -3 ($M)	1.50	1.20	1.50	2.10	Triangular
DCSRV	Design, Codes Standards Cost-RV ($M)	0.90	0.60	0.90	1.20	Triangular
DCSHD1	Design, Codes Standards Cost-HD-1 ($M)	1.20	0.90	1.20	1.50	Triangular
DCSHD2	Design, Codes Standards Cost-HD-2 ($M)	1.50	1.20	1.50	2.10	Triangular
DCSHD345	Design, Codes Standards Cost-HD-3, -4, -5 ($M)	0.54	0.36	0.54	0.81	Triangular
MQIH1	Material Qualification - IHX-1 ($M)	1.80	1.53	1.80	2.40	Triangular
MQIH2	Material Qualification - IHX-2 ($M)	4.20	3.57	4.20	6.30	Triangular
MQIH345	Material Qualification - IHX-3, -4, -5 ($M)	4.56	3.88	4.56	6.84	Triangular
MQIV1	Material Qualification - IV-1 ($M)	0.60	0.45	0.60	0.75	Triangular
MQIV23	Material Qualification - IV-2, -3 ($M)	0.90	0.75	0.90	1.05	Triangular
MQRV	Material Qualification – RV ($M)	0.30	0.23	0.30	0.60	Triangular
MQHD345	Material Qualification - HD-3, -4, -5 ($M)	1.20	0.90	1.20	1.80	Triangular
TVVIH12345	Testing and V&V - IHX-1, -2, -3, -4, -5 ($M)	1.56	1.33	1.56	2.08	Triangular
TVVIV1	Testing and V&V - IV-1 ($M)	0.60	0.45	0.60	0.90	Triangular
TTVIV23	Testing and V&V - IV-2, -3 ($M)	1.50	1.20	1.50	1.80	Triangular
TTVHD345	Testing and V&V - HD-2, -3, -4, -5 ($M)	1.20	0.90	1.20	1.80	Triangular
CNLIH1	Capital and Non-Labor Cost - IHX-1 ($M)	1.70	1.45	1.70	2.55	Triangular
CNLIH2	Capital and Non-Labor Cost - IHX-2 ($M)	2.40	2.04	2.40	4.80	Triangular
CNLIH345	Capital and Non-Labor Cost - IHX-3, -4, -5 ($M)	2.40	2.04	2.40	4.80	Triangular
CNLRV	Capital and Non-Labor Cost – RV ($M)	1.50	1.00	1.50	3.00	Triangular
CNLIV1	Capital and Non-Labor Cost - IV-1 ($M)	1.00	0.50	1.00	2.00	Triangular
CNLIV23	Capital and Non-Labor Cost - IV-2, -3 ($M)	2.00	1.50	2.00	4.00	Triangular
CNLHD345	Capital and Non-Labor Cost - HD-3, -4, -5 ($M)	2.00	1.50	2.00	4.00	Triangular
CCFIH1	Capital Cost Adjustment factor - IH-1	1.00	0.80	1.00	1.30	Triangular
CCFIH2345	Capital Cost Adjustment factor - IH-2A, -3A, -4A, -5A	2.40	2.00	2.40	3.00	Triangular
CCFIHB	Capital Cost Adjustment factor - IH-2B, -3B, -4B, -5B	1.20	1.00	1.20	1.50	Triangular
CCFIV1	Capital Cost Adjustment factor - IV-1	1.00	0.90	1.00	1.20	Triangular
CCFIV23	Capital Cost Adjustment factor - IV-2A, -3A	2.00	1.80	2.00	2.50	Triangular
CCFIVB	Capital Cost Adjustment factor - IV-2B, -3B	1.20	1.10	1.20	1.40	Triangular
CCFRV	Capital Cost Adjustment factor - RV	1.00	0.90	1.00	1.20	Triangular
CCFHD1	Capital Cost Adjustment factor - HD-1	1.00	0.90	1.00	1.20	Triangular
CCFHD2	Capital Cost Adjustment factor - HD-2	1.20	1.00	1.20	1.50	Triangular
CCFHD345	Capital Cost Adjustment factor - HD-3, -4, -5	1.40	1.20	1.40	1.80	Triangular
RIHX2	IHX and IHX vessel replacement interval - IH-2 (years)	14.00	12.00	14.00	18.00	Triangular
RIHX345	IHX and IHX vessel replacement interval - IH-3, -4, -5 (years)	8.00	6.00	8.00	12.00	Triangular
OCF	IHX Replacement Outage Duration (months)	3.00	2.00	3.00	4.00	Triangular

Table 2-6 Constants Assumed in Cost Uncertainty Analysis

Name	Value	Description	Units
LR	300	Labor Rate	$K/man-year
DR	0.1	Discount Rate per year	no units
RIF	1.4	IHX Removal Installation Factor (for replacements)	no units
LF	0.7	IHX Cost learning factor (for replacements)	no units
CCIH	45	IHX Capital Cost -nominal	$/kWt
CCIV	20	IHX Vessel Capital Cost - nominal	$/kWt
CCHD	10	COP Capital Cost - nominal	$/kWt
RPW	510	Reactor Thermal Power	MWt
OCN	8.5	Outage cost - non discounted	$M/month
IAPW	160	IHX A Thermal Power	MWt
IBPW	350	IHX B Thermal Power	MWt

16. The cost contributors are then combined statistically utilizing Monte Carlo routines to determine the respective probability uncertainty distributions. From these distributions, the means and selected percentiles are used to describe the key parameters of the uncertainty. Both frequency and cumulative distribution function charts are used to document the results.

Additional factors related to cost are involved for those cases where the replacement of the high temperature IHX (i.e., IHX A) and its vessel is anticipated due to uncertainties in the component lifetimes of this high temperature component. In terms of the replacement cost for IHX A, a cost factor of 1.4 is applied to the capital cost of the IHX to account for its removal and subsequent replacement. A further "learning curve" cost factor of 0.7 is applied to account for experience gained relative to the original installation of this FOAK component. Other items associated with these cost estimates for replacement of the IHX include:

- The replacement IHX and its vessel are of the same material and design as the original and must be acquired 1 year before its replacement.
- The number of replacements will be an integral number based on the uncertainty in the component lifetime and the minimum number of components required to support an assumed 60-year reactor operating life. The outages for replacement are assumed not to be aligned with planned maintenance outages.
- The replacement costs include the capital costs for replacement, as described above, plus a loss of opportunity generation (replacement power costs) based on an uncertainty input on the duration of the forced outages for replacements and an assumed $8.5M per month for replacement power.
- IHX life extensions of 5 years and 3 years are assumed for the initial installations of the 950°C designs (Cases IHX-3 and IHX-4) when they are initially operated at 760°C and 850°C, respectively.

3 SCHEDULE RISK ASSESSMENT

This section of the report describes and discusses the schedule evaluation for each of the selected metallic components (i.e., the IHX, the IHX vessel, the RPV and the COP)

3.1 IHX and IHX Vessel Schedule Risk

3.1.1 IHX Operating and Design Parameters and Associated Materials

The operating parameters considered for the IHX and its vessels were the reactor outlet temperature (ROT), the reactor inlet temperature (RIT), primary system helium pressure and reactor power. In the cases where the IHX design temperature is <760°C, its material of construction is Fe/Ni-base Alloy 800H; in all other cases the material is Ni-base Alloy 617.

The cases evaluated for the IHX are shown in Table 3-1. Note that constant values for RIT (350°C), primary system pressure (9 MPa), and reactor power (510MWt) are assumed. Changes to these parameters do not appear to provide benefits in terms of schedule risk reduction. Further, these operating parameters are consistent with utilization of the DPP reactor unit and there is little flexibility for change.

Case IHX-1 in Table 3-1 is for an IHX designed for and operated at <760°C. This would be a single IHX unit constructed of Alloy 800H. Case IHX-2 is for a split unit, IHX A and IHX B, with IHX B operated as for Case IHX-1 and IHX A designed for and operated at 900°C using Alloy 617. The IHXs for Cases IHX-3, IHX-4 and IHX-5 are all designed for operation of IHX A at 950°C, but initial operation in Cases IHX-3 and IHX-4 is at temperatures of <760°C and 850°C, respectively.

Table 3-1 Operating Parameter Cases Evaluated for the IHX

Case	Design / Initial Operating Parameters				Materials
	RIT	Power Level	Primary Press.	ROT	
	(C)	(MWt)	(MPa)	(C)	
IHX-1	350	500	9	<760 / <760	800H
IHX-2				900 / 900	IHX A - 617 IHX B - 800H
IHX-3				950 / <760	IHX A - 617 IHX B - 800H
IHX-4				950 / 850	IHX A - 617 IHX B - 800H
IHX-5				950 / 950	IHX A - 617 IHX B - 800H

3.1.2 IHX Schedule Contributors

Contributors to the schedules for the IHX cases are shown in tabular form in Table 3-2. They include durations for design & development, code case development and licensing, supplier readiness, long lead orders, and transportation to the reactor site.

Table 3-2 Schedule Contributors for Cases IHX-1 through 5

Case	Design / Initial Operating Parameters					Contributors to Schedule (expected values and uncertainty distributions to be assessed)					
	ROT	RIT	Power Level	Primary Press.	Mat'ls	Development	Code Case Development	Supplier Readiness	Long Lead Orders	Fabrication	Transportation
	(C)	(C)	(MWt)	(MPa)		(Months)					
IHX-1	<760 / <760				800H						
IHX-2	900 / 900				IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-3	950 / <760	350	500	9	IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-4	950 / 900				IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-5	950 / 950				IHX A - 617						
					IHX B - 800H	same as case IHX-1					

3.1.2.1 Design and Development

The best estimates and upper and lower bounds for the durations of IHX design and development are shown in Table 3-3. Notice that the best estimate for IHX-1 (Alloy 800H IHX only) is 12 months less than those for IHX-2 through 5 that employ Alloy 617 in IHX A and Alloy 800H in IHX B. Notice also in these cases that the differences between the best estimate and the 95% upper bound are significantly greater than those between the best estimate and the 5% lower bound.

Table 3-3 Durations of IHX Design and Development

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / 760C	800H	30	36	42
IHX-2 ROT 900C / 900C	IHX A 617	42	48	63
IHX-3 ROT 950C / <760C	IHX A 617	45	48	66
IHX-4 ROT 950C / 850C	IHX A 617	45	48	66
IHX-5 ROT 950C / 950C (Reference)	IHX A 617	45	48	66

3.1.2.2 Code Development

The best estimates and upper and lower bounds for the durations of IHX code development are shown in Table 3-4. The best estimate for IHX-1 (Alloy 800H IHX only) is 12 months less than those for IHX-2 through 5 that employ Alloy 617 in IHX A and Alloy 800H in IHX B. For all of these cases the delta in time between the best estimates and the upper and lower bounds are equivalent. Initial operating parameters have no impact. Table 3-5 shows the best estimates and bounds for additional time to complete Code Case development subsequent to the completion of design and development. This duration is defined as the "unoverlap" and is the same for all cases.

Table 3-4 Durations of IHX Code Case Development

Design /Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate Duration (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C /760C	800H	24	30	42
IHX-2 ROT 900C /900C	IHX A 617	36	42	54
IHX-3 ROT 950C /<760C	IHX A 617	36	42	54
IHX-4 ROT 950C /850C	IHX A 617	36	42	54
IHX-5 ROT 950C /950C (Reference)	IHX A 617	36	42	54

3.1.2.3 Supplier Readiness

Table 3-6 gives the best estimates and upper and lower bounds of times to achieve supplier readiness for the IHX. They are equivalent in all cases. Supplier readiness is partially in parallel with code case development.

Table 3-5 Durations for IHX Code Case Development Partially in Parallel with Design and Development

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate Unoverlap (Add'l. Time to Complete Code Case Dev. after Design & Dev.) (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / 760C	800H	6	12	18
IHX-2 ROT 900C / 900C	IHX A 617	6	12	18
IHX-3 ROT 950C / <760C	IHX A 617	6	12	18
IHX-4 ROT 950C / 850C	IHX A 617	6	12	18
IHX-5 ROT 950C / 950C (Reference)	IHX A 617	6	12	18

Table 3-6 Durations of Supplier Readiness for the IHX

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / 760C	800H	21	24	30
IHX-2 ROT 900C / 900C	IHX A 617	21	24	30
IHX-3 ROT 950C / <760C	IHX A 617	21	24	30
IHX-4 ROT 950C / 850C	IHX A 617	21	24	30
IHX-5 ROT 950C / 950C (Reference)	IHX A 617	21	24	30

3.1.2.4 Long Lead Orders

The schedule durations for long lead orders for materials of the IHX are shown in Table 3-7. Long lead orders are partially in series with design and development and their durations and upper and lower bounds are identical for all cases.

Table 3-7 Durations of Long Lead Orders for the IHX

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate to Complete after Design & Dev (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C /760C	800H	12	15	18
IHX-2 ROT 900C /900C	IHX A 617	12	15	18
IHX-3 ROT 950C /<760C	IHX A 617	12	15	18
IHX-4 ROT 950C /850C	IHX A 617	12	15	18
IHX-5 ROT 950C /950C (Reference)	IHX A 617	12	15	18

3.1.2.5 Fabrication

Table 3-8 shows schedule durations and upper and lower bounds for fabrication of IHXs for IHX-1 through 5. They are the same for all of the cases. Fabrication is in series with supplier readiness.

3.1.2.6 Transportation

Table 3-9 gives the best estimates and upper and lower bounds for the transportation of the IHX to the reactor site. Because of the relatively small size of the IHX units it is assumed that there would be no difference in schedule between a coastal site and the INL site. The schedules are identical for all of the cases. Transportation is in series with fabrication.

Table 3-8 Durations of IHX Fabrication

Design /Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C /760C	800H	21	24	30
IHX-2 ROT 900C /900C	IHX A 617	21	24	30
IHX-3 ROT 950C /<760C	IHX A 617	21	24	30
IHX-4 ROT 950C /850C	IHX A 617	21	24	30
IHX-5 ROT 950C /950C (Reference)	IHX A 617	21	24	30

Table 3-9 Durations of Transportation

Design /Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C /760C	800H	1	2	3
IHX-2 ROT 900C /900C	IHX A 617	1	2	3
IHX-3 ROT 950C /<760C	IHX A 617	1	2	3
IHX-4 ROT 950C /850C	IHX A 617	1	2	3
IHX-5 ROT 950C /950C (Reference)	IHX A 617	1	2	3

3.1.3 IHX Vessel Schedule Contributors

There are two IHX vessel cases as shown in Table 3-10. In IV-1 the ROT is <760°C and in IV-2 it is 950°C. The RIT, reactor power level, and primary system pressure are identical for both cases. The vessel material is conventional SA-508/SA-533 low-alloy steel for both.

Table 3-11 provides the schedule estimates for all of the schedule contributors. For example, note under "Design Development" for IV-1 the numerals 36-6+12. This can be read as a best estimate duration of 36 months with a 5% lower bound of 30 months and a 95% upper bound of 48 months. The best estimate for design development for IV-2 is 12 months longer. No code case development is required and all other schedule contributors are the same for both cases. The IHX vessel and the IHX internals are needed at the reactor site 27 months prior to 2018 initial plant operation.

Table 3-10 IHX Vessel Matrix of Cases

	Operating Parameters & Corresponding Mat'ls				
Case	**ROT**	RIT	Power Level	Primary Pressure	Mat'ls
	(C)	**(C)**	(MWt)	(MPa)	
IV-1	**<760**	350	500	9	IHX B 508/533
IV-2	**950**	350	500	9	IHX A 508/533

Table 3-11 Schedule Contributors to IHX Vessel

Case	**ROT**	**RIT**	Power Level	Primary Pressure	Mat'ls	**Design Development**	**Code Case Development**	**Long Lead Orders**	**Fabrication**	**Transportation**	**Assembly**
	(C)	**(C)**	(MWt)	(MPa)		**(Months)**					
IV-1	**<760**	**350**	510	9	IHX B 508/533	36-6+12	nil	30-6+12/ start after 25% dev	24-6+6/ starts after long lead order	2-1+1/ after fab	6-2+2/ after asembly, max from IHX
IV-2	**950**	**350**	510	9	IHX A 508/533	48-6+18	nil	30-6+12/ start after 25% dev	24-6+6/ starts after long lead order	2-1+1/ after fab	6-2+2/ after asembly, max from IHX

3.1.4 Overall IHX and IHX Vessel Schedule Logic

The integrated IHX and IHX Vessel schedule is shown as a Gant Chart in Figure 3-1. Paths 1 and 2 are for the IHX and paths 3 and 4 are for the IHX vessel. Which of these paths is the schedule critical path is determined by the technical approach described below.

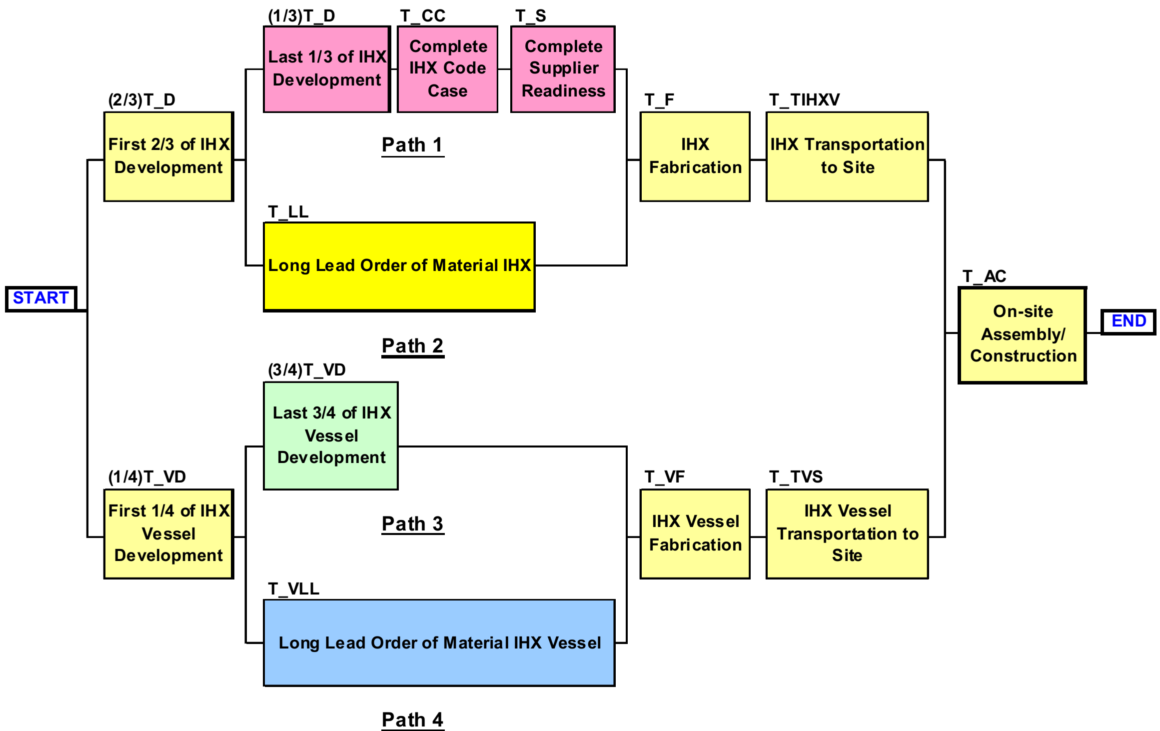

Figure 3-1 Gant Chart for the Integrated IHX and IHX Vessel Schedule

The durations of all the IHX and IHX Vessel schedule contributors are modeled as triangular distributions. The best estimate value is assigned to the mode (most likely value) and the upper and lower bounds are set to the 5%-tile and 95%-tile values. The Gant Charts are then converted to cell equations in Excel spreadsheets with the sum used to model tasks in series and the maximum used to model tasks in parallel. Start times for tasks done in parallel were provided by an expert panel and only non-overlapping parts of overlapping tasks shown in series were modeled. Separate models were used for the overall schedule as well as for each path through the Gant Chart. Monte Carlo techniques and Crystal Ball software were applied in 10,000 simulations.

3.1.5 IHX and IHX Vessel Schedule Risk

The overall schedule for IHX-1 with vessel IV-1 is shown in Figure 3-3. The mean value for completion of this IHX/vessel combination is ~90 months versus an available time of 96 months (denoted as the certainty minimum in the figure) before 2018 operation for an expected margin of 6 months. The probability of exceeding the allotted time is ~20%. Thus, the certainty of meeting the schedule is ~80%.

The overall schedule risk for IHX-2 with IV-2 (900°C ROT) is given in Figure 3-4. In this instance the mean is ~103 months and the probability of not achieving operation in 2018 is

~79%. Thus, in this case there is no expected margin (negative 7 months) and the certainty of meeting the schedule is only 21%.

Figure 3-5 gives the schedule risk for IHX-3 through 5 with IV-2 (950°C). The mean schedule value has increased slightly to ~105 months and the probability of not achieving 2018 operation is ~87%. These cases also are not expected to meet the target schedule.

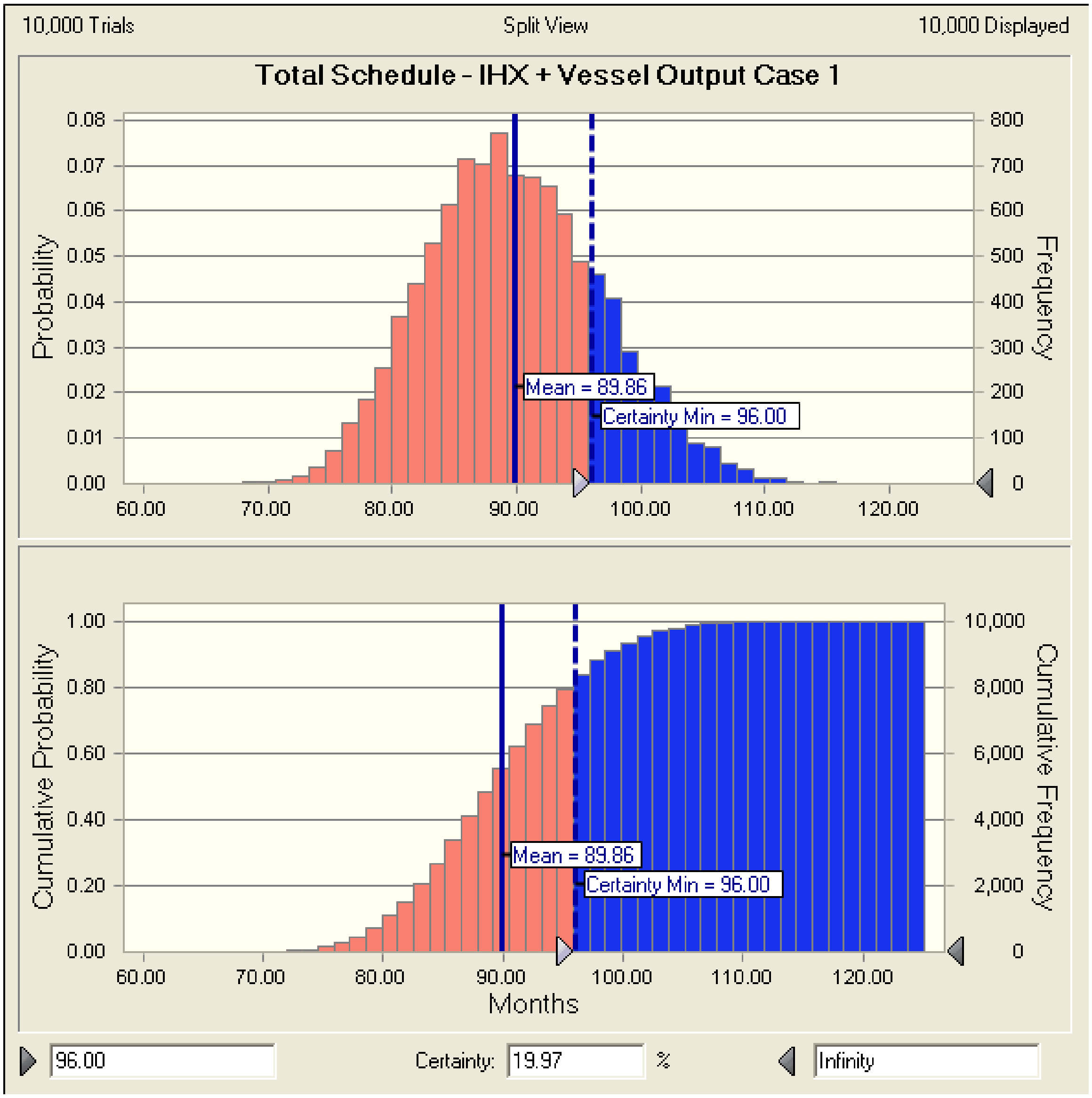

Figure 3-2 Overall Schedule Risk for IHX-1 and IV-1

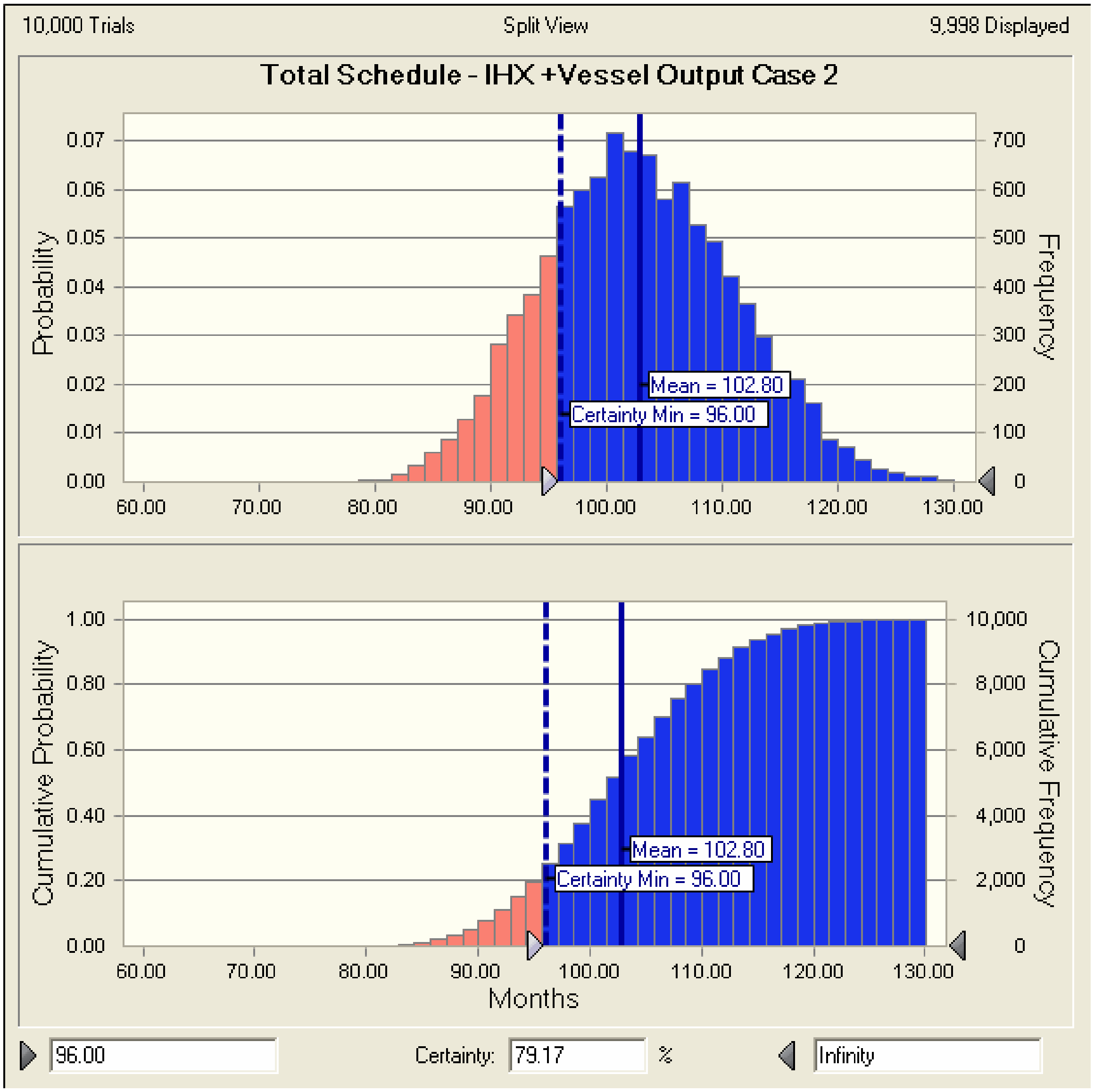

Figure 3-3 Overall Schedule Risk for IHX-2 and IV-2

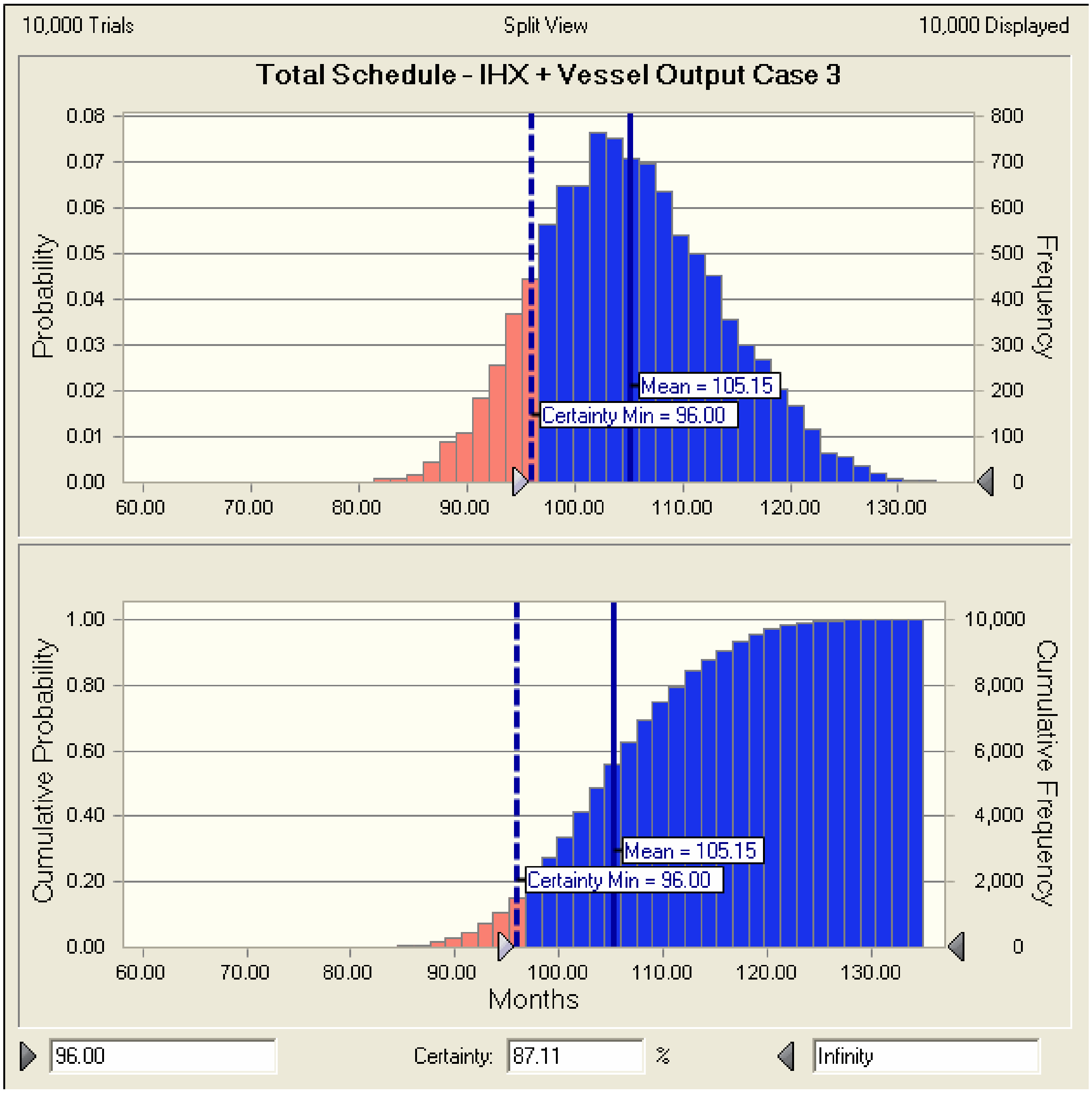

Figure 3-4 Overall Schedule Risk for IHX-3 to IHX-5 and IV-2

A summary of the integrated IHX and IHX vessel schedule risk results is provided in Table 3-12. Gant Charts in Figure 3-1 show the four paths relative to the combined schedules for the IHX and its vessel. The schedule durations for each of these paths for the three Output Cases (IHX Case IHX-1 + IHX Vessel Case IV-1, IHX Case IHX-2 + IHX Vessel Case IV-2, and IHX Cases IHX-3 through IHX-5 + IHX Vessel Case IV-2) are documented in Table 3-12. Note that Path 1 (design and development + code case development + supplier readiness) fixes the total or critical schedule for each of the output cases. The mean critical durations range from ~90 months for Output Case 1 to ~105 months for Output Case 3. Further, the probabilities for achieving operation in 96 months (the year 2018) track with the IHX results: ~80% for Output Case 1 to ~13% for Output Case 3. Thus, only Output Case 1 (<760°C ROT) has a reasonable expectation of operation in 2018. The others, with higher ROTs, have very low probabilities for operation in 2018, even when initial operation is postulated for lower temperatures.

Table 3-12 Summary of IHX and IHX Vessel Schedule Risk Results

Output Case	IHX Case	IHX Vessel Case	Gant Chart Path	Schedule Duration in Months					Probability ≥ 96mo
				Best Estimate	5%tile	50%tile	Mean	95%tile	
1	IHX-1	IV-1	Total Schedule	86	78.8	89.4	89.9	101.9	20.0%
			Path 1	86	77.6	89.4	89.6	101.9	
			Path 2	71	65.7	73.8	73.8	82.3	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	
2	IHX-2	IV-2	Total Schedule	98	89.9	102.5	102.8	116.7	79.2%
			Path 1	98	89.9	102.5	102.8	116.7	
			Path 2	79	74.0	82.4	82.6	92.0	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	
3	IHX-3,4,5	IV-2	Total Schedule	98	92.5	104.6	105.1	119.5	87.1%
			Path 1	98	92.5	104.6	105.1	119.5	
			Path 2	79	75.6	83.9	84.2	93.8	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	

Finally, it was stated in Section 3.1.1 that changes to operating parameters such as RIT, primary system pressure, and reactor power level would not appear to provide schedule risk benefits. For example, it can be seen from the information in Table 3-13 that reducing the reference reactor power level by 50% would have little or no effect on schedule.

Table 3-13 Sensitivity of IHX Schedule to Reactor Power Level

Schedule Contributor on Critical Path (Path 1)	Range of Best Estimate Durations for Cases at 500MWt (mo)	Impact of 250MWt
Design & Development	36-48	Not a function of size
Code Case Development (unoverlap)	12	Not a function of size
Supplier Readiness (unoverlap)	6	IHX size not limiting
Fabrication	24	IHX size not limiting
Transportation to IHX Vessel	2	IHX size not limiting
Transportation to Site	2	IHX size not limiting
Assembly /Construction at Site	6	Potential for savings

3.2 Reactor Vessel Schedule Risk

3.2.1 RPV Operating and Design Parameter and Associated Materials

Table 3-14 shows the single case (RV-1) considered in the present evaluation of the RPV schedule for the NGNP. Neither the ROT, RIT, primary system helium pressure nor reactor power level significantly influence the schedule risk for the RPV, and the latter three parameters are consistent with the utilization of developed and developing DPP technology, including the use of conventional Class SA-508/SA-533 materials.

Table 3-14 Reactor Pressure Vessel Operating Parameters and Materials

	Operating Parameters & Corresponding Mat'ls				
Case	ROT (C)	**RIT (C)**	Power Level (MWt)	Primary Pressure (MPa)	Mat'ls
RV-1	950	**350**	500	9	508/533

3.2.2 RPV Schedule Contributors

Schedule contributors for the RPV include design development, long lead orders, fabrication, and transportation. Best estimates and 5% and 95% ranges for the durations of these activities are shown in Table 3-15 for transportation to a coastal site and in Table 3-16 for the INL site. For design development, for example, the best estimate is 36 months with a 5% lower bound of 24 months and a 95% upper bound of 48 months. Long lead orders can be placed 6 months into design development and its duration is 24 to 42 months with a best estimate of 30 months. The other significant activity in terms of schedule is fabrication with a range of 36 to 48 months and a best estimate of 42 months. The time to develop the RPV transportation infrastructure for the INL site was assessed as 60 months. Since this path was far off the critical path for the RPV, no uncertainty in this figure was assigned. Note that there is no code case development required.

Table 3-15 RPV Schedule Contributors for a Coastal Site

Case	ROT	**RIT**	Power Level	Primary Pressure	Mat'ls	**Design Development**	**Code Case Development**	**Long Lead Orders**	**Fabrication**	**Transportation**
	(C)	**(C)**	(MWt)	(MPa)		**(Months)**				
RV-1	950	**350**	500	9	508/533	36-12+12	nil	30-6+12, after 6 mos of development	42-6+6	2-1+1

Table 3-16 RPV Schedule Contributors for INL Site

Case	ROT	**RIT**	Power Level	Primary Pressure	Mat'ls	**Design Development**	**Code Case Development**	**Long Lead Orders**	**Fabrication**	**Transportation**
	(C)	**(C)**	(MWt)	(MPa)		**(Months)**				
RV-2	950	**350**	500	9	508/533	36-12+12	nil	30-6+12, after 6 mos of development	42-6+6	6-1.25+4.5

3.2.3 Overall RPV Schedule Logic

The scheme and modeling logic for the RPV schedule are as described for the IHX and its vessel in Section 3.1.4. The Gant Chart for the RPV to a coastal site is given below as Figure 3-5. Paths 1 and 2 lead to equivalent schedule end points. Figure 3-6 provides the corresponding Gant Chart for the RPV to the INL site. An additional path is provided for the necessary preparation of the infrastructure (e.g., roads, bridges and tunnels).

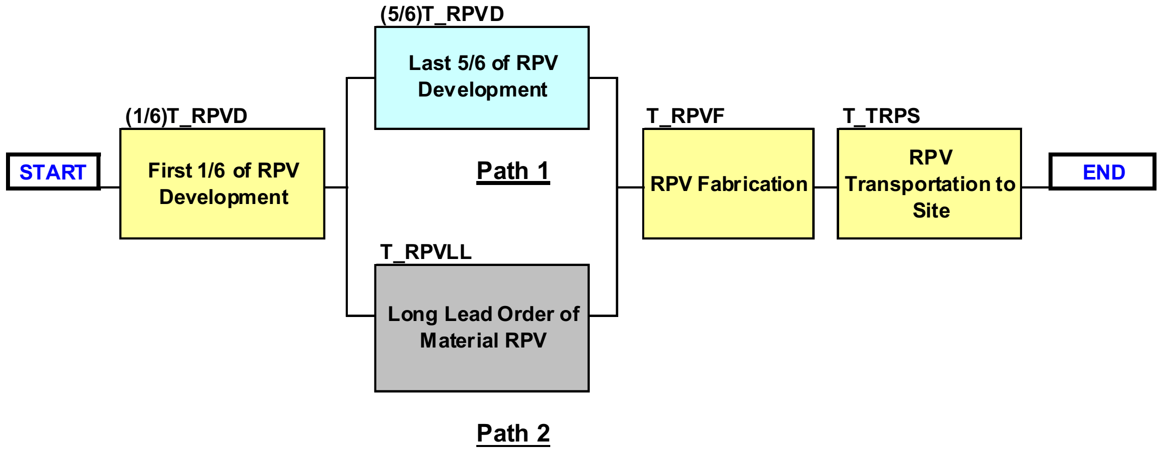

Figure 3-5 Gant Chart for the RPV Schedule for a Coastal Site

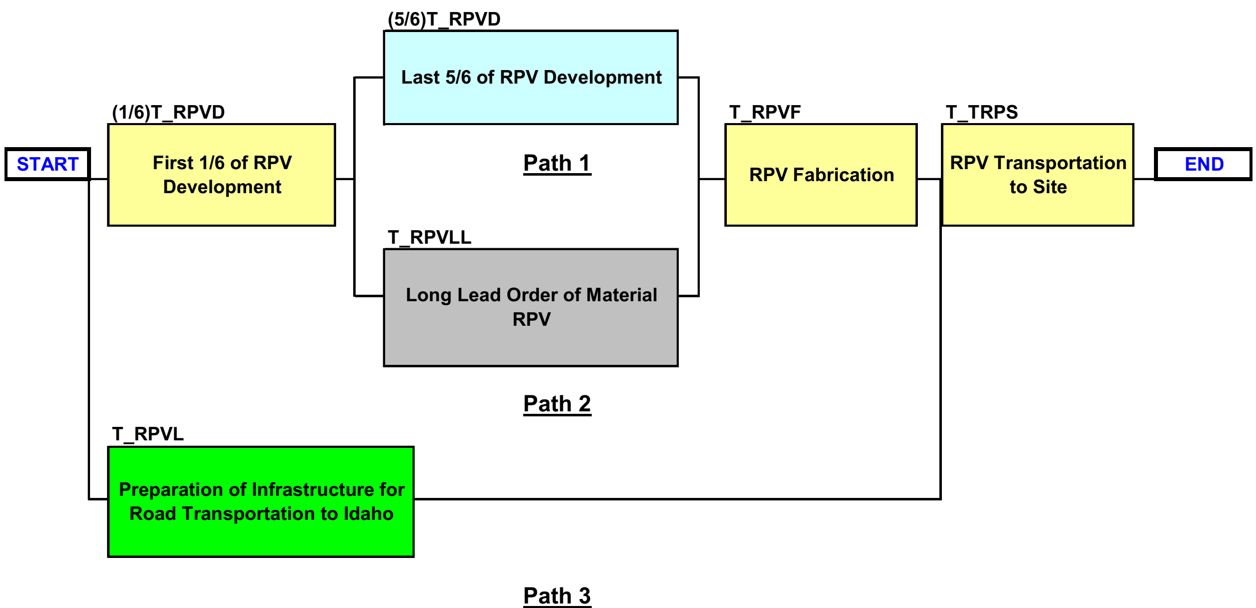

Figure 3-6 Gant Chart for the RPV Schedule for the INL Site

3.2.4 RPV Schedule Risk

The schedule risk for the single RPV case treated is shown in Figure 3-7. First, the RPV is required at the reactor site 30 months prior to operation. This would be month 93 (see Certainty Minimum in Figure 3-7) from the beginning of FY2009. The mean value of time for the RPV schedule is ~85.5 months. Thus, there is an expected margin of ~7.5 months and a probability of nominally 88% for achieving the target for operation in 2018 for a coastal site.

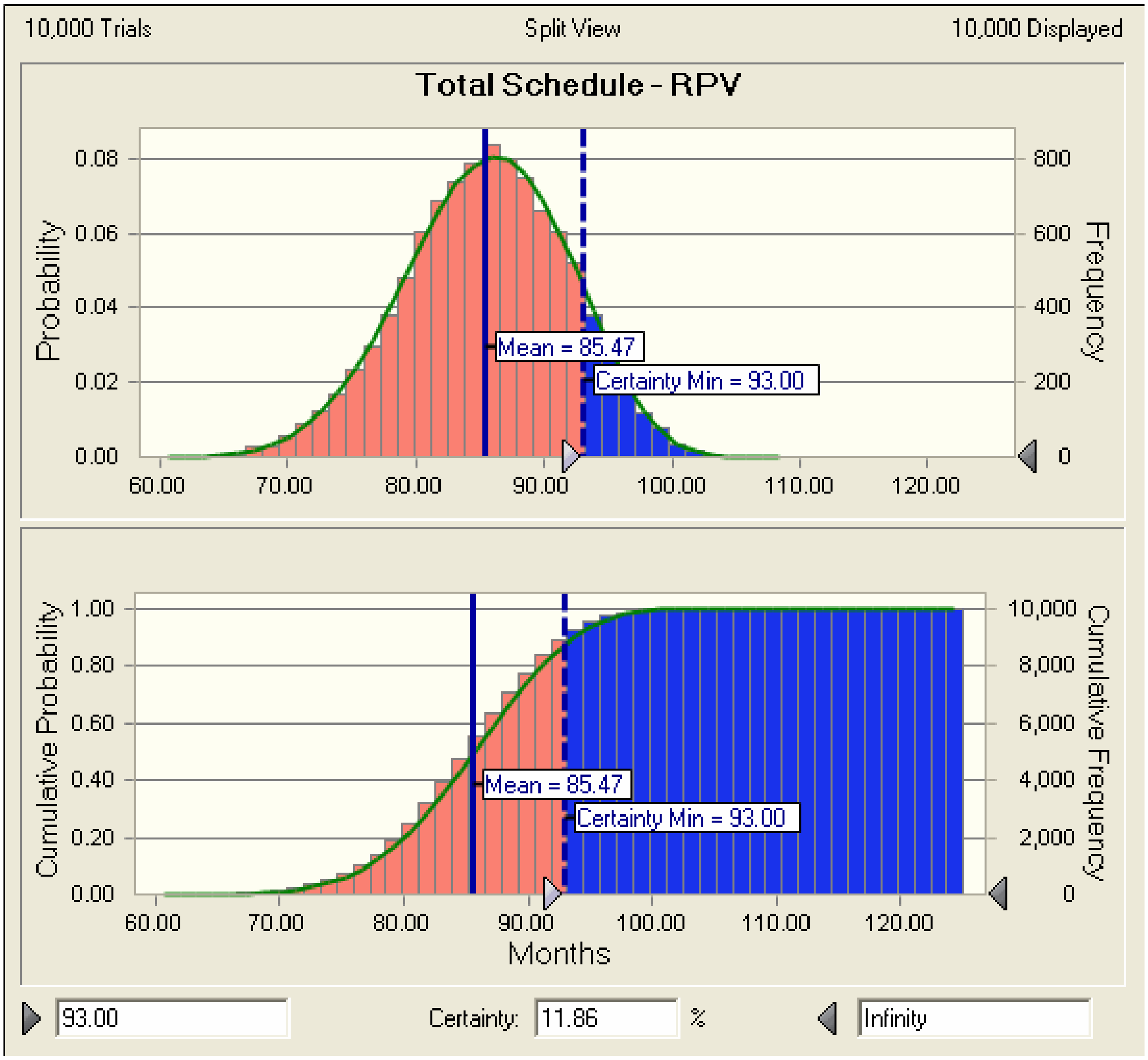

Figure 3-7 Schedule Risk for the RPV at a Coastal Site

The corresponding figure for the INL site is shown in Figure 3-8. With the longer transportation time, the expected margin is only ~2 months, and the probability of achieving initial plant operation drops to nominally 63%.

The use of conventional LWR vessel material (i.e., SA-508/SA-533 low-alloy steel) and the adoption of DPP technology are key reasons that the target operation date should be achieved.

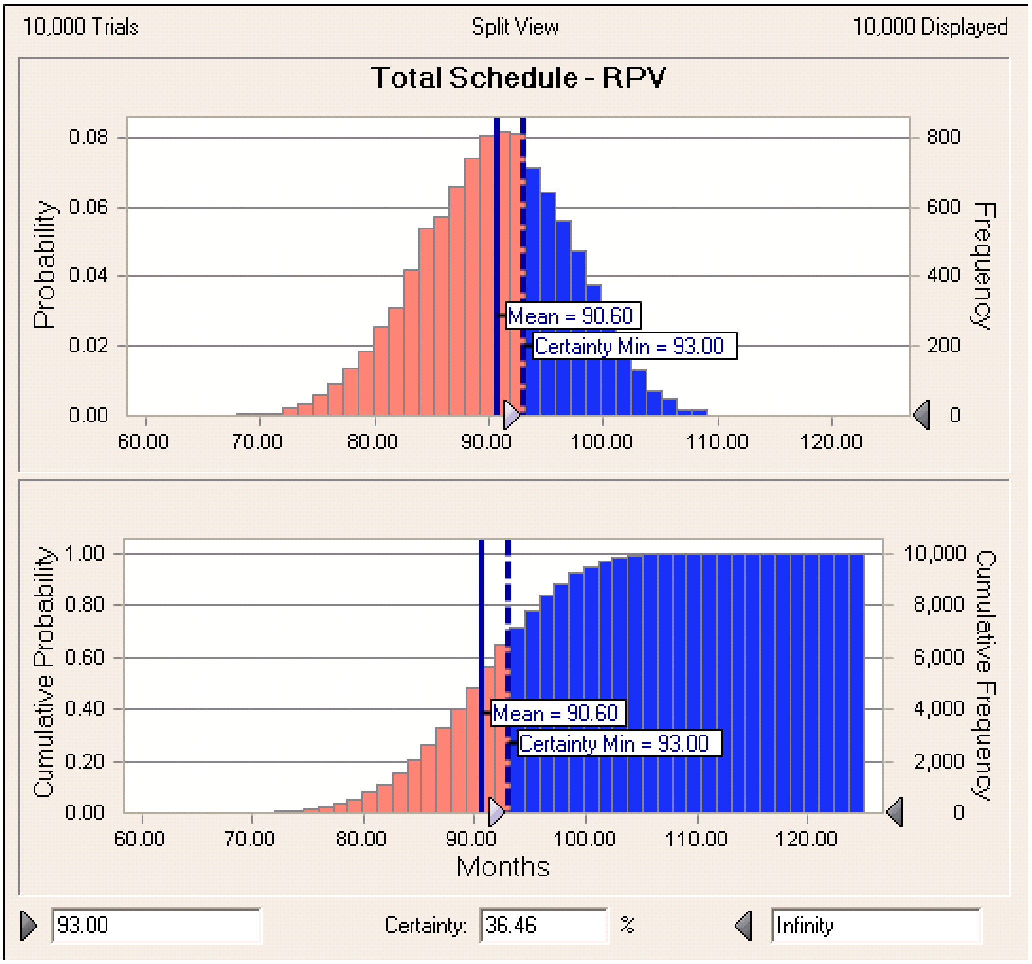

Figure 3-8 Schedule Risk for the RPV at the INL Site

Finally, the sensitivity of schedule risk for the RPV relative to reactor power level (500 MWt versus 250 MWt) is shown in Table 3-17. The best estimate durations of 36 and 42 months for RPV development and RPV fabrication, respectively, are not a function of reactor power level. The only potential benefit to schedule risk is associated with the delivery of the RPV to an inland site.

Table 3-17 Sensitivity of Reactor Pressure Vessel Schedule to Reactor Power Level

Schedule Contributor on Critical Path (Path 1)	Range of Best Estimate Durations for Cases at 500MWt (mo)	Impact of 250MWt
Design & Development	36	Not a function of size
Long Lead Order (unoverlap)	0	-
Fabrication	42	Vessel size not limiting
Transportation to Site	2-6	Potential for savings for inland sites

3.3 Core Outlet Pipe Schedule Risk

3.3.1 COP Operating and Design Parameters and Associated Materials

Operating parameters considered for the COP were ROT, RIT, primary system helium pressure, and reactor power. Consistent with decisions relative to the IHX, IHX vessel, and RPV, only the former (ROT) has the potential to significantly affect the schedule risk for the COP. In this regard, five cases (COP-1 through COP-5) were evaluated here in terms of their schedule risk. These are shown in Table 3-18. COP-1 involves an ROT of <760°C and uses Alloy 800H as the hot duct liner and SA-533 steel as the external primary pressure boundary pipe. Case COP-2 is for a design and initial operation temperature of 900°C; materials are the same as those for COP-1. Cases COP-1, COP-2, and COP-3 are all for an ROT of 950°C but with initial operation at <760°C, 850°C, and 950°C, respectively. The proposed material for the hot duct liner in these three cases is Hastelloy X or the improved Hastelloy XR variant; the external pressure boundary pipe remains as SA-533 steel.

3.3.2 COP Schedule Contributors

The durations of the schedule contributors for the five COP Cases shown in Table 3-18 are given in Table 3-19. Neither code development nor supplier readiness contributes to the schedules for any of these cases. Long lead orders and fabrication, however, are significant schedule factors with best estimate values of 51 months and 20 months, respectively. Design development and transportation to the reactor site also contribute to the overall schedule, but to a much lesser extent. The only schedule differences among the five cases are associated with design development. Case COP-1 (<760°C ROT) and Case COP-2 (900°C ROT) have best estimate values of 6 months and benefit from the COP designs for the DPP. The 5% lower bounds for both are 3 months while the 95% upper bounds are 9 and 12 months, respectively. All of the 950°C designs (Cases COP-3 through COP-5) have best estimate values of 9 months with lower bounds of 6 months and upper bounds of 15 months.

Table 3-18 Matrix of Cases for Core Outlet Pipe

Case	Design / Initial Operating Parameters				
	ROT	RIT	Power Level	Primary Press.	Mat'ls
	(C)	(C)	(MWt)	(MPa)	
COP-1	<760 / <760*	350	500	9	800H
COP-2	900 / 900				800H
COP-3	950 / <760				Hastelloy
COP-4	950 / 850				Hastelloy
COP-5	950 / 950				Hastelloy

Table 3-19 Schedule Contributors to Core Outlet Pipe

Case	ROT (C)	RIT (C)	Power Level (MWt)	Primary Press. (MPa)	Hot Duct / Piping Mat'ls	Design Develop. (Months)	Codes Develop. (Months)	Supplier Readiness (Months)	Long Lead Orders (Months)	Fabrication (Months)	Transportation (Months)
COP-1	<760 / <760	350	500	9	800H / SA533	6-3+3	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-2	900 / 900				800H / SA533	6-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-3	950 / <760				HastelloyX/XR / SA533	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-4	950 / 850				HastelloyX/XR / SA533	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-5	950 / 950				HastelloyX/XR / SA533	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1

3.3.3 Overall COP Schedule Logic

The logic for treating the schedule risk for the five COP Cases is as described in Section 3.1.4; the Gant Chart used for these cases is shown in Figure 3-9. Path 2 provides the critical path.

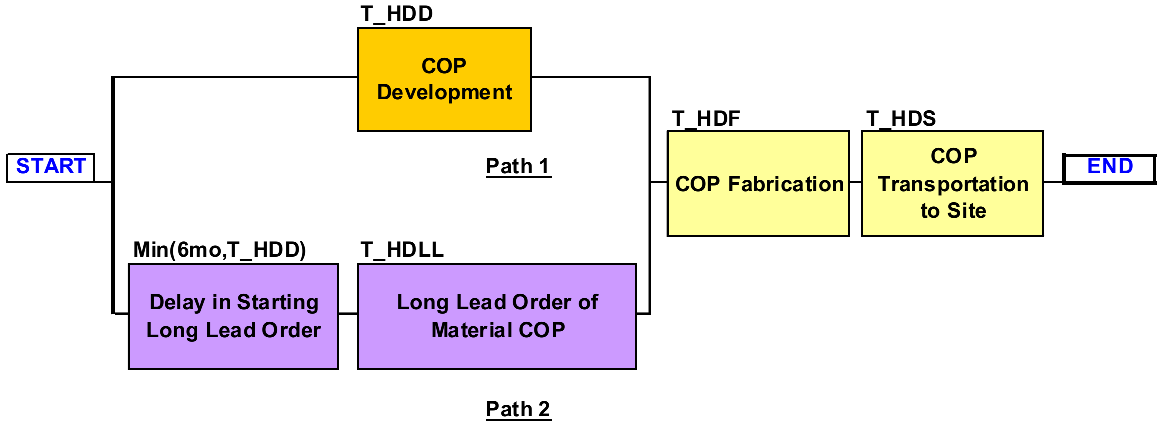

Figure 3-9 Gant Chart for Core Outlet Pipe Schedule

3.3.4 COP Schedule Risk

The schedule risk for Case COP-1 (design ROT <760°C) is shown in Figure 3-10. The mean value for this case is ~80 months, versus a window for operation in 2018 of 96 months (the COP like the IHX and its vessel needs to arrive ~3 months after the RPV). This equates to a 100% probability for achieving a 2018 operation.

The overall schedule risk for Case COP-2 (design ROT of 900°C) is shown in Figure 3-11. The mean schedule value is increased very slightly to 80 months versus that for COP-1, but is still well within the Certainty Minimum for achieving operation. Probability for operation in 2018 is 100%.

Finally, the overall probability risk for Cases COP-3, COP-4, and COP-5 is given in Figure 3-12. In all of these cases, the design operating temperature is 950°C, but initial operation for COP-3 and COP-4 are proposed as <760°C and 850°C, respectively. The mean value for time to readiness for operation is ~91 months for all of three cases, and the certainty for achieving operation in 2018 is 100%.

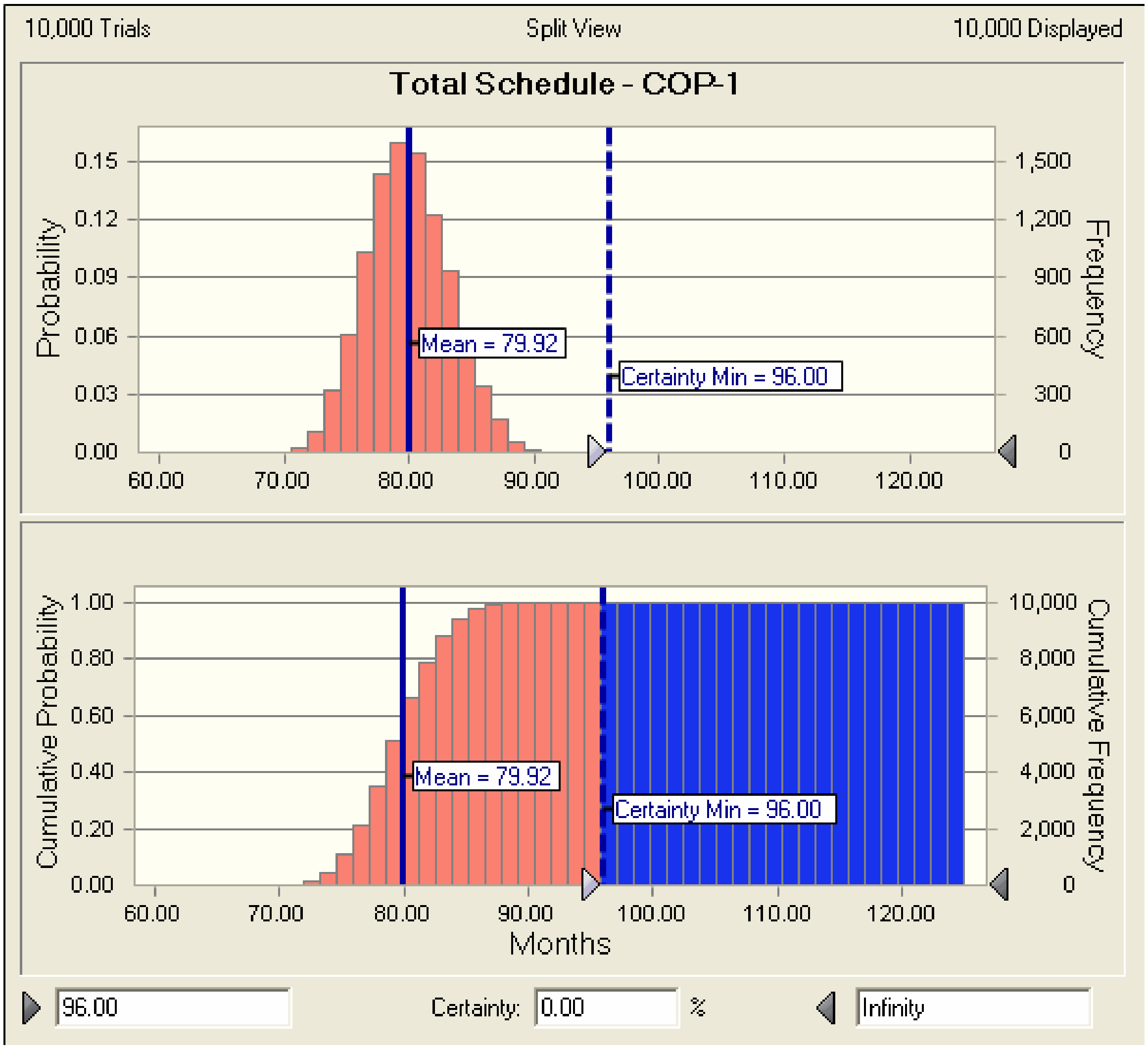

Figure 3-10 Core Outlet Pipe Schedule Risk for Case COP-1

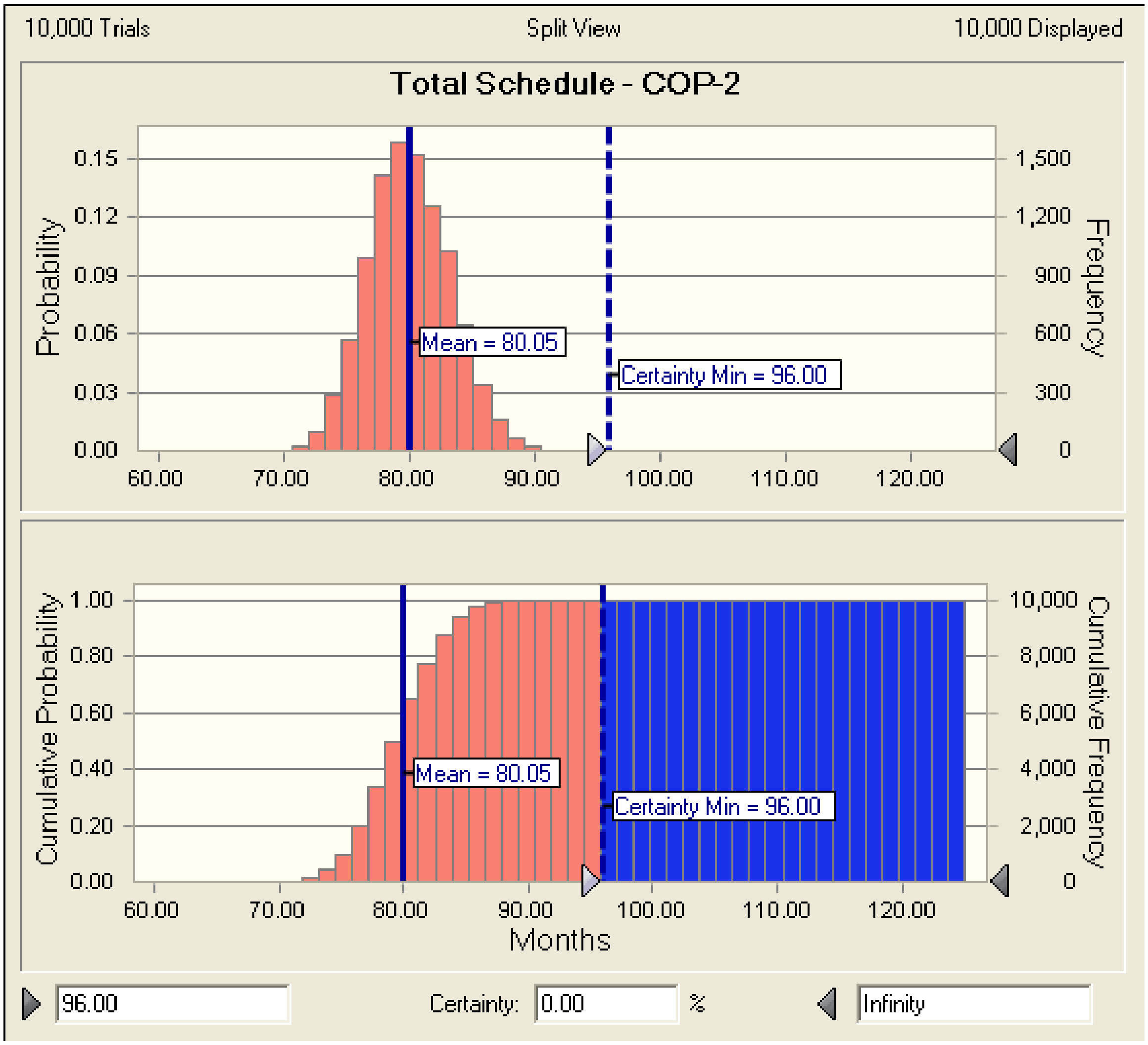

Figure 3-11 Core Outlet Pipe Schedule Risk for Case COP-2

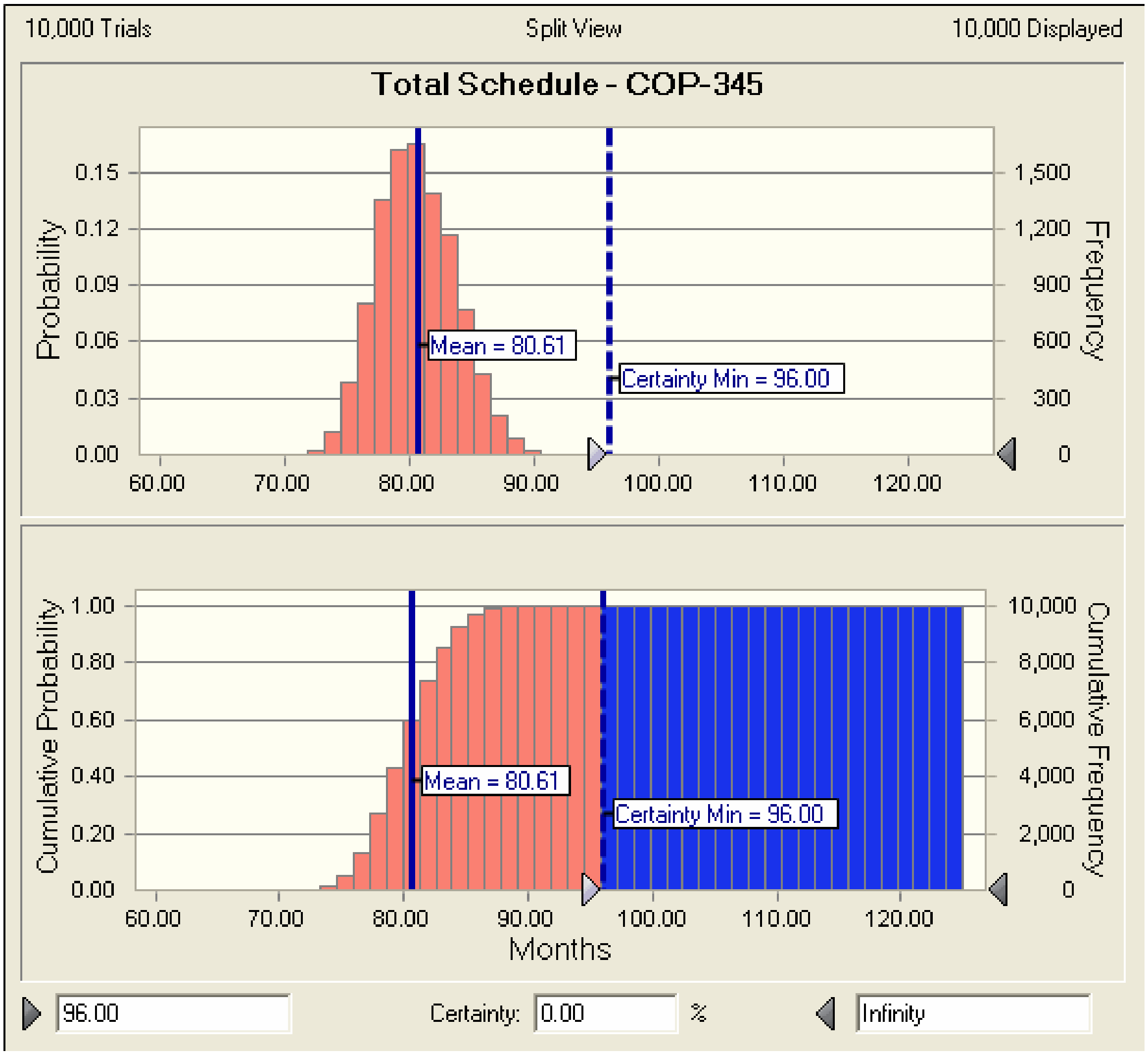

Figure 3-12 Core Outlet Pipe Schedule Risk for Cases COP-3, COP-4, and COP-5

A summary of the COP schedule risk results is given in Table 3-20. Path 2, shown in Figure 3-10, is the critical path in each instance. Best estimate, 5%-tile, 50%-tile, mean, and 95%-tile values are shown. The probability of not achieving operation in 2018 is 0%. Based on mean values, there are >12-month margins for all cases to achieve operation in 2018 and overall schedule risks are negligible. The schedule critical path is associated with long lead orders.

Table 3-20 Summary of COP Schedule Risk Results

COP Case	Gant Chart Path	Schedule Duration in Months					Probability ≥ 96Mo
		Best Estimate	5%tile	50%tile	Mean	95%tile	
COP-1	**Total Schedule**	79	74.7	79.8	79.9	85.4	0.0%
	Path 1	28	24.8	29.5	29.7	35.0	
	Path 2	79	74.7	79.8	79.9	85.4	
COP-2	**Total Schedule**	79	74.9	79.9	80.0	85.4	0.0%
	Path 1	28	24.9	30.6	30.8	37.2	
	Path 2	79	74.9	79.9	80.0	85.4	
COP-3,4,5	**Total Schedule**	79	75.8	80.5	80.6	85.9	0.0%
	Path 1	31	28.0	33.6	33.8	40.1	
	Path 2	79	75.8	80.5	80.6	85.9	

4 COST UNCERTAINTY ASSESSMENT

This section presents and discusses the evaluation of cost and its uncertainty associated with the IHX, the IHX vessel, the RPV, and the COP. Development, capital, and – where appropriate – replacements costs are developed and presented. The majority of the assumptions and the approach relative to this task were noted in Sections 1 and 2.2, respectively. Operating and design parameters and materials for the components treated are the same as those addressed in the schedule risk evaluation.

4.1 IHX Cost Uncertainty

This section is devoted to presentation and discussion of the costs associated with the IHX. The matrix of cases is identical to that considered in the schedule risk evaluation but is repeated here in Table 4-1 for convenience.

Table 4-1 Matrix of IHX Cases

Case	Design / Initial Operating Parameters				Materials
	RIT	Power Level	Primary Press.	ROT	
	(C)	(MWt)	(MPa)	(C)	
IHX-1	350	500	9	**<760 / <760**	800H
IHX-2				**900 / 900**	IHX A - 617 IHX B - 800H
IHX-3				**950 / <760**	IHX A - 617 IHX B - 800H
IHX-4				**950 / 850**	IHX A - 617 IHX B - 800H
IHX-5				**950 / 950**	IHX A - 617 IHX B - 800H

4.1.1 IHX Cost Contributors

This section presents and describes the specifics associated with the cost contributors to the IHX. Specifically, these are development costs, capital costs, and replacement costs. Best estimate and mean values of cost are developed and presented. The IHX is specified only as being of compact design and, thus, could be either a plate-fin or Heatric type. Costs in the present treatment are considered as equivalent, but this remains to be confirmed.

A matrix of IHX cases and their cost contributors is shown in Table 4-2. The table indicates that overall cost is comprised of development cost (treated below in this Section), capital cost of the IHX, and the capital cost for IHX replacement. The capital cost best estimate is assumed as \$45 per kWt for Case IHX-1 (510 MWt) with upper and lower bound multipliers of 0.8 and 1.3, respectively. For the case of IHX-2, the best estimate cost per kWt is 1.2 x \$45 per kWt for IHX B (350 MWt) and 2.4 x \$45 per kWt for IHX A (160 MWt). This holds as well for Cases IHX- 3 through IHX-5. Upper and lower bound cost factors for these cases are as shown in the table.

The Capital Replacement column indicates the multipliers, described earlier in Section 2.2, on the initial capital cost to give the capital replacement cost. The next two columns in the table show the presumed replacement intervals and the associated outage periods, nominally 3 months for each. The outage cost is estimated at \$8.5M per month to account for replacement power.

There is some degree of uncertainty associated with the replacement intervals shown in Table 4-2, even given the lower and upper bound values specified in the table. The values provided are only estimates and remain to be proven. As noted in the table, the current best estimates for the IHX of IHX-1 and the IHX B units for all other IHX Cases is full-life or 60 years. Maximum temperature in these instances is <760°C. The best estimate for the replacement interval for IHX A of Case IHX-2 (ROT of 900°C) is 14 years and the minimum value is 12 years. The replacement intervals for the 950° cases (IHX-3, IHX-4, and IHX-5) are given as 8 years with 6 years minimum. However, given the fact that it is planned to initially operate IHX-3 and IHX-4 at lower temperatures will likely lengthen their first replacement interval. For example, IHX-3 may be operated at <760°C for 5 years and IHX-4 at 850°C for 3 years. This is reflected in capital replacement and total costs later in the report. More information on the modeling of the cost of replacements as well as the discounting treatment of these costs is found in Section 2.2.

The major factor in replacement interval uncertainty is the ability of the thin heat exchange sections associated with the compact heat exchanger designs to withstand the corrosive effects of the impurities normally contained in the helium environment of gas-cooled reactors. Although these corrosion phenomena have been studied over the past several decades, most of the work has been qualitative (i.e., does the material oxidize, carburize, or decarburize) as opposed to quantitative (i.e., how much and how fast). While adequate for conventional shell and tube heat exchangers, which have relatively thick tubes, these data are not adequate for thin-section components, such as the heat transfer surface of compact heat exchangers. For the latter, good quantitative data addressing rates of oxidation, internal oxidation, and alloy depletion are critical to defining useful lifetime and, thus, replacement interval. These need to be acquired for times up to at least 10,000 hours in environments representative of the NGNP primary and secondary systems. Until this is available, replacement interval uncertainty will remain large.

Table 4-2 IHX Matrix Cases and Cost Contributors

Case	Design / Initial Operating Parameters					Contributors to Cost				
	ROT	RIT	Power Level	Primary Press.	Mat'ls	Separate Devel Cost Table	Cap Cost (CC) (1=45$/kWt)	Cap Replace	Replacement Interval (RI)	Outage for Replacement
	(C)	(C)	(MWt)	(MPa)		(M$)	($/kWt)	($/kWt)	(Yr)	(Months)
IHX-1	**<760 / <760***				**800H**		.8/1.0/1.3 x 510		>60	0/0/0
IHX-2	**900 / 900**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	12/14/18	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-3	**950 / <760**	350	500	9	**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-4	**950 / 850**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-5	**950 / 950**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0

4.1.1.1 IHX Development Costs Contributors and Cost

Development costs for the IHX are comprised of design development including codes and standards, materials qualification, testing and methods verification and validation (V&V), and capital and non-labor related to the above. Capital and non-labor costs will include costs for test articles and FOAK costs for manufacture of these test articles. Costs are in 2008 dollars with no IDC. The fully burdened average labor rate is $300K per year in 2008 dollars.

Table 4-3 provides an example as to how the elements of development cost were estimated. Expert opinion was used to provide best estimate values of levels of man-year effort and upper and lower bounds to complete the design development for each of the IHX Cases.

The details of the elements of IHX development costs are provided in Table 4-4. Effort is broken out as both man-year levels and associated costs (man-years x $300K/man-year) for design/codes and standards, materials qualification, and testing and methods V&V. Capital and non-labor is shown as total dollars. The development costs for the IHX of IHX-1 (<760°C ROT) are significantly lower than those for the other cases, and the development costs for IHX-2 through IHX-5 are identical except for a lower materials qualification cost for IHX-2 (900°C ROT versus 950°C ROT for the others).

Table 4-3 Estimated Man-Year Levels of Effort for IHX Design Development

Design /Initial Operating Temperature	Material	Lower Bound (5%) Estimate (M-Yr)	Best Estimate (M-Yr)	Upper Bound (95%) Estimate (M-Yr)
Case 1 ROT<760C /760C	800H	8	9	10
Case 2 ROT 900C /900C	800H /617	11	12	13
Case 3 ROT 950C /<760C	800H /617	11	12	13
Case 4 ROT 950C /850C	800H /617	11	12	13
Case 5 ROT 950C /950C (Reference)	800H /617	11	12	13

Table 4-4 Details of IHX Development Costs

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
IHX-1	2.2	2.6	3.4	1.5	1.8	2.4	1.3	1.6	2.1	1.4	1.7	2.6
IHX-2	2.9	3.5	5.8	3.6	4.2	6.3	1.3	1.6	2.3	2.0	2.4	4.8
IHX-3	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8
IHX-4	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8
IHX-5	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8

The development costs for each of the IHX cases are shown in Figure 4-1 through Figure 4-3. For IHX-1 (Figure 4-1), the mean value of the development is seen as ~$8.3M with 5%-tile and 95%-tile values of ~$7.5M and ~$ 9.3M, respectively. Figure 4-2 shows that there is a significantly higher development cost for IHX-2; the range is from ~$11.5M to $16.4M, with a mean value of $13.8M. Lastly, Figure 4-3 provides the development cost for IHX-3, IHX-4, and IHX-5. They are marginally higher than those for IHX-2. All of these cases have design ROTs of 950°C.

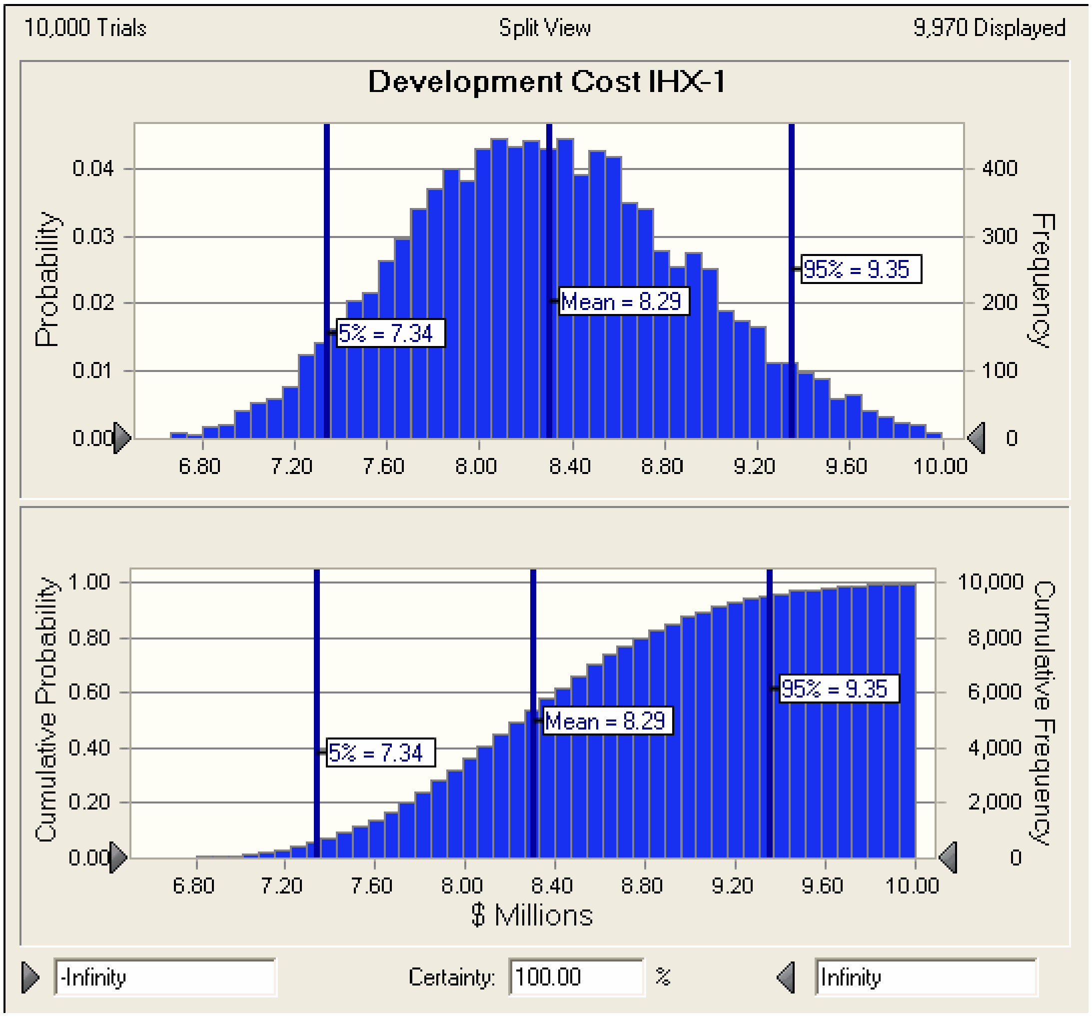

Figure 4-1 Development Cost for IHX-1

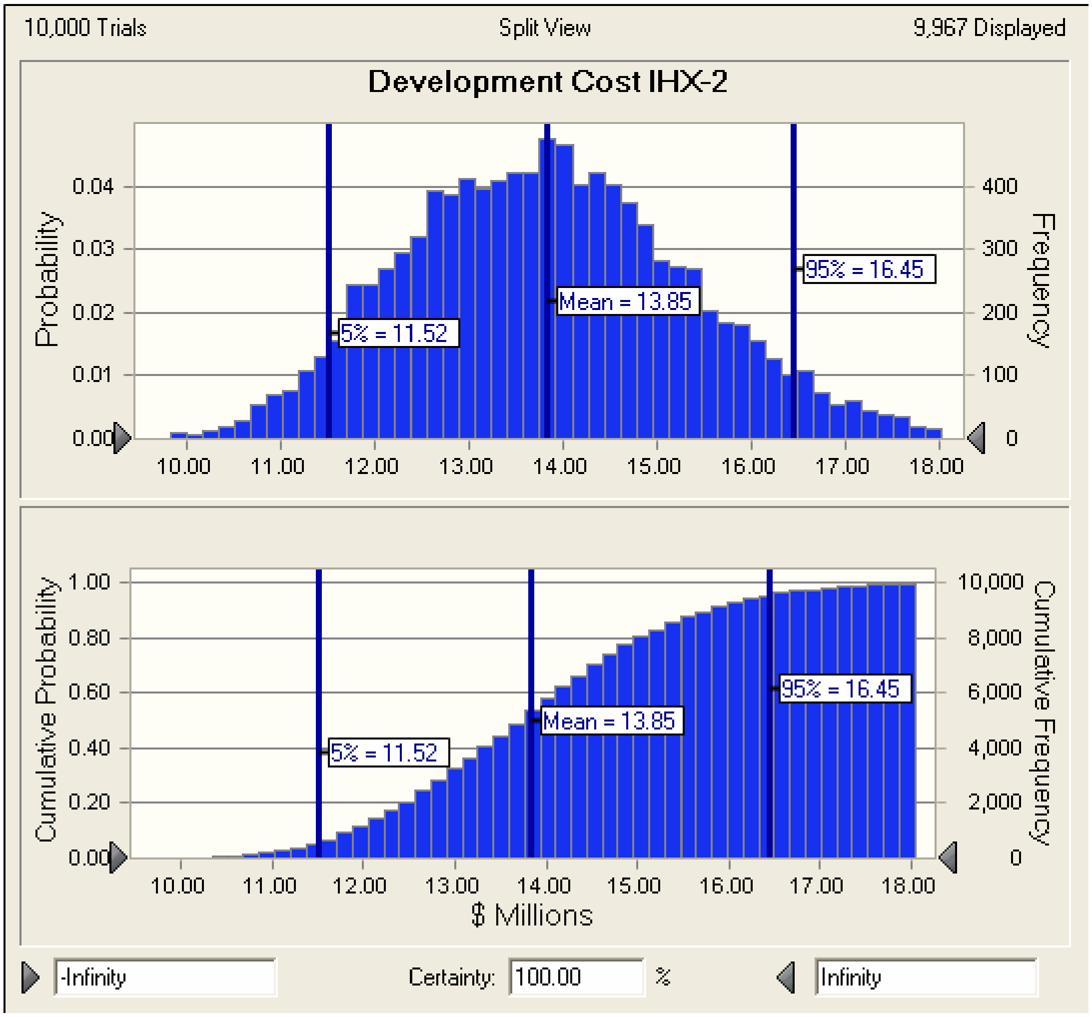

Figure 4-2 Development Cost for IHX-2

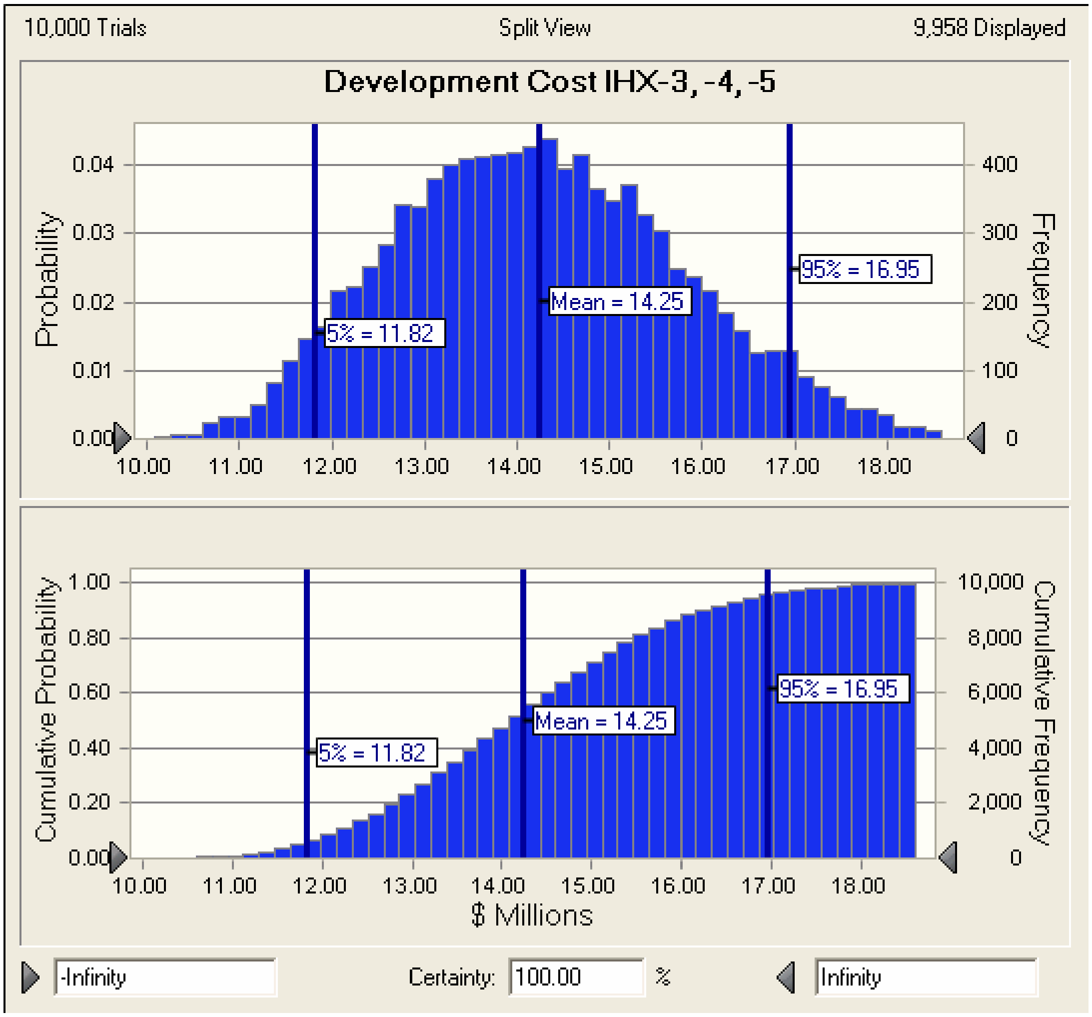

Figure 4-3 Development Costs for IHX-3, IHX-4, and IHX-5

4.1.1.2 IHX Capital Costs

Capital costs for the IHX are for the bare component and do not include IDC, shipping, or installation. A review of the expected capital costs for each IHX Case was provided in Table 4-2 in Section 4.1.1.

4.1.1.3 IHX Replacement Costs

IHX cost replacement contributors include the capital cost of the replacement unit, removal of the old unit, installation of the new unit, and loss of power generation revenue during the replacement outage. All of these were provided in Table 4-2 of Section 4.1.1. All costs are discounted to a 2018 date of operation at a 10% discount rate. As explained more fully in Section 2.2, capital costs of replacement were discounted from 1 year before the replacement outage whereas the replacement power costs were discounted from the date of the initiation of the replacement outage.

Figure 4-4 shows probabilities associated with the number of replacements for Case IHX-2 and Figure 4-5 gives the related total replacement cost (capital + outage). The mean value is ~$18.1M with 5%-tile and 95%-tile values of ~$11.8M and $25.5M, respectively.

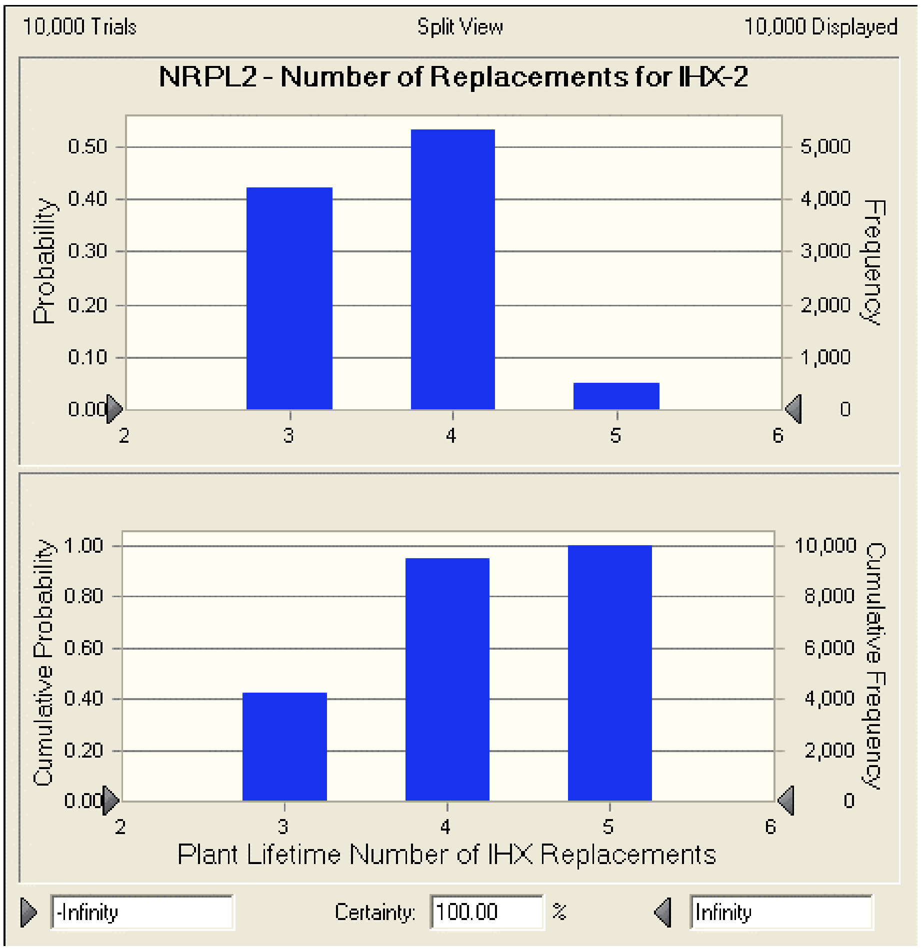

Figure 4-4 Number of IHX Replacements for IHX-2

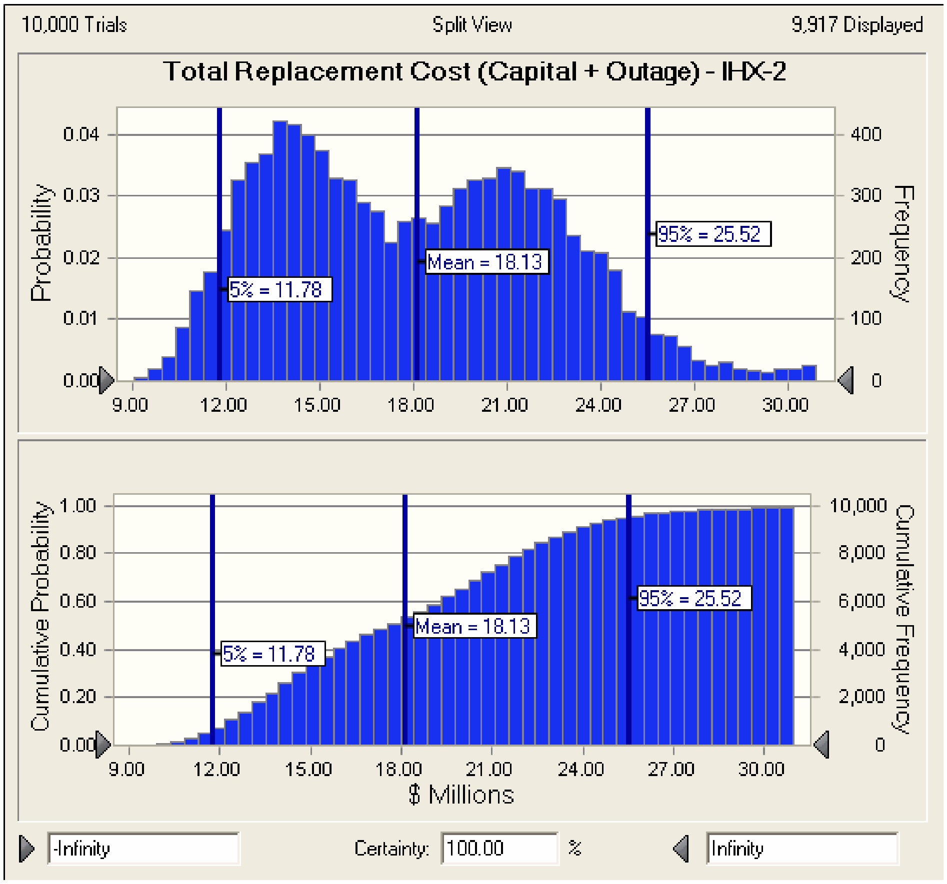

Figure 4-5 Cost of Replacements for IHX-2

The number of replacements and associated replacement costs for Case IHX-3 are given in Figure 4-6 and Figure 4-7, respectively. The number of IHX replacements considered during plant lifetime ranges up to eleven. Mean cost is shown in Figure 4-7 to be \$24.9M; 5%-tile and 95%-tile bounds are ~\$13.9M and ~\$40.0M, respectively.

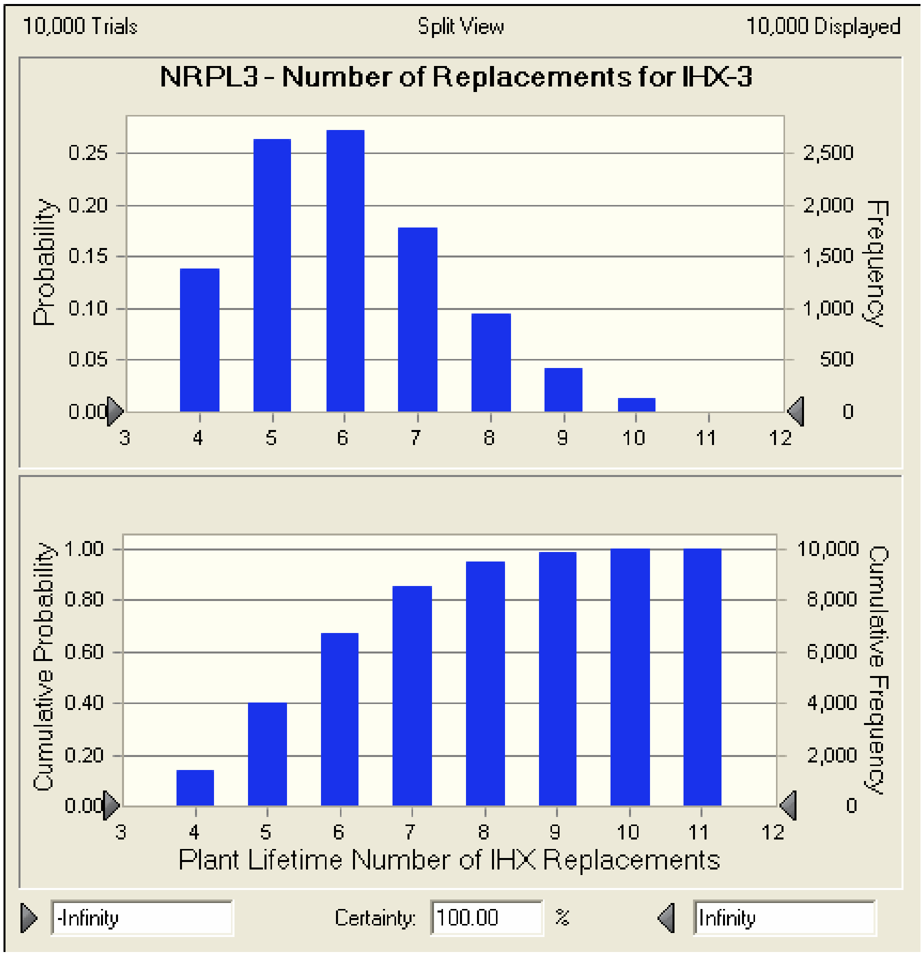

Figure 4-6 Number of IHX Replacements for IHX-3

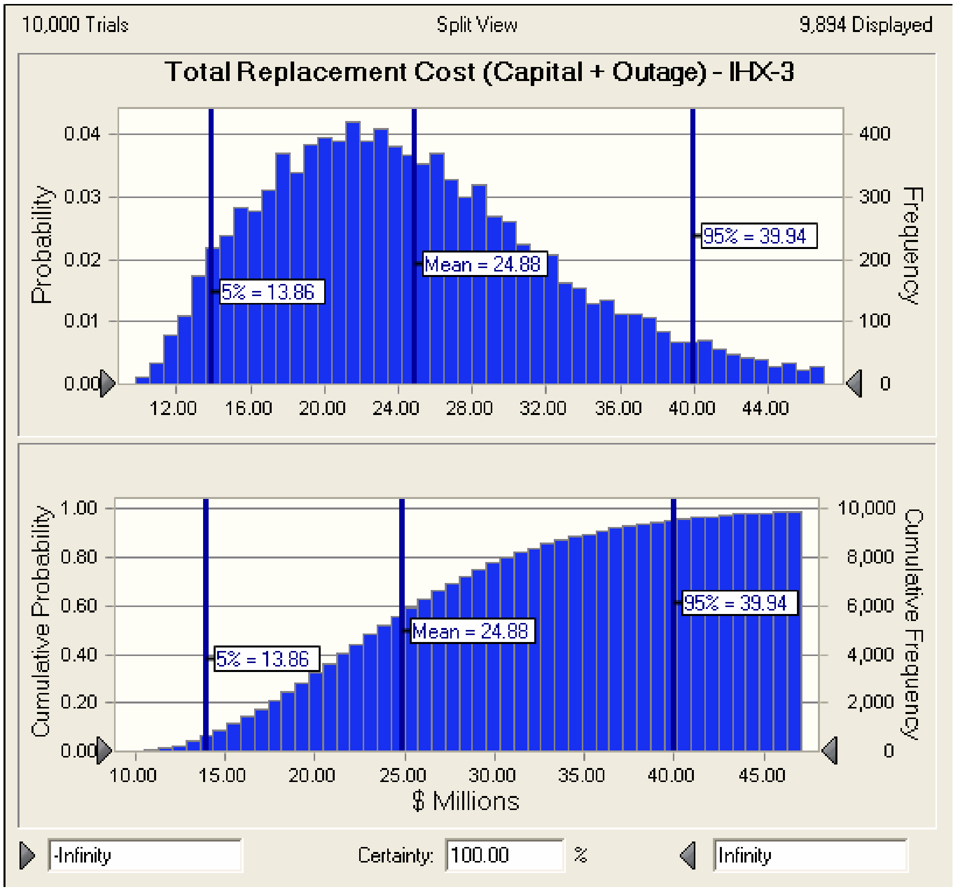

Figure 4-7 Cost of Replacements for IHX-3

The number of IHX replacements for Case IHX-4 is shown in Figure 4-8 and associated replacement cost is given in Figure 4-9. The mean value for replacement costs is ~$30M with bounds of ~$16.7M and $47.9M.

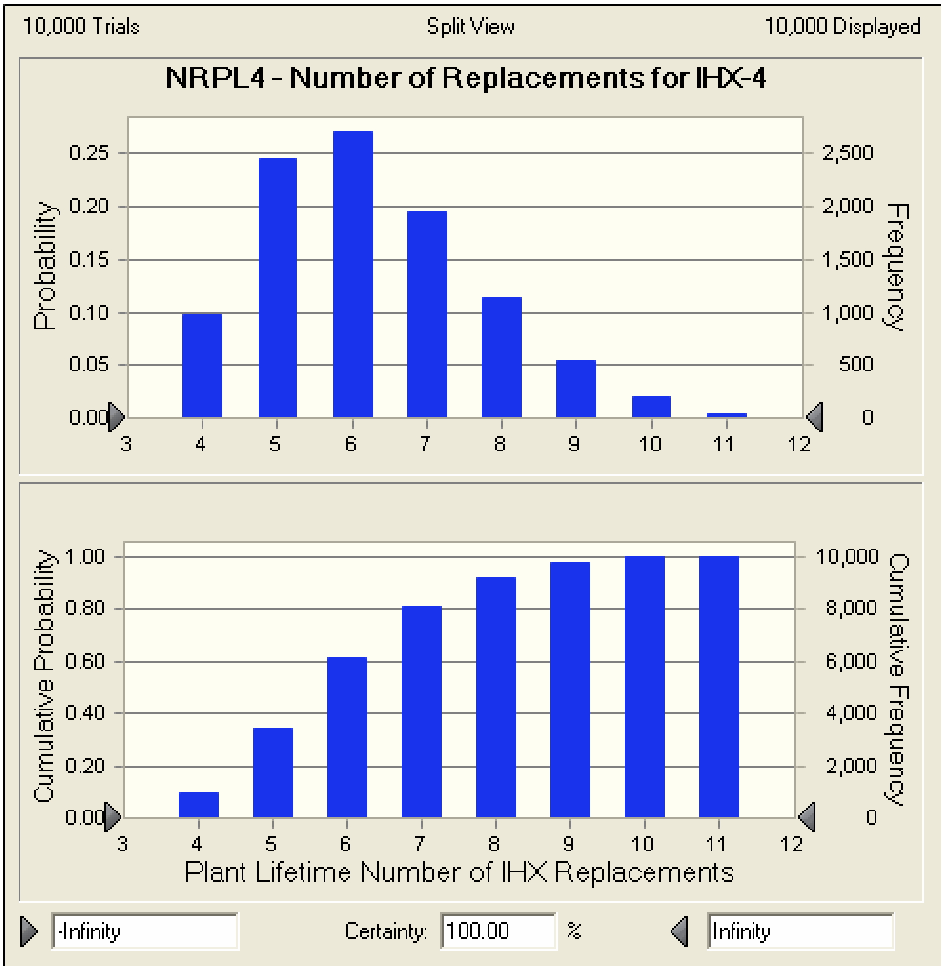

Figure 4-8 Number of IHX Replacements for IHX-4

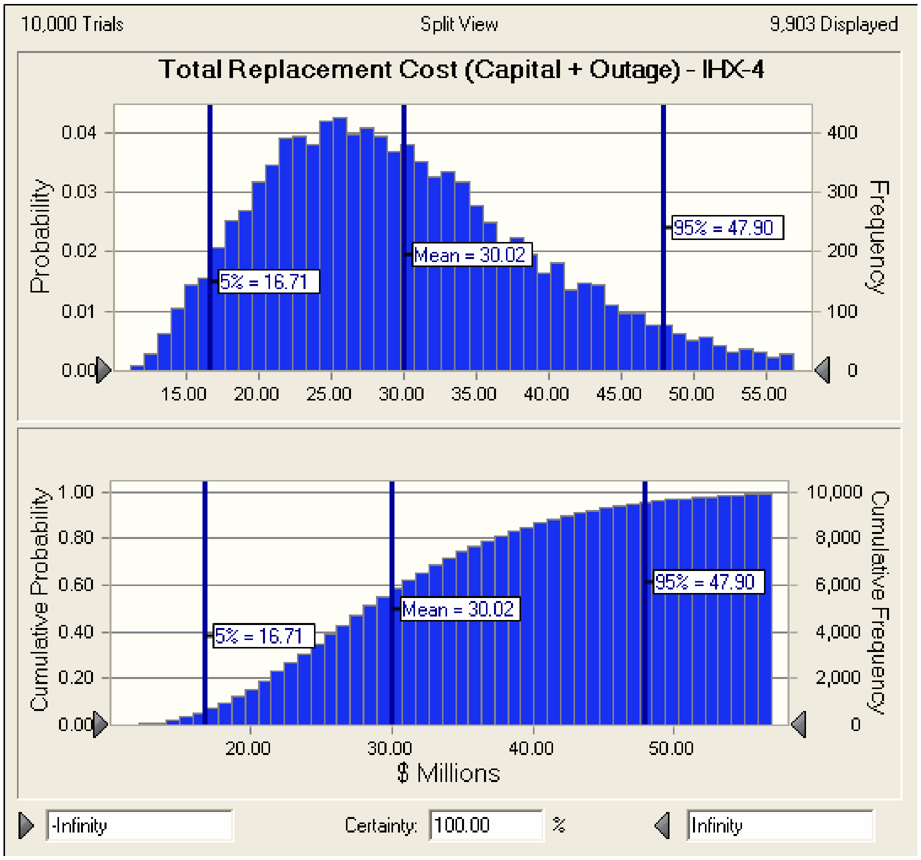

Figure 4-9 Cost of Replacements for IHX-4

Finally, Figure 4-10 addresses the number of full lifetime IHX replacements for the Case IHX-5 and Figure 4-11provides the cost distribution for these replacements. The mean value for replacement costs is ~$39.8M with bounds of ~$22.3M and ~$64.1M.

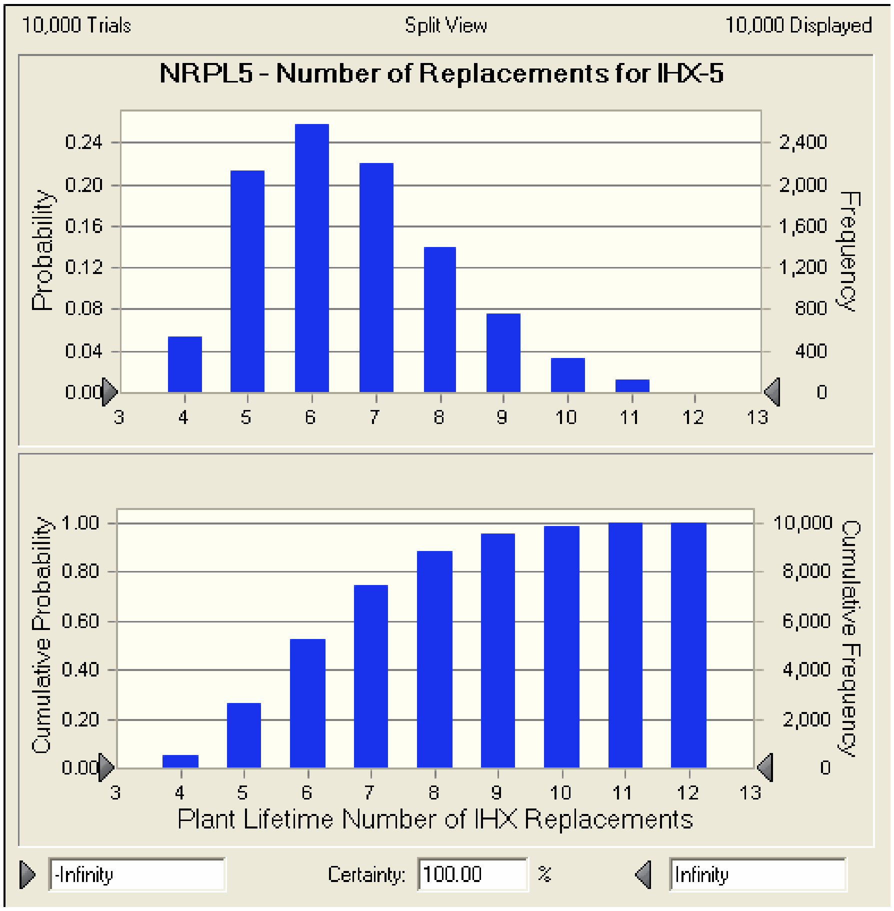

Figure 4-10 Number of IHX Replacements for IHX-5

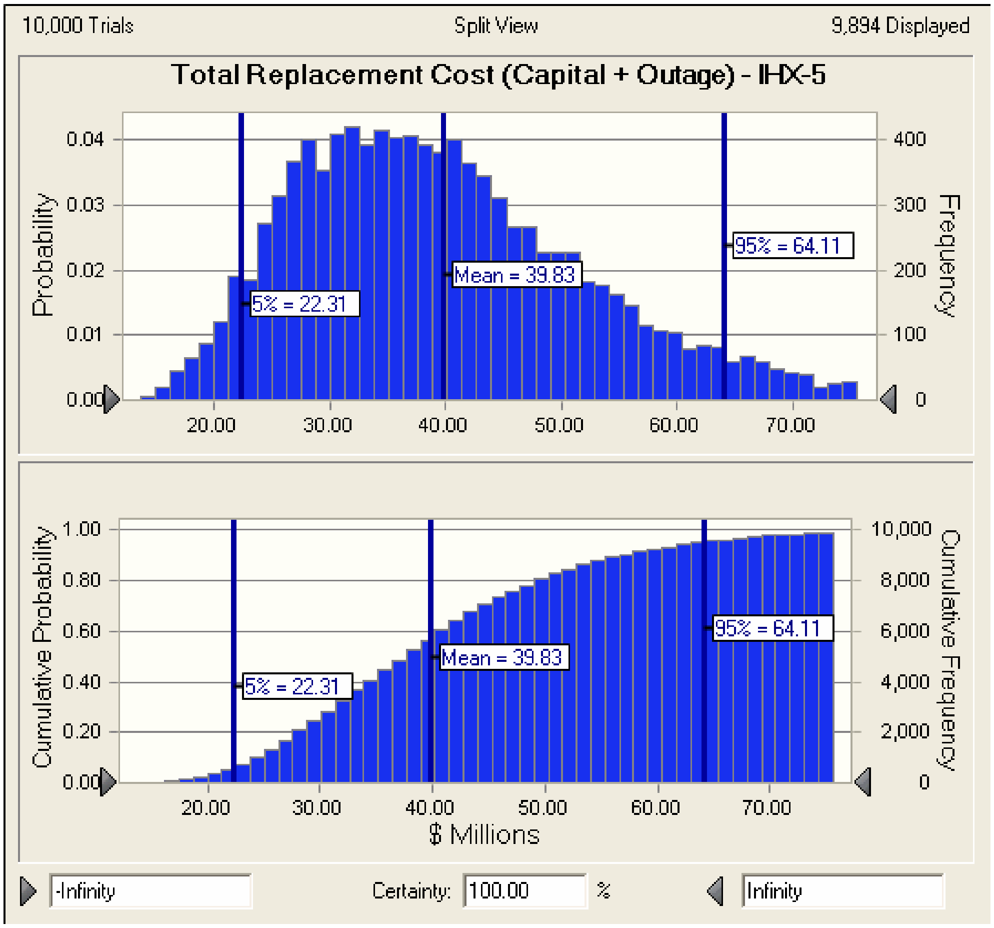

Figure 4-11 Cost of Replacements for IHX-5

4.1.2 Total IHX Cost Uncertainty

The total cost for each of the five IHX Cases is presented in Figure 4-12, Figure 4-13, Figure 4-14, Figure 4-15, and Figure 4-16. For Cases IHX-2 through IHX-5 the total cost is the sum of the development cost, the capital cost, and the replacement cost. No replacement cost is involved for Case IHX-1. The mean cost for IHX-1 is ~$32.2M. Those for the replacement cases range from ~$69.4M for IHX-2 to ~$91.5M for IHX-5. The lower 5%-tile and the upper 95%-tile bounds are as shown on the figures.

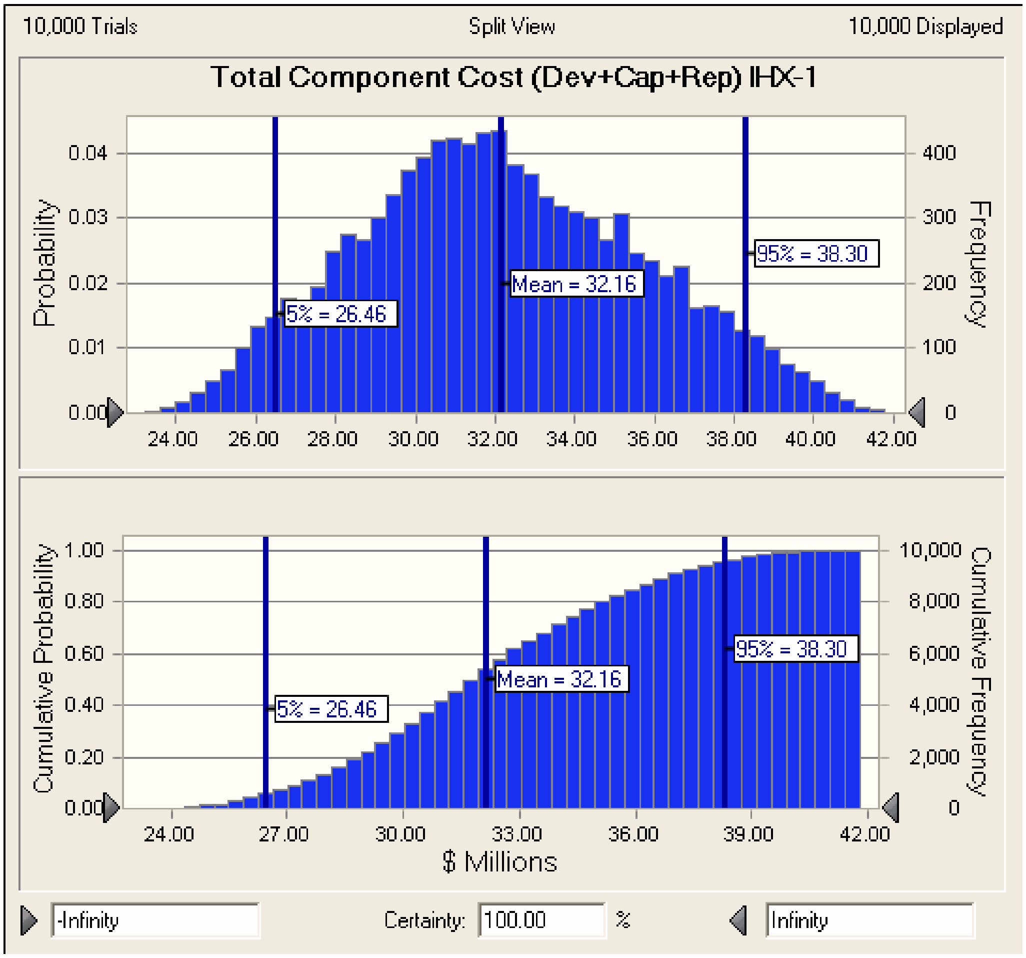

Figure 4-12 Total Cost for IHX-1 (Development and Capital)

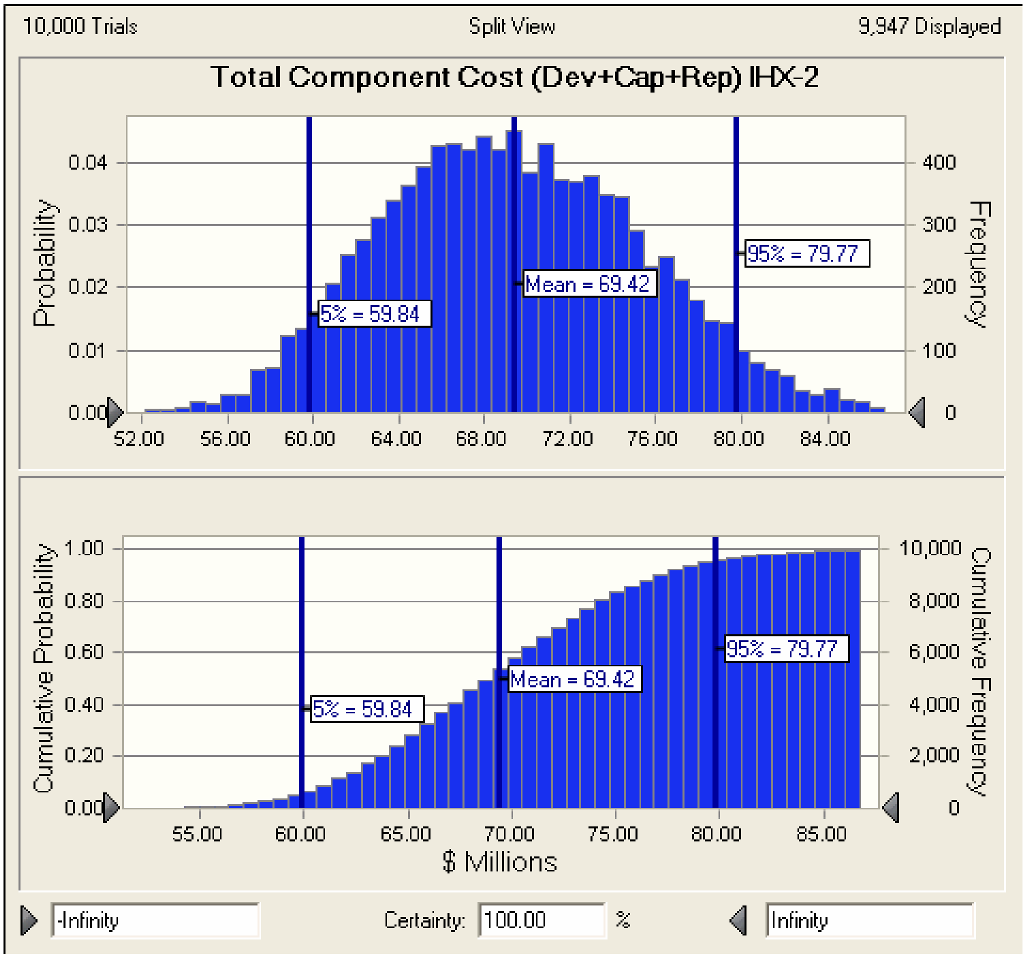

Figure 4-13 Total Cost for IHX-2 (Development, Capital, and Replacement)

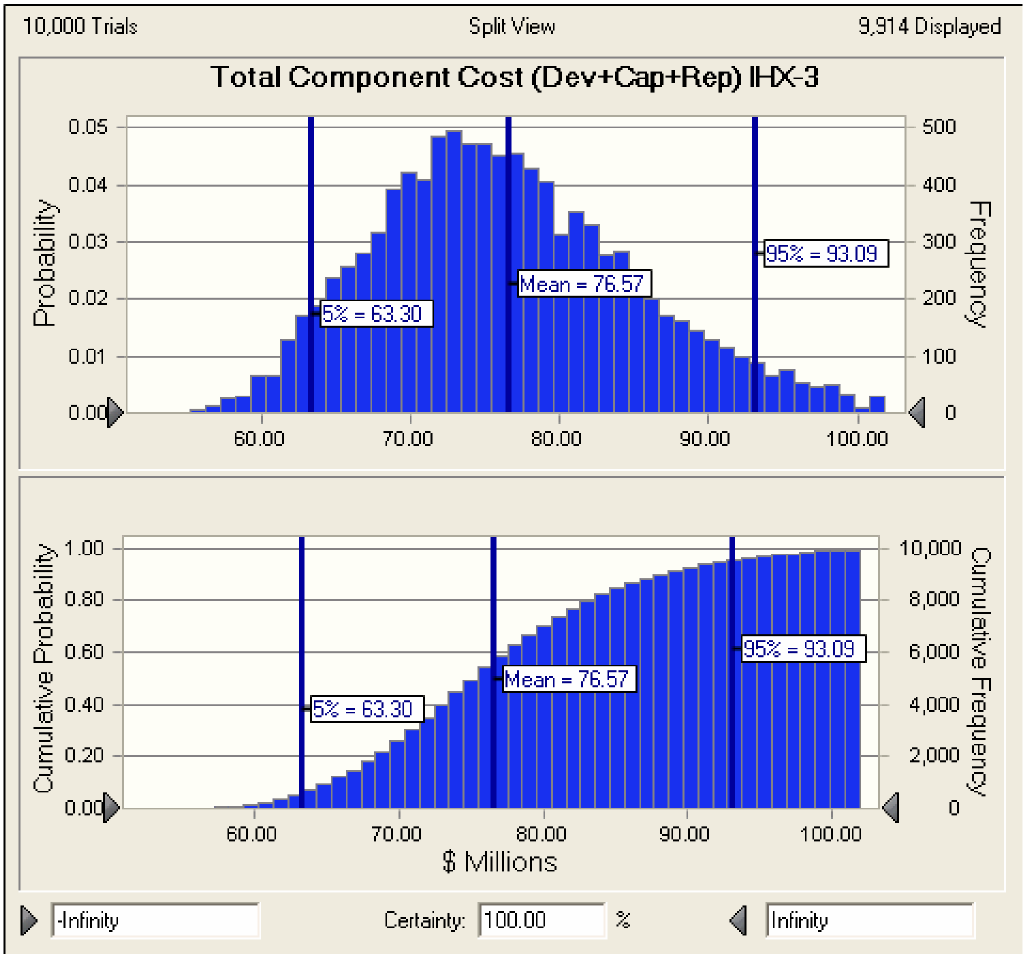

Figure 4-14 Total Cost for IHX-3 (Development, Capital, and Replacement)

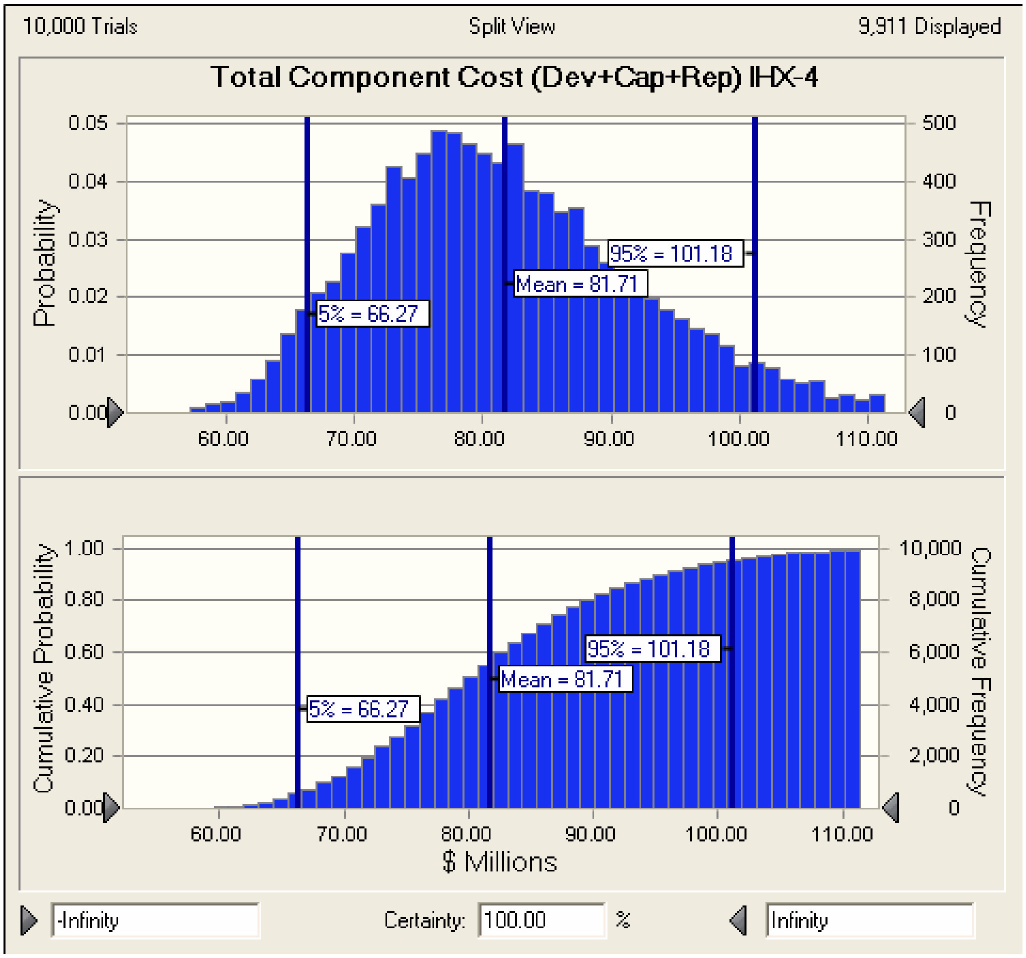

Figure 4-15 Total Cost for IHX-4 (Development, Capital, and Replacement)

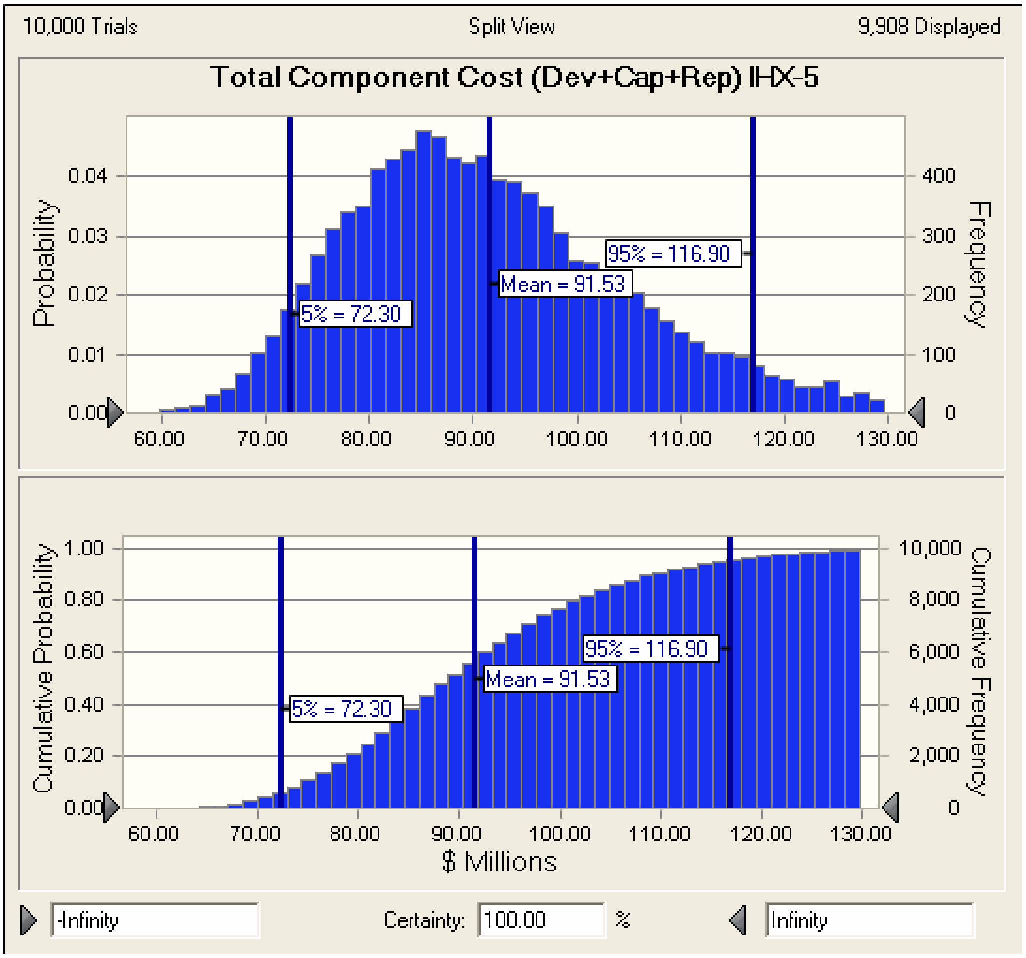

Figure 4-16 Total Cost for IHX-5 (Development, Capital, and Replacement)

4.2 IHX Vessel Cost Uncertainty

The matrix of IHX vessel cases considered here is shown in Table 4-5. There are essentially three cases involved. The first case, IV-1, is for a full life operating temperature of <760°C with no IHX or IHX vessel replacements. Case IV-2A/B is for an operating temperature of 900°C with a replacement schedule as described for IHX-2 in sections above and repeated in sections below. Case IV-345A/B is for the systems that are designed for operation at 950°C.

Table 4-5 Matrix of Cases for the IHX Vessel

	Operating Parameters & Corresponding Mat'ls				
Case	ROT	RIT	Power Level	Primary Pressure	Mat'ls
	(C)	(C)	(MWt)	(MPa)	
IV-1	<760	350	500	9	508/533
IV-2 A	900				
IV-2 B	<760				
IV-345 A	950				
IV-345 B	<760				

The cost analysis provided for the IHX vessel cases assumes that the vessel for IHX A replacement units will be replaced at the same time as the IHX itself. That is, the IHX and its vessel will be removed as a unit and replaced as a unit. This is conservative in a sense, but the cost of a new IHX vessel is probably more than compensated for by the convenience this will provide, especially in the first replacement. Removal of the IHX heat exchange unit from its vessel in-place would be quite difficult because of limited access and the possibility of contamination. For subsequent replacements, refurbishment of removed vessels might be considered as a means of reducing cost.

4.2.1 IHX Vessel Cost Contributors

The cost contributors to the IHX vessel are development, capital, and replacement.

4.2.1.1 IHX Vessel Development Costs

The elements of IHX vessel development cost are given in Table 4-6. They include design/codes and standards, materials qualification, testing and V&V, and capital and non- labor. Best estimates and 5%-tile and 95%-tile bounds are shown for both man-years and cost for all IHX vessel cases. As expected, the development costs for IV-1 (<760°C operation) are less than for the cases with higher operating temperatures but there are no differences in development costs between the higher temperature cases.

The overall development costs are illustrated in Figure 4-17 and Figure 4-18.

Table 4-6 IHX Vessel Development Costs

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
IV-1	0.6	1.2	1.5	0.5	0.6	0.8	0.5	0.6	0.9	0.5	1.0	2.0
IV-2	1.2	1.5	2.1	0.8	0.9	1.1	1.2	1.5	1.8	1.5	2.0	4.0
IV-3, 4, 5	1.2	1.5	2.1	0.8	0.9	1.1	1.2	1.5	1.8	1.5	2.0	4.0

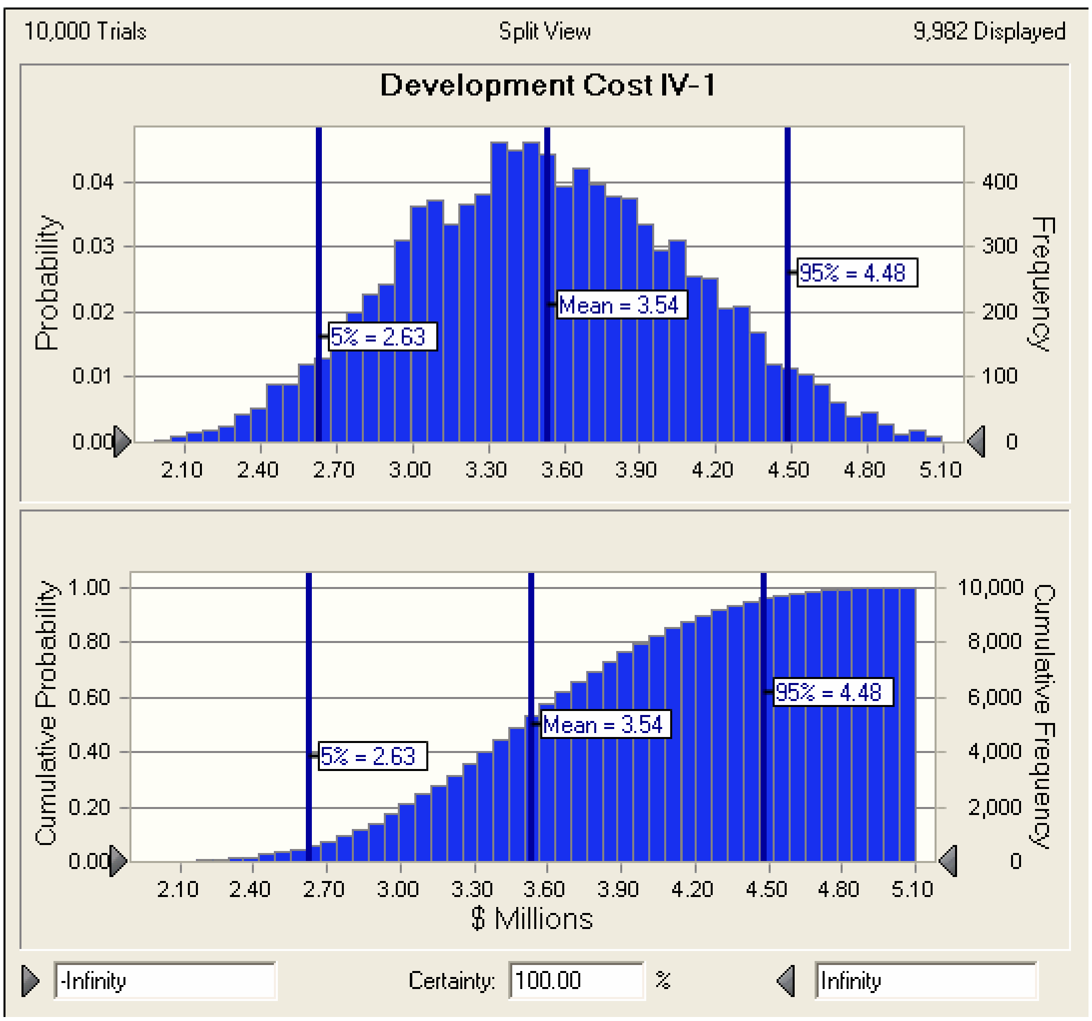

Figure 4-17 IHX Vessel Case IV-1 Development Cost

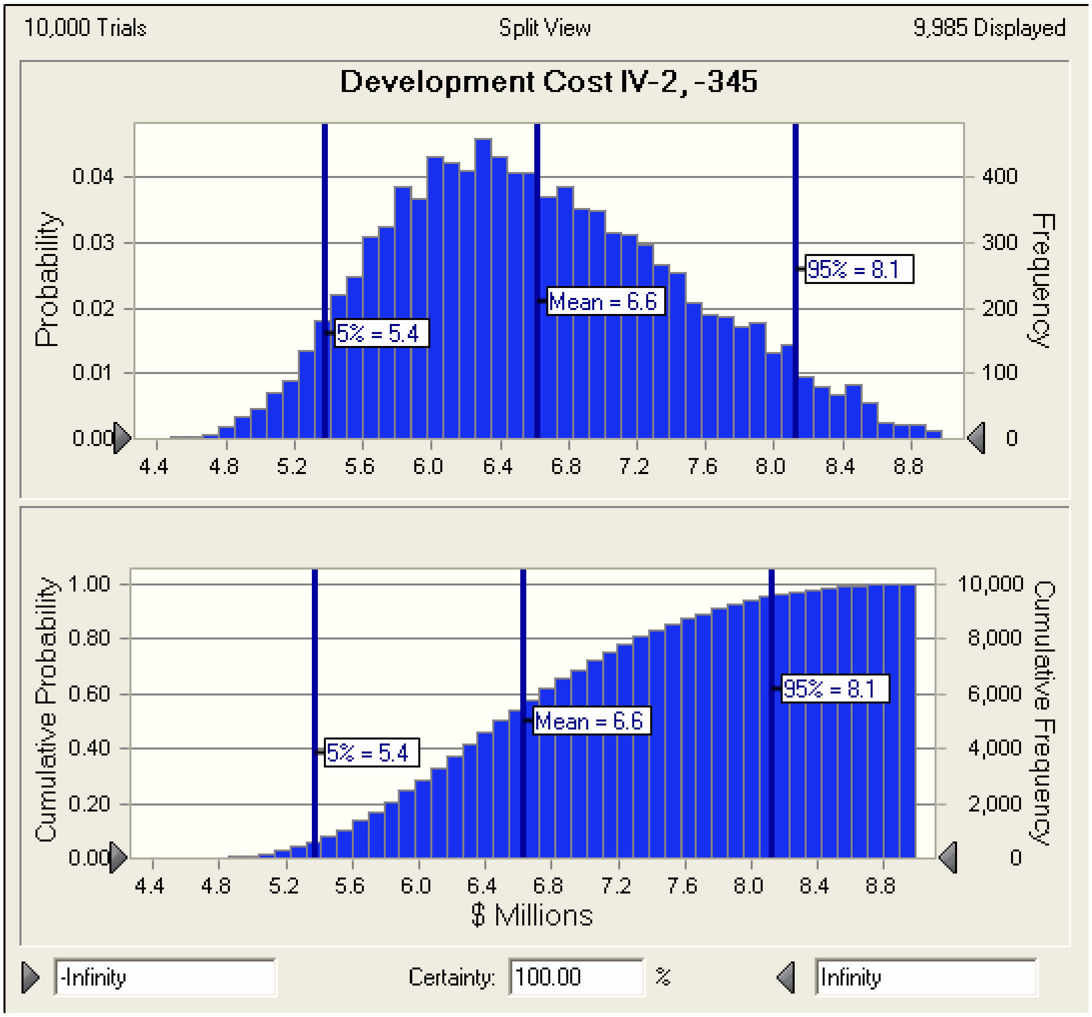

Figure 4-18 IHX Vessel Cases IV-2A/B and IV-345A/B Development Costs

4.2.1.2 IHX Vessel Capital Costs

Capital costs for the IHX vessel cases are shown in Table 4-7. For Case IV-1 the best estimate capital cost is ~$20K/kWt for a size of 510MWt. The lower bound cost has a multiplier of 0.9 and the upper bound multiplier is 1.2. Costs can be similarly derived for all of the other cases. Those for Cases IV-2A and IV-345A (160 MWt) are identical as are those for Cases IV-2B and IV-345B (350MWt).

Table 4-7 IHX Vessel Capital Costs

IHX Vessel Case	Capital Cost at \$20/kWt x Size	Replacement Interval (years)	Outage for Replacement (months)
IV-1	0.9/1.0/1.2 x 510 MWt	>60	-
IV-2A	1.8/2.0/2.5 x 160 MWt	12/14/18	2/3/4
IV-2B	1.1/1.2/1.4 x 350 MWt	>60	-
IV-345A	1.8/2.0/2.5 x 160 MWt	6/8/12	2/3/4
IV-345B	1.1/1.2/1.4 x 350 MWt	>60	-

4.2.1.3 IHX Vessel Replacement Costs

The capital costs for replacement of the IHX vessel is set as the capital cost of the original unit times a factor of 1.4 for removal and reinstallation times a factor of 0.7 based on lessons learned from the first installation. In addition, power loss during the replacement outage is estimated as $8.5M per month. Replacement intervals for these cases are shown in Figure 4-19, Figure 4-21, Figure 4-23, and Figure 4-25. Costs for replacement of the IHX vessels are shown in Figure 4-20, Figure 4-22, Figure 4-24, and Figure 4-26, respectively. The vessel replacement costs range from ~$13.3M for Case IV-2 to ~$29.3M for Case IV-5.

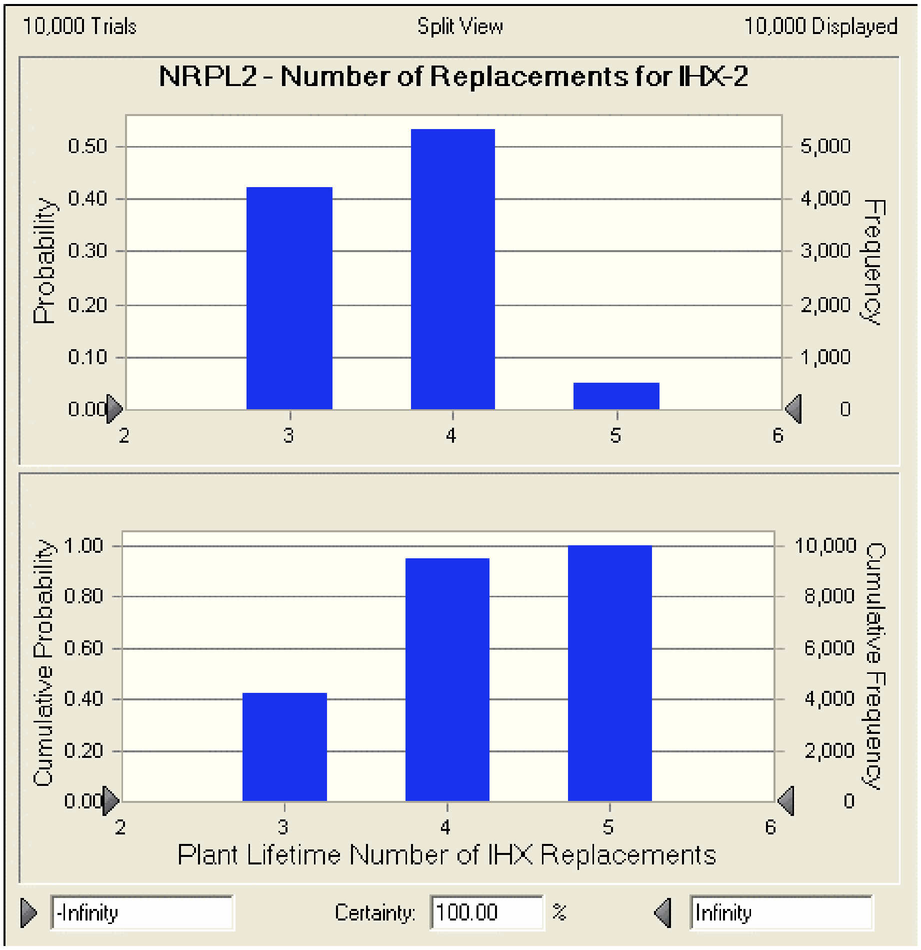

Figure 4-19 Number of IHX Vessel Replacements for IHX-2

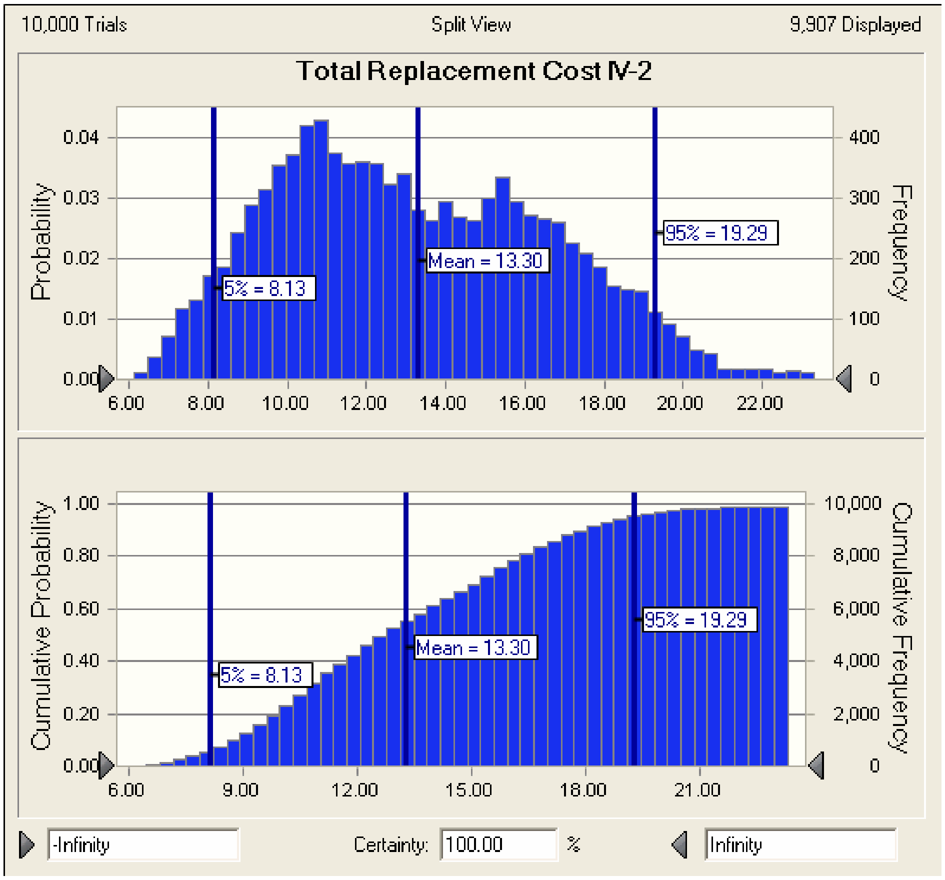

Figure 4-20 IHX Vessel Replacement Cost for IHX-2

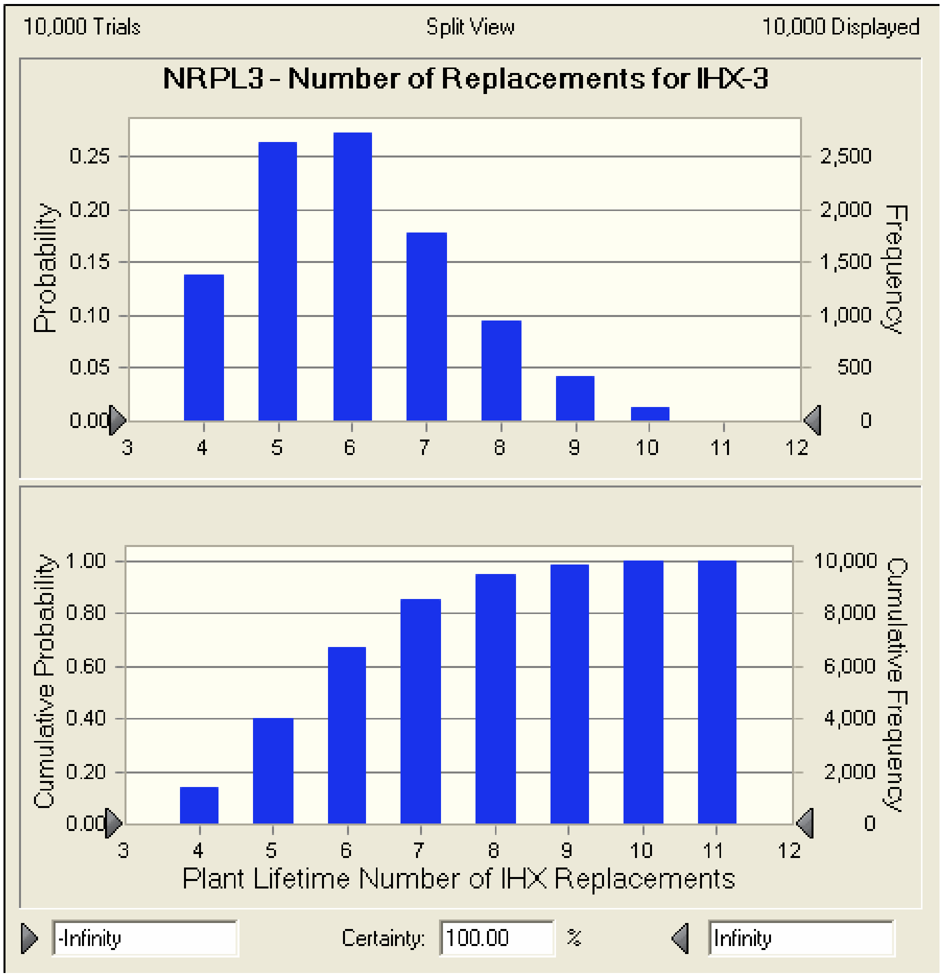

Figure 4-21 Number of IHX Vessel Replacements for IHX-3

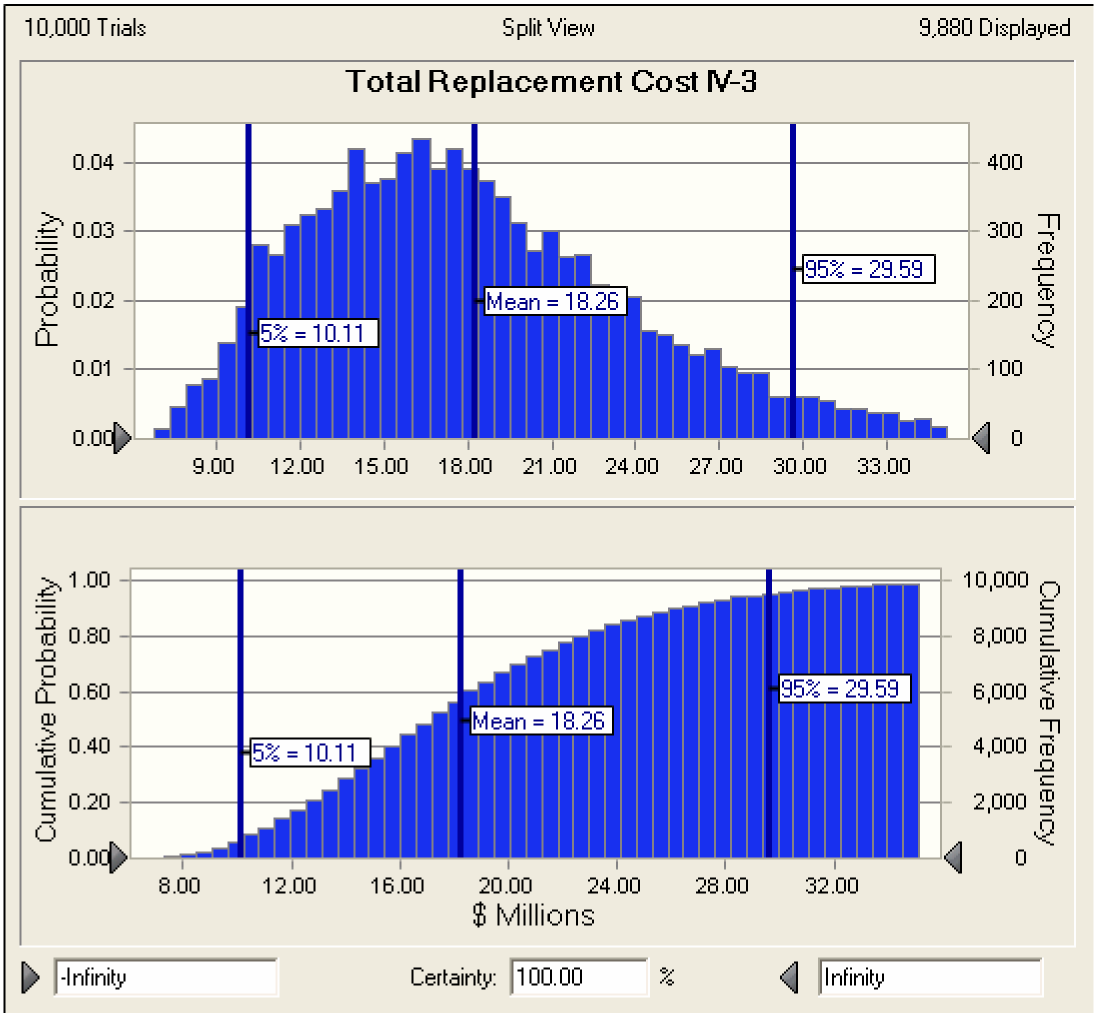

Figure 4-22 IHX Vessel Replacement Cost for IHX-3

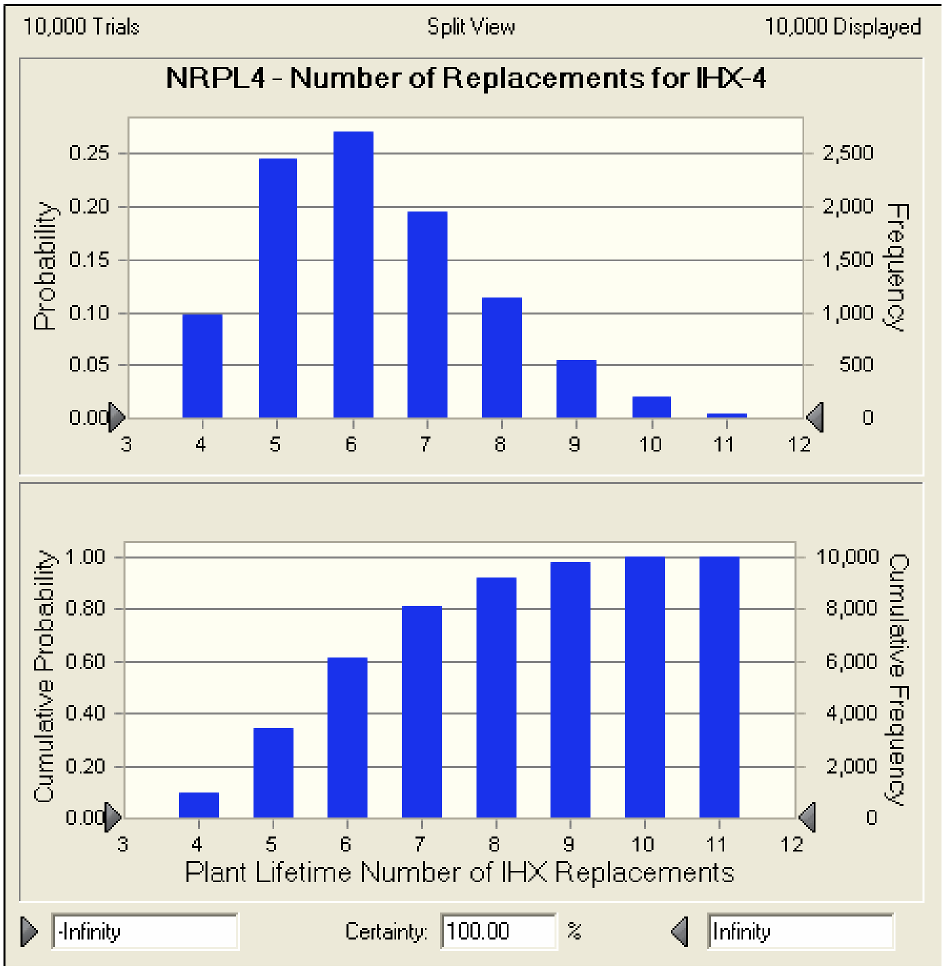

Figure 4-23 Number of IHX Vessel Replacements for IHX-4

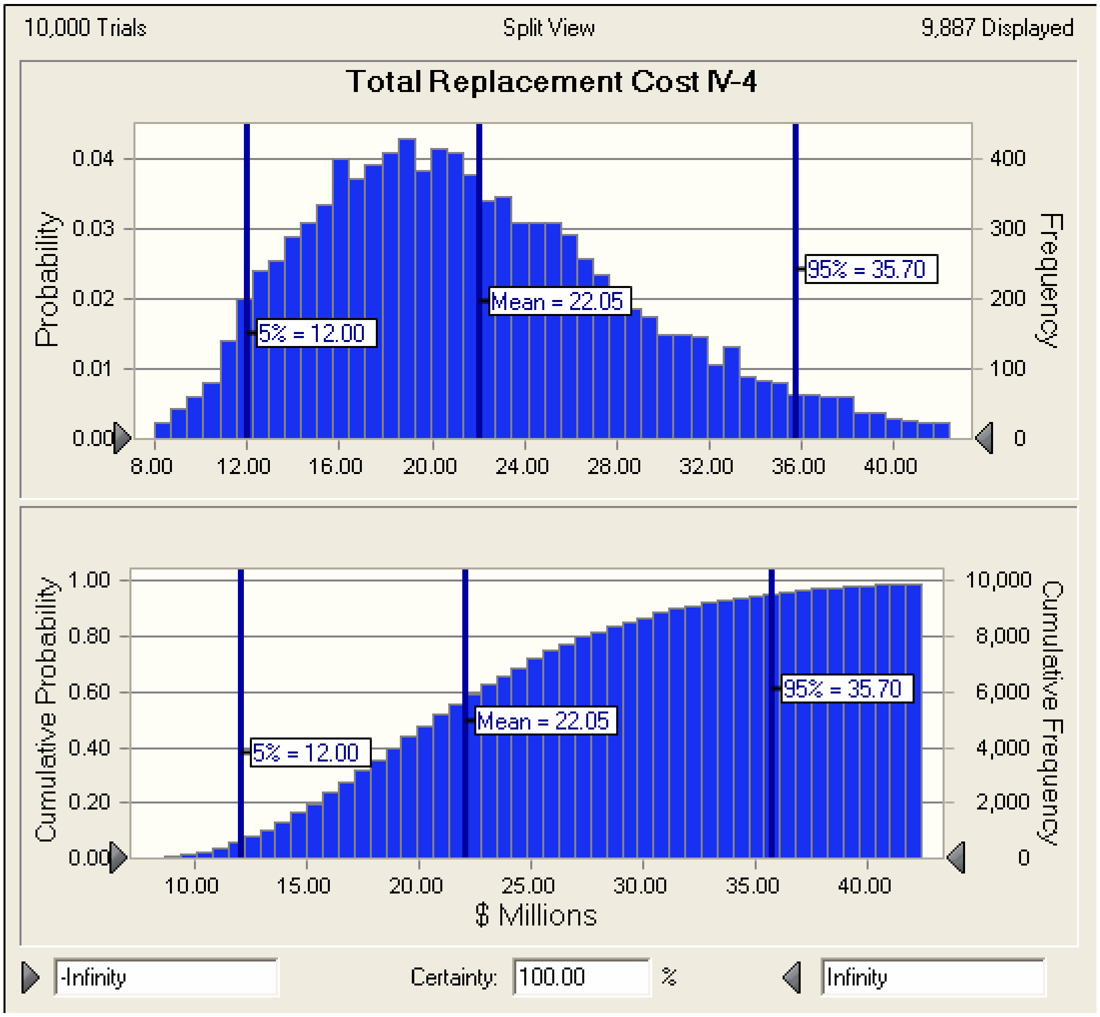

Figure 4-24 IHX Vessel Replacement Cost for IHX-4

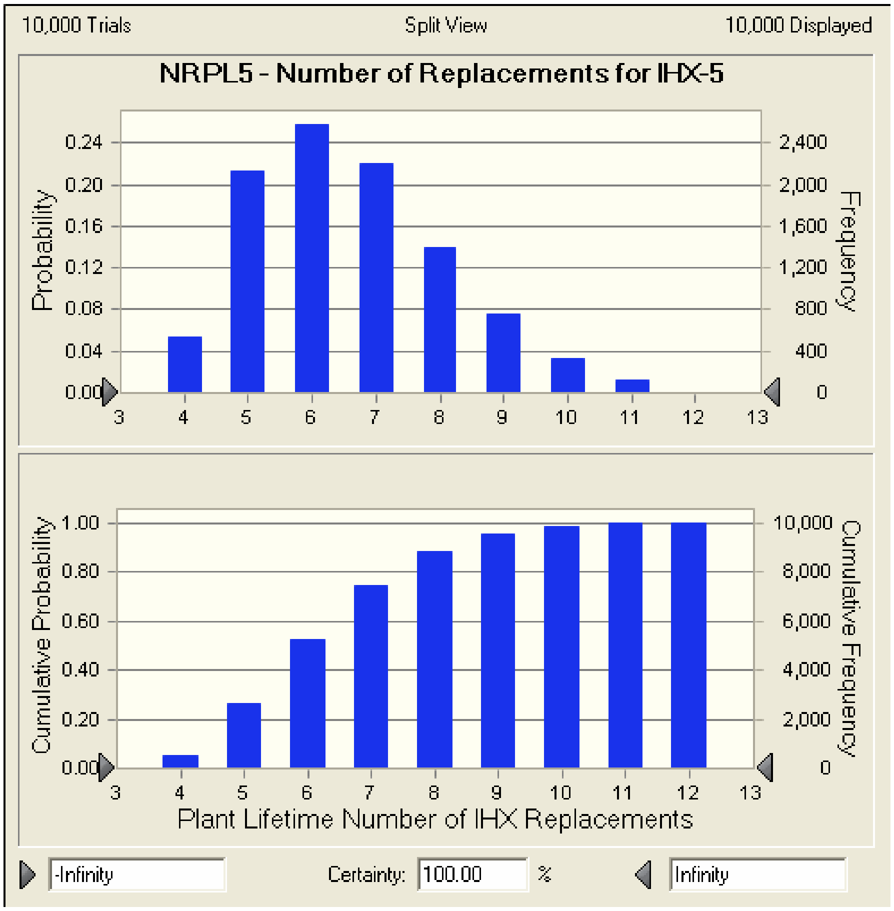

Figure 4-25 Number of IHX Vessel Replacements for IHX-5

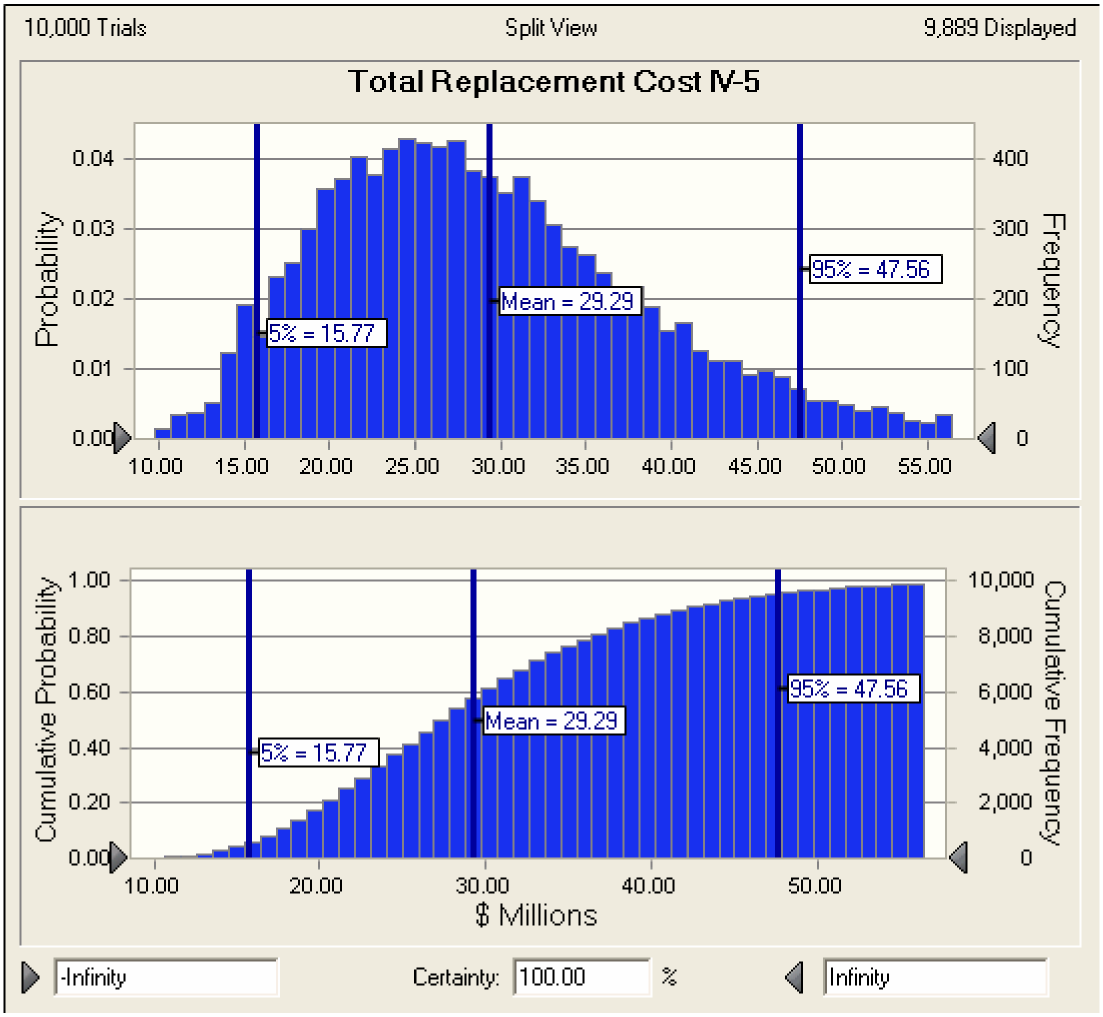

Figure 4-26 IHX Vessel Replacement Cost for IHX-5

4.2.2 IHX Vessel Cost Uncertainty

The total cost of IHX vessels for IHX-1, IHX-2, IHX-3, IHX-4, and IHX-5 is shown in Figure 4-27 through Figure 4-31, respectively. The mean value IHX vessel cost for Case IHX-1 is ~$14.2M with 5%-tile and 95%-tile bounds of ~$12.5M and ~$16.0M, respectively. For Case IHX-2, the mean vessel cost is ~$35.4M with a lower bound of $29.7M and an upper bound of $41.9M. Cases IHX-3 through IHX-5 have mean values of ~$40.3M, ~$44.1M, and ~$51.4M, respectively.

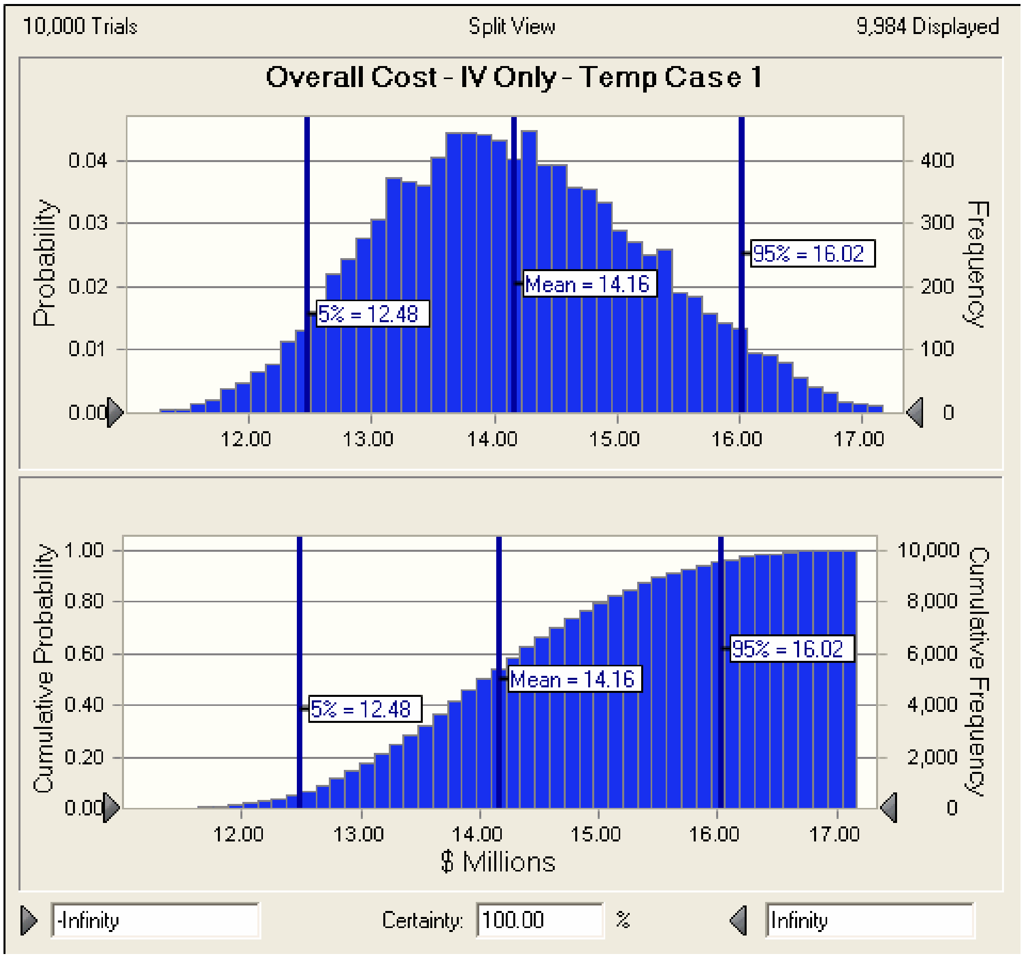

Figure 4-27 Total Vessel Cost for IHX-1

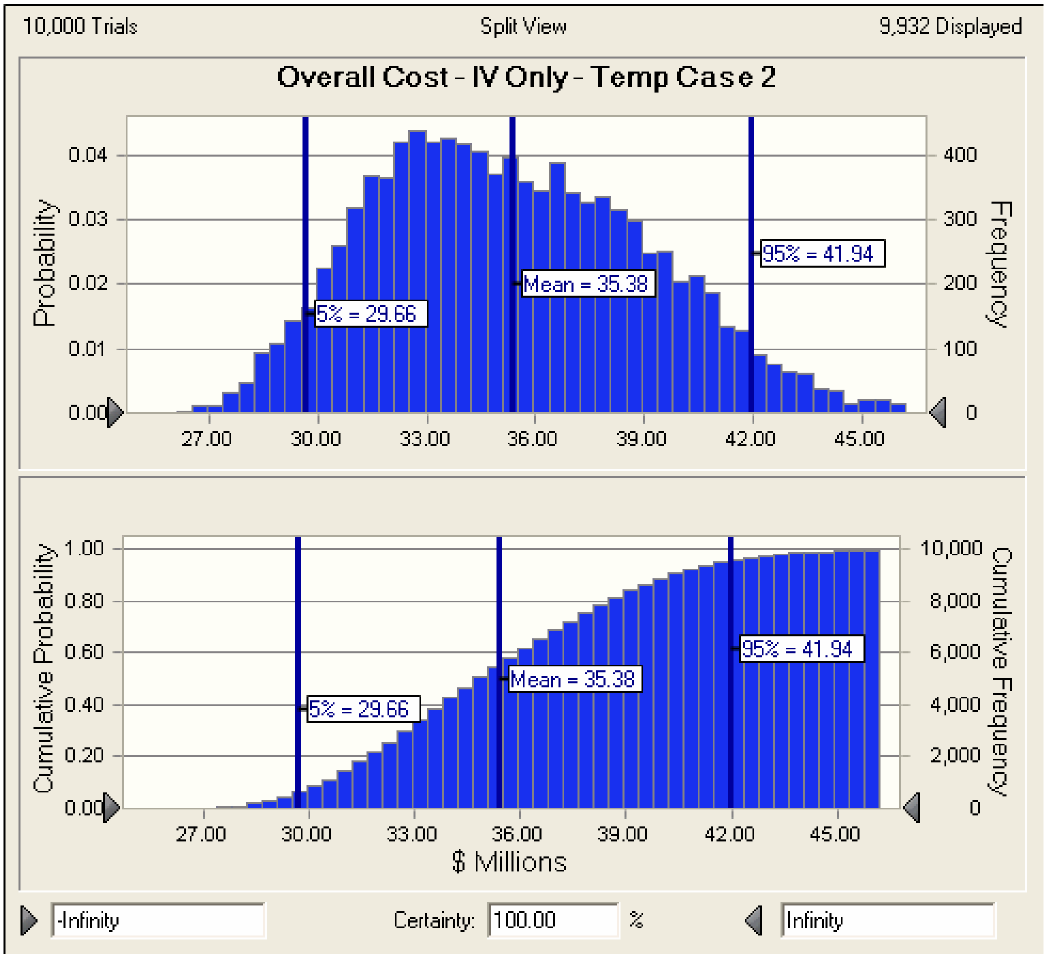

Figure 4-28 Total Vessel Cost for IHX-2

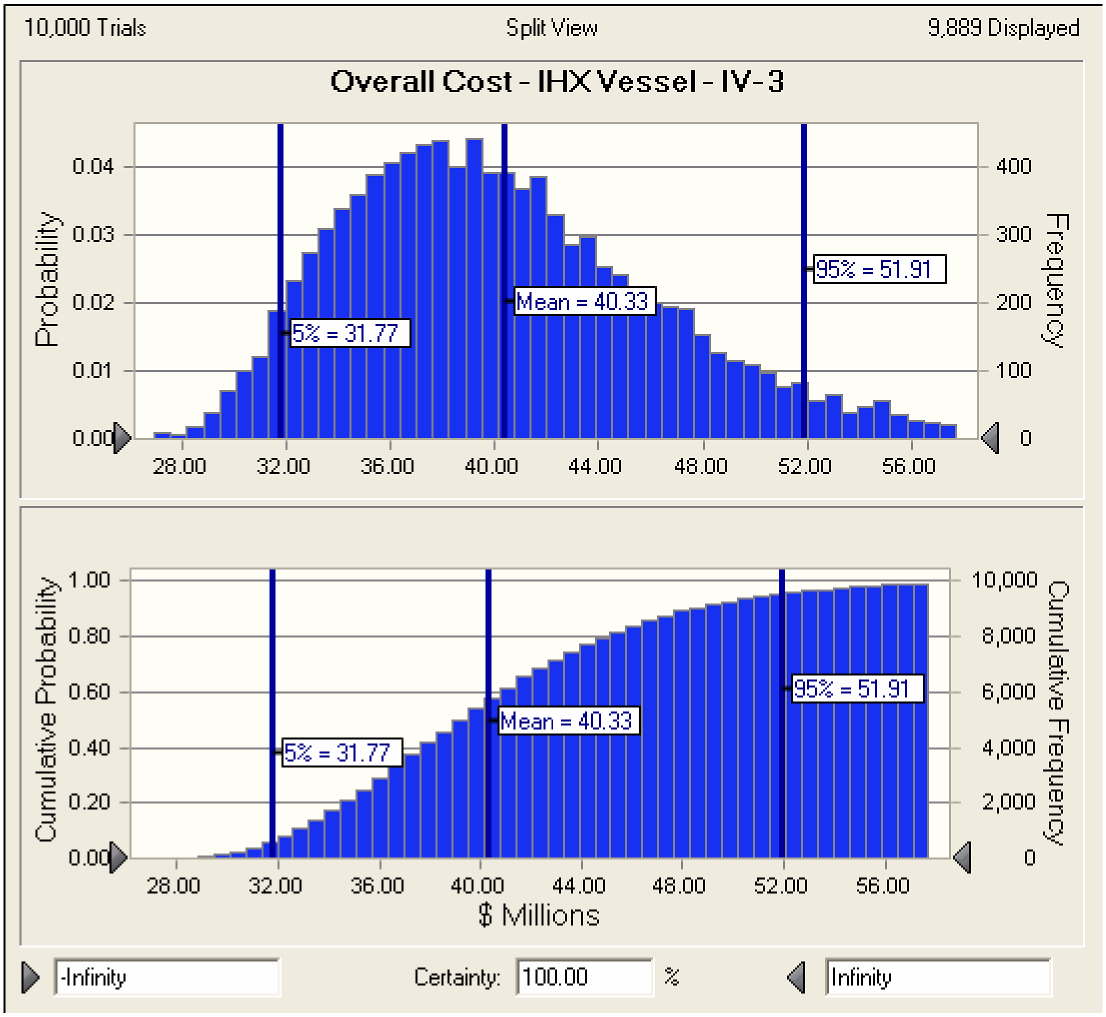

Figure 4-29 Total Vessel Cost for IHX-3

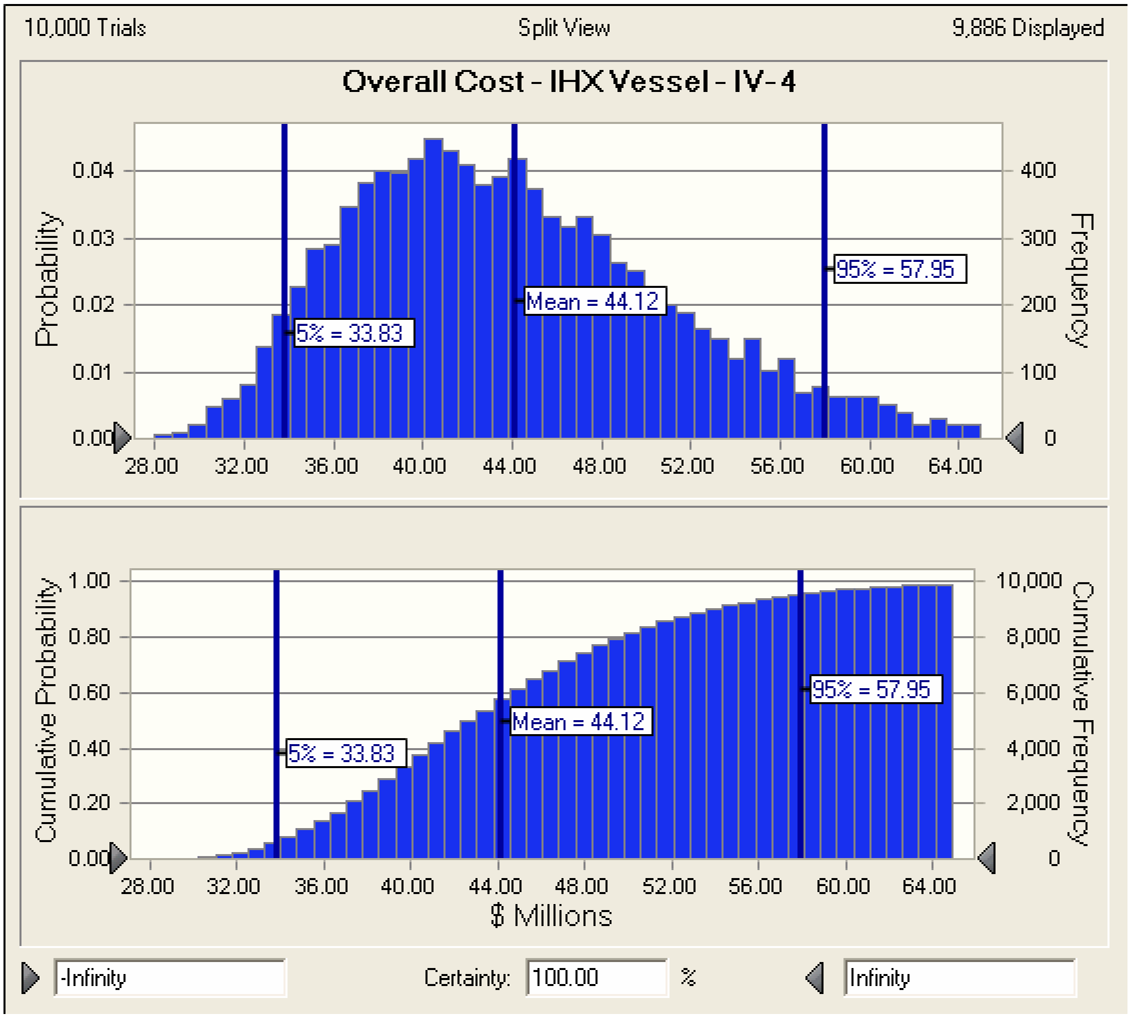

Figure 4-30 Total Vessel Cost for IHX-4

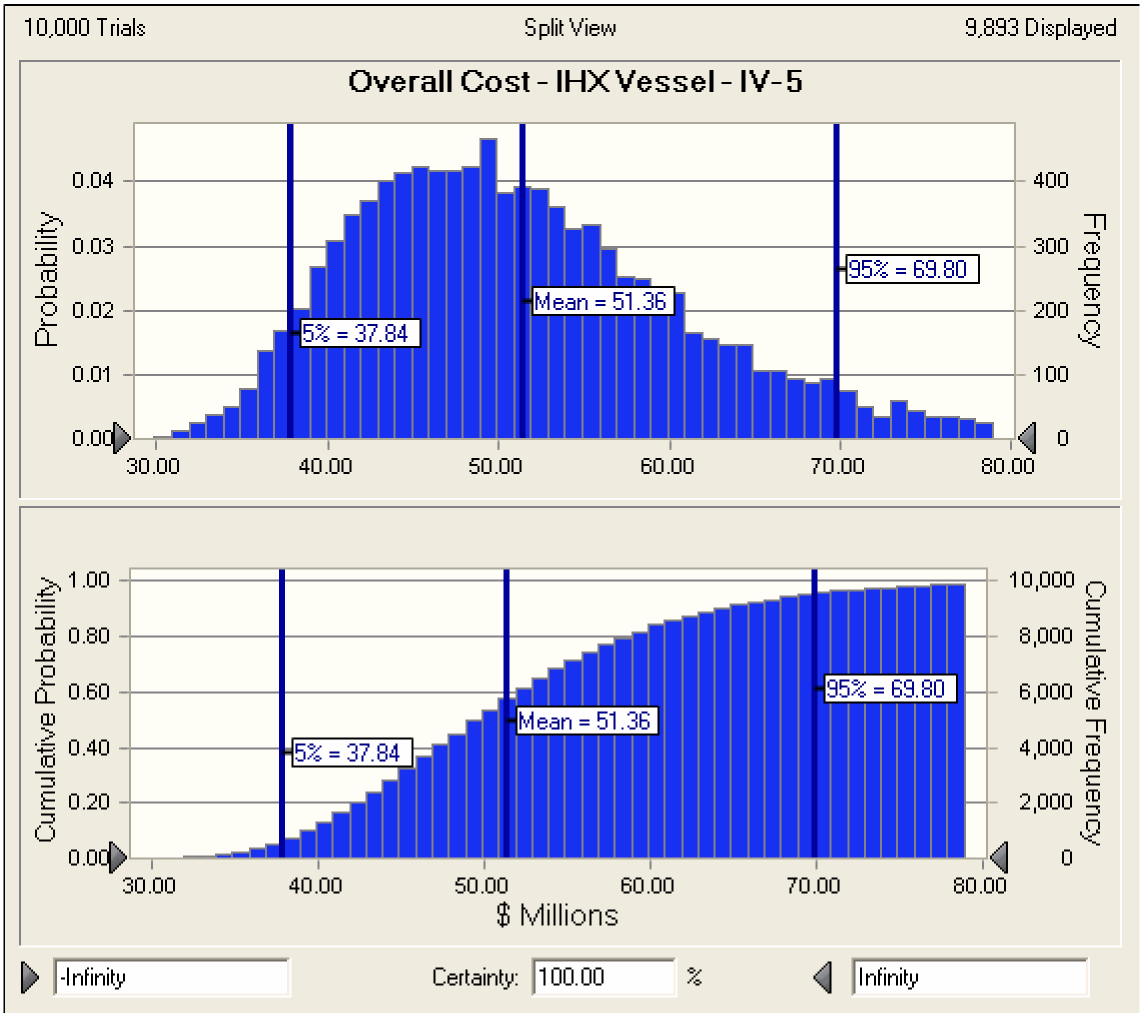

Figure 4-31 Total Vessel Cost for IHX-5

4.3 Combined IHX/IHX Vessel Cost Uncertainty

This section provides for description of total development, replacement, and total overall costs for the five IHX Cases under consideration.

4.3.1 IHX and IHX Vessel Development Costs

The combined development costs for the IHX and the IHX vessel are given in Table 4-8. The central value in each of the cells is the best estimate while the other figures give the 5%-tile and 95%-tile bounds. Figure 4-32 provides a graphic overlay of the total development costs input for the IHX and its vessel for all cases. As expected the lower temperature case has the lower development costs.

Table 4-8 Total IHX and IHX Vessel Development Cost

Case	Cost ($M)			
	Design, Codes, and Standards	Materials Qualification	Testing and V&V	Capital and Non-Labor
IHX-1/IV-1	2.8/3.8/5.9	2.0/2.4/3.2	1.8/2.2/3.0	1.9/2.7/4.6
IHX-2/IV-2	4.1/5.0/7.9	4.4/5.1/7.4	2.5/3.1/4.1	3.5/4.4/8.8
IHX-3/IV-3	4.1/5.0/7.9	4.7/5.7/7.9	2.5/3.1/4.1	3.5/4.4/8.8
IHX-4/IV-3	4.1/5.0/7.9	4.7/5.7/7.9	2.5/3.1/4.1	3.5/4.4/8.8
IHX-5/IV-3	4.1/5.0/7.9	4.7/5.7/7.9	2.5/3.1/4.1	3.5/4.4/8.8

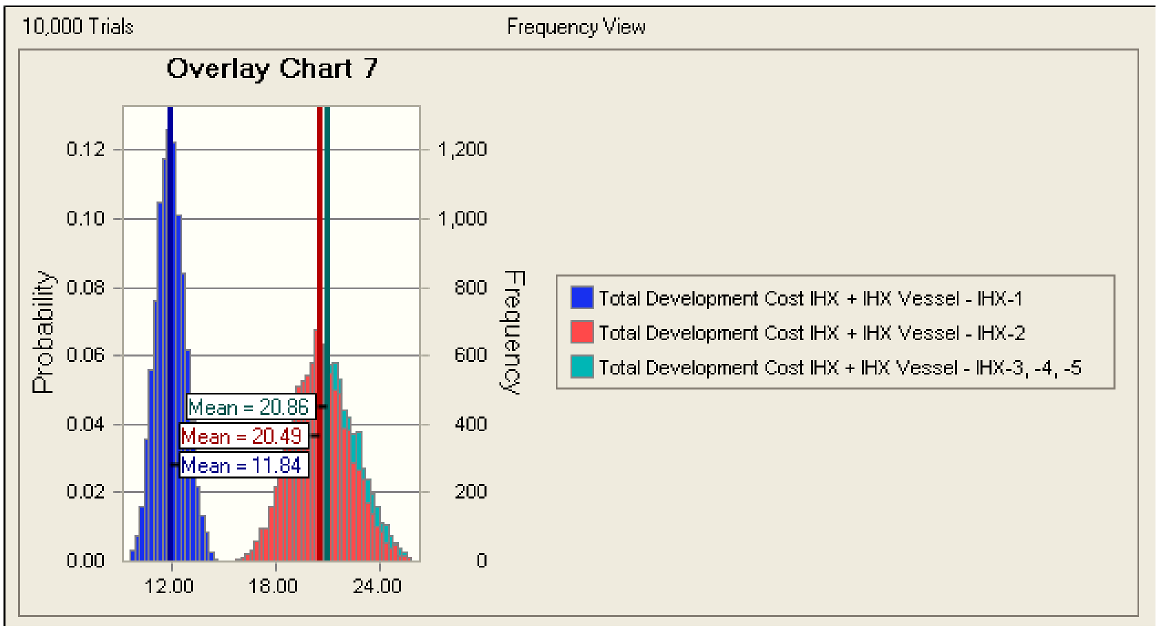

Figure 4-32 Total IHX and Vessel Development Cost

4.3.2 IHX and IHX Vessel Capital Cost Inputs

Figure 4-33 provides the capital cost inputs for the combined IHX and IHX vessel cases. The lower temperature case has a mean of ~$34M compared to the higher temperature cases at ~$52M.

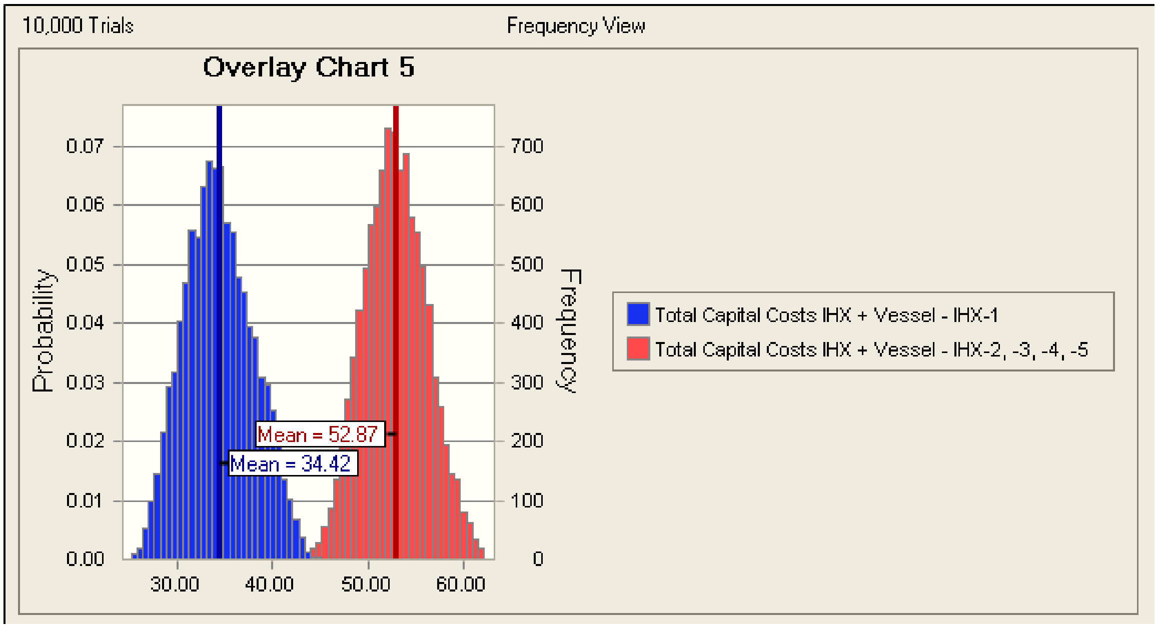

Figure 4-33 Total IHX and Vessel Capital Cost Inputs

4.3.3 IHX and IHX Vessel Replacement Cost

Figure 4-34 shows a comparison of the total replacement cost for the IHX and IHX vessel for IHX-2, IHX-3, IHX-4 and IHX-5. The mean value of the IHX/vessel replacement cost for IHX-2 (900°C ROT) is ~$31.4M. Mean values for IHX-3 through IHX-5 (designed for 950°C ROT, but operated initially at lower temperatures for IHX-3 and IHX-4) are ~$54.1M, $59.2M, and $69.0M.

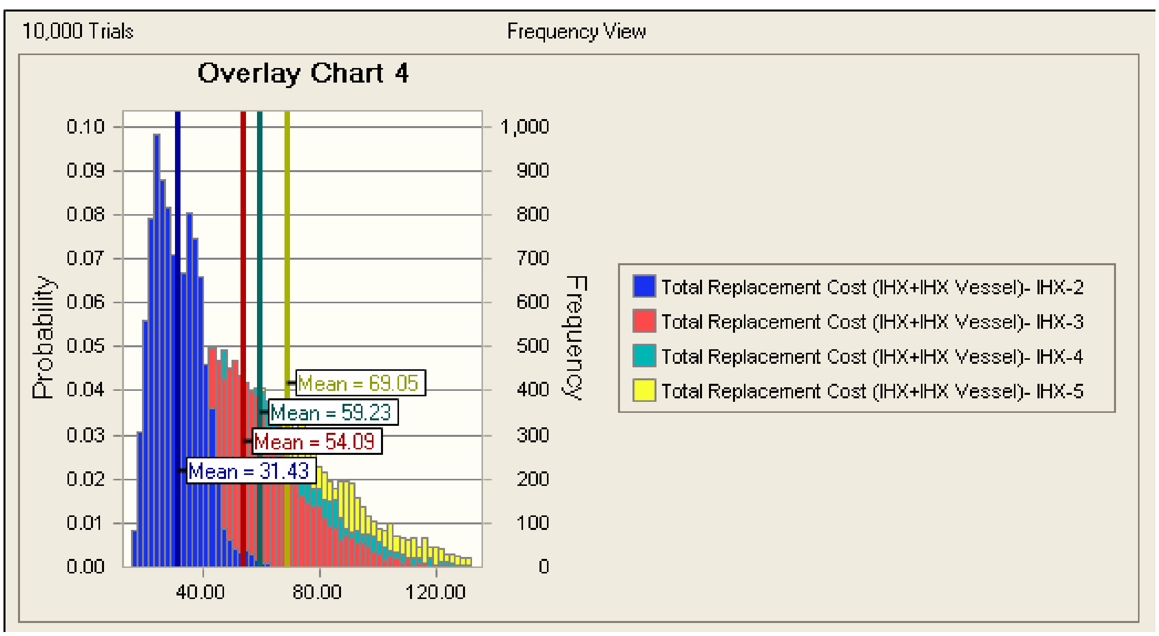

Figure 4-34 Total IHX and Vessel Replacement Cost

4.3.4 IHX and Vessel Overall Cost

A comparison of total IHX plus IHX vessel costs for all IHX cases is given in Figure 4-35. The mean value of total IHX/vessel cost for IHX-1 (<760°C operation and no replacements) is ~$46.3M. The total mean value costs for those cases where replacements occur as described earlier (IHX-2 through IHX-5) range from ~$104.8M to ~$142.8M. The sensitivity of these costs to reactor power level was assessed and indicated that there was no effect of a half-scale (250 MWt) reactor unit on development or replacement efforts for the IHX/vessel combination. However, the smaller size components would have lower capital costs with an estimated scaling factor of 0.6.

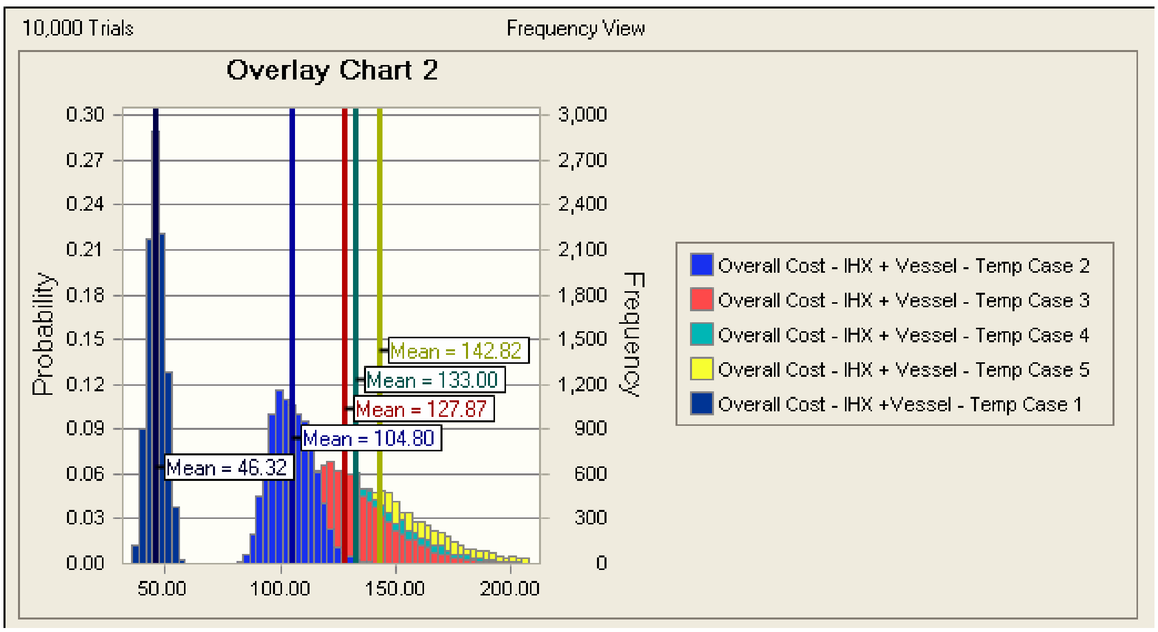

Figure 4-35 Total IHX and IHX Vessel Overall Cost

4.4 Reactor Vessel Cost Uncertainty

4.4.1 RPV Operating and Design Parameters and Materials

Only a single case is involved with consideration of RPV costs. The RPV is designed for a ROT of 950°C and a RIT of 350°C. The reactor power level is 510 MWt and the primary system pressure is nominally 9 MPa. The RPV materials are SA-508/SA-533 steel, as are used in the reactor vessels for LWRs.

4.4.2 RPV Cost Contributors and Costs

The RPV cost contributors are development cost (~$3M), shown in Table 4-9 in man-years and dollars and in Figure 4-36 as dollars, and capital costs. The capital cost of the RPV in the present case is as that for the DPP. A normalized RPV capital cost is shown in Figure 4-37 since the vessel for the DPP is under contract and the value of this contract is proprietary.

Table 4-9 RPV Development Cost

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
RV-1	0.6	0.9	1.2	0.225	0.3	0.6	0.0	0	0.0	1	1.5	3

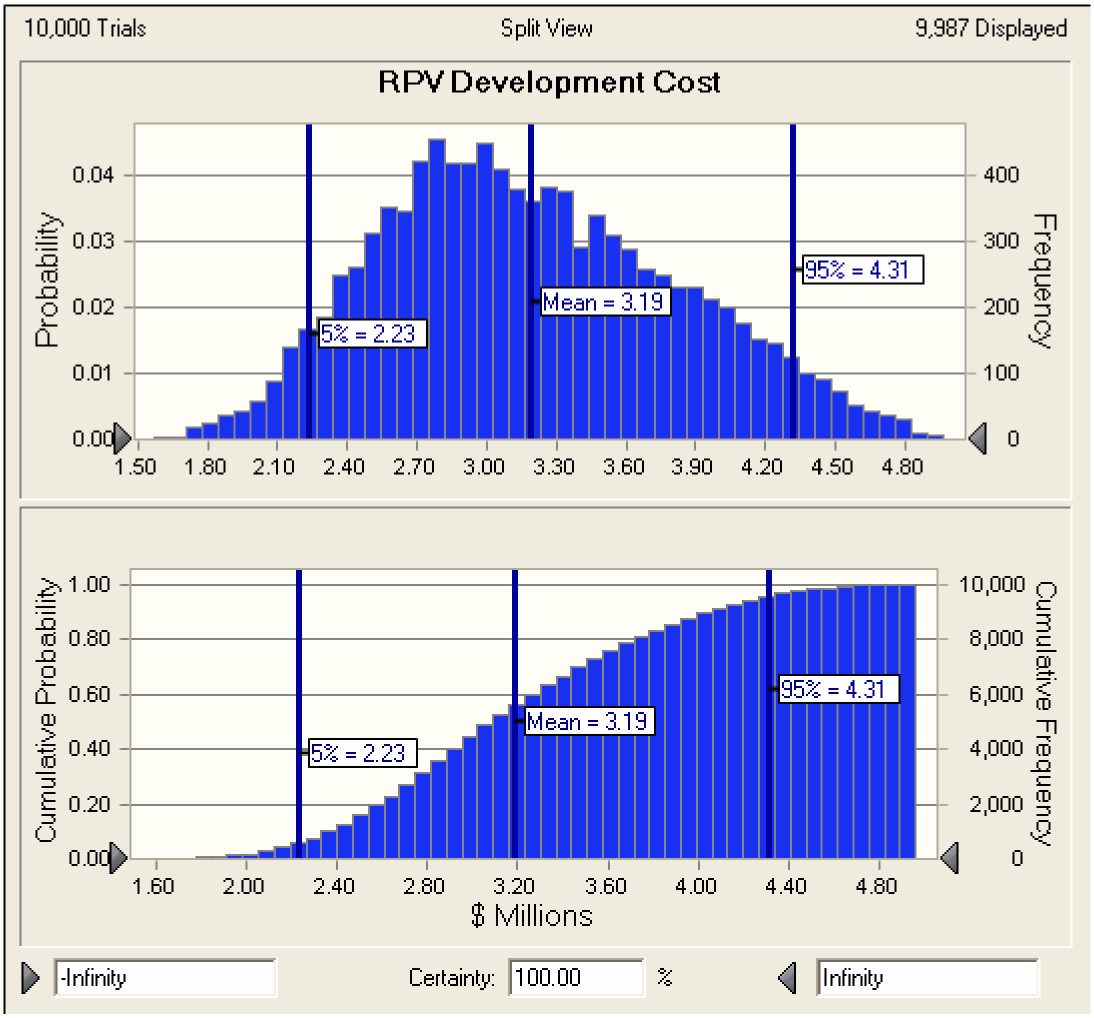

Figure 4-36 Development Costs for the Reactor Pressure Vessel

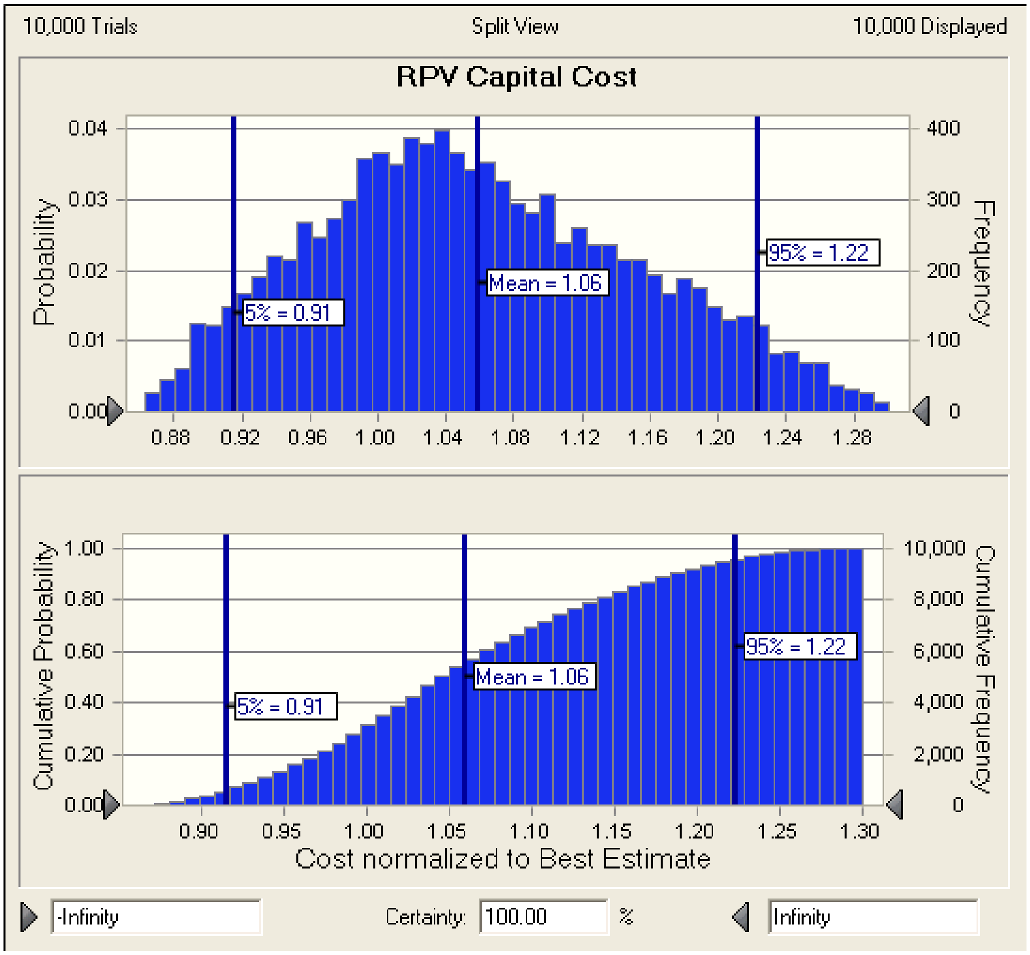

Figure 4-37 Normalized Capital Cost of the Reactor Pressure Vessel

4.5 Core Outlet Pipe Cost Uncertainty

4.5.1 Operating and Design Parameters and Materials for the COP

The design and initial operating parameters and materials for the COP cases are shown in Table 4-10. The RIT and the primary system helium pressure are identical in all cases but the ROT varies with case. For Case COP-1, the COP is designed for and operated at <760°C and uses Alloy 800H as the hot duct liner. (The external pressure boundary pipe is of SA-508/SA-533 steel in all cases.) Design and operation for Case COP-2 is for 900°C and it too uses Alloy 800H as the liner. Cases COP-3 through COP-5 are designed for a ROT of 950°C but COP-3 and COP-4 operate initially at <760°C and 850°C, respectively. The hot duct liner material for these latter three cases is Ni-base alloy Hastelloy X or its improved version, Hastelloy XR.

Table 4-10 Matrix of Cases for the Core Outlet Pipe

Case	Design / Initial Operating Parameters				
	ROT	RIT	Power Level	Primary Press.	Mat'ls
	(C)	(C)	(MWt)	(MPa)	
COP-1	<760 / <760*	350	500	9	800H
COP-2	900 / 900				800H
COP-3	950 / <760				Hastelloy
COP-4	950 / 850				Hastelloy
COP-5	950 / 950				Hastelloy

4.5.2 Core Outlet Pipe Cost Contributors

Cost contributors for the COP are development costs given in Section 4.5.2.1 and capital costs described in Section 4.5.2.2.

4.5.2.1 Development Cost for the Core Outlet Pipe

The development costs for the five COP Cases are given in terms of design/codes and standards, materials qualification, testing and V&V, and capital and non-labor are given in Table 4-11. Man-year efforts are also given except for the capital/non-labor element. Cost plots are provided for development costs in Figure 4-38, Figure 4-39, and Figure 4-40. The mean value of development costs is ~$1.2M for Case COP-1 (<760°C design and operating temperature) with 5%-tile and 95%-tile bounds of ~$0.9M and ~$1.5M, respectively. Values and bounds for Case COP-2 are ~$2.9M, ~$2.3M, and~ $3.6m, respectively. The mean value of development cost for Cases COP-3 through COP-5 is ~$5.8M with bounds as shown on Figure 4-40.

Table 4-11 Development Costs for the Core Outlet Pipe

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
COP-1	0.9	1.2	1.5	0	0.0	0	0.0	0	0.0	0	0.0	0
COP-2	0.9	1.2	1.8	0	0.0	0	0.0	0	0.0	0	0.0	0
COP-3	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4
COP-4	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4
COP-5	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4

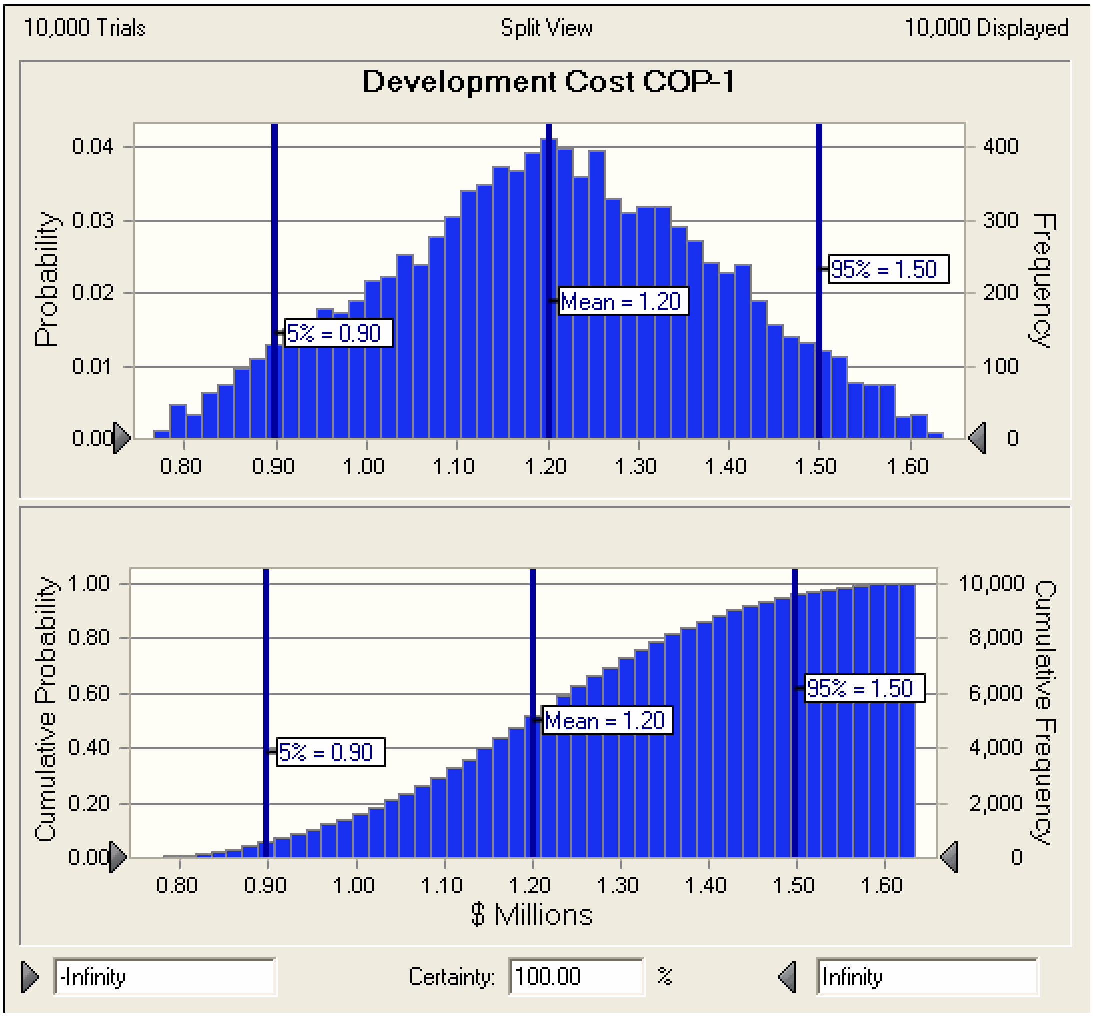

Figure 4-38 Development Cost for COP-1

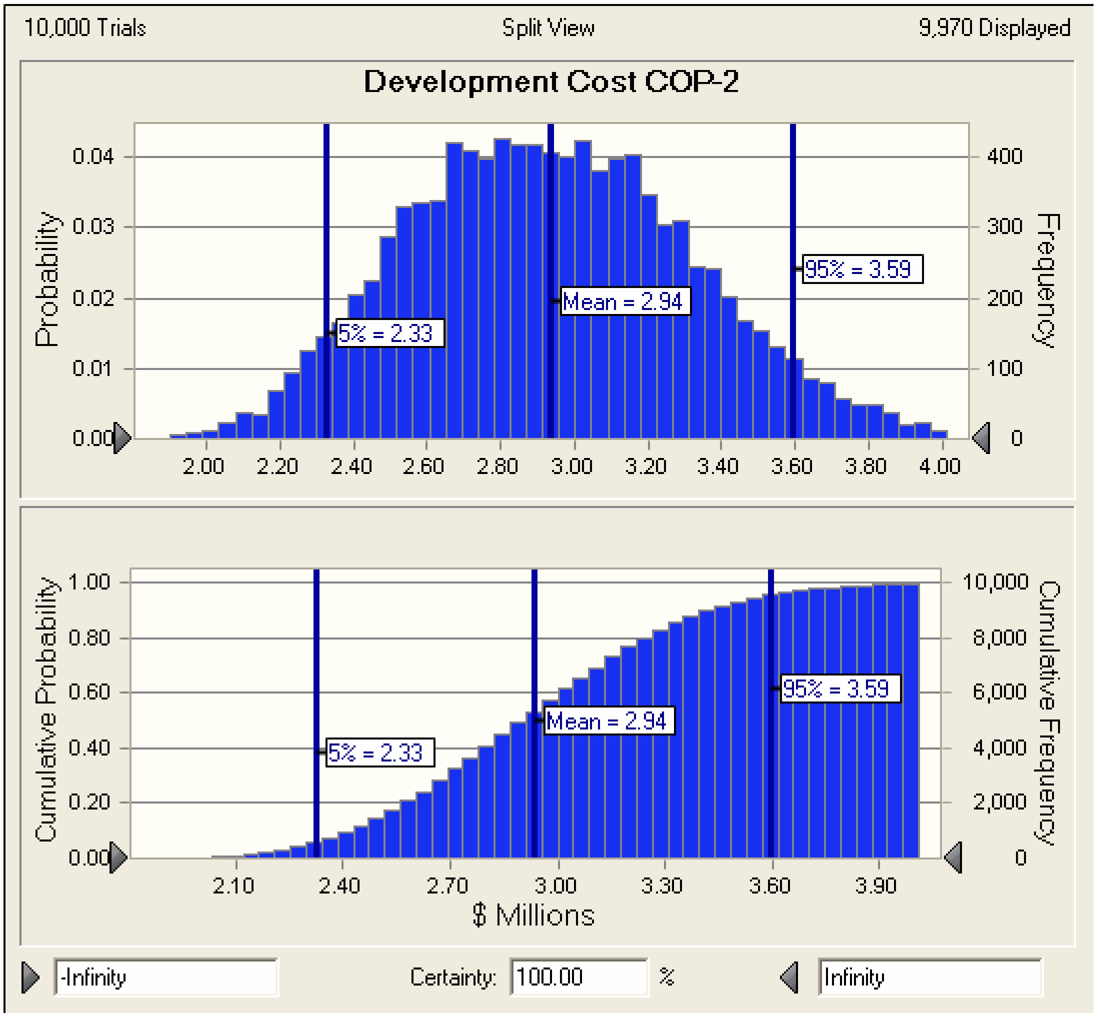

Figure 4-39 Development Cost for COP-2

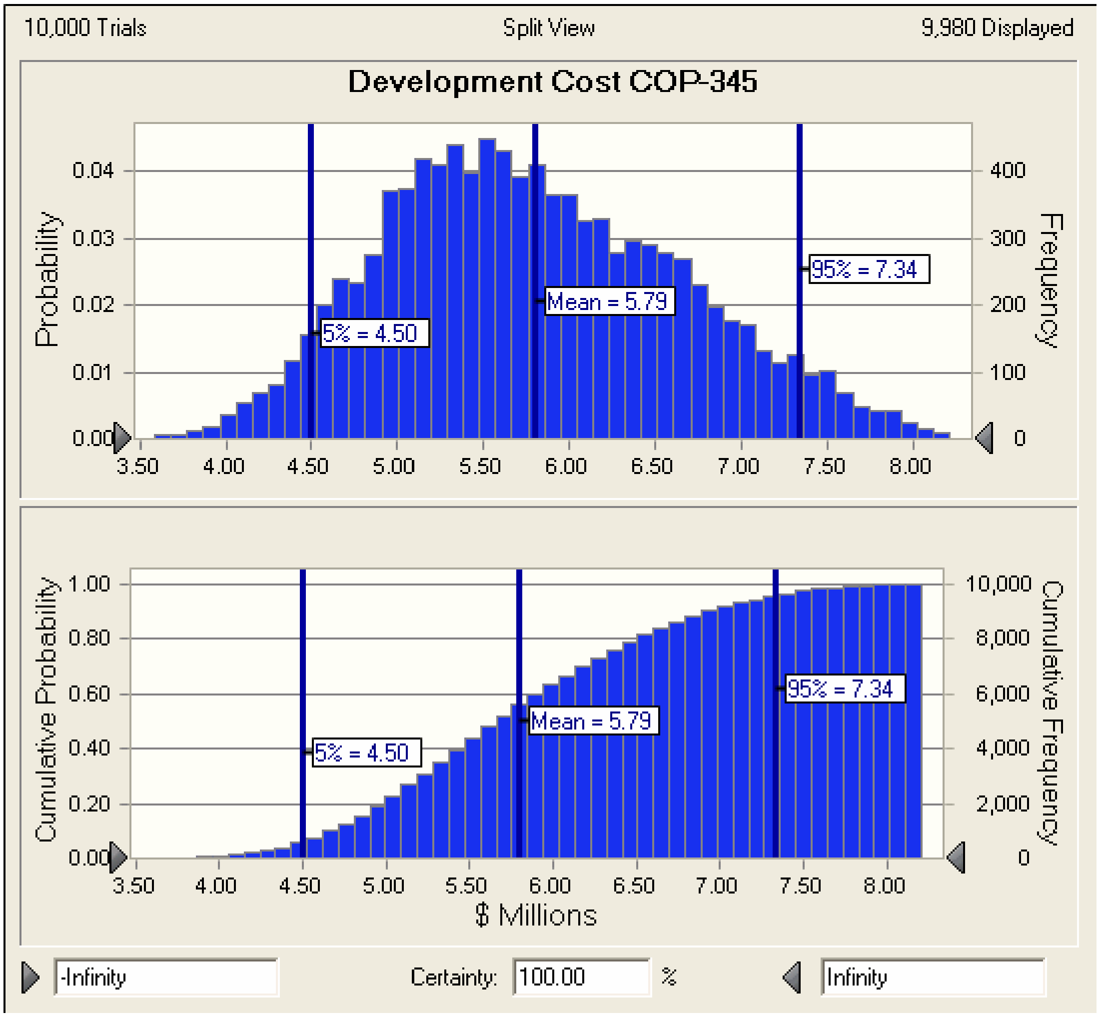

Figure 4-40 Development Costs for COP-3, COP-4, and COP-5

4.5.2.2 Core Outlet Pipe Capital Costs

The capital costs for COP Cases COP-1 through COP-5 can be calculated using information presented in Table 4-12. Mean value capital costs for the COP cases are determined by using the basic cost of $10 per kWt (the best estimate for COP-1) times the associated cost factor (e.g., 1.2 for COP-2) times total power. These factors and their upper and lower bounds are given in Table 4-12.

Table 4-12 Capital Cost Factors for the Core Outlet Pipe

Case	Design/Initial Operating Temperature (°C)	Capital Cost Factor with 1.0 = $10/kWt
COP-1	<760/<760	0.9/1.0/1.2
COP-2	900/900	1.0/1.2/1.5
COP-3	950/<760	1.2/1.4/1.8
COP-4	950/850	1.2/1.4/1.8
COP-5	950/950	1.2/1.4/1.8

4.5.3 Core Outlet Pipe Cost Uncertainty

The overall cost of Case COP-1 is shown in Figure 4-41; the mean value is ~$6.5M with 5%-tile and 95%-tile bounds of ~$5.7M and ~$ 7.4M 3, respectively. Figure 4-42 gives the overall cost for Case COP-2 with a mean value of ~$9.3M and lower and upper bounds of $7.9M and $10.7M, respectively. The mean (~$13.3M), lower bound (~$11.3M), and upper bound (~$15.5m) total cost for COP Cases COP-3, COP-4, and COP-5 are identical and shown in Figure 4-43. The COP capital cost would be reduced ~40% by going to a reactor power level of 250 MWt but development costs would increase substantially since the COP is based on the current DPP design of 500 MWt.

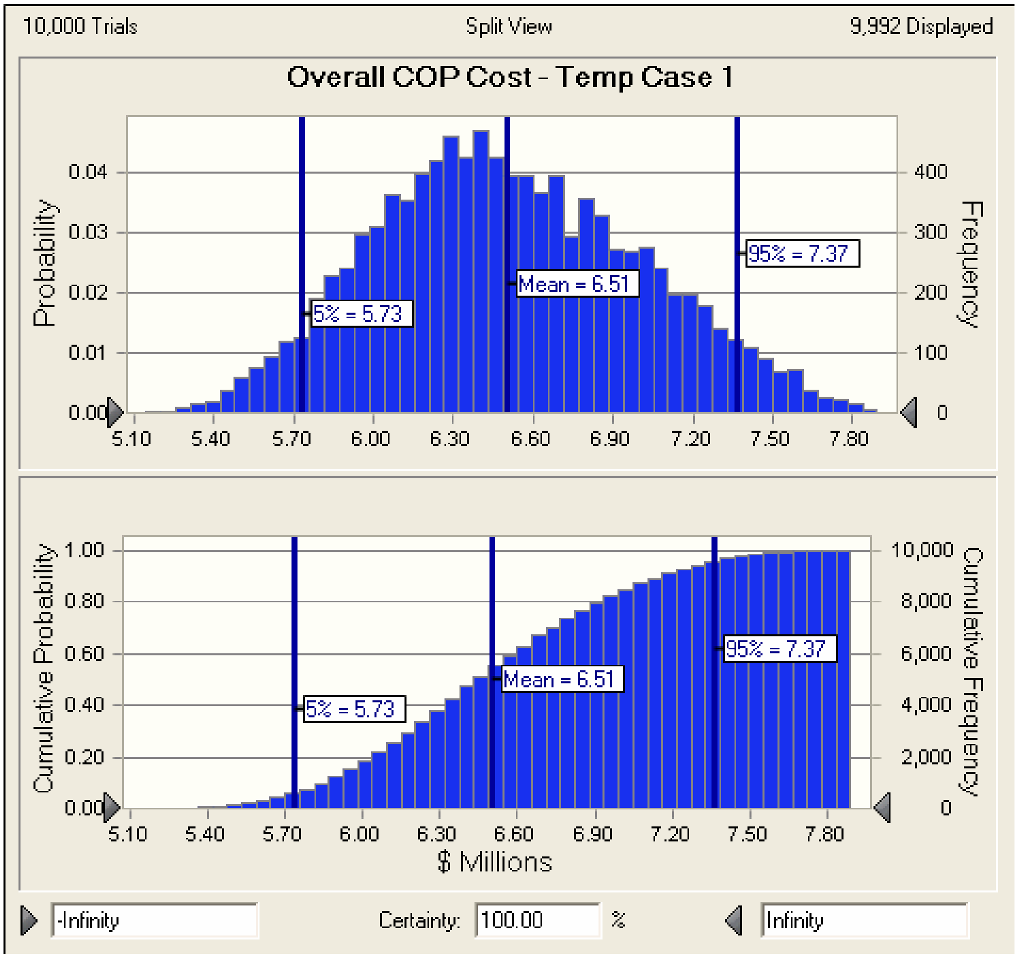

Figure 4-41 Overall Cost for COP-1

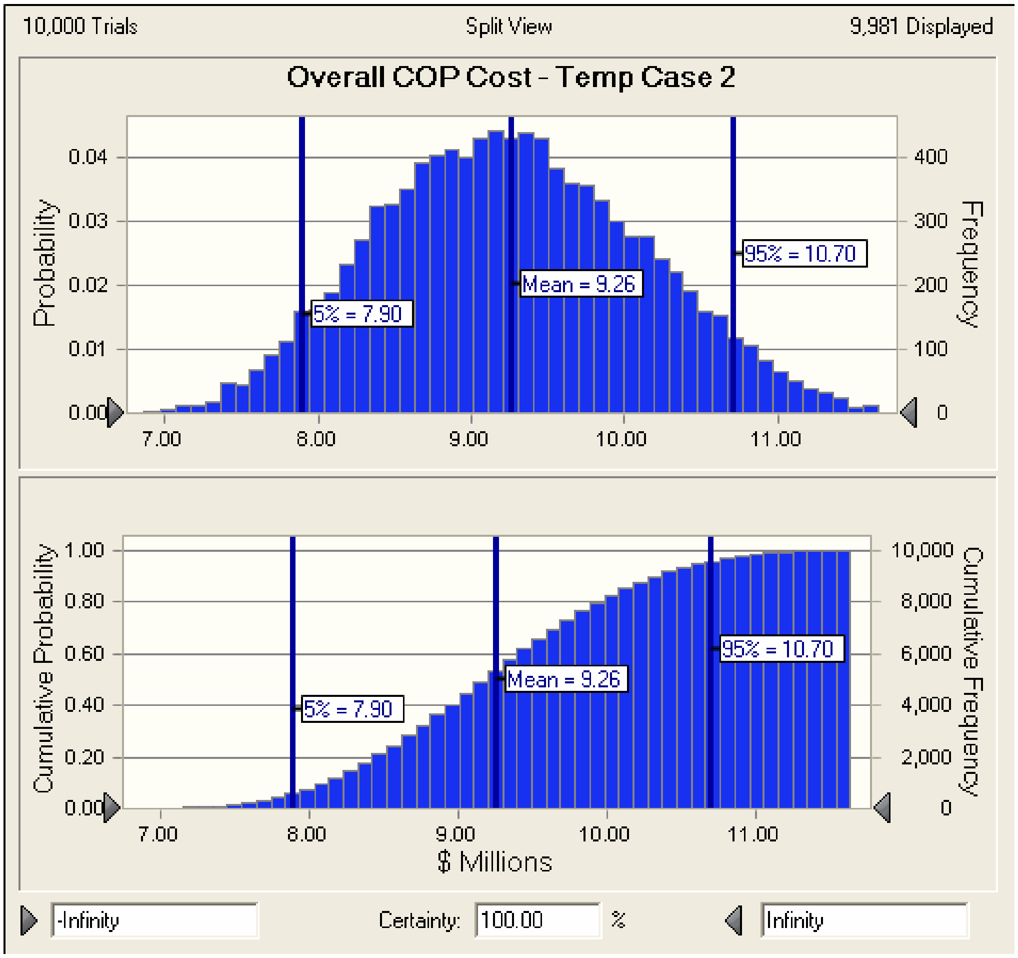

Figure 4-42 Overall Cost for COP-2

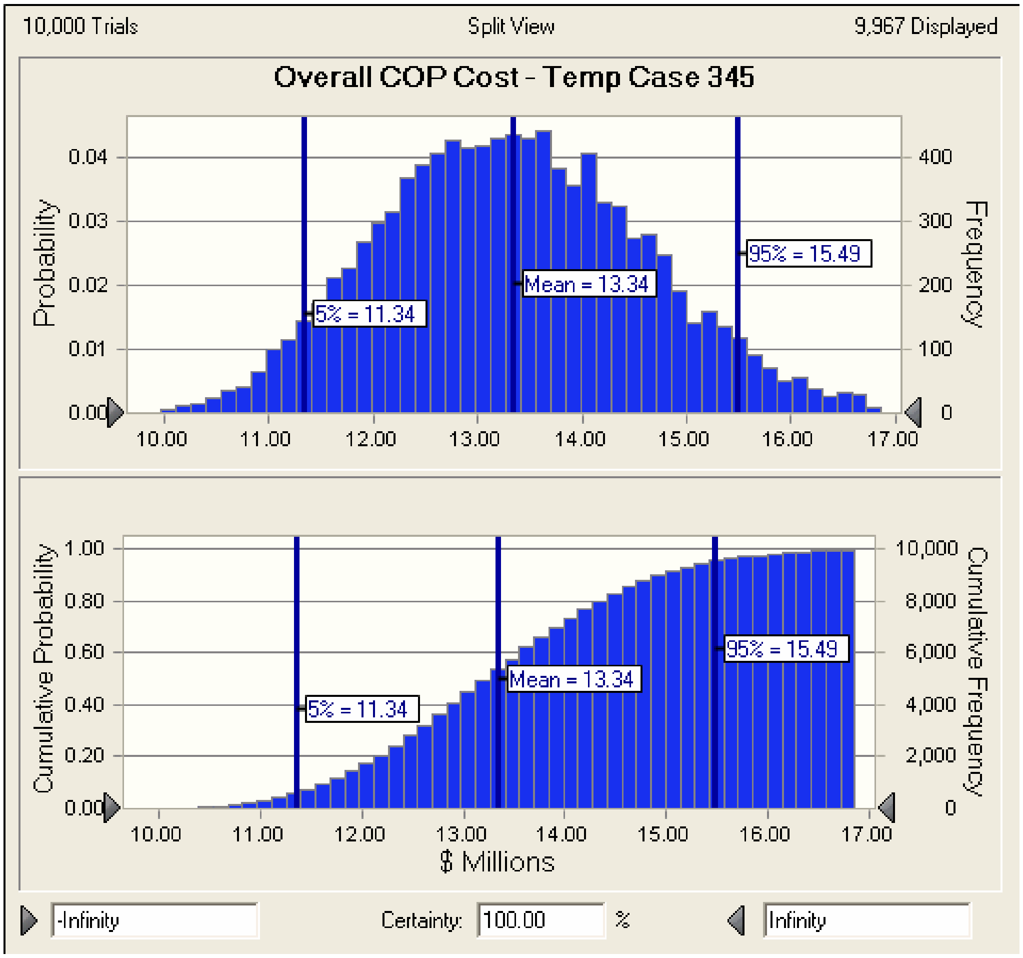

Figure 4-43 Overall Cost for COP-3, COP-4, and COP-5

4.6 Development Cost Uncertainty for All Selected Metallic Components

Figure 4-44, Figure 4-45 and Figure 4-46 provide the expected value and uncertainty distributions for the development costs for all the selected metallic components (IHX, IHX Vessel, Reactor Vessel, and Core Outlet Pipe) for the <760, 900, and 950°C temperature cases, respectively. The trends are as expected with the mean values increasing with temperature from ~$16M to ~$30M with increasing uncertainty of cost.

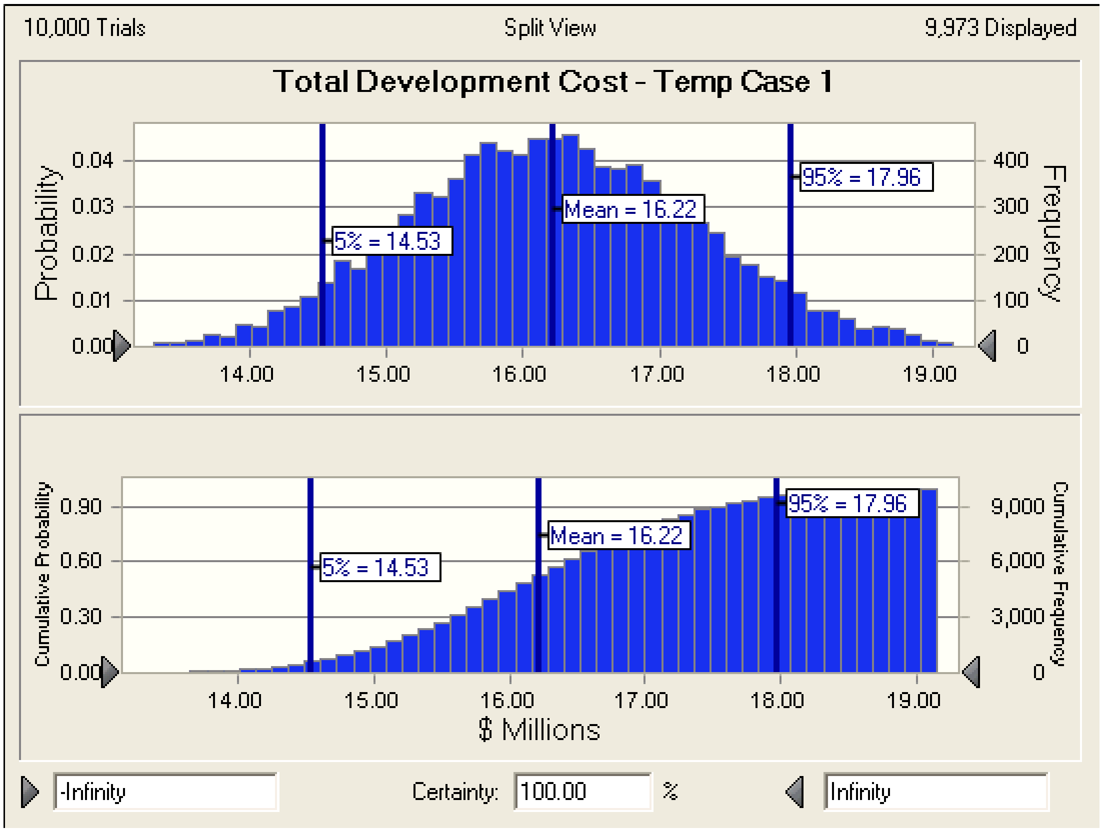

Figure 4-44 Development Cost for All Selected Metallic Components for <760°C ROT Case

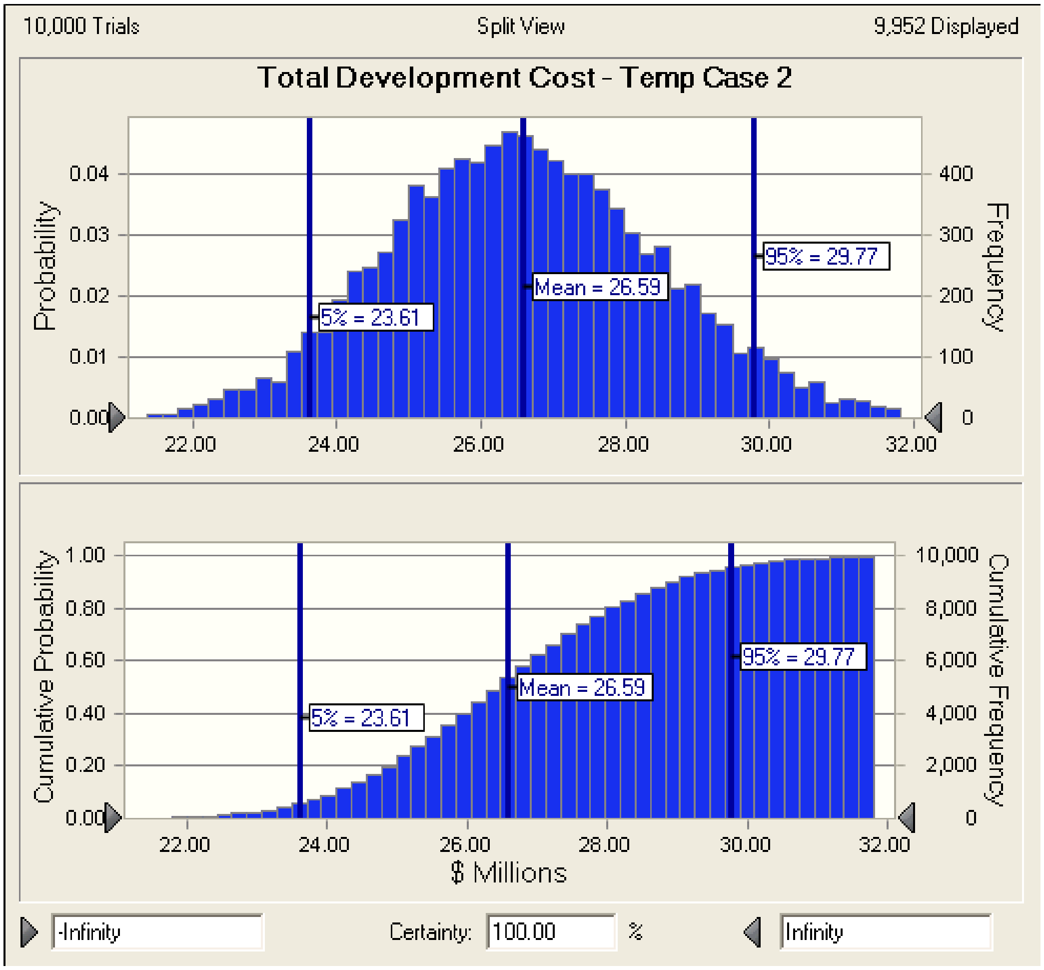

Figure 4-45 Development Cost for All Selected Metallic Components for 900°C ROT Case

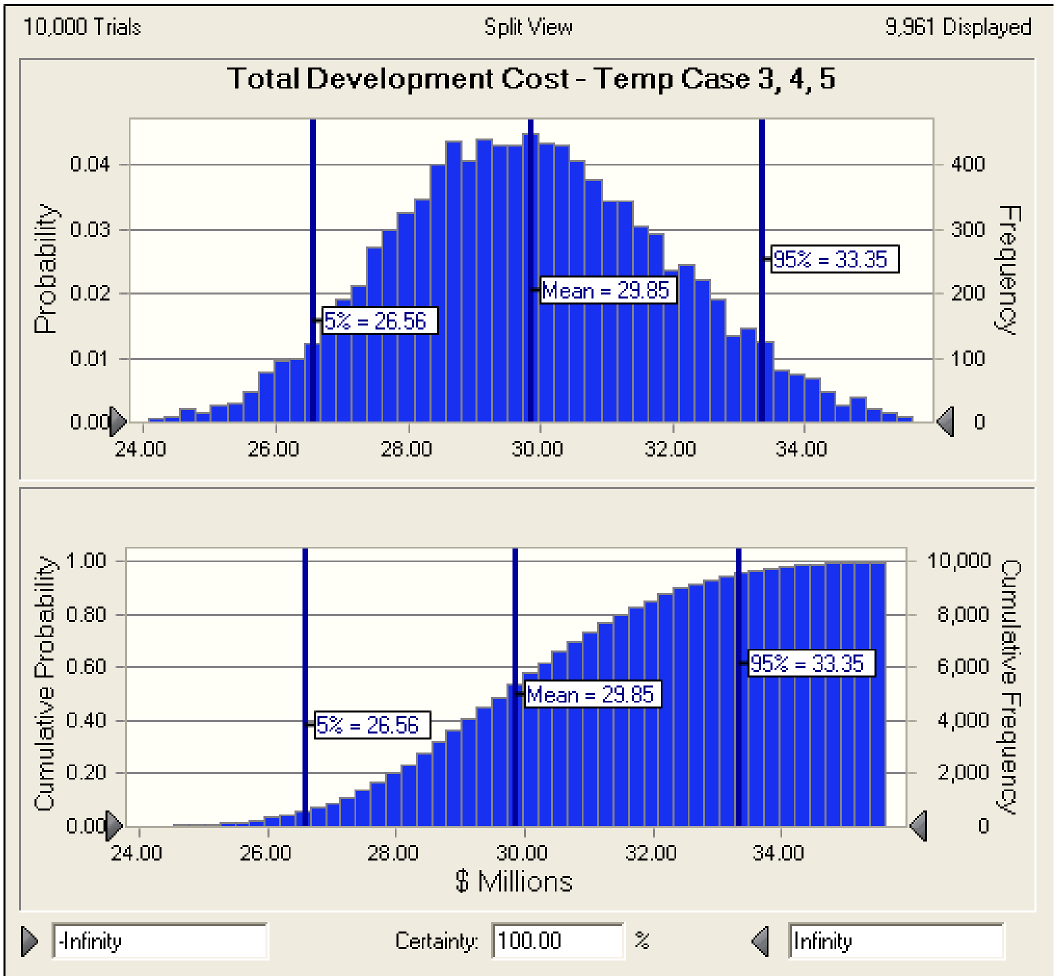

Figure 4-46 Development Cost for All Selected Metallic Components for 950°C ROT Cases

4.7 Metallic Component Cost Uncertainty Summary and Conclusions

The IHX and its vessel are major cost components and the ROT is the major driver for increased cost. For example, the IHX + vessel mean cost increases from ~$46.2M for an ROT of <760°C to ~$104.8M for an ROT of 900°C and then to ~$142.8M for the highest ROT, 950°C. Mean replacement costs for the IHX plus its vessel increase from zero for the <760°C case to ~$31.4M for a 900°C ROT and to ~$69.0M for the 950° ROT case with initial operation at 950°C. The impact of lower initial operating temperatures for the 950°C design on mean cost is limited. In the case where the initial operation is at <760° for 5 years, the delay in replacement reduces replacement mean cost only from ~$69.0M to about $54.1M; operation at 850°C for 3 years reduces mean cost from ~$69.0M to ~$59.2M.

The RPV is a high cost item but with relatively little uncertainty in overall cost. Reactor operating temperatures in the range <760° to 950°C have no effect on cost.

The COP is a relatively low cost component with cost uncertainties on the order of those for the IHX. The total mean cost for the COP is ~$6.5M for a <760°C ROT, ~$9.3M for a 900°C ROT, and ~$13.3M for an ROT of 950°C. There is no reduction in mean cost where the 950°C COP design is initially operated at lower temperatures for 3 to 5 years as the COP is a full lifetime component.

5 REFERENCES

1. *NGNP and Hydrogen Production Preconceptual Design Report, NGNP-ESR-RPT-001, Revision 1, Westinghouse Electric Company LLC, June 2007.*

2. *NGNP and Hydrogen Production Preconceptual Design Study, IHX and Heat Transport System, NGNP-HTS 60-IHX, Revision 0, Westinghouse Electric Company LLC, April 2008.*

3. *NP-MHTGR INEL Component Transportation Assessment, DSG-9-264, Revision 0, ABB Combustion Engineering Nuclear, October 1991.*

APPENDIX A: 90% REVIEW PRESENTATION SLIDES

P B M R

Metallic Component Schedule and Cost Risk Assessment

90% Design Review

April 10, 2008

Objectives of Study

- Determine the impact of operating parameters and associated selected metallic materials on the certainty of achieving NGNP initial operation in 2018
  - IHX
  - IHX Vessels
  - Reactor Vessel
  - Core Outlet Pipe

- Evaluate the impact of the same range of operating parameters and associated selected metallic materials on the related development, component and replacement costs

Presentation Outline

- Background and Framework
- Schedule Risk Assessment
- Cost Risk Assessment

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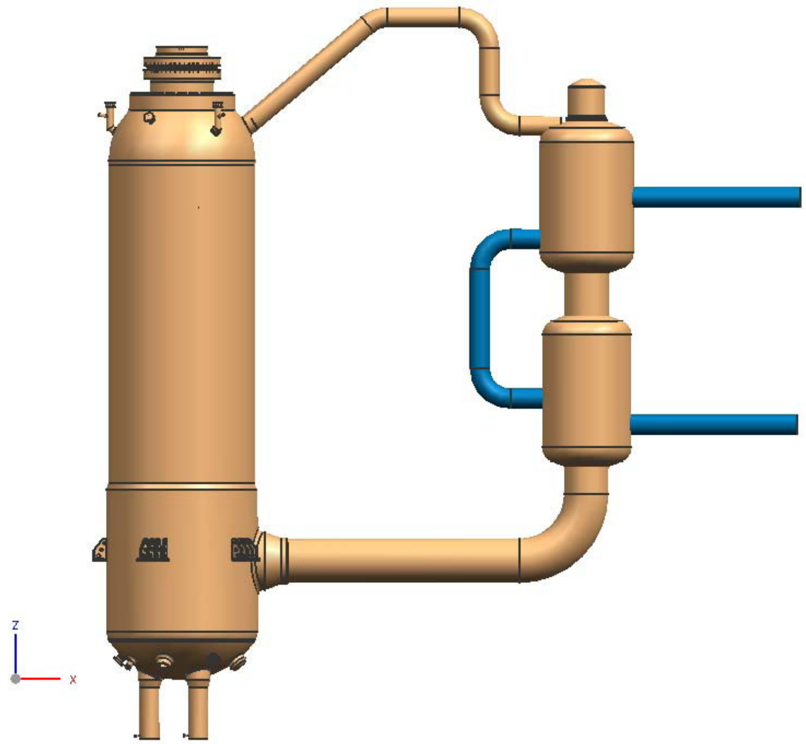
Selected Metallic Components for Risk Assessment



- IHX A and IHX B
- IHX A and B Vessels
- Reactor Vessel
- Core Outlet Piping

Study Assumptions

- No funding, resource, or programmatic constraints beginning FY2009
- Target schedule is initial power operation by end of CY2018
- Schedule and cost risk reduction limited to specified metallic components in PHTS
- Options to consider initial plant operation for 3 to 5 years at less than the 950C ROT require code cases for 950C
- PBMR NGNP reference is PCDR design
- Site is either a coastal site or the INL site

Contributors to Expert Solicitation

- PBMR: Michael Correia, Roger Young, James McKinnell
- Westinghouse: Sten Caspersson
- Shaw: Ed Brabazon, Bob Wilmer
- Technology Insights: Scott Penfield, Phil Rittenhouse, Dan Mears, Karl Fleming, Fred Silady, Dan Allen
- Brayton Energy: Jim Nash, Jim Kesseli

Presentation Outline

- Background and Framework

▶ Schedule Risk Assessment
  - Approach
  - IHX and IHX Vessel
  - Reactor Vessel (coastal site and INL)
  - Core Outlet Pipe
  - Summary

- Cost Risk Assessment

Schedule Risk Reduction Approach

1. Determine range of design operating parameters applicable to each component

2. Select cases: one for each design operating parameter and, if different, one for each initial operating parameter

3. Determine contributors to schedule

4. For first case and first schedule contributor, use consensus of experts to estimate and characterize uncertainty for its duration

5. Proceed to estimate durations for the subsequent cases for the first schedule contributor

6. Proceed to estimate durations for the subsequent cases for the second schedule contributor

Schedule Risk Reduction Approach (continued)

7. For the second schedule contributor, determine whether it is in series, fully in parallel, or partially in parallel; if partially in parallel, estimate overlap (the time its start lags a previous contributor's start) or un-overlap (the time its end extends beyond a previous contributor's end)

8. Complete structure of a Gant chart and duration estimates for all schedule contributors for the given component

9. Determine the required time the component must be on site to meet the end of CY2018 initial plant operation

10. Combine the schedule contributors statistically utilizing a Monte Carlo routine to determine the margin to the target startup date and the probability that target date is exceeded

Step 1: Operating Parameters Considered for IHX & IHX Vessel

- **Reactor Outlet Temperature**
  - 950C – PBMR PHP and NGNP Reference for HyS process
  - 900C – less demanding, matches with Steam Methane Reforming application
  - <760C – least demanding, matches with process steam and cogeneration applications
  - Key parameter for schedule and cost risk reduction
- **Reactor Inlet Temperature**
  - 350C - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP 508/533 reactor vessel; little flexibility to change
  - Little or no benefit to schedule risk reduction
- **Primary Helium Pressure**
  - 9MPa - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit; little flexibility to change
  - Little or no benefit to schedule risk reduction
- **Reactor Power**
  - 500MWt - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit
  - Little or no benefit to schedule risk reduction

Steps 1 and 2: IHX Matrix of Cases

Case	Design / Initial Operating Parameters				Materials
	RIT	Power Level	Primary Press.	ROT	
	(C)	(MWt)	(MPa)	(C)	
IHX-1	350	500	9	**<760 / <760**	800H
IHX-2	350	500	9	**900 / 900**	IHX A - 617 IHX B - 800H
IHX-3	350	500	9	**950 / <760**	IHX A - 617 IHX B - 800H
IHX-4	350	500	9	**950 / 850**	IHX A - 617 IHX B - 800H
IHX-5	350	500	9	**950 / 950**	IHX A - 617 IHX B - 800H

Step 3: IHX Matrix of Cases & Schedule Contributors

Case	Design / Initial Operating Parameters					Contributors to Schedule (expected values and uncertainty distributions to be assessed)					
	ROT	RIT	Power Level	Primary Press.	Mat'ls	Development	Code Case Development	Supplier Readiness	Long Lead Orders	Fabrication	Transportation
	(C)	(C)	(MWt)	(MPa)		(Months)					
IHX-1	<760 / <760	350	500	9	800H						
IHX-2	900 / 900				IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-3	950 / <760				IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-4	950 / 900				IHX A - 617						
					IHX B - 800H	same as case IHX-1					
IHX-5	950 / 950				IHX A - 617						
					IHX B - 800H	same as case IHX-1					

Steps 4 and 5: Durations of IHX Design & Development

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / 760C	800H	30	36	42
IHX-2 ROT 900C / 900C	IHX A 617	42	48	63
IHX-3 ROT 950C / <760C	IHX A 617	45	48	66
IHX-4 ROT 950C / 850C	IHX A 617	45	48	66
IHX-5 ROT 950C / 950C (Reference)	IHX A 617	45	48	66

Design & testing at higher temperatures for 617 material takes longer

Step 6: Durations of IHX Code Case Development

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate Duration (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / **760C**	800H	24	30	42
IHX-2 ROT 900C / **900C**	IHX A 617	36	42	54
IHX-3 ROT 950C / **<760C**	IHX A 617	36	42	54
IHX-4 ROT 950C / **850C**	IHX A 617	36	42	54
IHX-5 ROT 950C / **950C** (Reference)	IHX A 617	36	42	54

Code case development longer for 617; initial operating parameters have no impact

Step 7: IHX Code Case Development Partially in Parallel with Design & Development

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate Unoverlap (Add'l. Time to Complete Code Case Dev. after Design & Dev.) (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / **760C**	800H	6	12	18
IHX-2 ROT 900C / **900C**	IHX A 617	6	12	18
IHX-3 ROT 950C / **<760C**	IHX A 617	6	12	18
IHX-4 ROT 950C / **850C**	IHX A 617	6	12	18
IHX-5 ROT 950C / **950C** (Reference)	IHX A 617	6	12	18

Unoverlap same for all Cases

Step 8: Durations of IHX Supplier Readiness
(Partially in Parallel with Code Case)

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / **760C**	800H	21	24	30
IHX-2 ROT 900C / **900C**	IHX A 617	21	24	30
IHX-3 ROT 950C / **<760C**	IHX A 617	21	24	30
IHX-4 ROT 950C / **850C**	IHX A 617	21	24	30
IHX-5 ROT 950C / **950C** (Reference)	IHX A 617	21	24	30

Same for all Cases

Step 8: Durations of IHX Fabrication

(In Series with Supplier Readiness)

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / 760C	800H	21	24	30
IHX-2 ROT 900C / 900C	IHX A 617	21	24	30
IHX-3 ROT 950C / <760C	IHX A 617	21	24	30
IHX-4 ROT 950C / 850C	IHX A 617	21	24	30
IHX-5 ROT 950C / 950C (Reference)	IHX A 617	21	24	30

Same for all Cases

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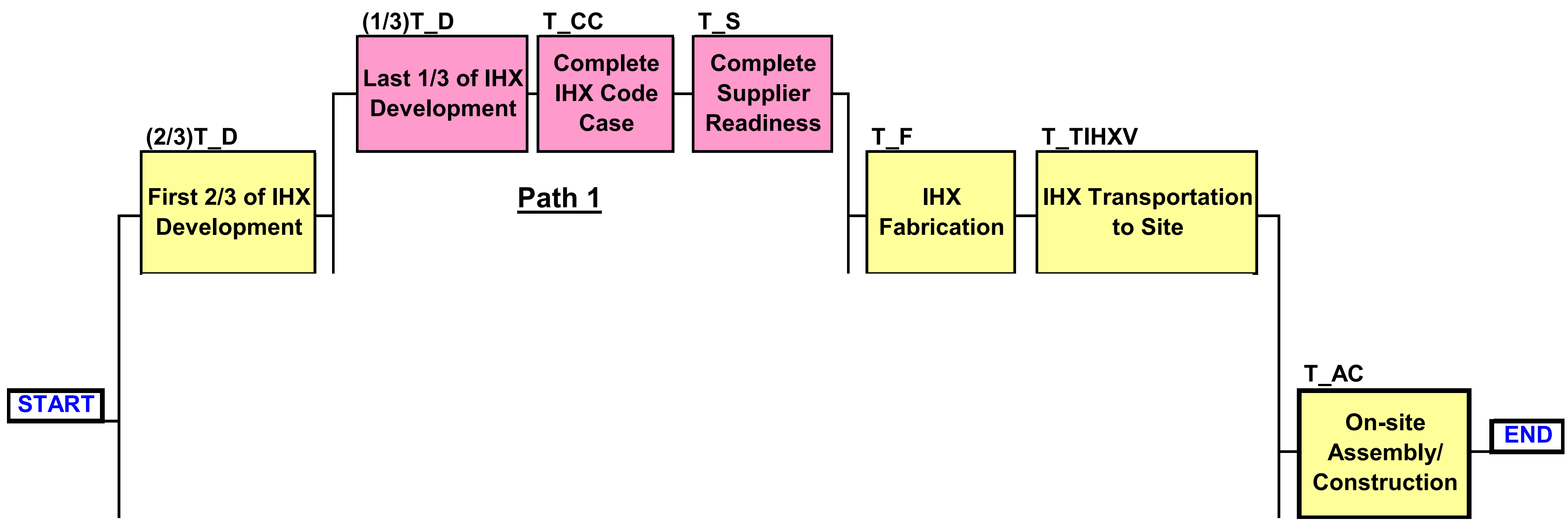
Step 8: Durations of Transportation to Site
(In Series with Fabrication)

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / **760C**	800H	1	2	3
IHX-2 ROT 900C / **900C**	IHX A 617	1	2	3
IHX-3 ROT 950C / **<760C**	IHX A 617	1	2	3
IHX-4 ROT 950C / **850C**	IHX A 617	1	2	3
IHX-5 ROT 950C / **950C** (Reference)	IHX A 617	1	2	3

Same for all Cases

Partial Gant Chart for IHX Path 1



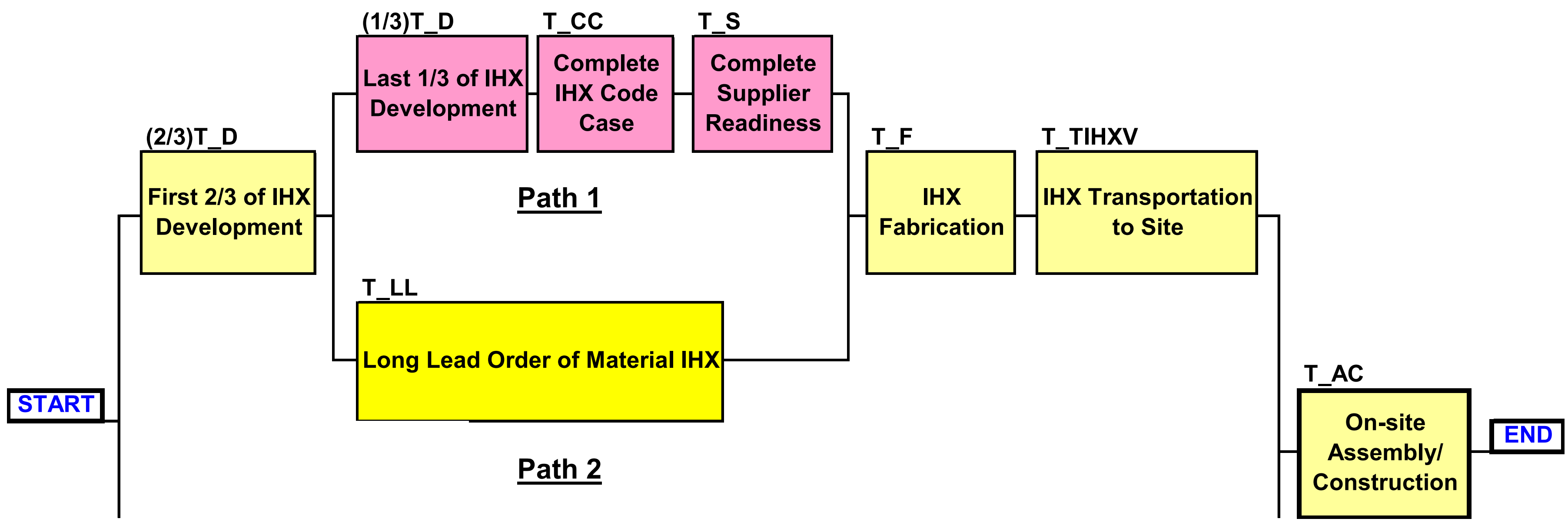
Step 8: Durations of Long Lead Orders

(In Series with portion of Design & Development)

Design / Initial Operating Temperature	Material	Lower Bound (5%) Estimate (Mo)	Best Estimate to Complete after Design & Dev (Mo)	Upper Bound (95%) Estimate (Mo)
IHX-1 ROT<760C / **760C**	800H	12	15	18
IHX-2 ROT 900C / **900C**	IHX A 617	12	15	18
IHX-3 ROT 950C / **<760C**	IHX A 617	12	15	18
IHX-4 ROT 950C / **850C**	IHX A 617	12	15	18
IHX-5 ROT 950C / **950C** (Reference)	IHX A 617	12	15	18

Same for all Cases

Gant Chart of IHX Paths 1 and 2



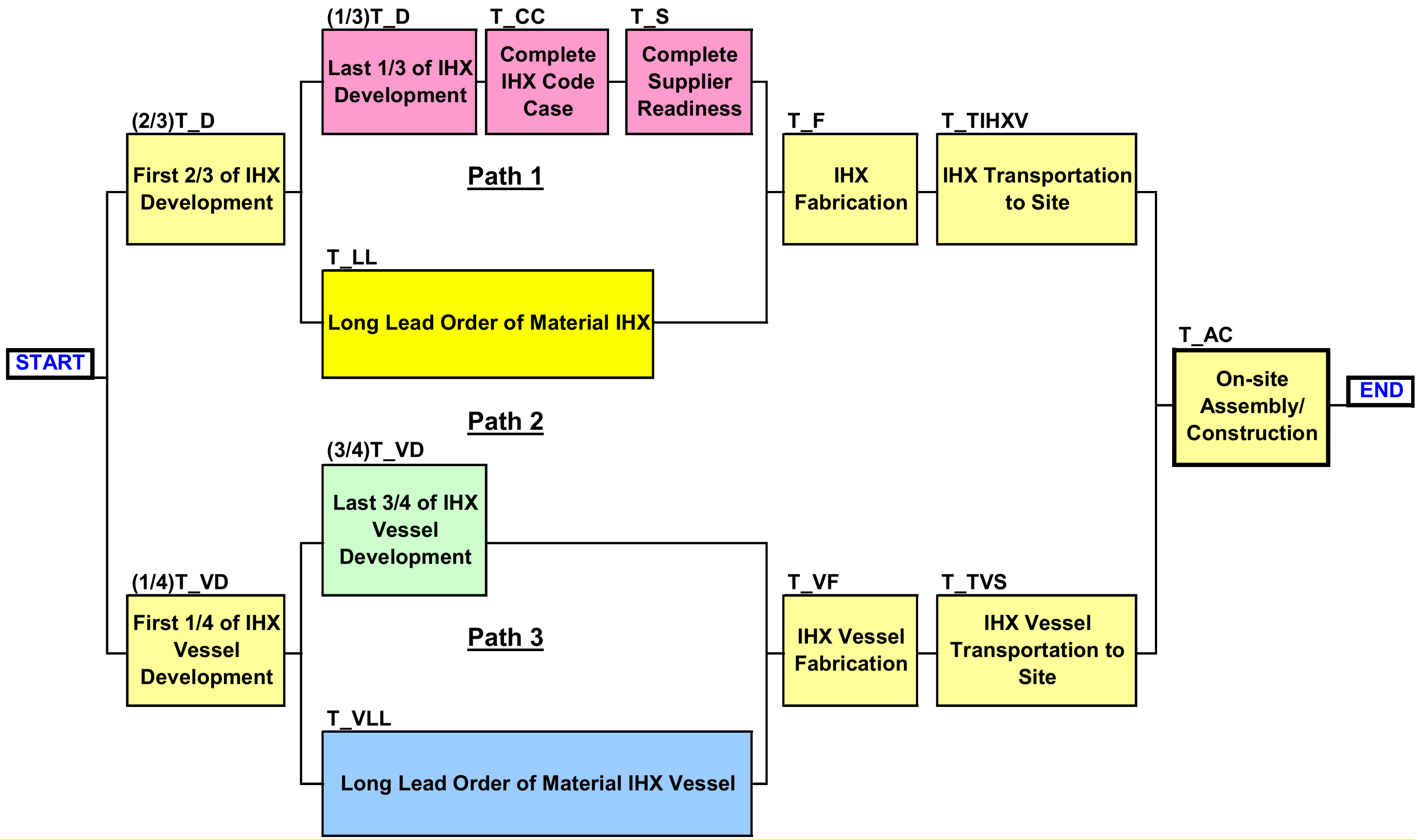
IHX Vessel Matrix of Cases

	Operating Parameters & Corresponding Mat'ls				
Case	**ROT** (C)	**RIT** **(C)**	Power Level (MWt)	Primary Pressure (MPa)	Mat'ls
IV-1	**<760**	**350**	500	9	IHX B 508/533
IV-2	**950**	**350**	500	9	IHX A 508/533

IHX Vessel Matrix of Cases & Schedule Contributors

Case	ROT	RIT	Power Level	Primary Pressure	Mat'ls	Design Development	Code Case Development	Long Lead Orders	Fabrication	Transportation	Assembly
	(C)	(C)	(MWt)	(MPa)		(Months)					
IV-1	<760	350	500	9	IHX B 508/533	36-6+12	nil	30-6+12/ start after 25% dev	24-6+6/ starts after long lead order	2-1+1/ after fab	6-2+2/ after asembly, max from IHX
IV-2	950	350	500	9	IHX A 508/533	48-6+18	nil	30-6+12/ start after 25% dev	24-6+6/ starts after long lead order	2-1+1/ after fab	6-2+2/ after asembly, max from IHX

Completed Gant Chart of Integrated IHX & Vessel Schedule



Path 4

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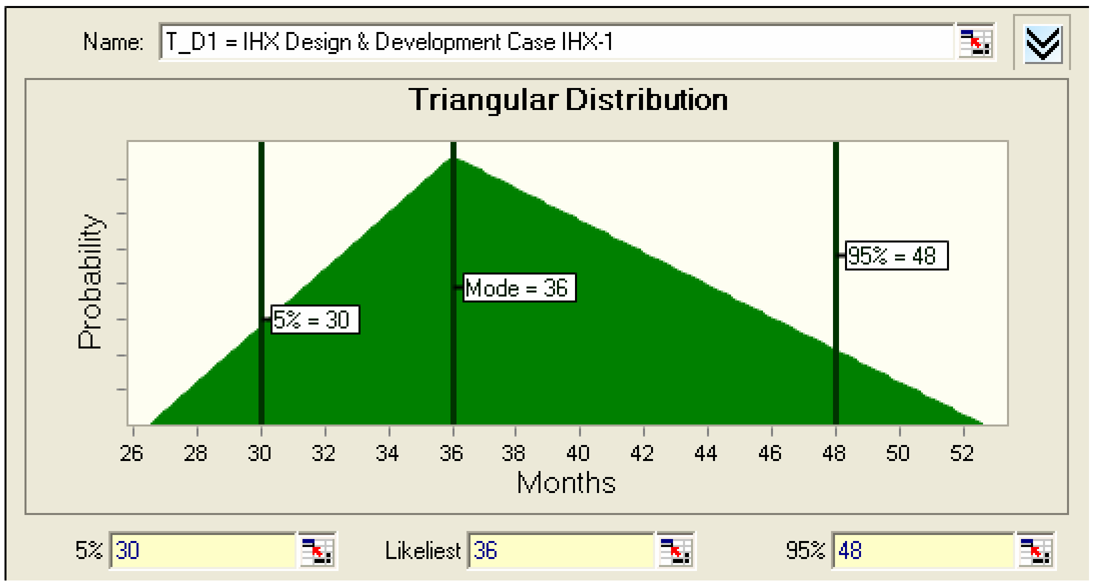
Step 9: Required Time for IHX and Vessel at Site Assembled to Meet CY2018 Startup

- Reactor Vessel needs to be at the site 30 months prior to initial power operation (month 93 from beginning of FY2009)
- Core Outlet Pipe, IHX and Vessel need to be assembled ~3mos after the Reactor Vessel arrives: 27 months prior initial power operation (month 96 from beginning of FY2009)

Step 10: Technical Approach to Uncertainty Analysis

- Input distributions modeled as triangle distributions
  - Best estimate assigned to mode or most likely value
  - Upper and lower bounds set to 5%-tile and 95%-tile values



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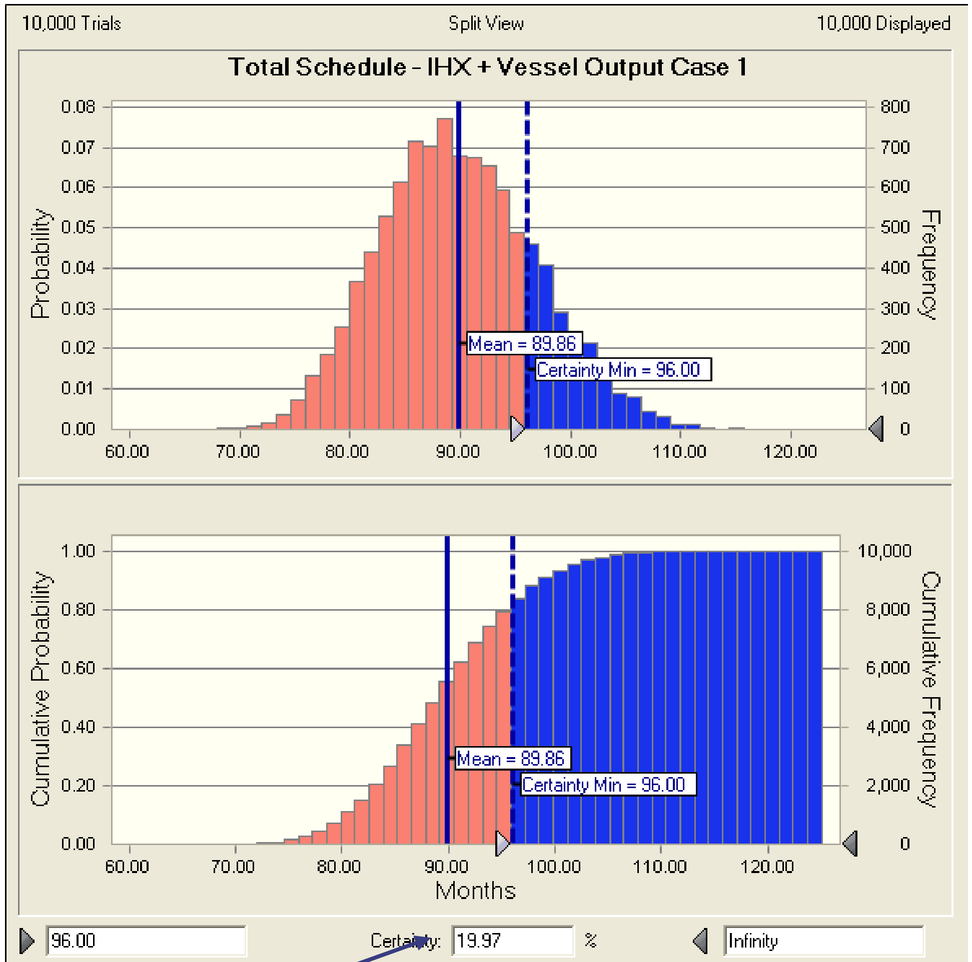
Step 10: Technical Approach to Uncertainty Analysis

- Gant Chart converted to cell equations in Excel Spreadsheet
  - Sum used to model tasks in series
  - Max used to model tasks in parallel
  - Expert panel provided input on task start times for tasks done in parallel
  - For overlapping tasks shown in series, only non-overlapping part was modeled
  - Separate models used to calculate durations for separate paths
- Monte Carlo Uncertainty Propagation via Excel add-in Crystal Ball
- 10,000 simulations
- Crystal Ball tools used for statistical analysis and charts

Step 10: Overall Schedule for IHX & Vessel Case 1 (Design ROT<760C)



Probability of not achieving 2018 Startup

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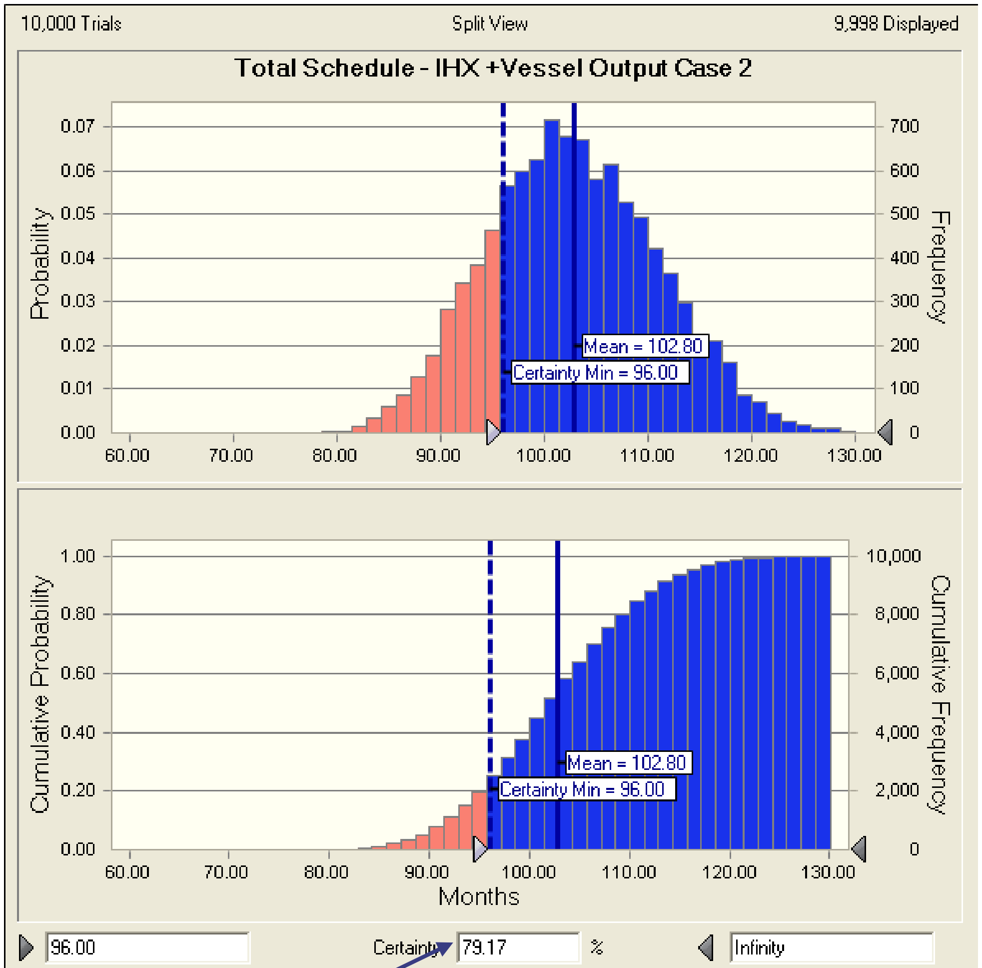
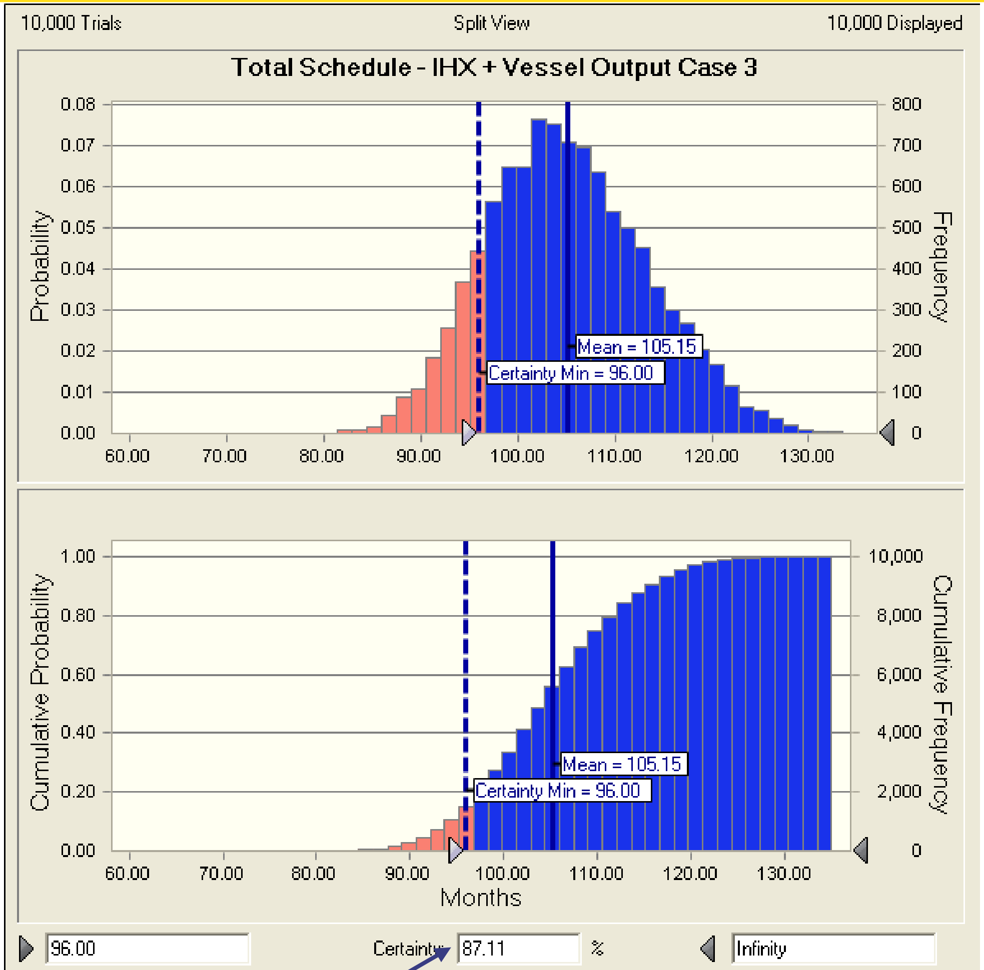
Overall Schedule Risk for IHX & Vessel Cases 2 (Design ROT=900C)



Probability of not achieving 2018 Startup

Overall Schedule Risk for IHX & Vessel Cases 3, 4 & 5 (Design ROT=950C)



Probability of not achieving 2018 Startup

Summary of Integrated IHX & Vessel Schedule Risk Results

Output Case	IHX Case	IHX Vessel Case	Gant Chart Path	Schedule Duration in Months					Probability ≥ 96mo
				Best Estimate	5%tile	50%tile	Mean	95%tile	
1	IHX-1	IV-1	Total Schedule	86	78.8	89.4	89.9	101.9	20.0%
			Path 1	86	77.6	89.4	89.6	101.9	
			Path 2	71	65.7	73.8	73.8	82.3	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	
2	IHX-2	IV-2	Total Schedule	98	89.9	102.5	102.8	116.7	79.2%
			Path 1	98	89.9	102.5	102.8	116.7	
			Path 2	79	74.0	82.4	82.6	92.0	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	
3	IHX-3,4,5	IV-2	Total Schedule	98	92.5	104.6	105.1	119.5	87.1%
			Path 1	98	92.5	104.6	105.1	119.5	
			Path 2	79	75.6	83.9	84.2	93.8	
			Path 3	68	59.8	70.2	70.4	81.6	
			Path 4	71	63.2	73.8	74.0	85.5	

Sensitivity of IHX Schedule to Power Level

Schedule Contributor on Critical Path (Path 1)	Range of Best Estimate Durations for Cases at 500MWt (mo)	Impact of 250MWt
Design & Development	36-48	Not a function of size
Code Case Development (unoverlap)	12	Not a function of size
Supplier Readiness (unoverlap)	6	IHX size not limiting
Fabrication	24	IHX size not limiting
Transportation to Site	2	IHX size not limiting
Assembly / Construction at Site	6	Potential for savings

Observations for IHX & Vessel Schedule Risk Results

- For Case 1 with the ROT <760C: ~6 month expected margin to achieve 2018 plant startup with a probability of achieving the target startup of ~80%
- However, the higher temperature Cases 2-5 have low probabilities of achieving the target 2018 startup
- The limiting path is through the IHX design & development, code case development, and supplier readiness path
- The required time of delivery to the site is the primary reason that the margins are less than reported at the 50% review
- Designing and developing code cases for 950C ROT and operating initially at a lower ROT does not impact the IHX schedule for startup---it may impact overall licensing schedule and other objectives

P B M R

Operating Parameters Considered for Reactor Vessel

- **Reactor Outlet Temperature**
  - 950C – PBMR PHP and NGNP Reference for HyS process
  - Lower temperatures do not impact reactor vessel schedule risk
- **Reactor Inlet Temperature**
  - 350C - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP 508/533 reactor vessel; little flexibility to change
  - Little or no benefit to schedule risk reduction
- **Primary Helium Pressure**
  - 9MPa - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit; little flexibility to change
  - Little or no benefit to schedule risk reduction
- **Reactor Power**
  - 500MWt - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit
  - Little or no benefit to schedule risk reduction

Reactor Vessel Case

	Operating Parameters & Corresponding Mat'ls				
Case	ROT (C)	**RIT (C)**	Power Level (MWt)	Primary Pressure (MPa)	Mat'ls
RV-1	950	**350**	500	9	508/533

Reactor Vessel Case Schedule Contributors

For a coastal site:

Case	ROT	RIT	Power Level	Primary Pressure	Mat'ls	Development	Codes & Licensing	Long Lead Orders	Fabrication	Transportation
	(C)	(C)	(MWt)	(MPa)		(Months)				
RV-1	950	**350**	500	9	508/533	36-12+12	nil	30-6+12	42-6+6	2-1+1

For INL site:

Case	ROT	RIT	Power Level	Primary Pressure	Mat'ls	Development	Codes & Licensing	Long Lead Orders	Fabrication	Transportation
	(C)	(C)	(MWt)	(MPa)		(Months)				
RV-1	950	**350**	500	9	508/533	36-12+12	nil	30-6+12	42-6+6	6-1.25+4.5

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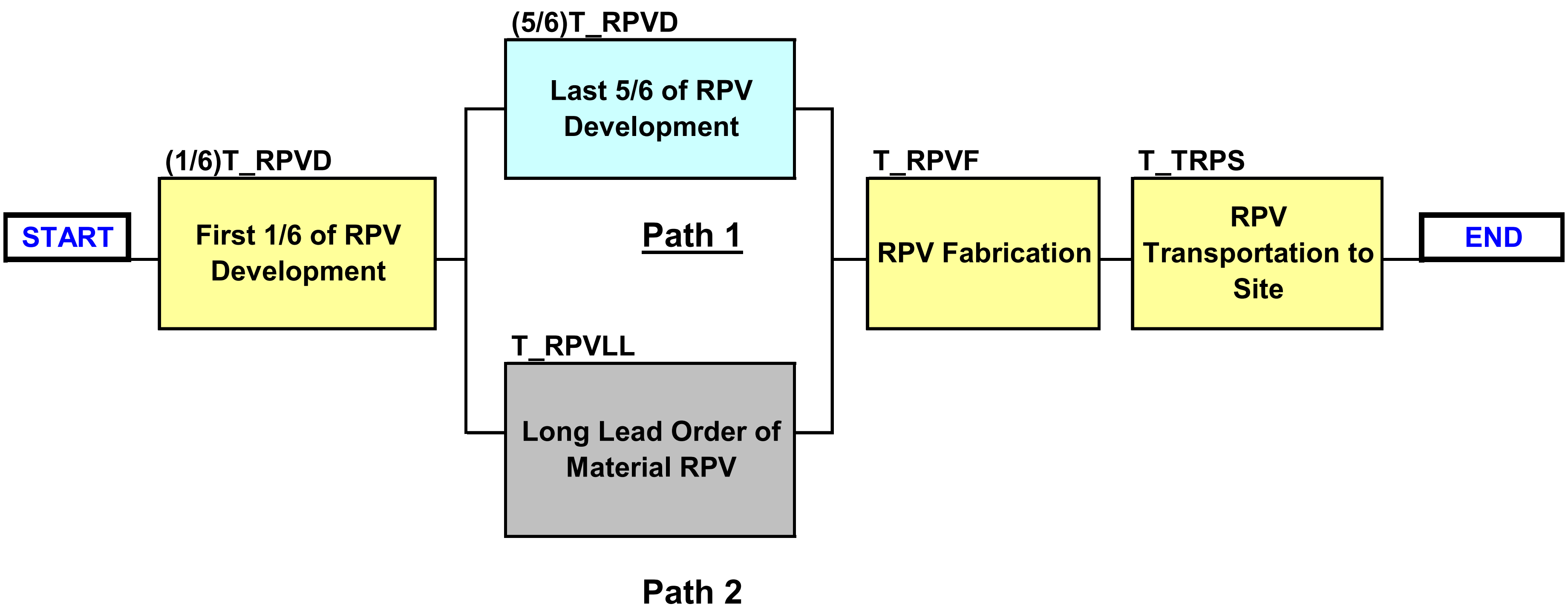
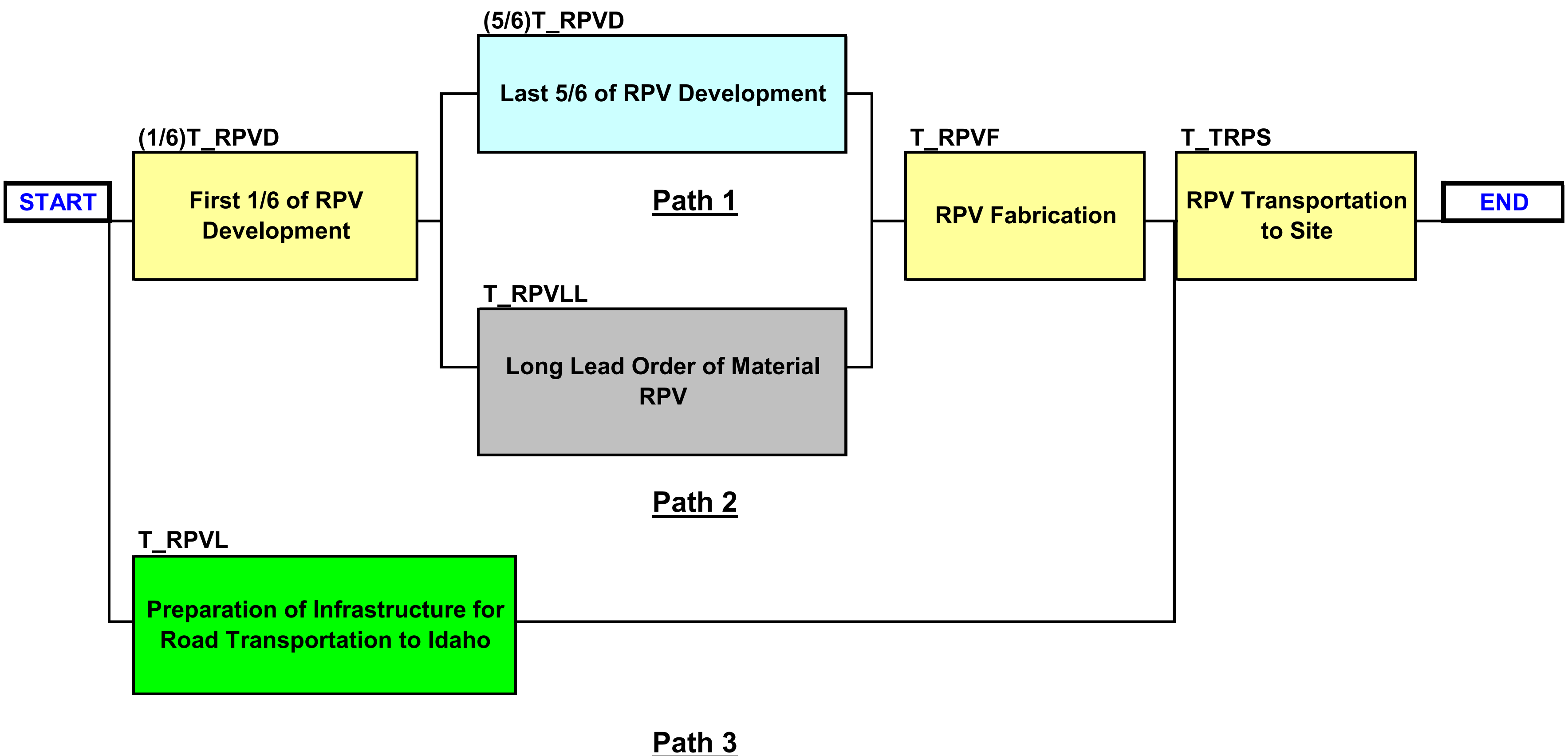
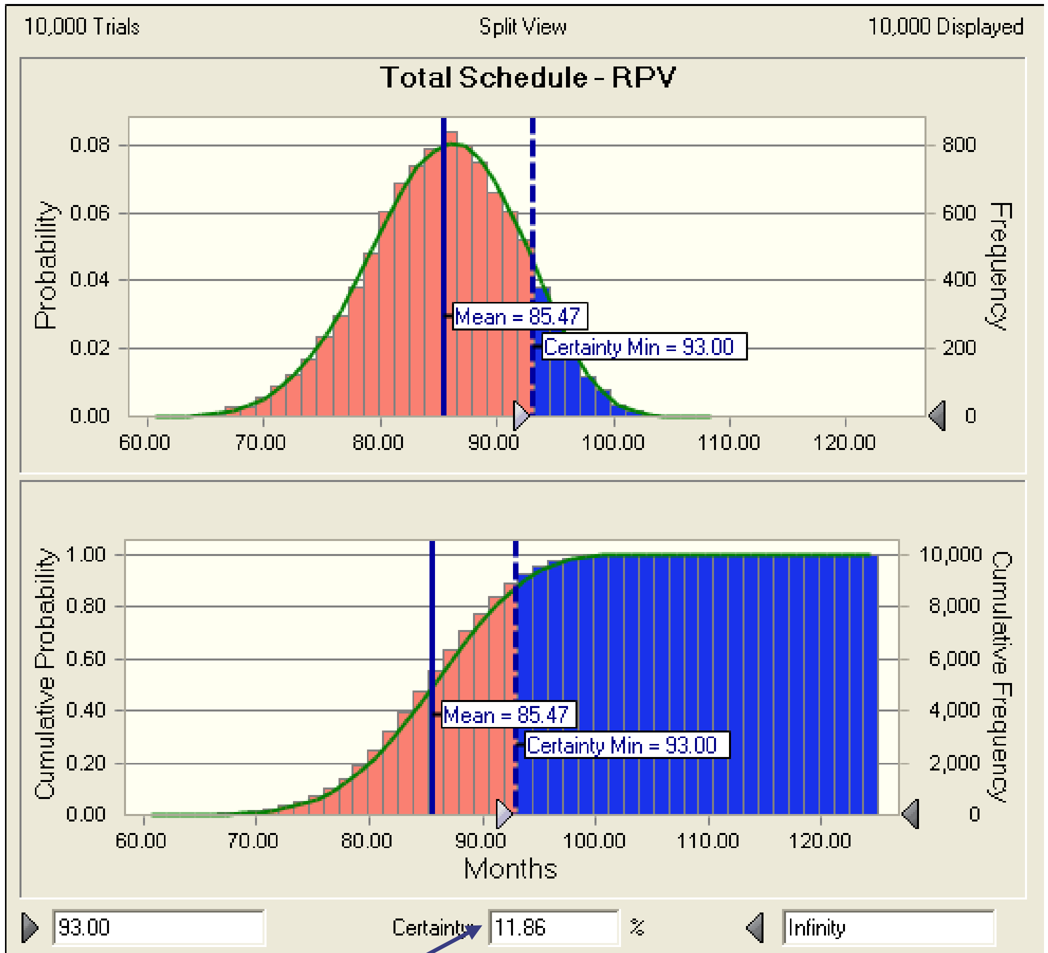
Gant Chart of Reactor Vessel Schedule for a Coastal Site



Gant Chart of Reactor Vessel Schedule for INL Site



Schedule Risk for Reactor Vessel Case for a Coastal Site



Probability of not achieving 2018 Startup

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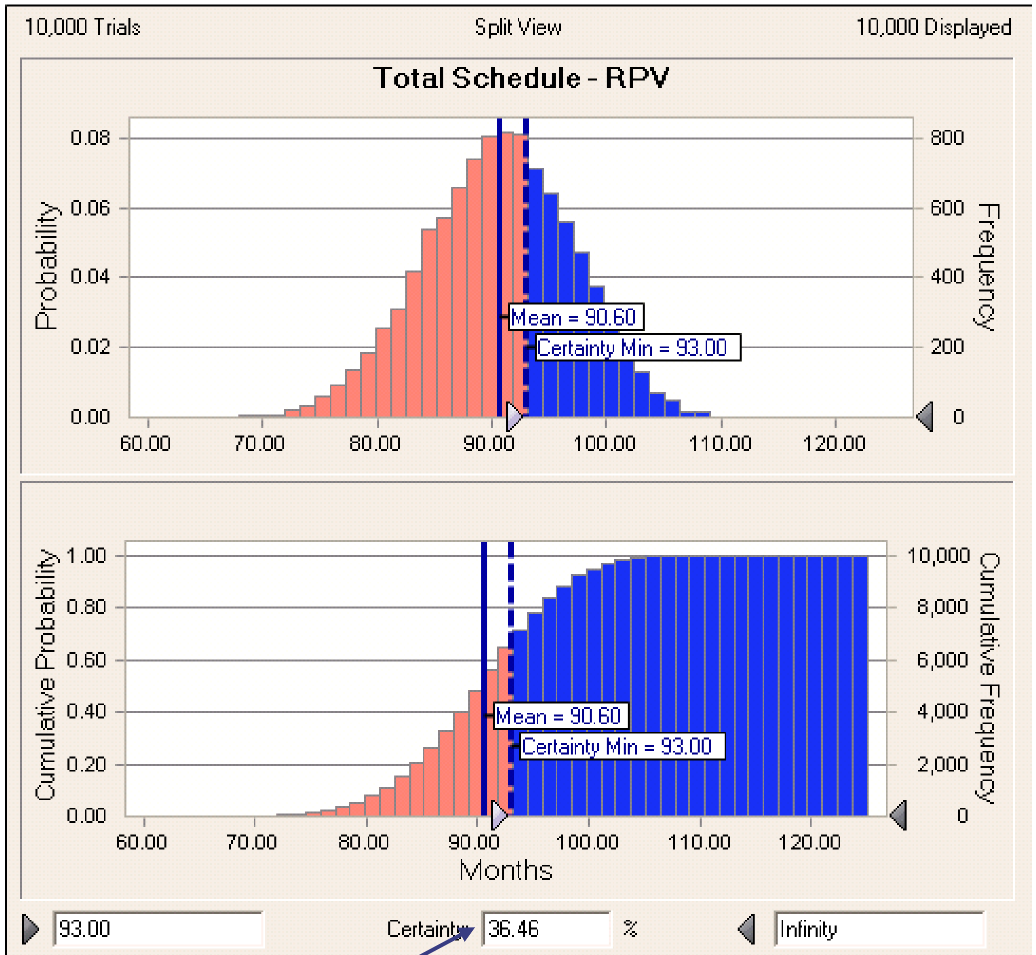
Schedule Risk for Reactor Vessel Case for INL Site



Probability of not achieving 2018 Startup

Observations for Reactor Vessel Schedule Risk Results

- For a coastal site:
  - ~7mo expected margin to achieve 2018 plant startup with a probability of achieving the target startup of ~88%
  - The required time of delivery to the Idaho site is the primary driver
- For the INL site:
  - ~3mo expected margin to achieve 2018 plant startup with a probability of achieving the target startup of ~63%
  - The required time and the time needed for delivery to the Idaho site is the primary driver
- The use of conventional LWR vessel material and the sizing of the reactor vessel are key reasons that the target initial power operation is achieved

Sensitivity of Reactor Vessel Schedule to Power Level

Schedule Contributor on Critical Path (Path 1)	Range of Best Estimate Durations for Cases at 500MWt (mo)	Impact of 250MWt
Design & Development	36	Not a function of size
Long Lead Order (unoverlap)	0	-
Fabrication	42	Vessel size not limiting
Transportation to Site	2-6	Potential for savings for inland sites

Operating Parameters Considered for Core Outlet Pipe

- **Reactor Outlet Temperature**
  - 950C – PBMR PHP and NGNP Reference for HyS process
  - 900C – less demanding, matches with High-temperature Steam Electrolysis and Steam Methane Reforming applications
  - <760C – least demanding, matches with process steam and cogeneration applications
  - Key parameter for schedule risk reduction for Core Outlet Pipe
- **Reactor Inlet Temperature**
  - 350C - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP 508/533 reactor vessel; little flexibility to change
  - Little or no benefit to schedule risk reduction of Core Outlet Pipe
- **Primary Helium Pressure**
  - 9MPa - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit; little flexibility to change
  - Little or no benefit to schedule risk reduction of Core Outlet Pipe
- **Reactor Power**
  - 500MWt - PBMR PHP and NGNP Reference
  - Consistent with utilization of DPP Reactor Unit
  - Little or no benefit to schedule risk reduction of Core Outlet Pipe

Core Outlet Pipe Matrix of Cases

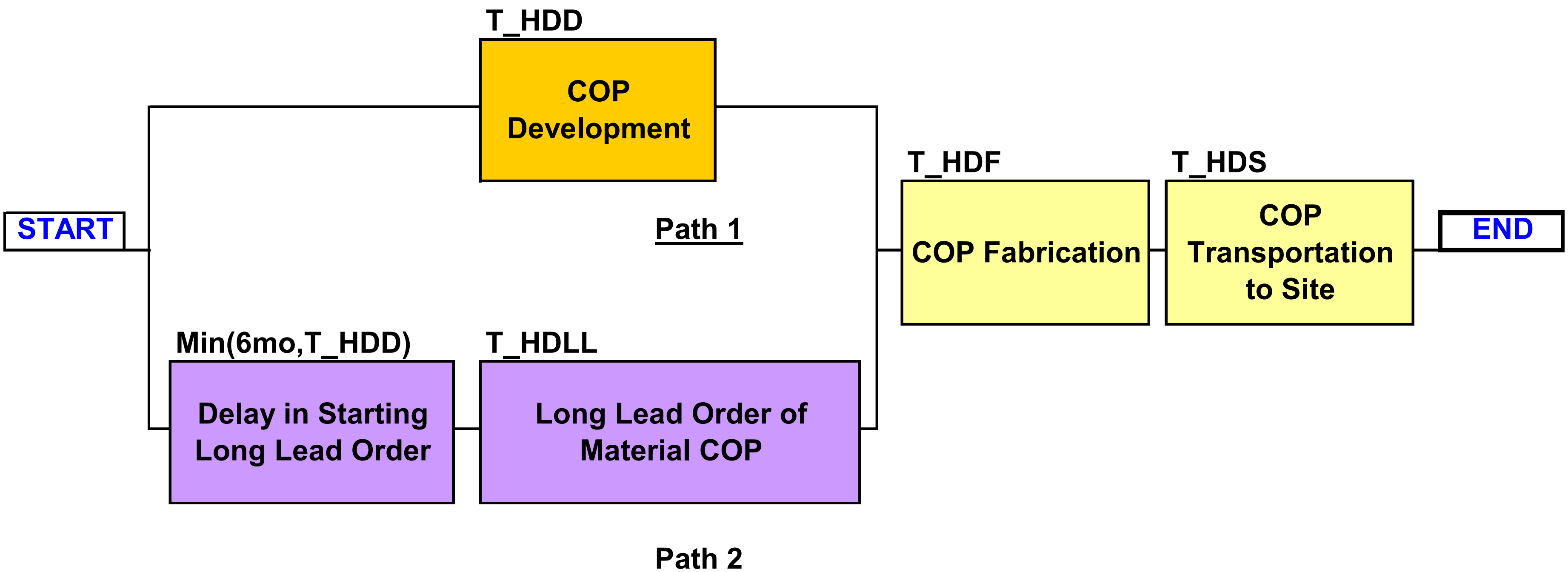
Case	Design / Initial Operating Parameters				
	ROT	RIT	Power Level	Primary Press.	Mat'ls
	(C)	(C)	(MWt)	(MPa)	
COP-1	<760 / <760*	350	500	9	800H
COP-2	900 / 900				800H
COP-3	950 / <760				Hastelloy
COP-4	950 / 850				Hastelloy
COP-5	950 / 950				Hastelloy

P B M R

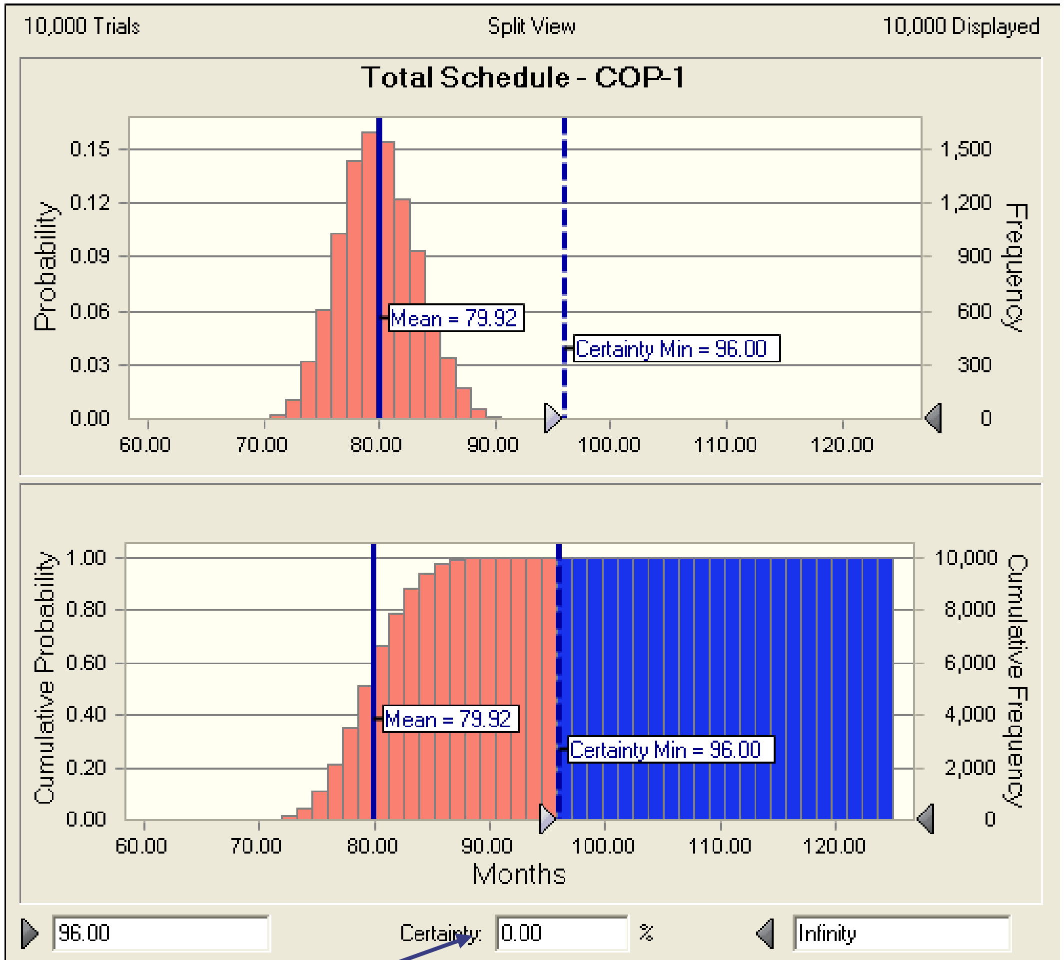
Core Outlet Pipe Matrix of Cases and Schedule Contributors

Case	ROT	RIT	Power Level	Primary Press.	Hot Duct / Piping Mat'ls	Design Develop.	Codes Develop.	Supplier Readiness	Long Lead Orders	Fabrication	Transportation
	(C)	(C)	(MWt)	(MPa)		(Months)					
COP-1	**<760 / <760**	350	500	9	**800H / SA533**	6-3+3	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-2	**900 / 900**				**800H / SA533**	6-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-3	**950 / <760**				**HastelloyX/XR / SA533**	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-4	**950 / 850**				**HastelloyX/XR / SA533**	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1
COP-5	**950 / 950**				**HastelloyX/XR / SA533**	9-3+6	nil	nil	51-3+3, starts 6 months into or after design dev., whichever sooner	20-2+6	2-1+1

Gant Chart of Core Outlet Pipe Schedule

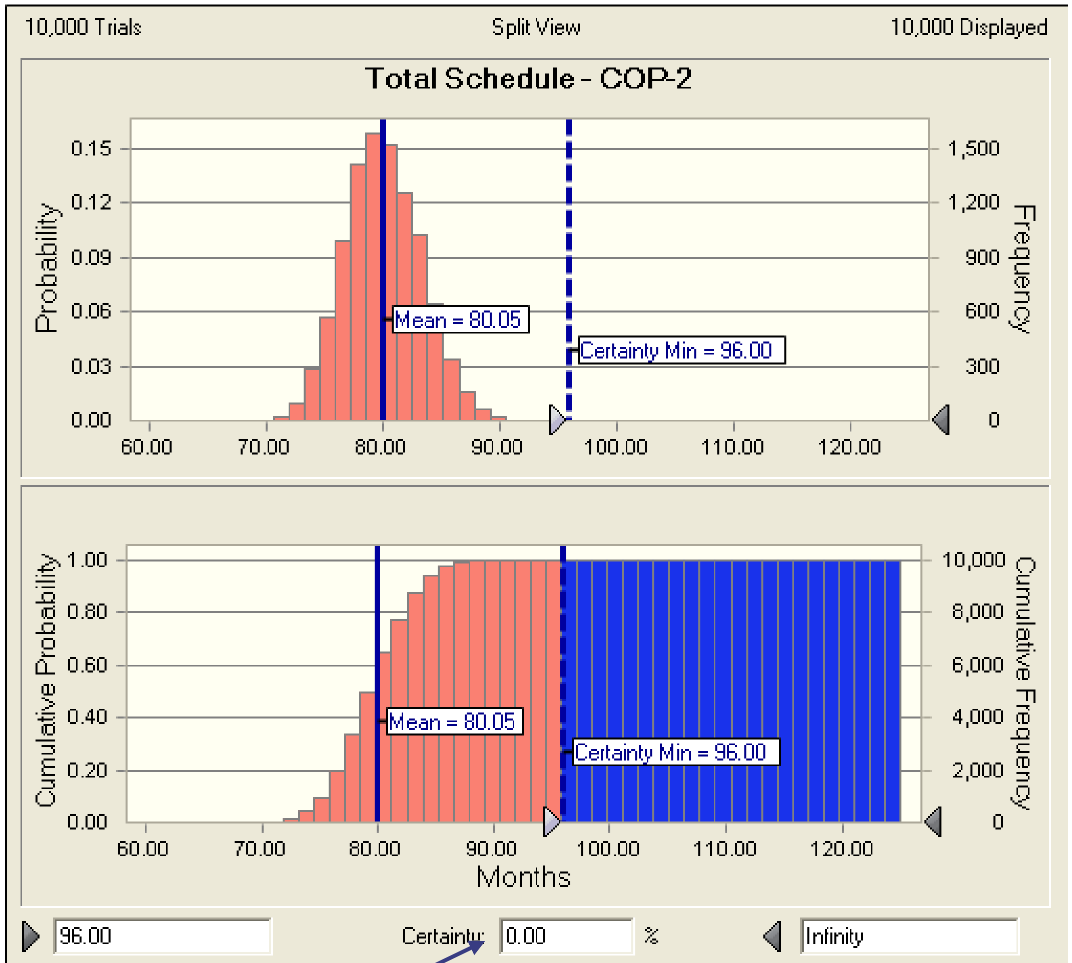


Overall Schedule for Core Outlet Pipe Case 1 (Design ROT<760C)



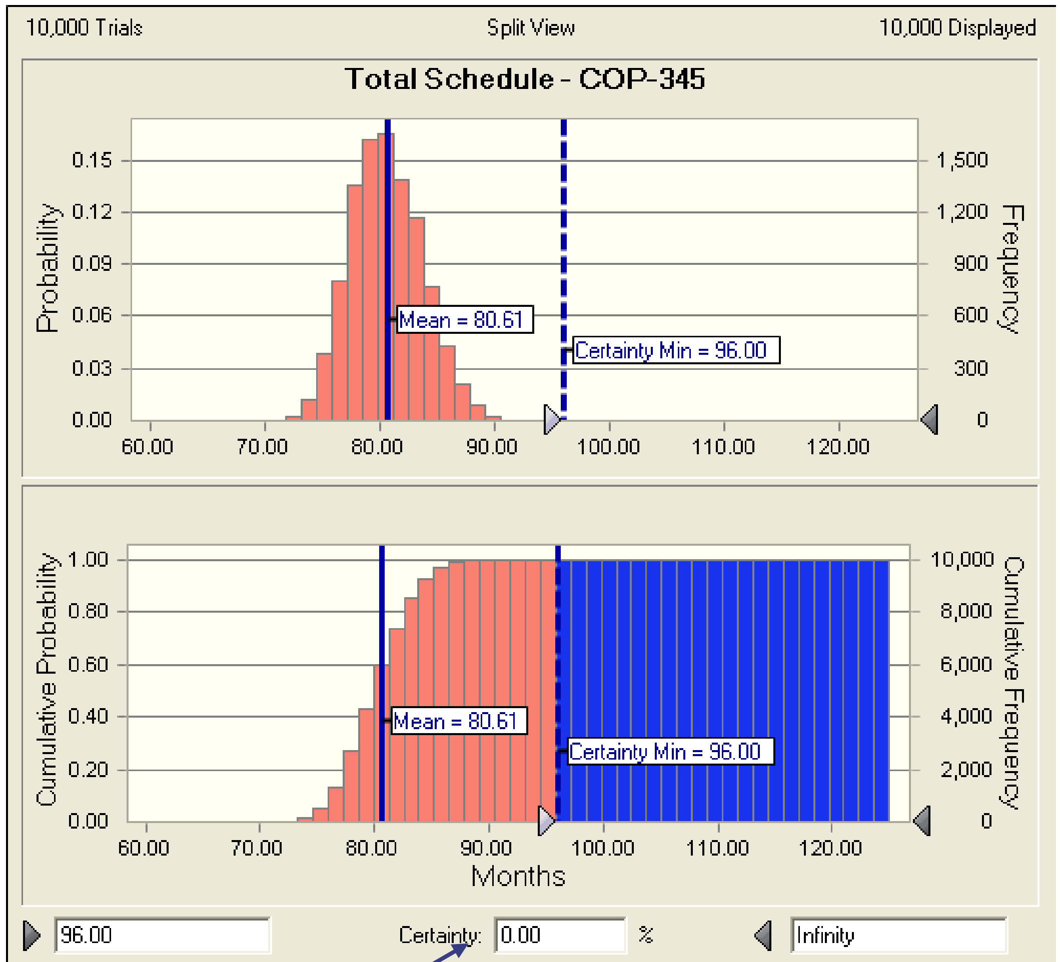
Probability of not achieving 2018 Startup

Overall Schedule Risk for Core Outlet Pipe Case 2 (Design ROT=900C)



Probability of not achieving 2018 Startup

Overall Schedule Risk for Core Outlet Pipe Cases 3, 4 & 5 (Design ROT=950C)



Probability of not achieving 2018 Startup

P B M R

Summary of Core Outlet Pipe Schedule Risk Results

COP Case	Gant Chart Path	Schedule Duration in Months					Probability ≥ 96Mo
		Best Estimate	5%tile	50%tile	Mean	95%tile	
COP-1	Total Schedule	79	74.7	79.8	79.9	85.4	0.0%
	Path 1	28	24.8	29.5	29.7	35.0	
	Path 2	79	74.7	79.8	79.9	85.4	
COP-2	Total Schedule	79	74.9	79.9	80.0	85.4	0.0%
	Path 1	28	24.9	30.6	30.8	37.2	
	Path 2	79	74.9	79.9	80.0	85.4	
COP-3,4,5	Total Schedule	79	75.8	80.5	80.6	85.9	0.0%
	Path 1	31	28.0	33.6	33.8	40.1	
	Path 2	79	75.8	80.5	80.6	85.9	

Observations for
Core Outlet Pipe Schedule Risk Results

- Based on mean values, there are >12mo margins to achieve 2018 initial plant operation

- Overall schedule risks are negligible

- Schedule critical path is the long lead orders as opposed to the design and development path

Summary and Conclusions of Schedule Risk Assessment

Given the assumptions of FY2009 start with no funding, resource, or programmatic constraints:

IHX and Vessel:

- Limiting metallic component
- ROT temperature is the key design parameter for the schedule
- Only the lower ROT IHX case can meet the 2018 startup target
- Initial operating temperature has no effect on schedule

Reactor Vessel:

- Next most limiting component, meets the schedule with little margin depending on site location

Core Outlet Pipe:

- ROT temperature is the key design parameter for the schedule
- All cases (ROT <760 to 950C) meet the 2018 initial plant operation target
- Initial operating temperature has no effect on schedule

Objectives of Study

– Determine the impact of operating parameters and associated selected metallic materials on the certainty of achieving NGNP initial plant operation in 2018
  - IHX
  - IHX Vessels
  - Reactor Vessel
  - Core Outlet Pipe

► Evaluate the impact of the same range of operating parameters and associated selected metallic materials on the related development, component and replacement costs

Presentation Outline

- Background and Framework
- Schedule Risk Assessment

► **Cost Risk Assessment**
  - Assumptions and Approach
  - IHX and Vessel
  - Reactor Vessel
  - Core Outlet Pipe
  - Total Development
  - Summary

PBMR

Cost-Specific Assumptions

- NGNP is second RPV and Core Outlet Pipe following DPP, first IHX and IHX Vessel
- Costs are 2008$ with no IDC; Replacement costs are discounted back to 2018 initial plant operation; Discount rate is 10%
- Development costs include Design, Materials Qualification and Testing, but exclude CTF costs
  - Fully burdened average labor rate = $300K/yr
- Capital costs addressed at bare component level, no shipping or installation
- Replacement costs include discounted capital, installation and loss revenue from outage

Cost-Specific Assumptions

- IHX-A Replacement assumes Vessel is also replaced based on practicality judgment
  - Factor of 1.4 applied for removal and installation
  - Factor of .7 applied for learning
  - Outage costs based on lost revenue per WEC PCDR – 8.5M$/mo
  - # of Replacements based on whole year increments over 60 years, but not aligned with planned maintenance outages
  - Replacements use the same design and material
  - IHX Vessel and IHX are replaced together
  - Replacement IHX + Vessel purchased 1 year before installation
  - 950C Design / <760C Operation - extends first replacement by 5 years
  - 950C Design / 850C Operation – extends first replacement by 3 years

Cost Risk Assessment Approach

1. Determine range of design operating parameters applicable to each component – same as for schedule

2. Select cases: one for each design operating parameter and, if different, one for each initial operating parameter – same as for schedule

3. Determine contributors to costs

4. Use consensus of experts to develop estimate and characterize uncertainty

5. Combine the cost contributors statistically utilizing a Monte Carlo routine to determine the respective probability distributions

Steps 1 and 2: IHX Matrix of Cases

Case	Design / Initial Operating Parameters				Materials
	RIT	Power Level	Primary Press.	ROT	
	(C)	(MWt)	(MPa)	(C)	
1	350	500	9	<760 / <760	800H
2				900 / 900	IHX A - 617 IHX B - 800H
3				950 / <760	IHX A - 617 IHX B - 800H
4				950 / 850	IHX A - 617 IHX B - 800H
5				950 / 950	IHX A - 617 IHX B - 800H

Step 3: Cost Contributors

- Development Costs
  - Design development, including codes and standards
  - Materials qualification
  - Testing and methods V&V
  - Capital and non-labor related to the above, e.g.
    - Test article, including adaptors
    - FOAK mfg for test article

- Capital Costs – Bare component – no IDC, shipping, installation, etc

- Replacement costs – including capital cost, removal and installation plus loss revenue

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Step 3: IHX Matrix of Cases & Cost Contributors

Case	Design / Initial Operating Parameters					Contributors to Cost				
	ROT	RIT	Power Level	Primary Press.	Mat'ls	Separate Devel Cost Table	Cap Cost (CC) (1=45$/kWt)	Cap Replace	Replacement Interval (RI)	Outage for Replacement
	(C)	(C)	(MWt)	(MPa)		(M$)	($/kWt)	($/kWt)	(Yr)	(Months)
IHX-1	<760 / <760*	350	500	9	**800H**		.8/1.0/1.3 x 510		>60	0/0/0
IHX-2	**900 / 900**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	12/14/18	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-3	**950 / <760**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-4	**950 / 850**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0
IHX-5	**950 / 950**				**IHX A - 617**		2.0/2.4/3.0 x 160	1.4x.7xDC	6/8/12	2/3/4
					IHX B - 800H		1.0/1.2/1.5 x 350		>60	0/0/0

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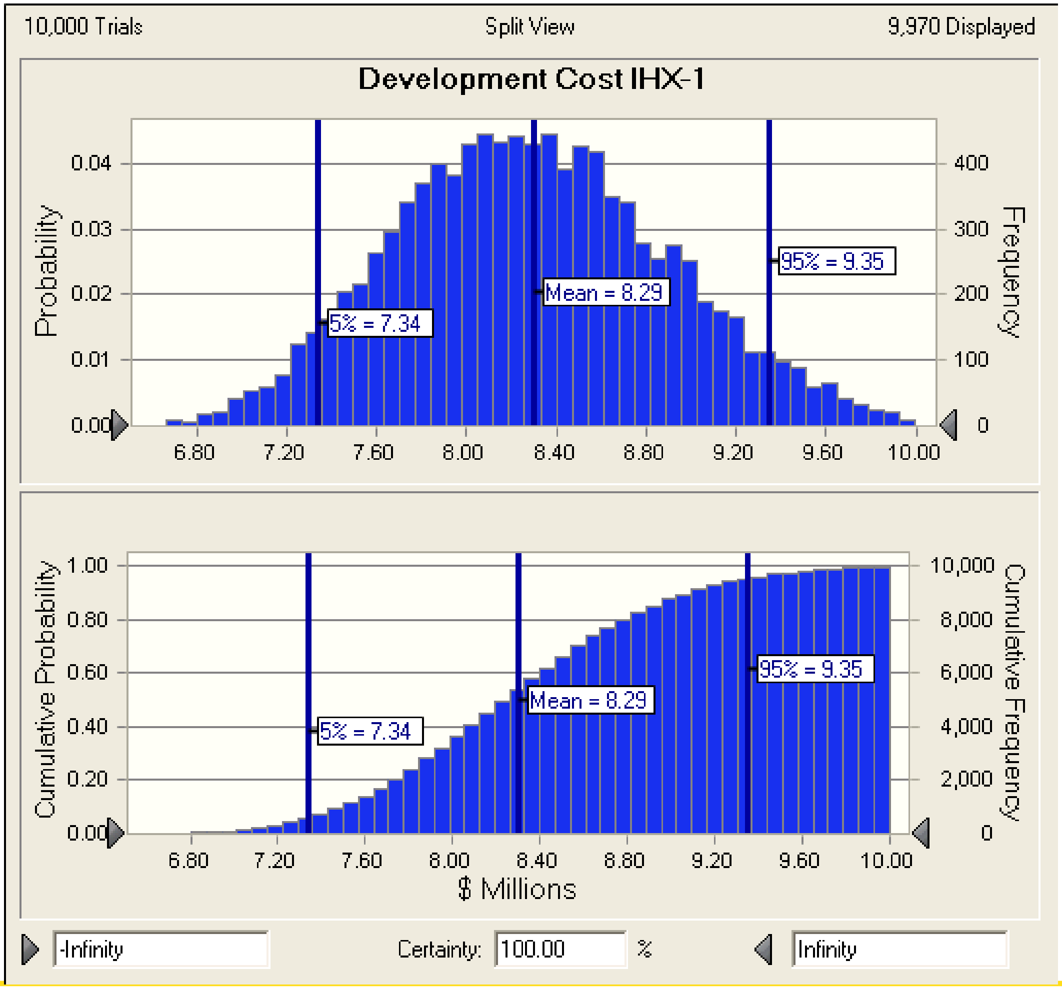
IHX Development Cost Input

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
IHX-1	2.2	2.6	3.4	1.5	1.8	2.4	1.3	1.6	2.1	1.4	1.7	2.6
IHX-2	2.9	3.5	5.8	3.6	4.2	6.3	1.3	1.6	2.3	2.0	2.4	4.8
IHX-3	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8
IHX-4	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8
IHX-5	2.9	3.5	5.8	3.9	4.6	6.8	1.3	1.6	2.3	2.0	2.4	4.8

IHX-1 Development Cost Distributions



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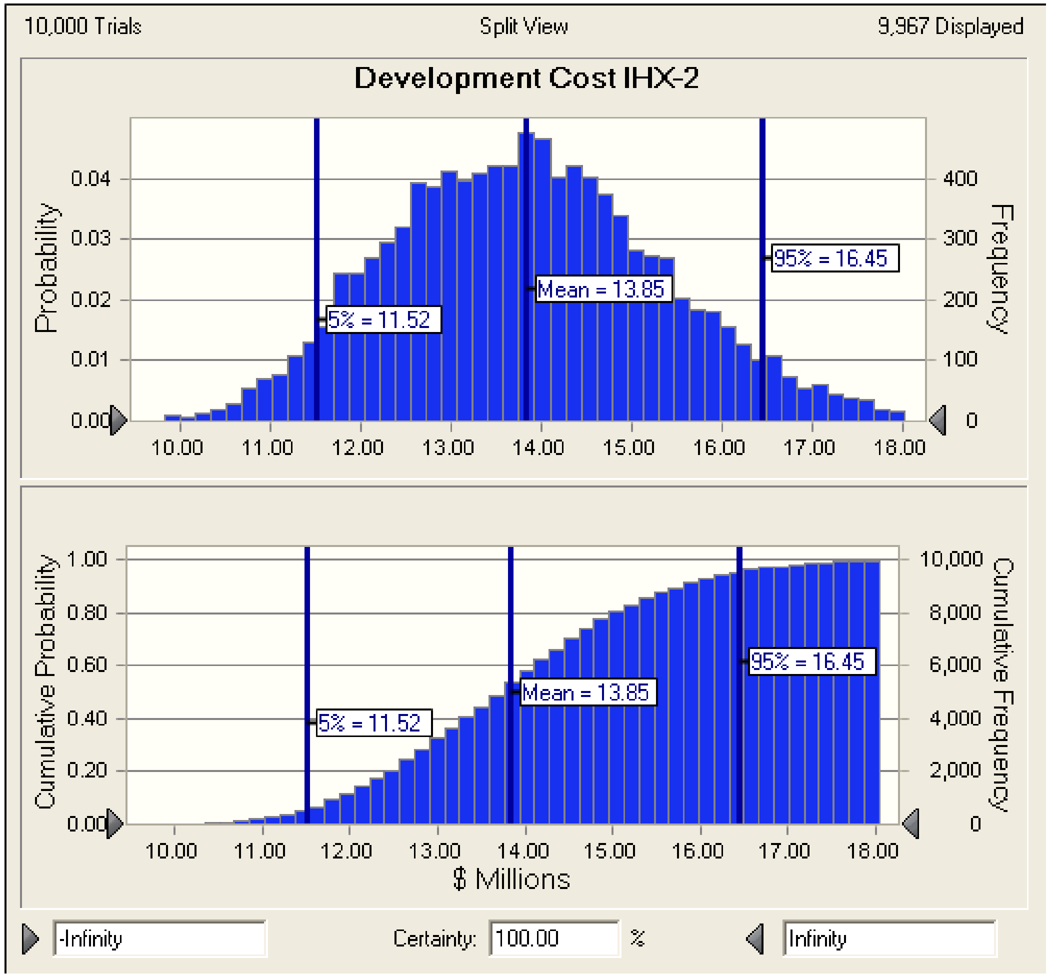
IHX-2 Development Cost Distributions



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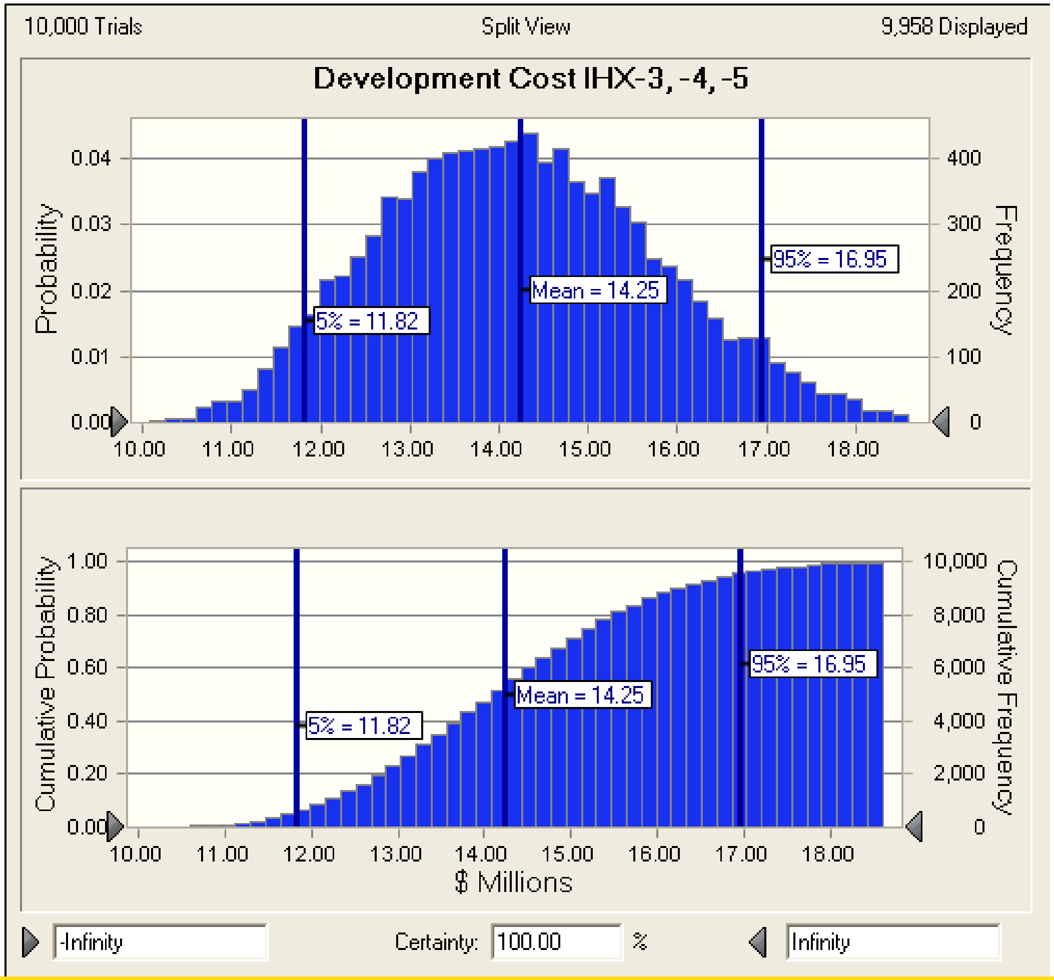
IHX-3, 4, 5 Development Cost Distributions



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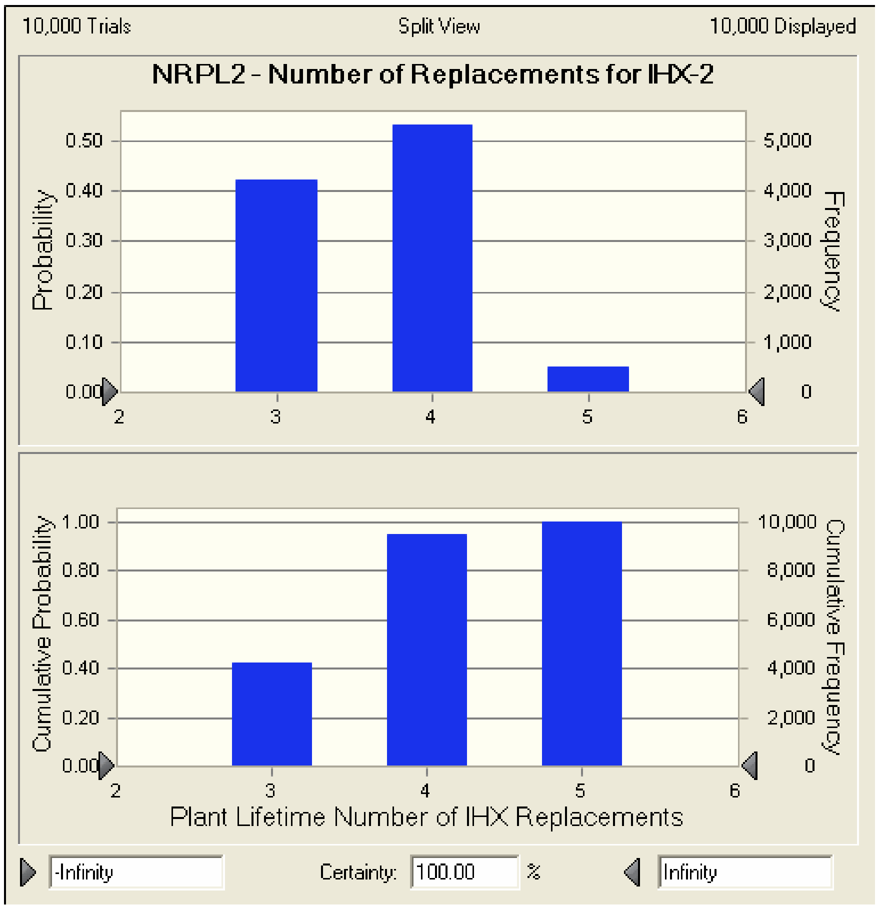
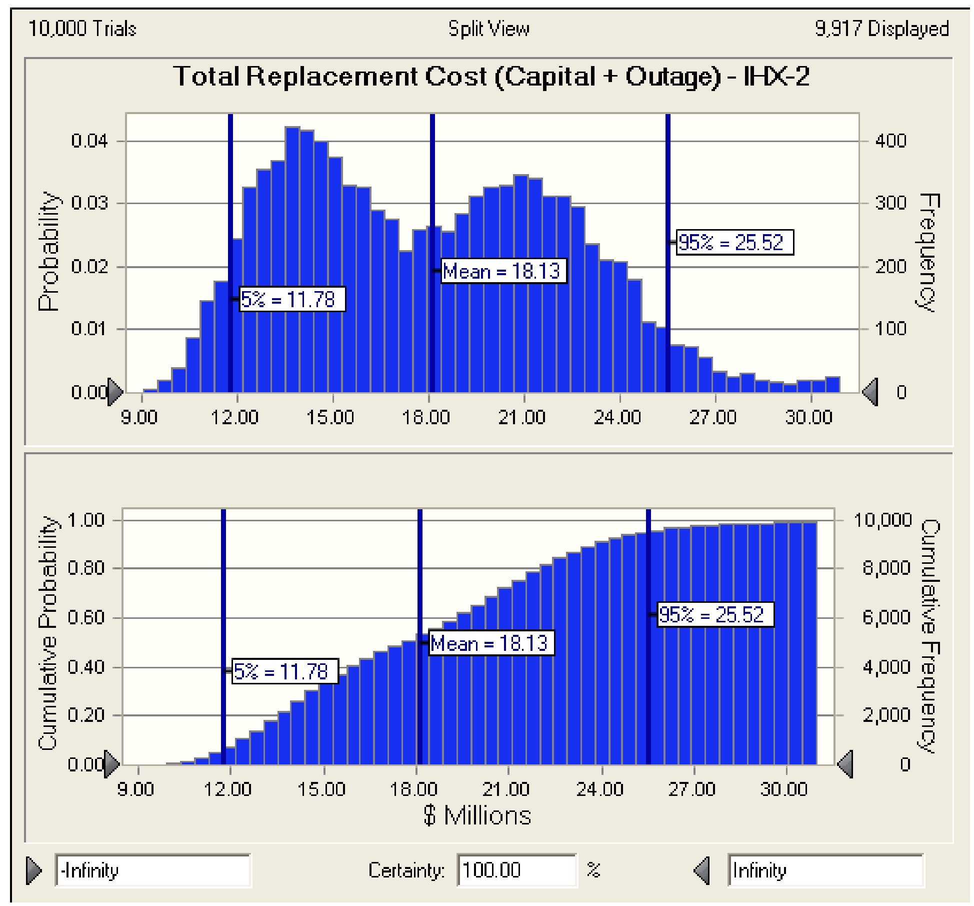
Number and Cost of Replacements for IHX-2





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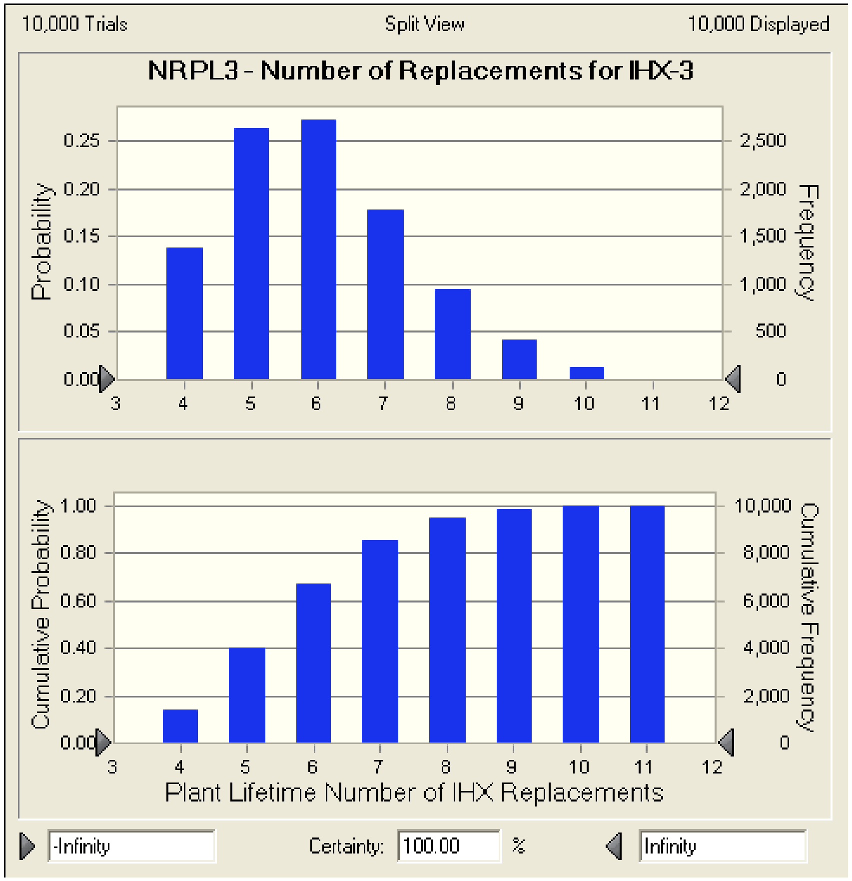
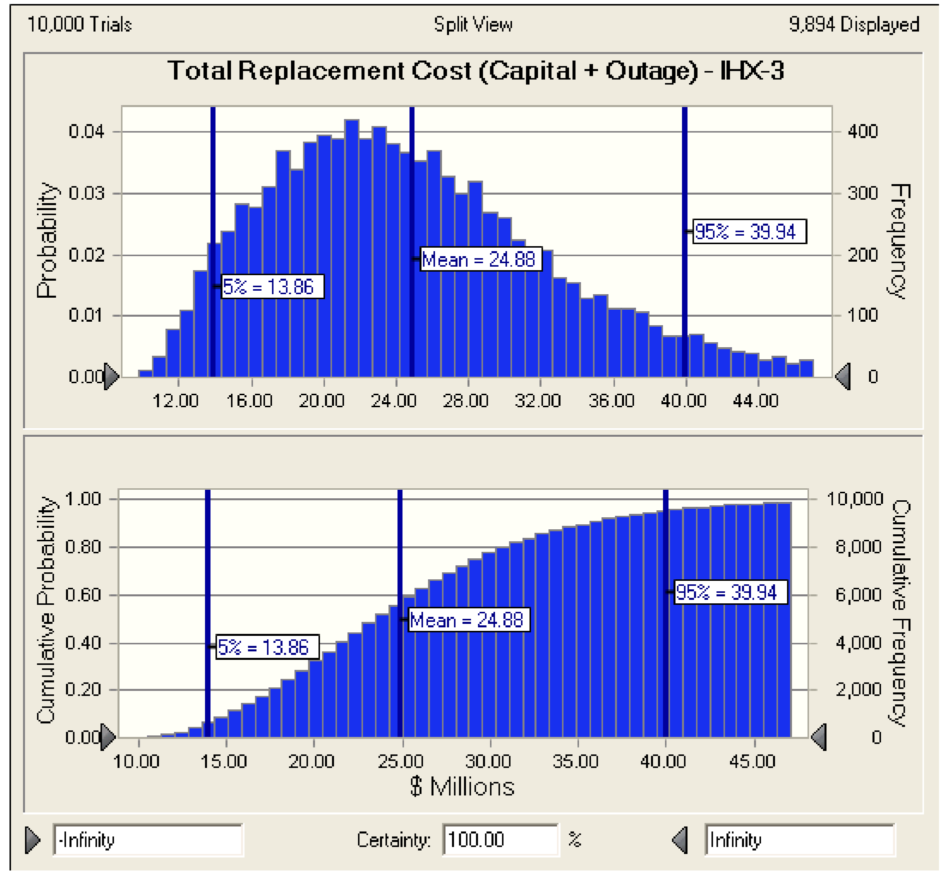
Number and Cost of Replacements for IHX-3





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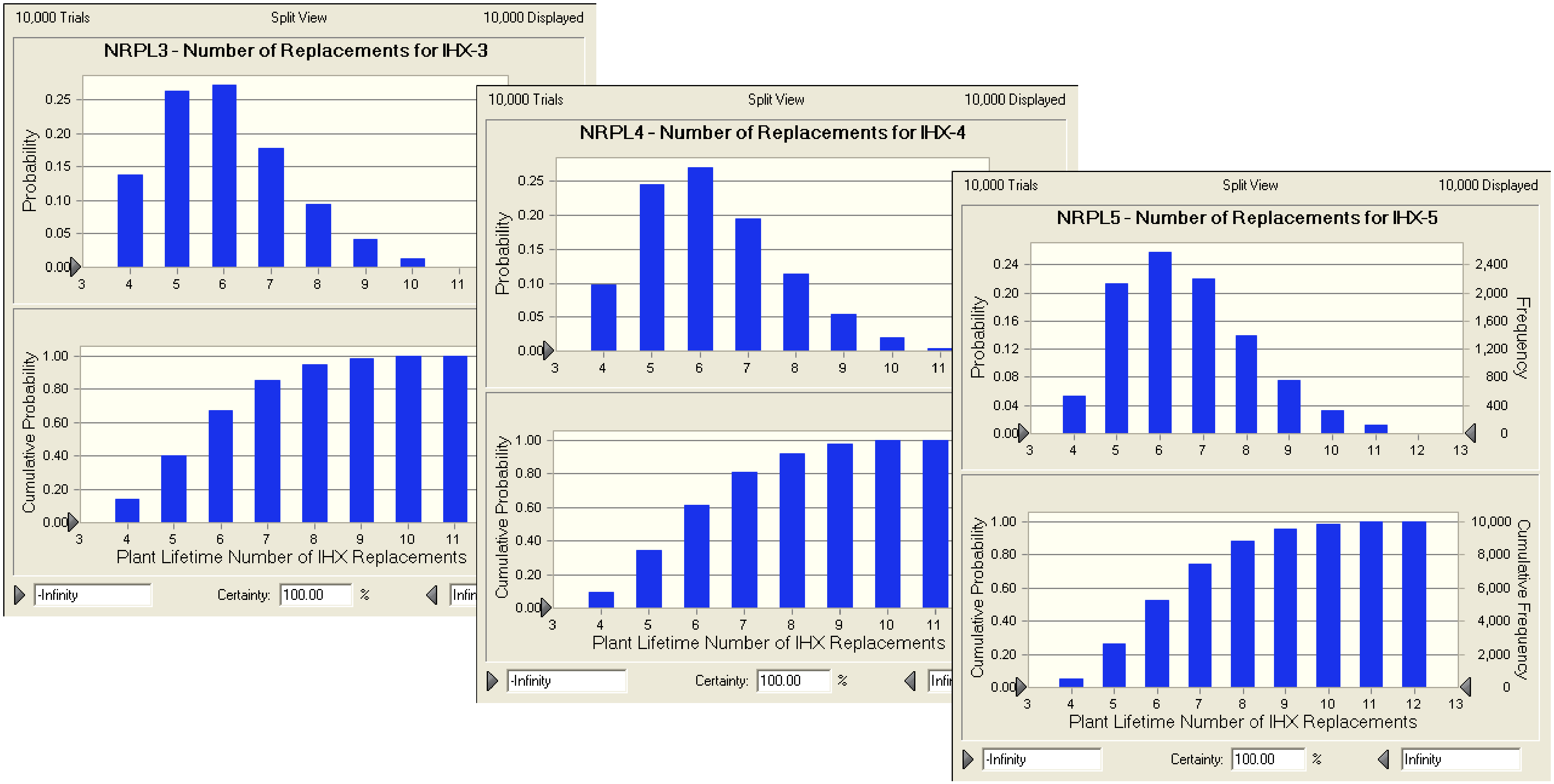
Number of Replacements for IHX Cases 3, 4 and 5



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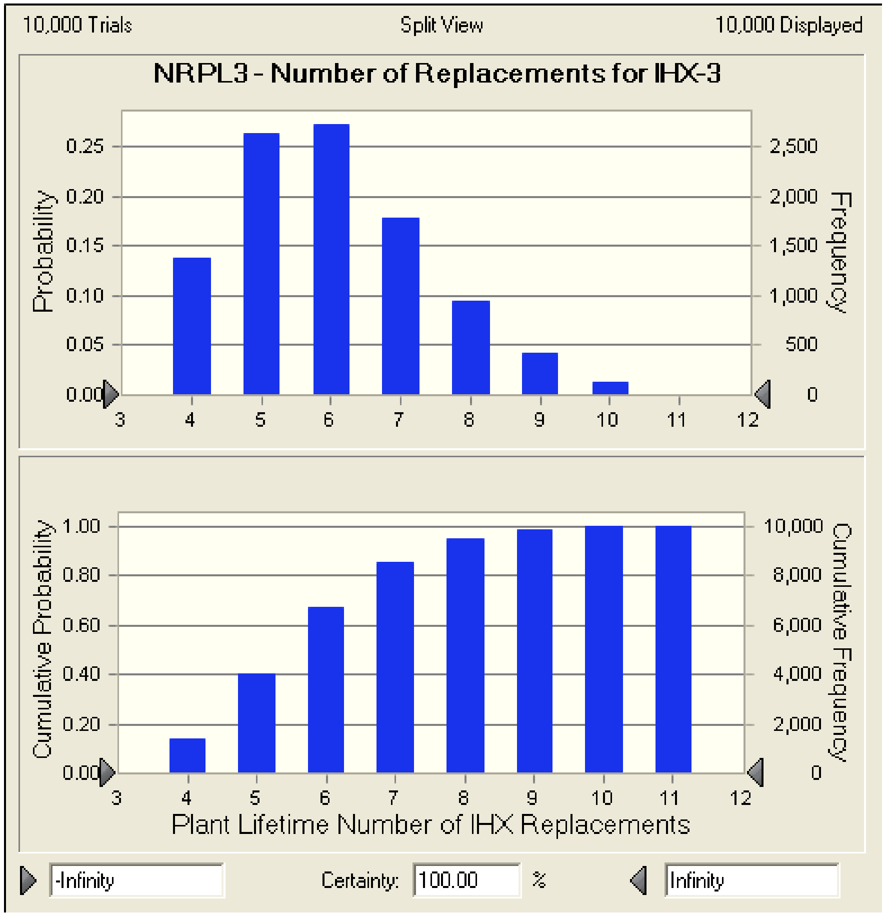
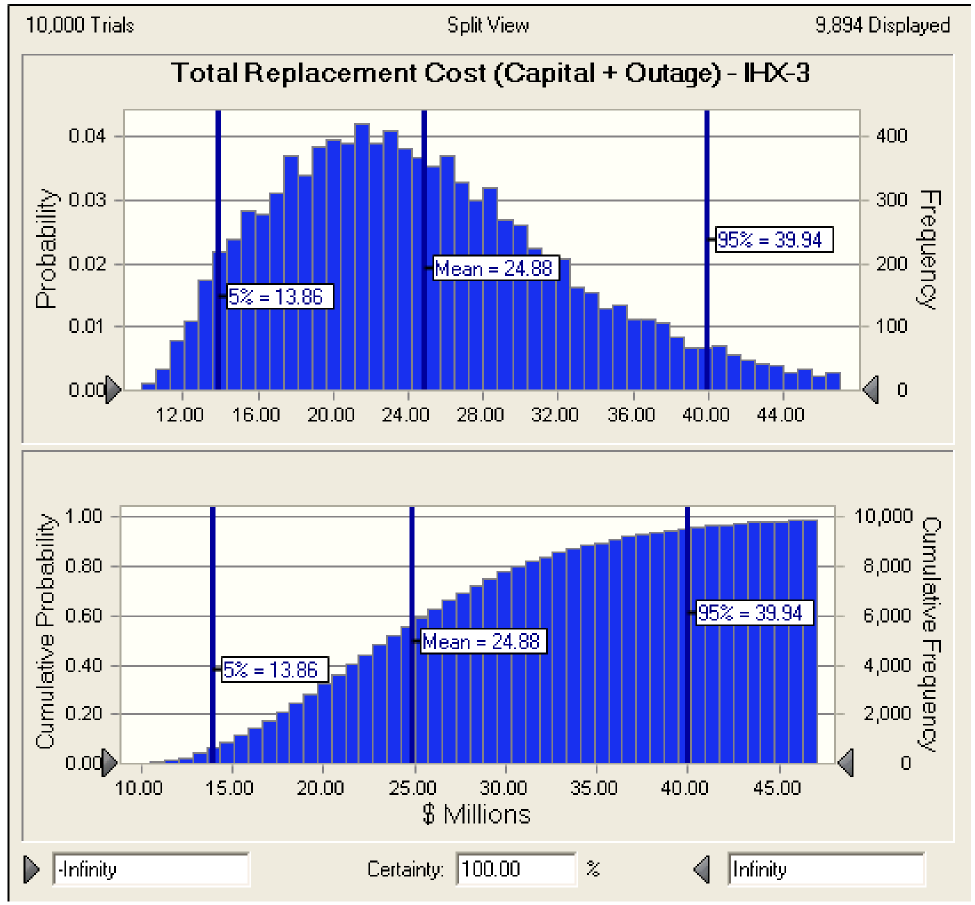
Number and Cost of Replacements for IHX-3





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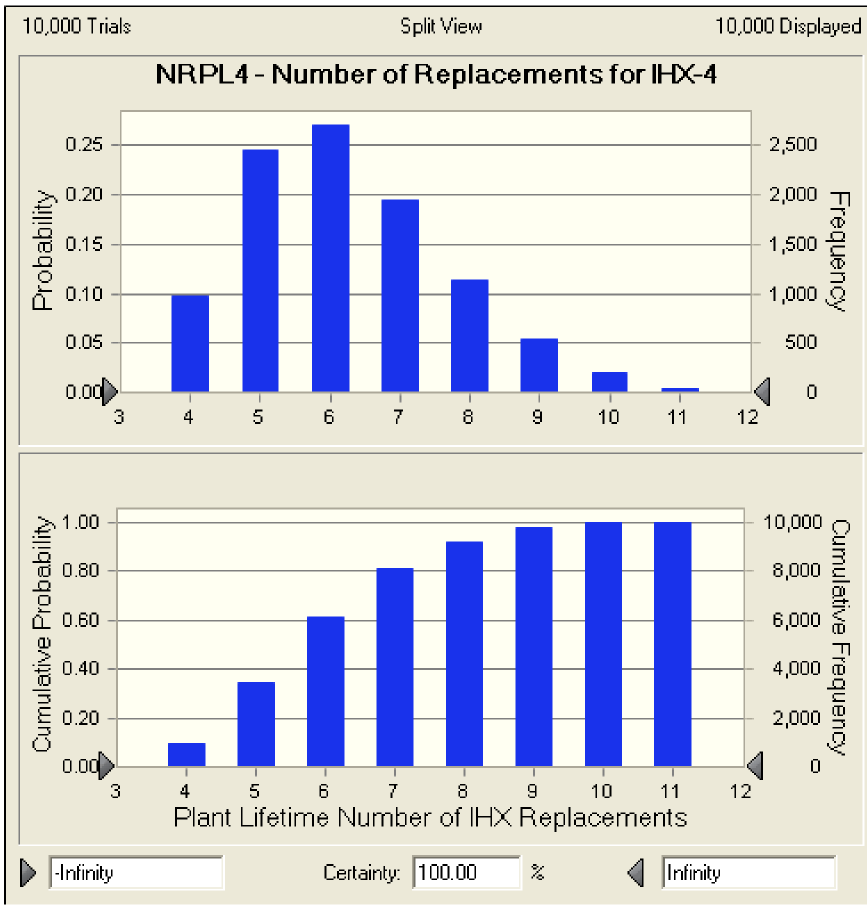
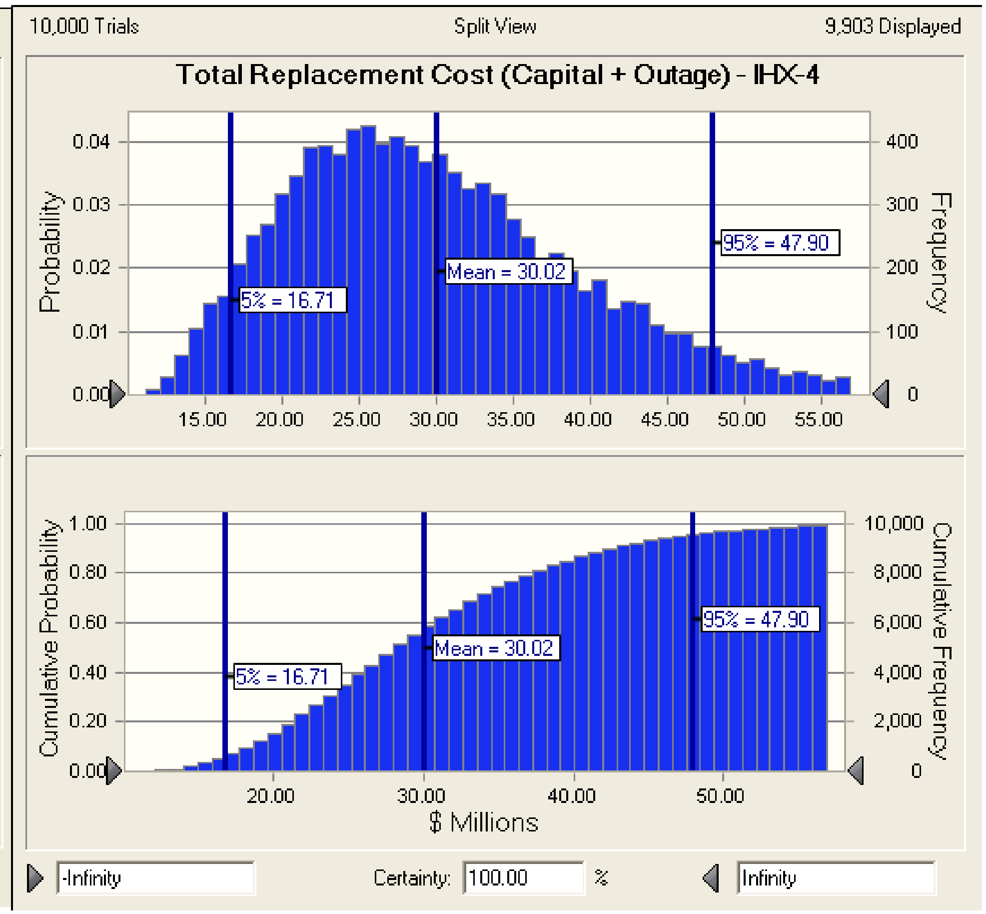
Number and Cost of Replacements for IHX-4





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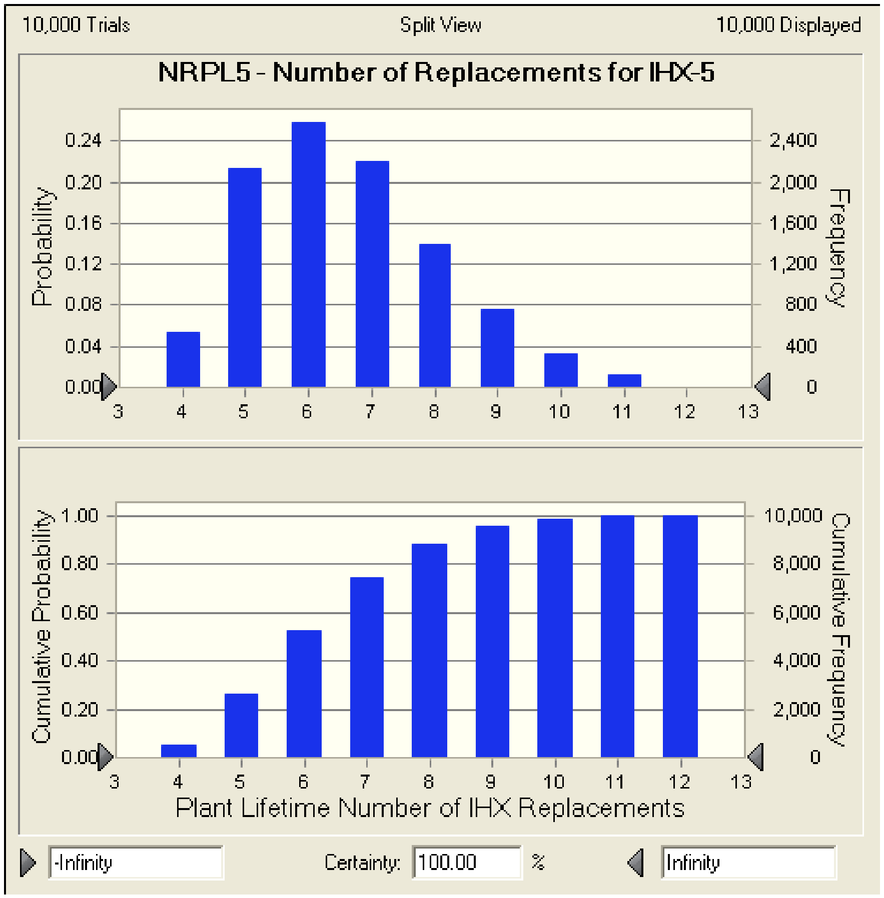
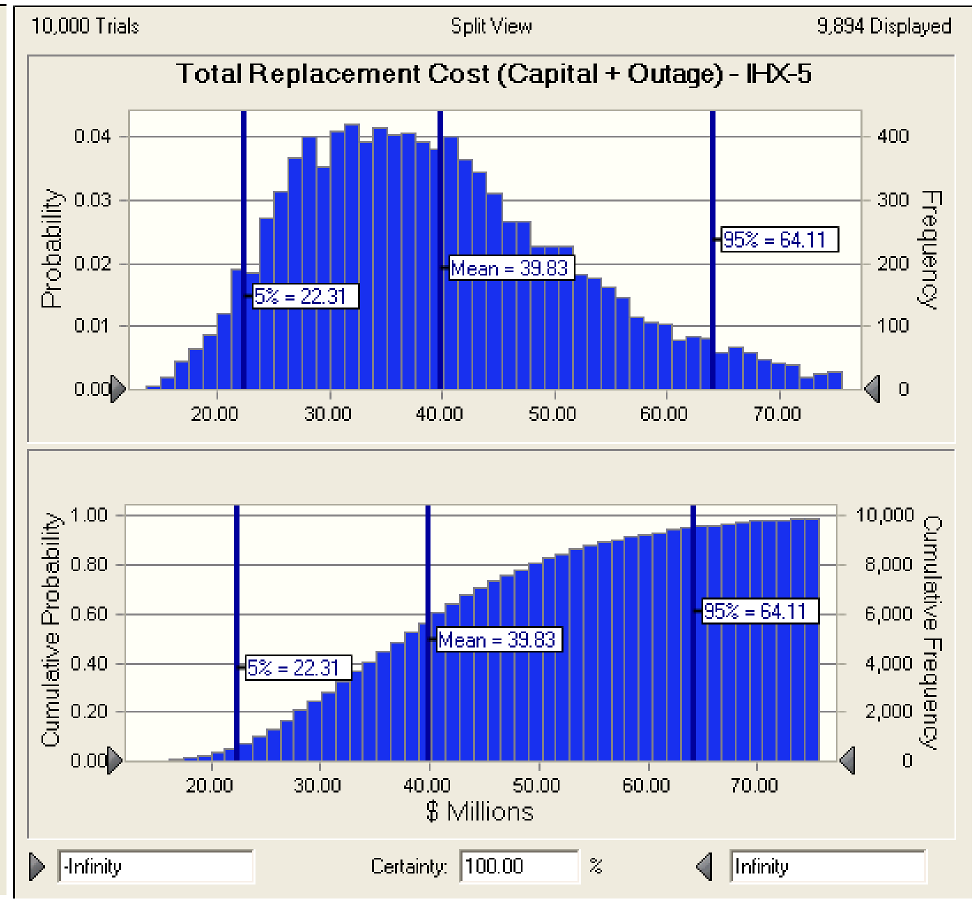
Number and Cost of Replacements for IHX-5





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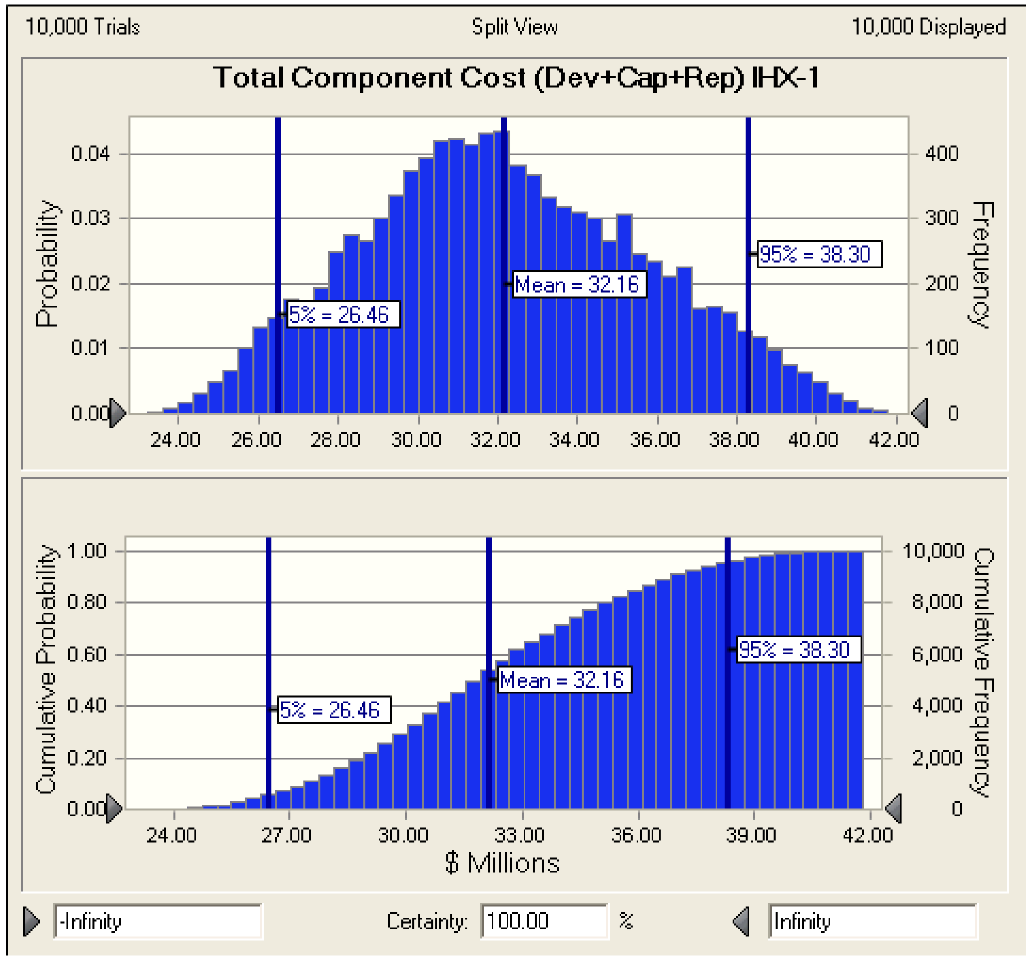
Total IHX 1 Cost (Development, Capital, and Replacement)



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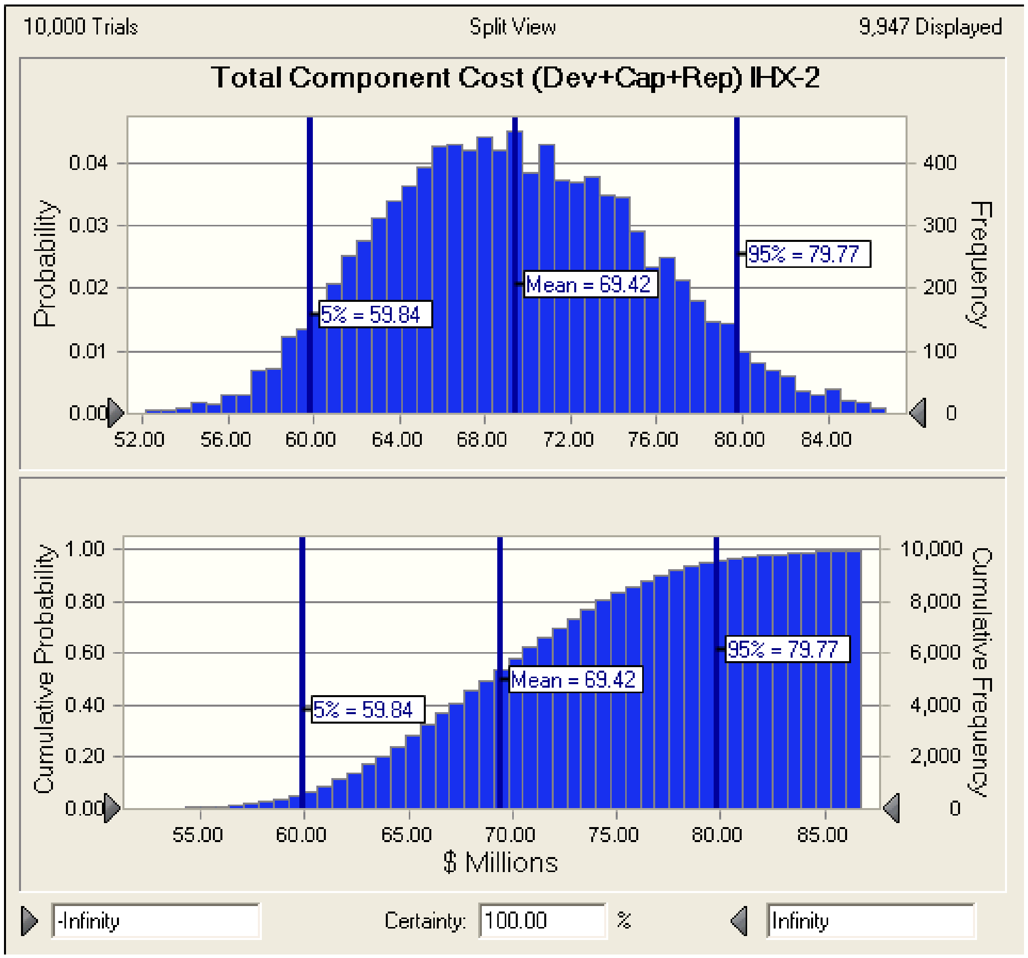
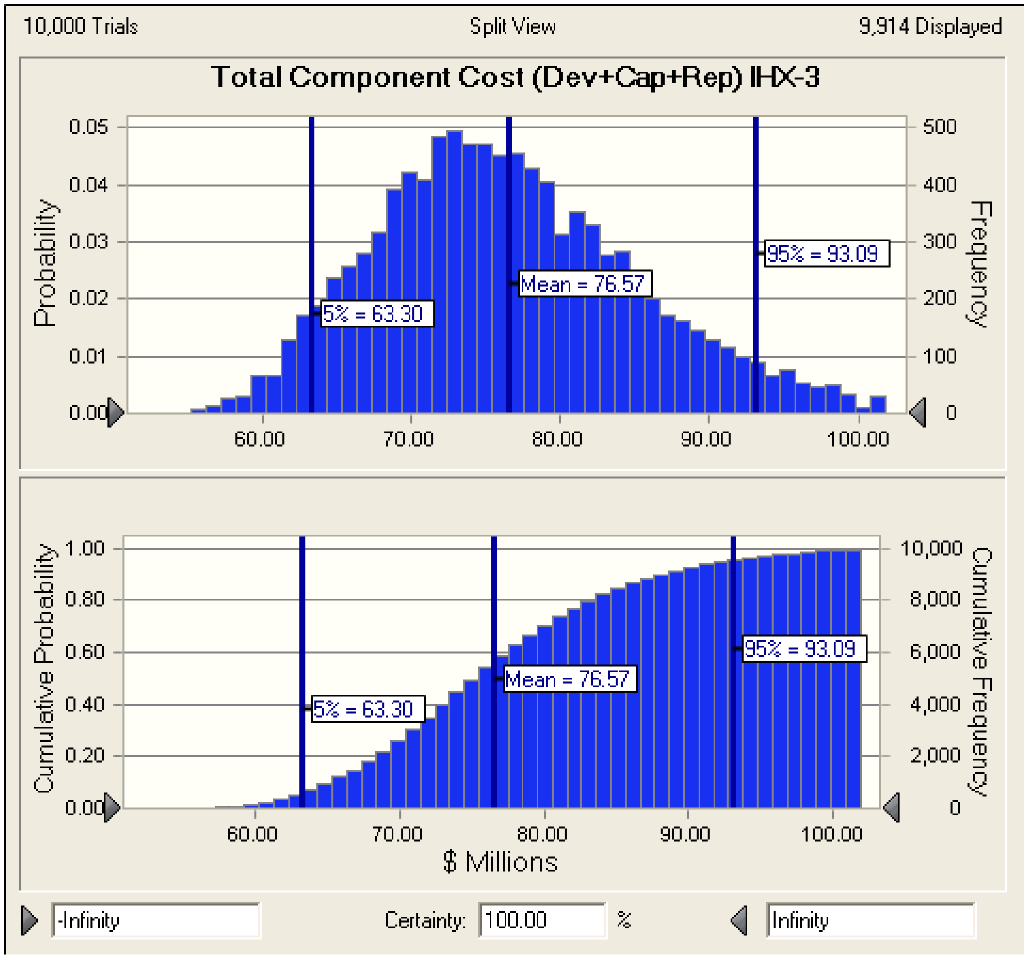
Total IHX 2 Cost
(Development, Capital, and Replacement)



Total IHX 3 Cost (Development, Capital, and Replacement)



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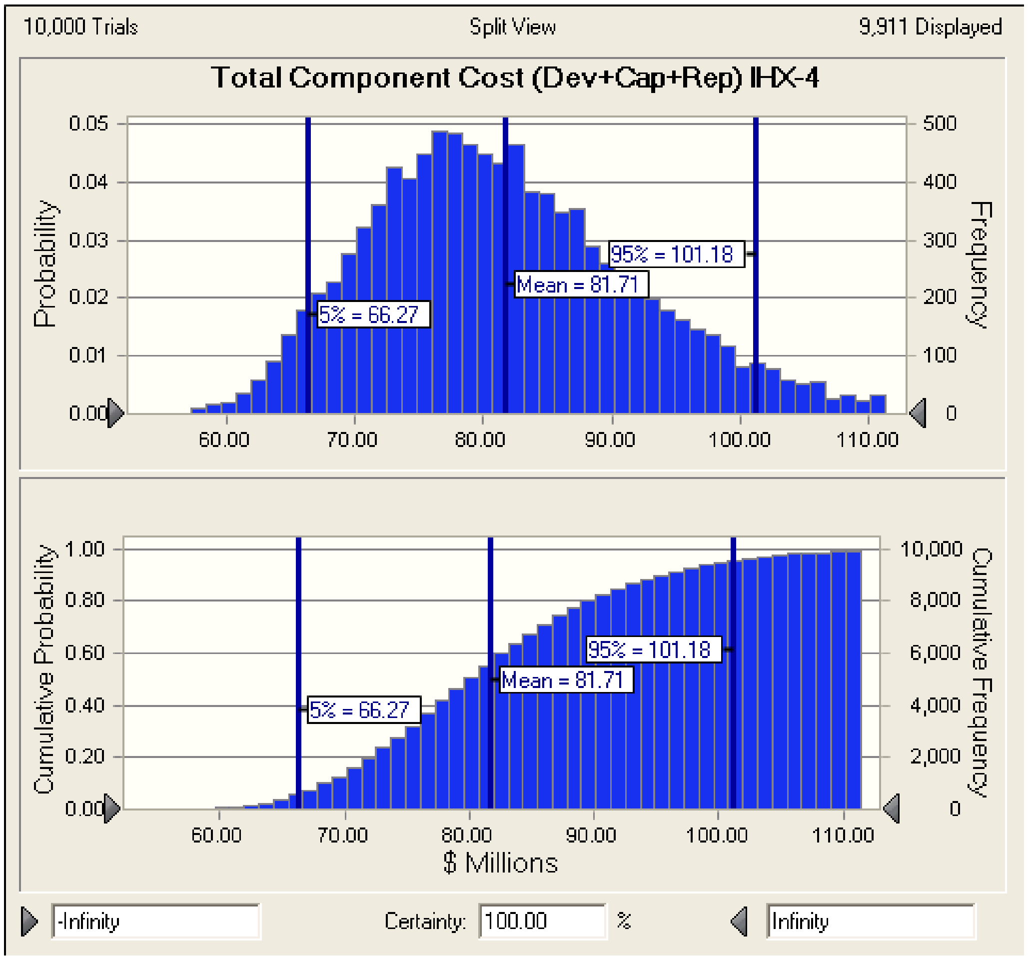
Total IHX 4 Cost (Development, Capital, and Replacement)



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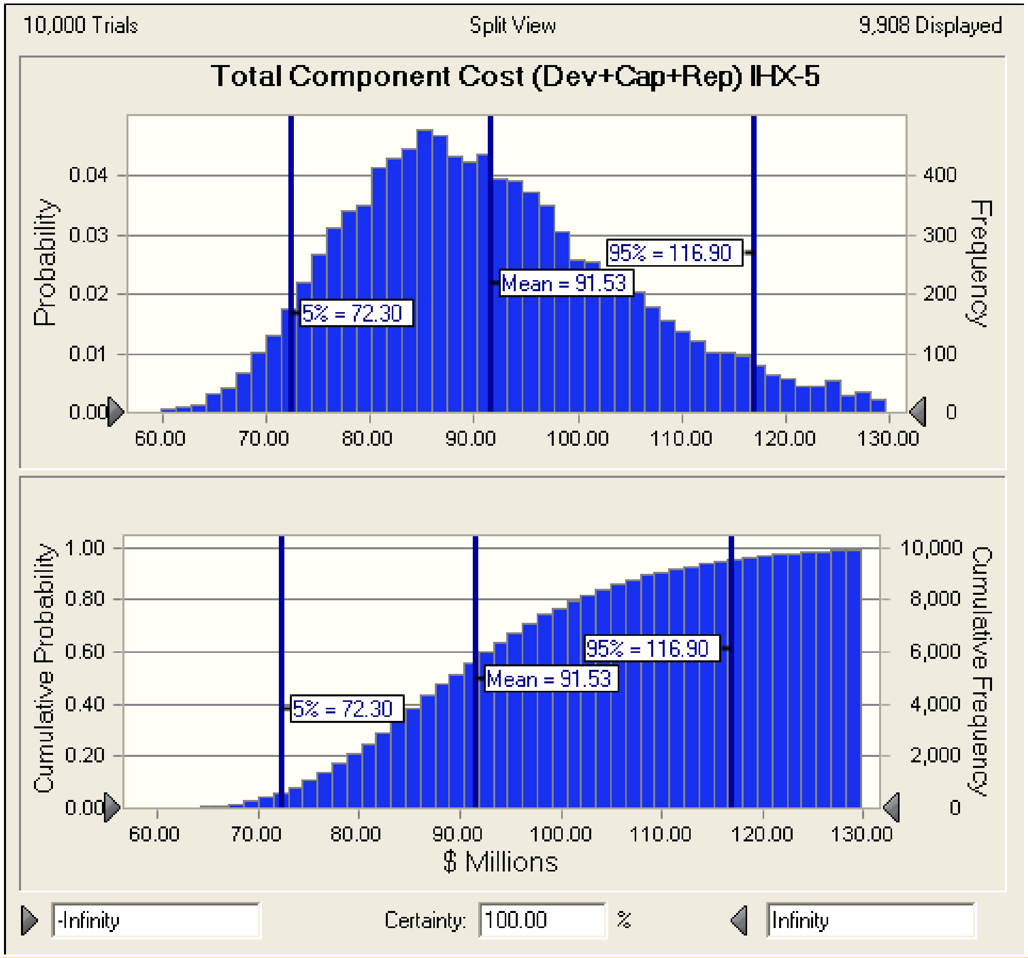
Total IHX 5 Cost (Development, Capital, and Replacement)



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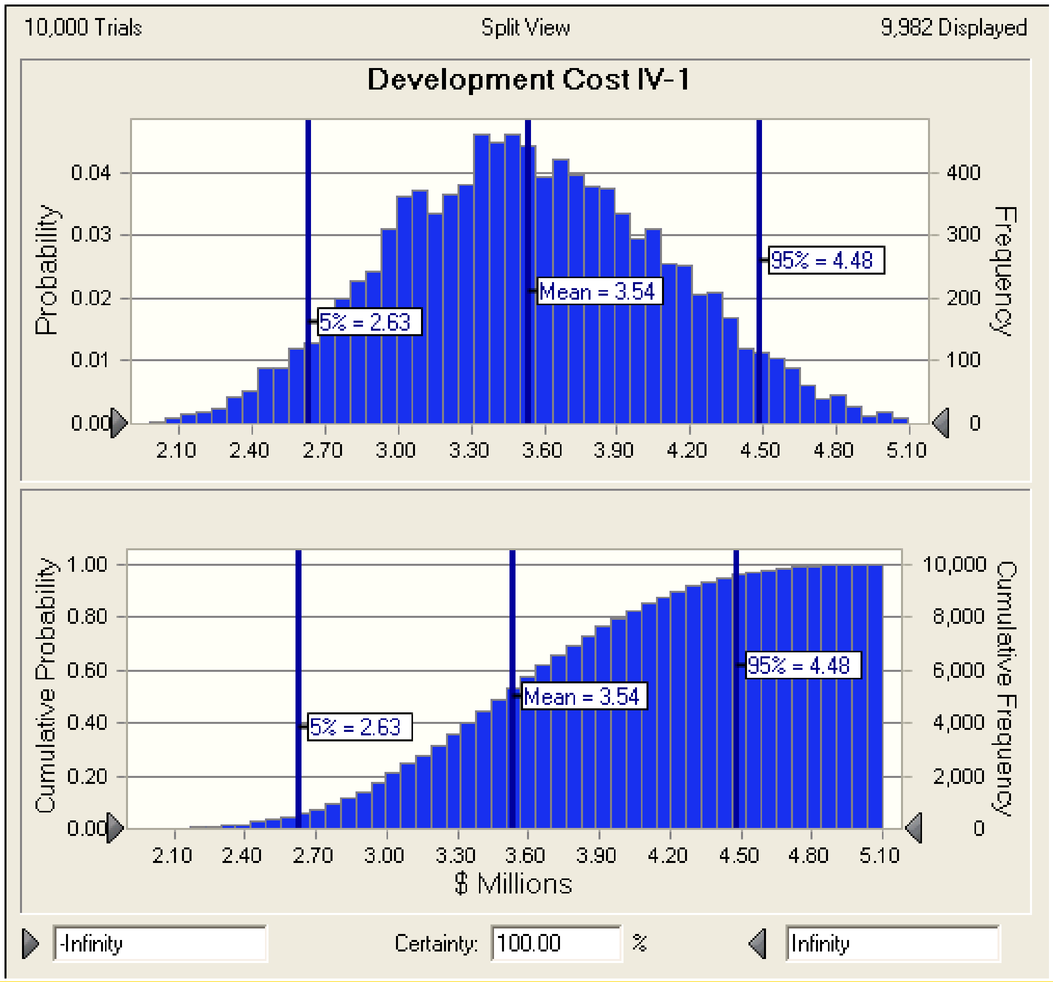
IHX Vessel Matrix of Cases

	Operating Parameters & Corresponding Mat'ls				
Case	ROT (C)	RIT (C)	Power Level (MWt)	Primary Pressure (MPa)	Mat'ls
IV-1	<760	350	500	9	508/533
IV-2 A	900				
IV-2 B	<760				
IV-345 A	950				
IV-345 B	<760				

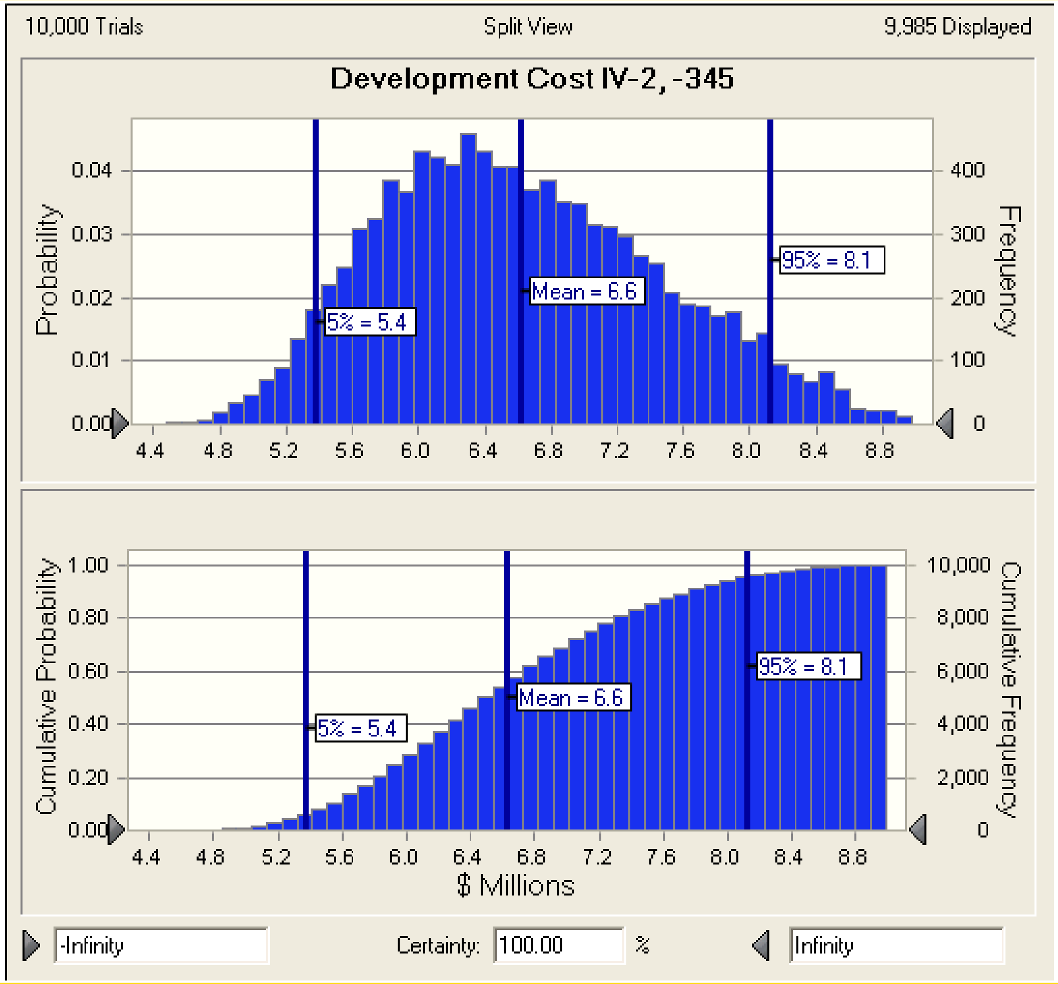
IHX Vessel Development Cost

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
IV-1	0.6	1.2	1.5	0.5	0.6	0.8	0.5	0.6	0.9	0.5	1.0	2.0
IV-2	1.2	1.5	2.1	0.8	0.9	1.1	1.2	1.5	1.8	1.5	2.0	4.0
IV-3, 4, 5	1.2	1.5	2.1	0.8	0.9	1.1	1.2	1.5	1.8	1.5	2.0	4.0

IV-1 Development Cost Distributions



IV-2, 3, 4, 5 Development Cost Distributions



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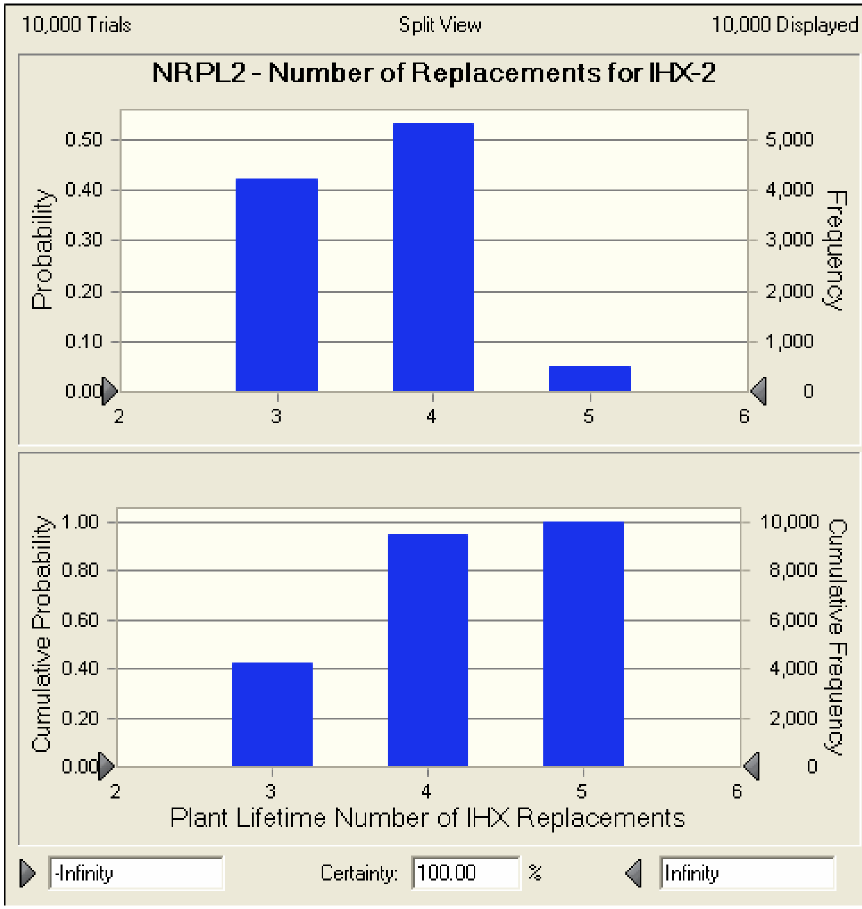
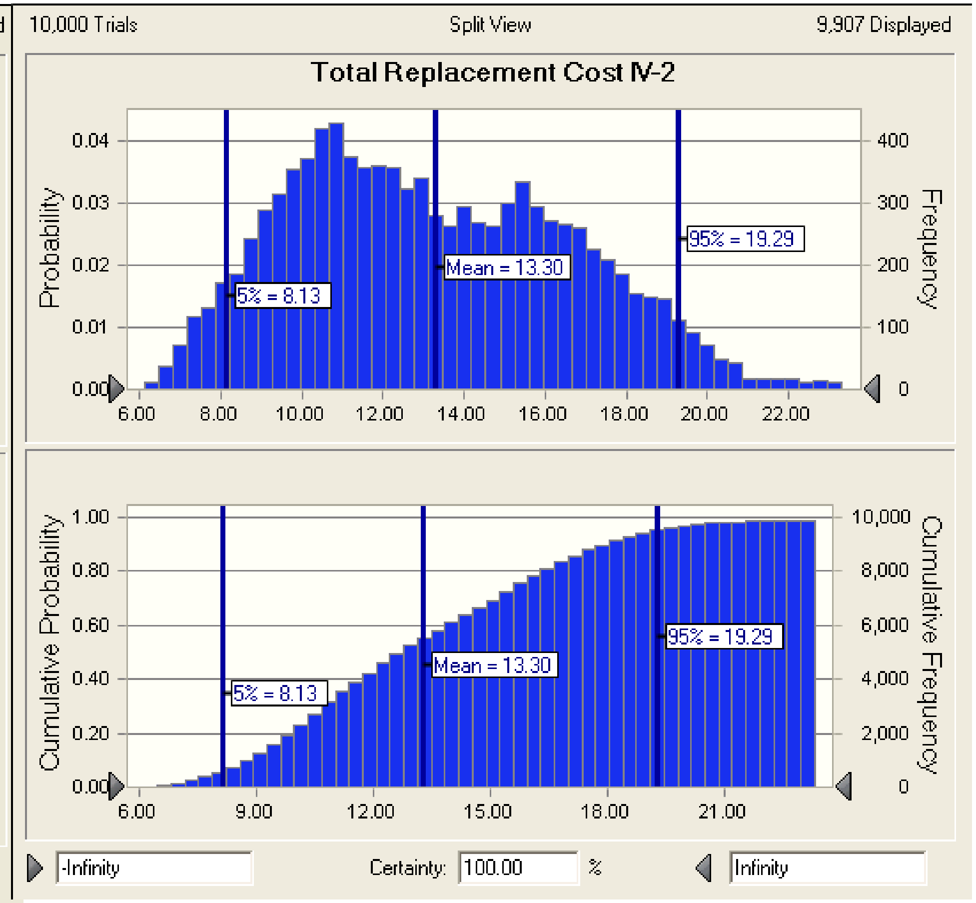
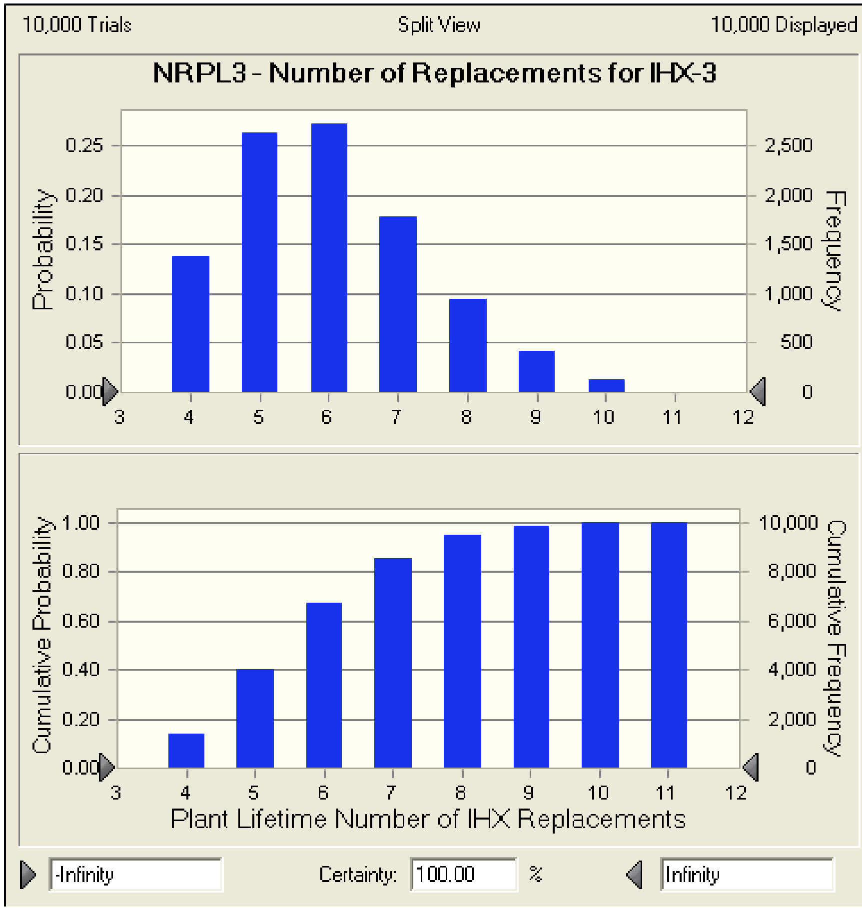
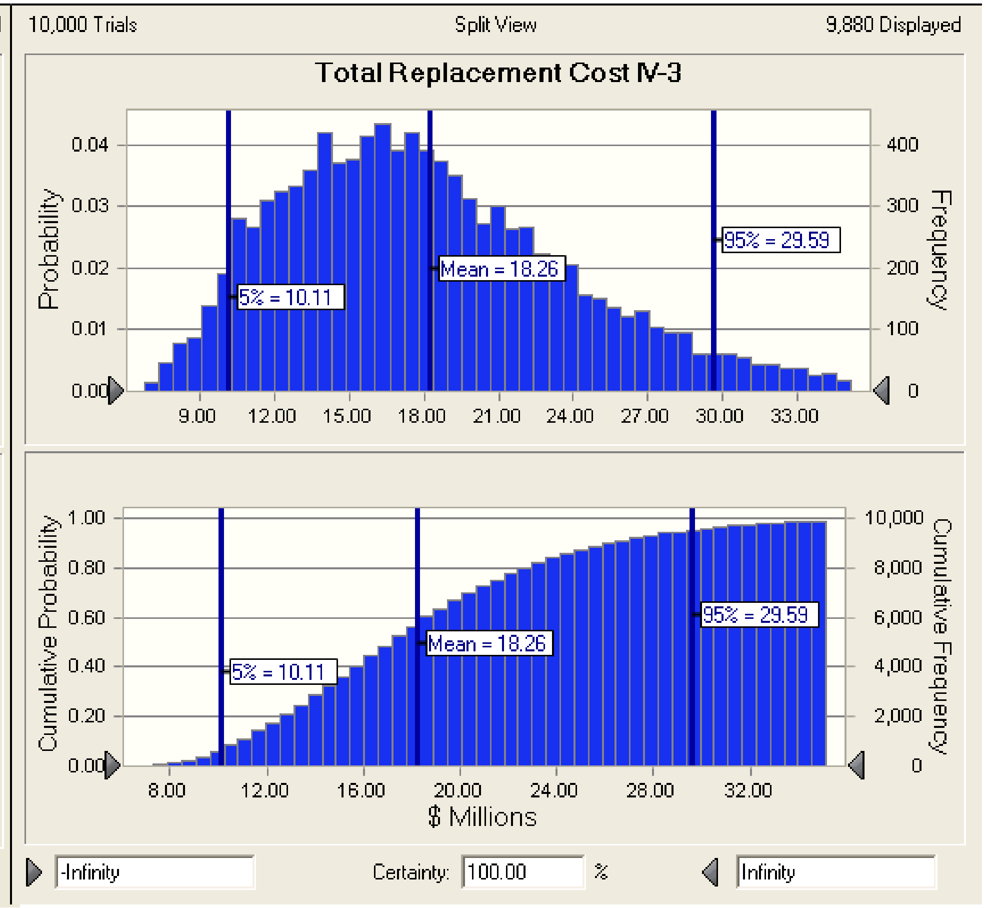
Number and Cost of Replacements for Vessel for IHX-2



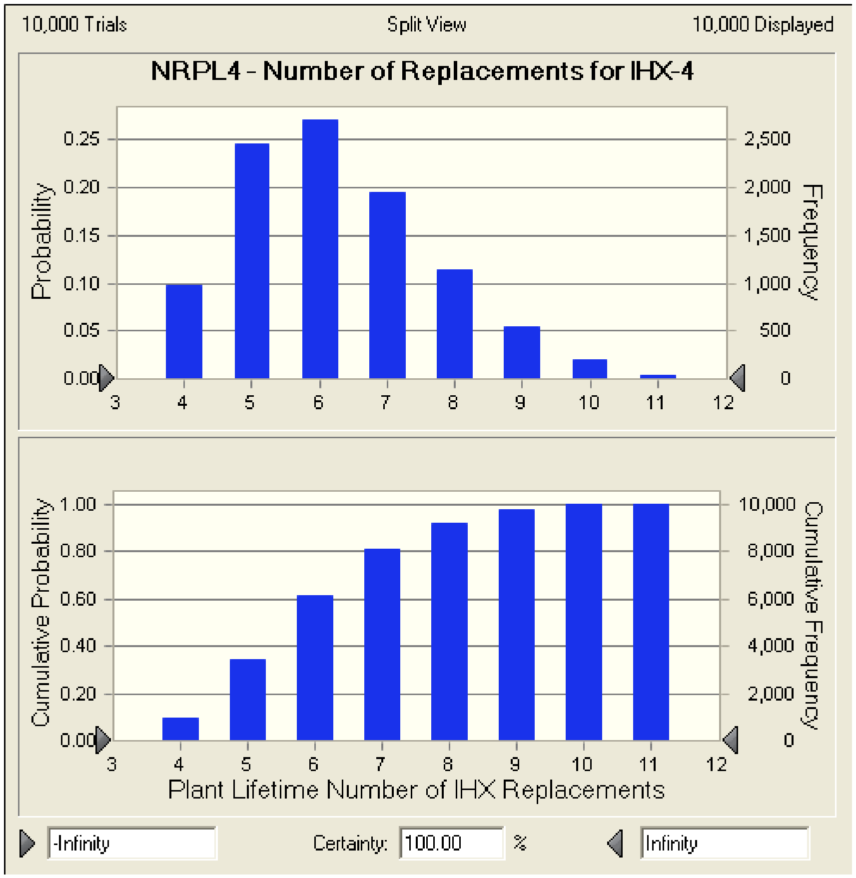


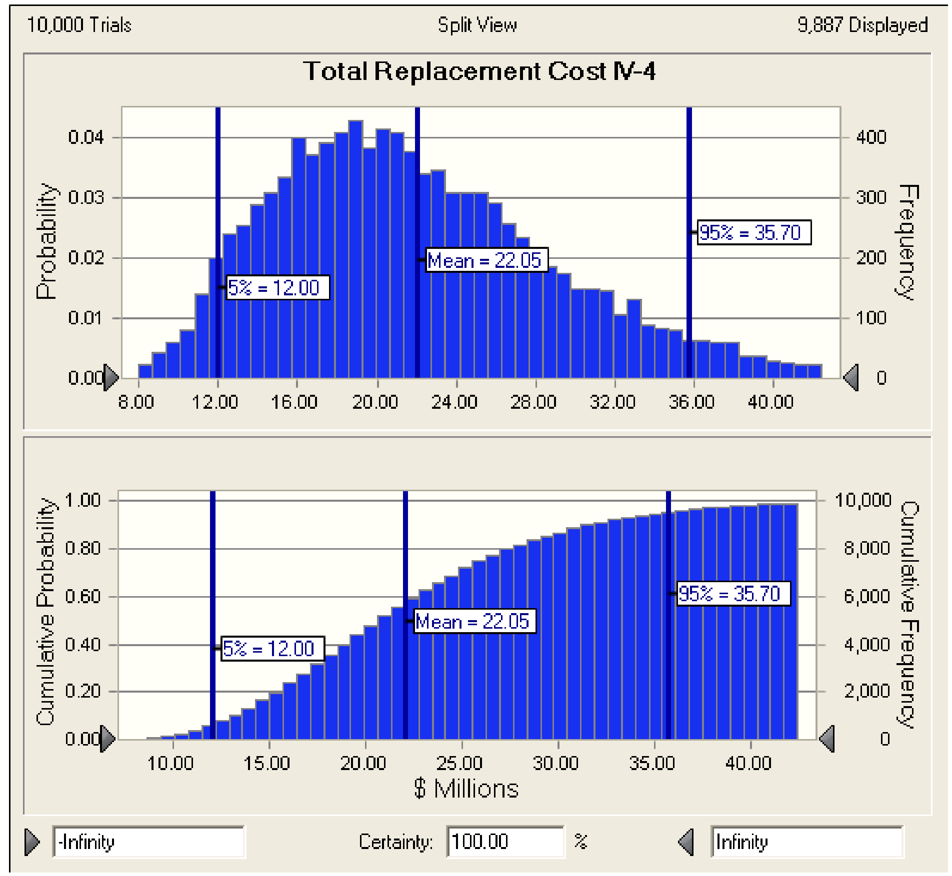
Number and Cost of Replacements for Vessel of IHX-3





Number and Cost of Replacements for Vessel for IHX-4





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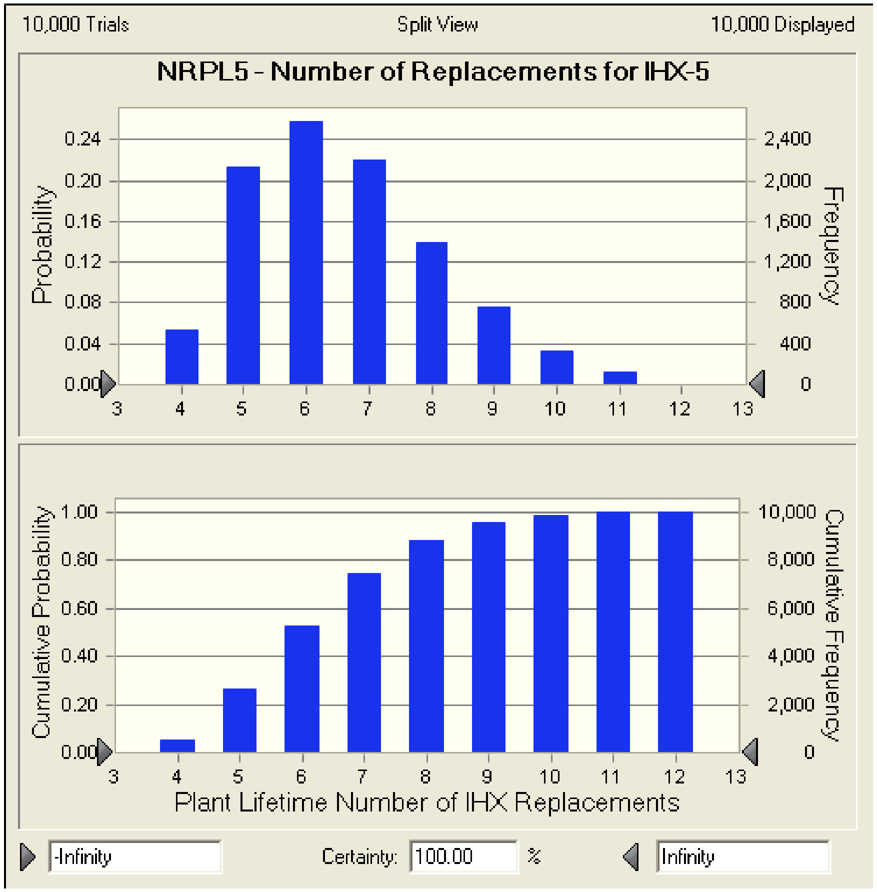
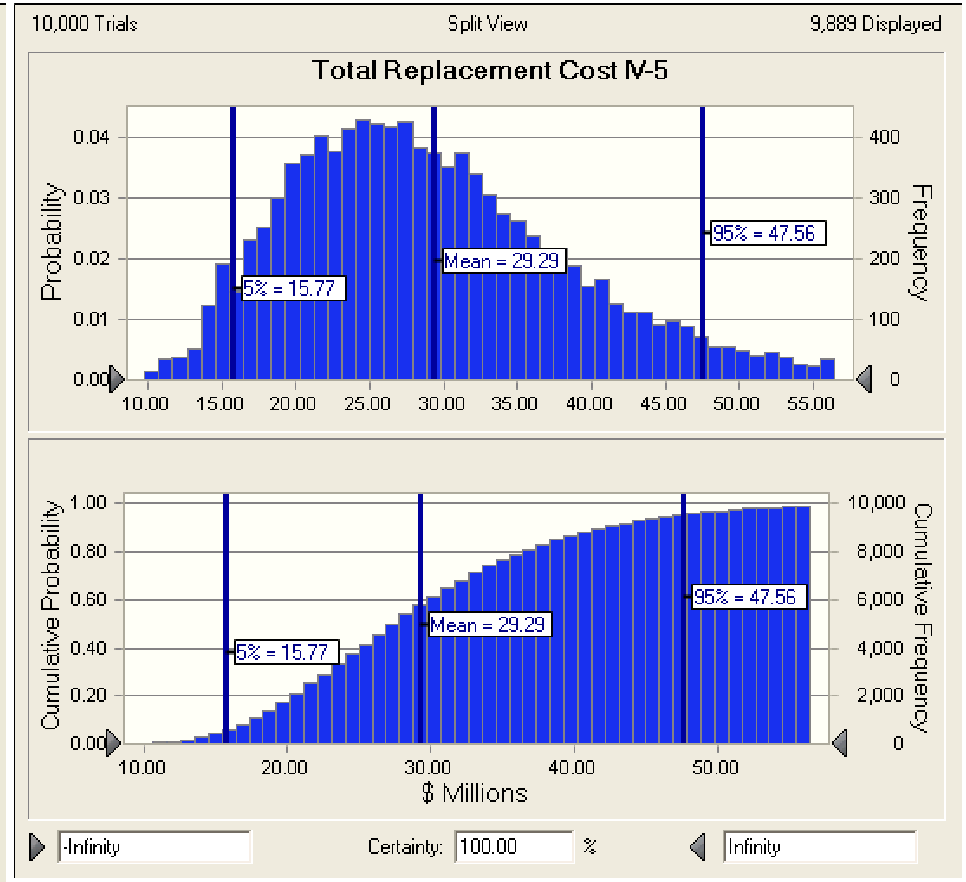
Number and Cost of Replacements for Vessel for IHX-5





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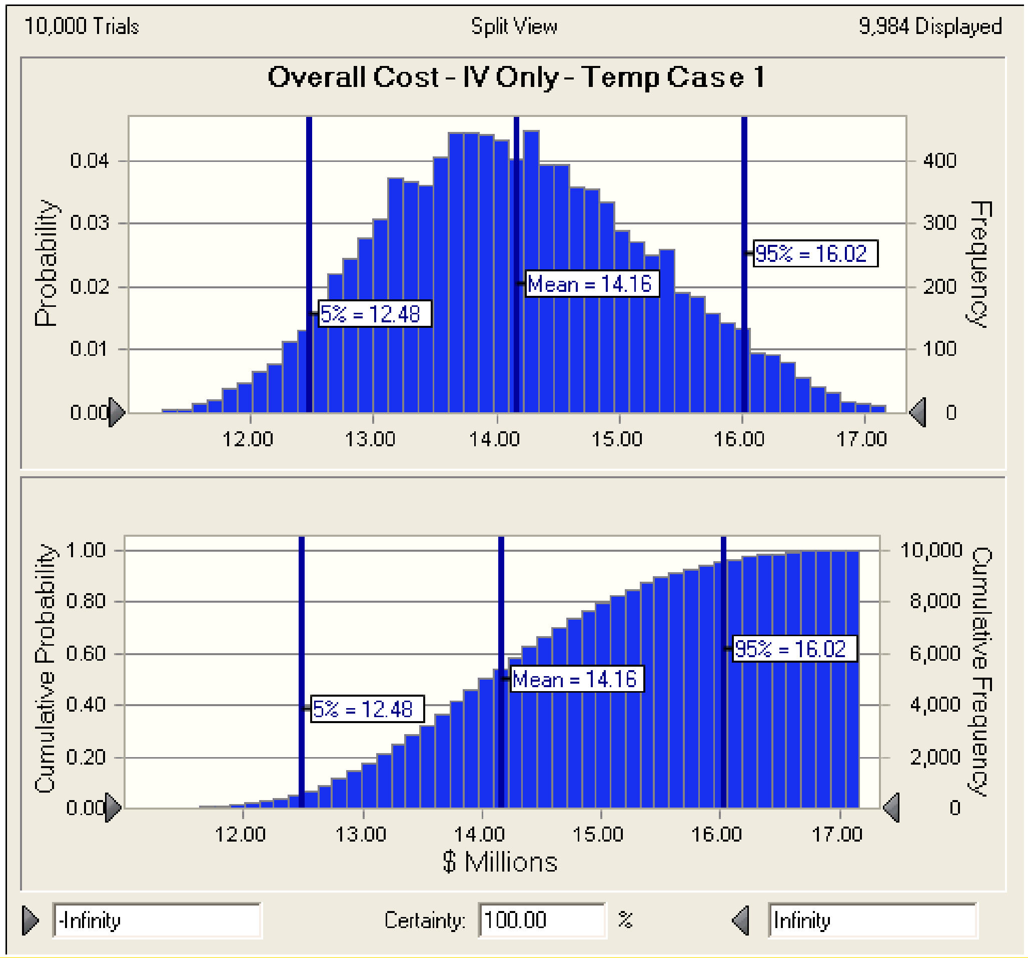
Total Vessel Cost for IHX-1
(Development, Capital, and Replacement)



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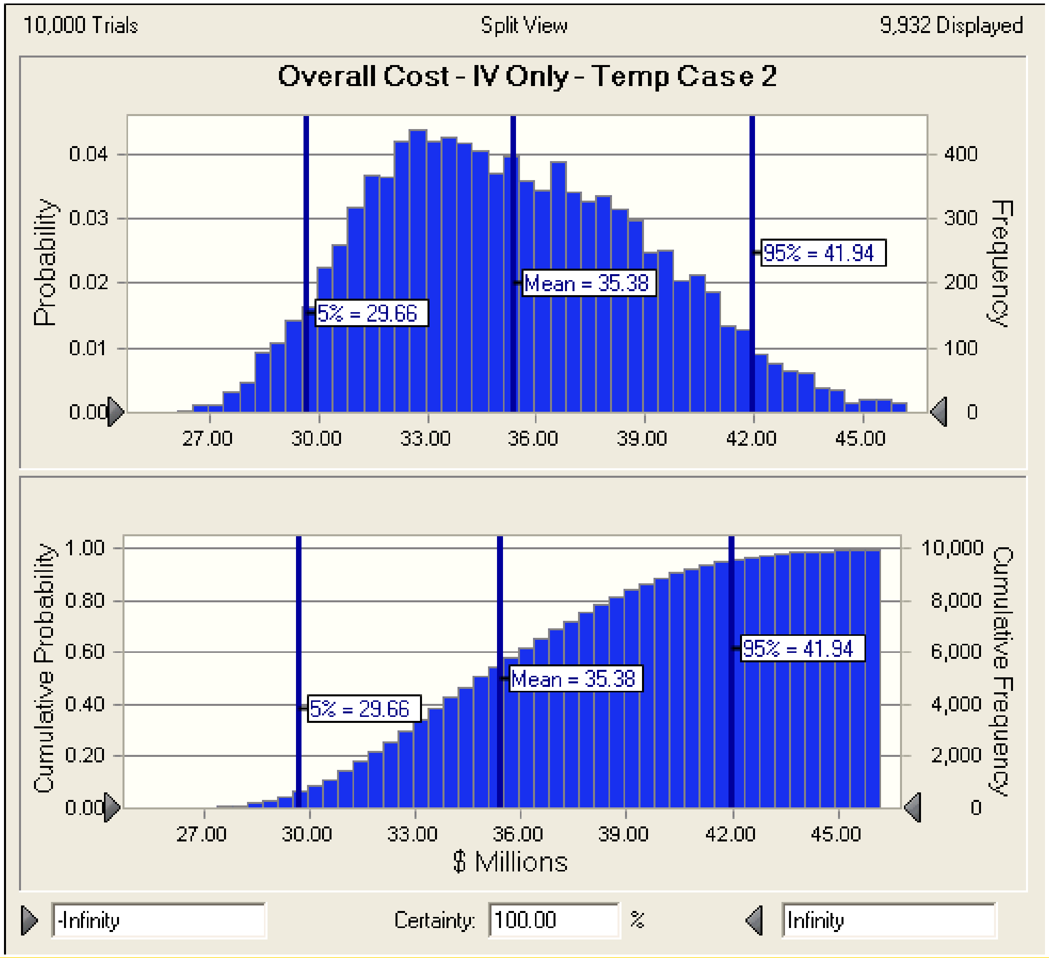
Total Vessel Cost for IHX-2
(Development, Capital, and Replacement)



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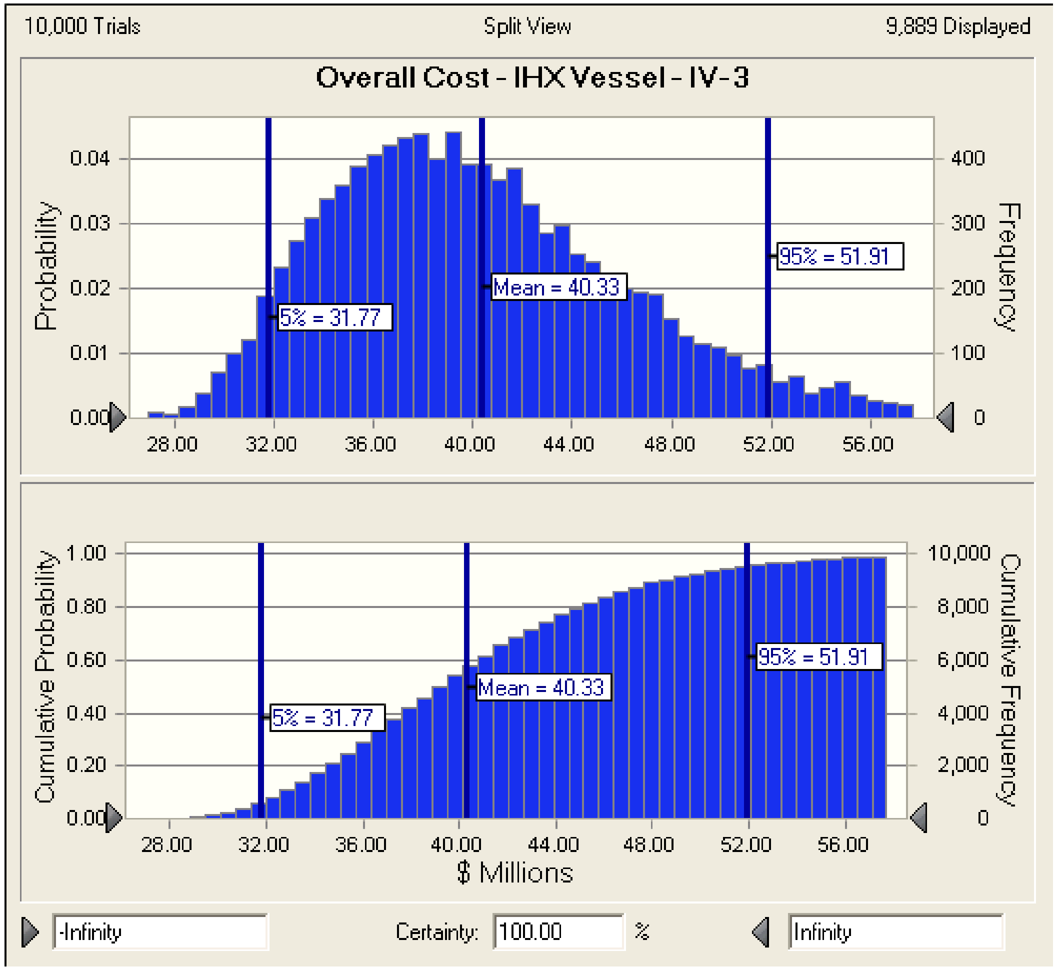
Total Vessel Cost for IHX-3
(Development, Capital, and Replacement)



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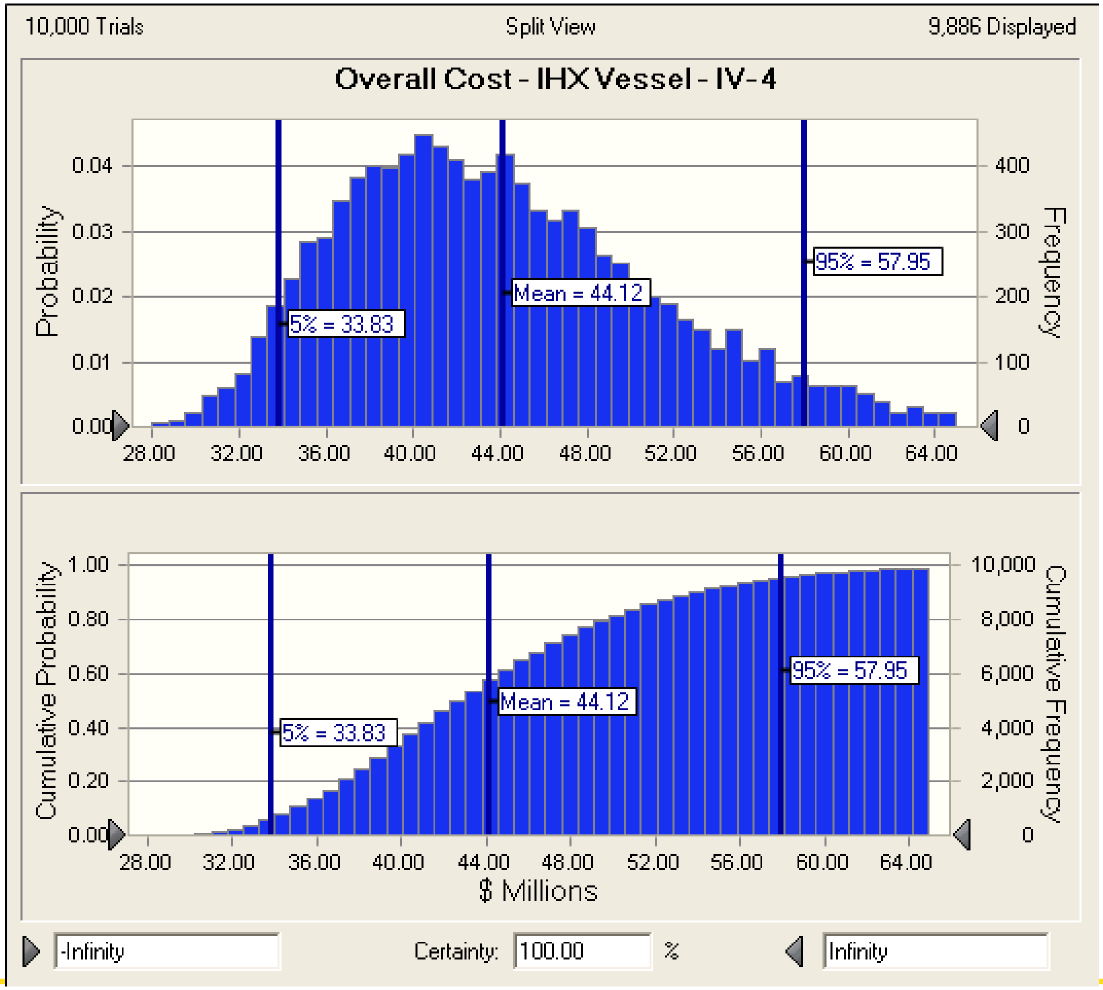
Total Vessel Cost for IHX-4
(Development, Capital, and Replacement)



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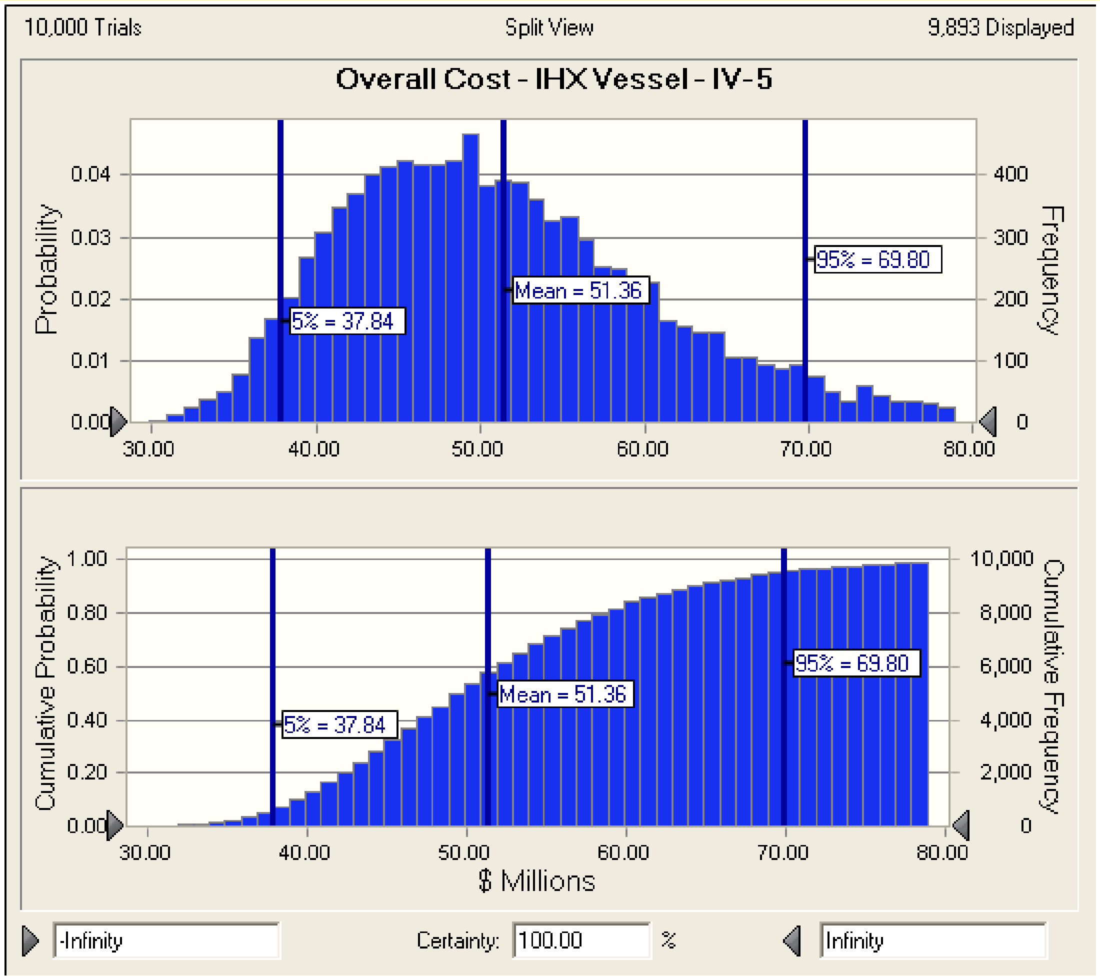
Total Vessel Cost for IHX-5
(Development, Capital, and Replacement)



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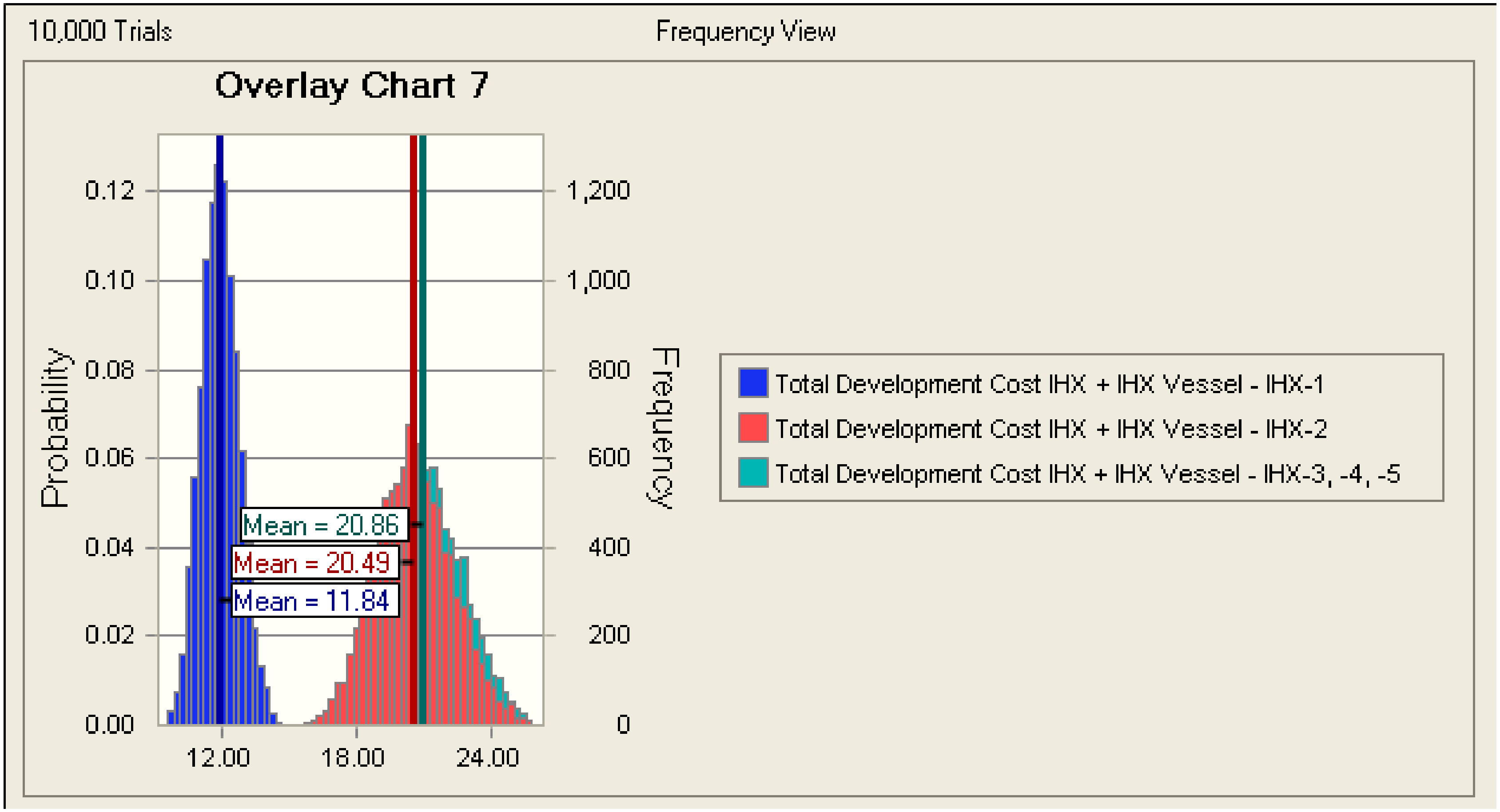
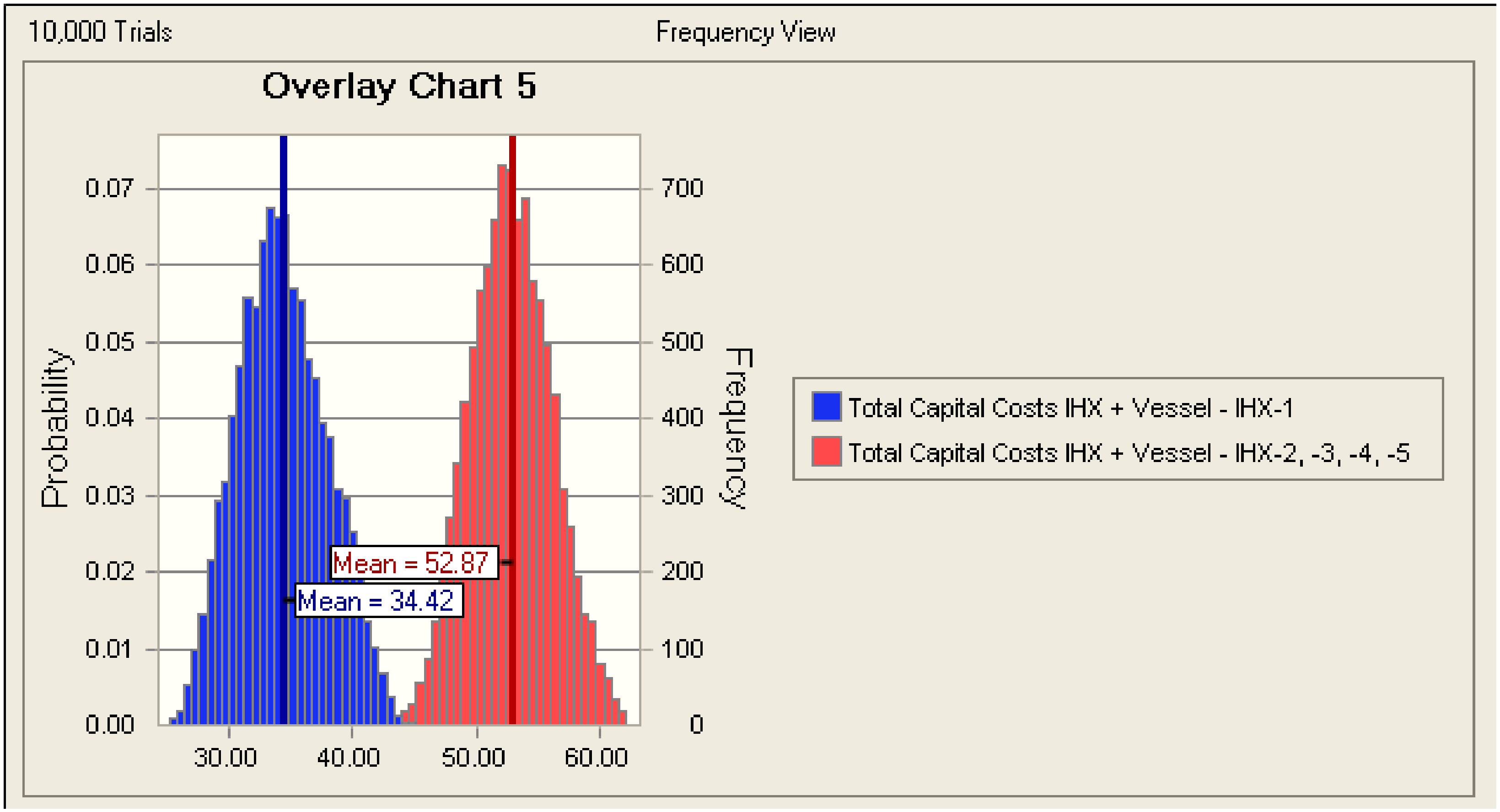
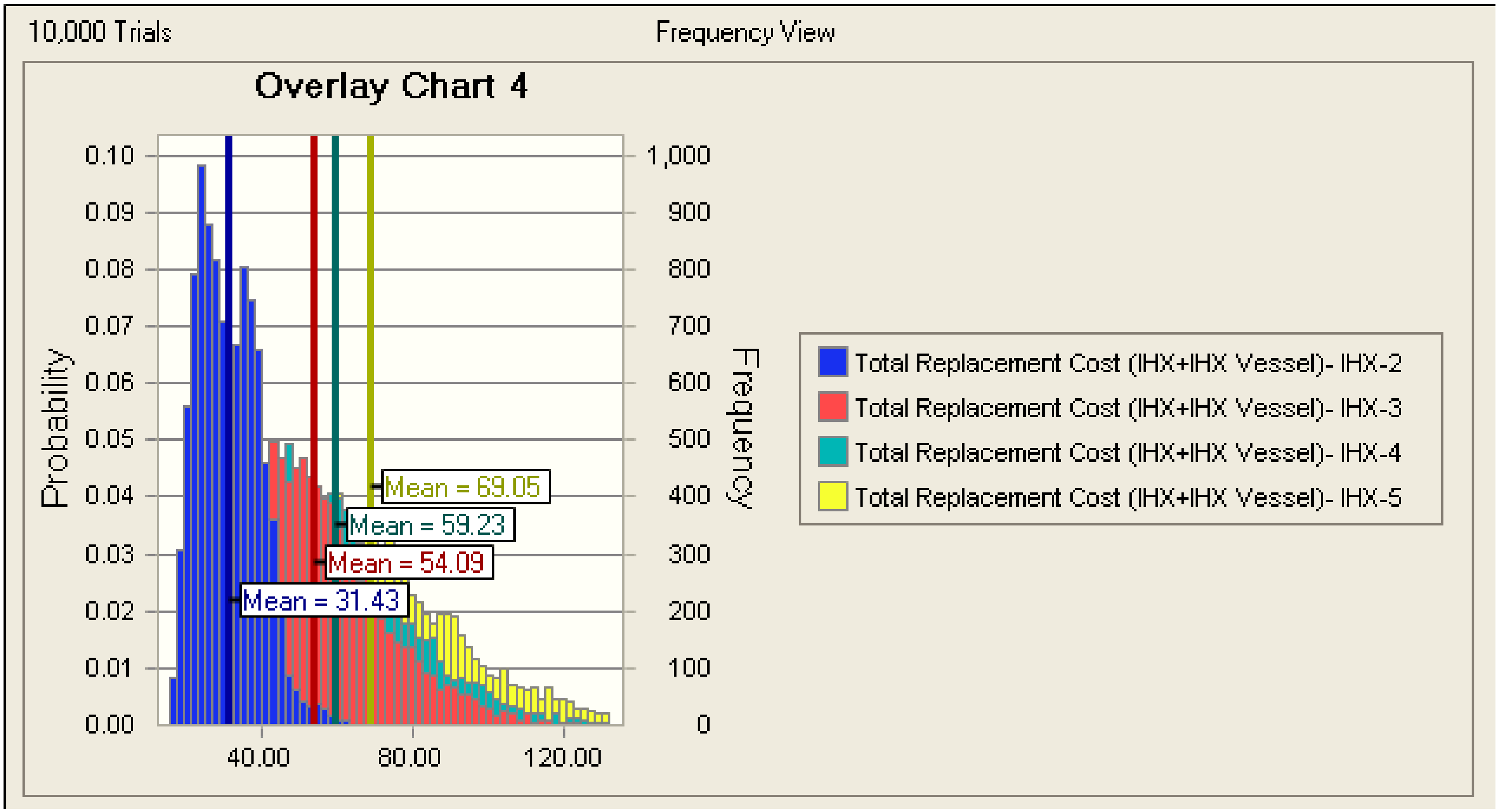
Total IHX and Vessel Development Cost



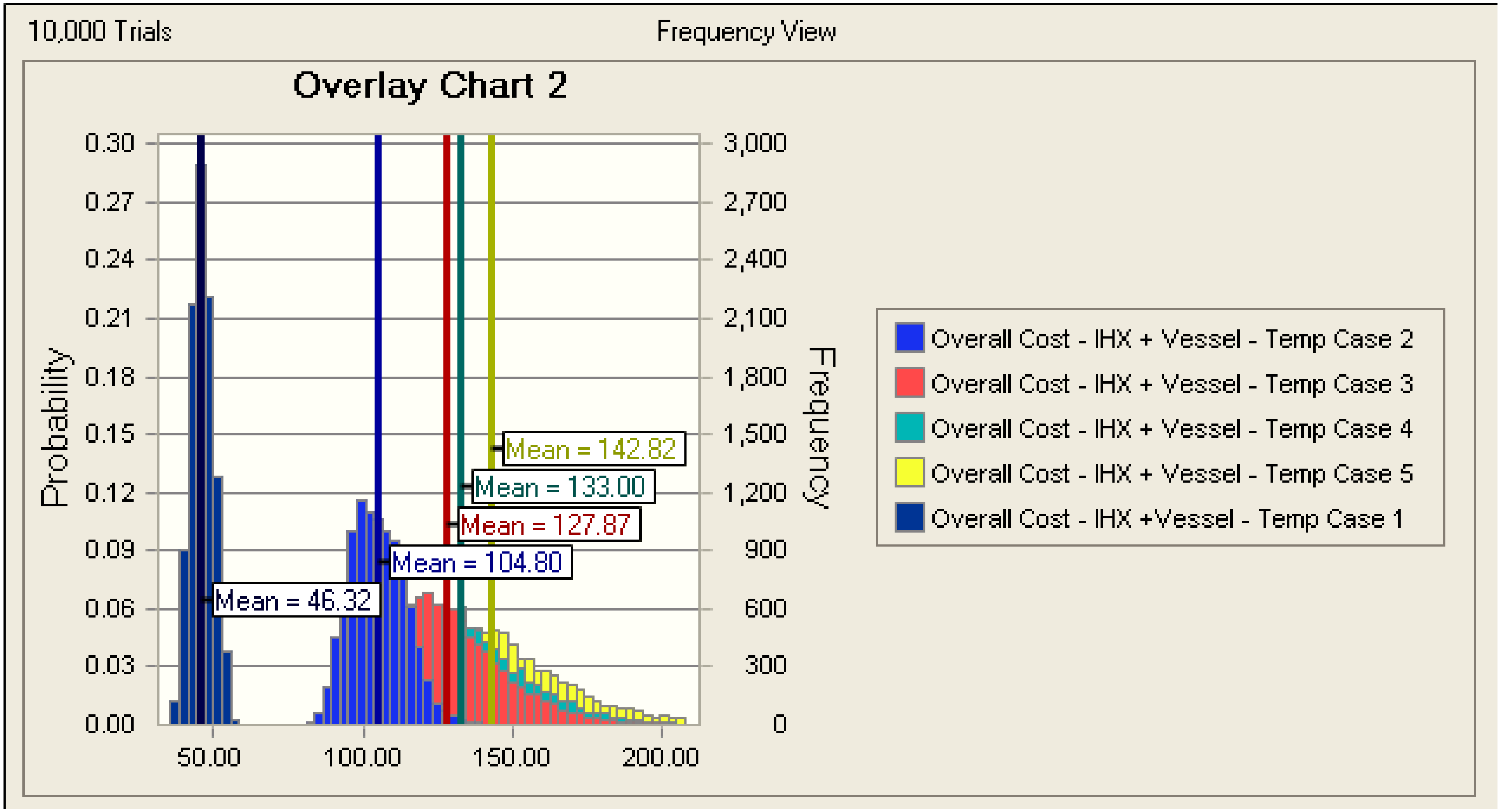
Total IHX and Vessel Capital Cost for all Cases



Total IHX and Vessel Replacement Cost for All Cases



Overall IHX and Vessel Overall Cost for All Cases (Development, Capital, and Replacement)



Sensitivity of IHX and Vessel Cost to Power Level

Cost Contributor	Impact of 250MWt
Development	No impact
Capital	Total cost savings, unit cost increase (.6 scale factor)
Replacement	No impact

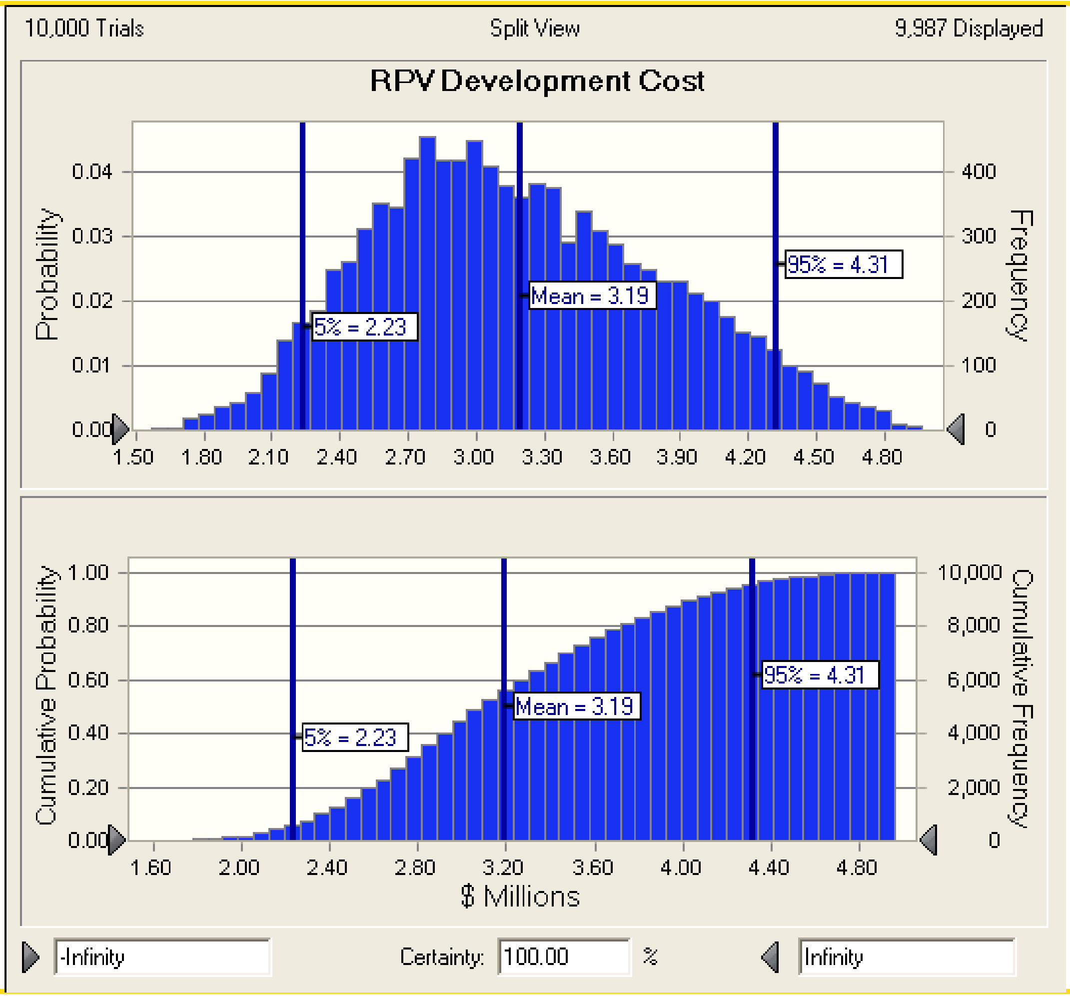
Reactor Vessel Case

	Operating Parameters & Corresponding Mat'ls				
Case	ROT	**RIT**	Power Level	Primary Pressure	Mat'ls
	(C)	**(C)**	(MWt)	(MPa)	
RV-1	950	**350**	500	9	508/533

Reactor Vessel Development Cost

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
RV-1	0.6	0.9	1.2	0.225	0.3	0.6	0.0	0	0.0	1	1.5	3

Reactor Vessel Development Cost



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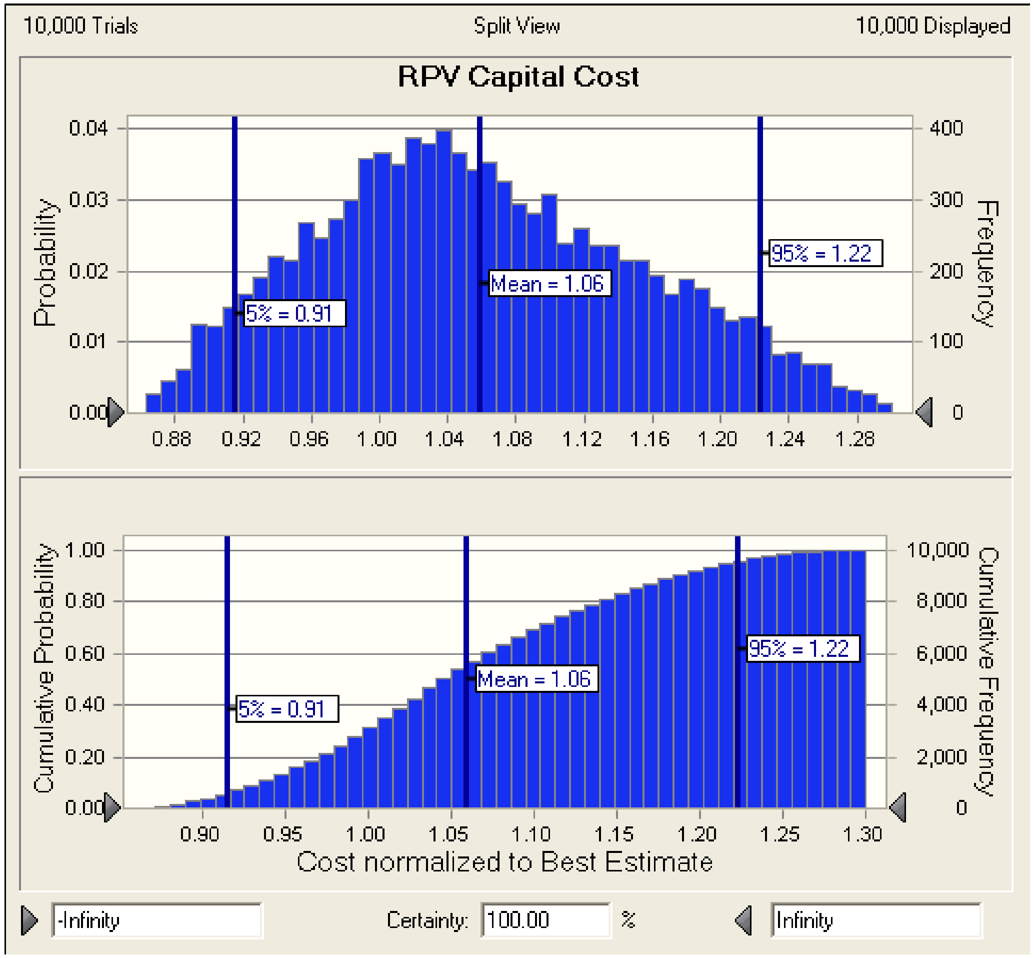
Normalized Reactor Vessel Capital Cost



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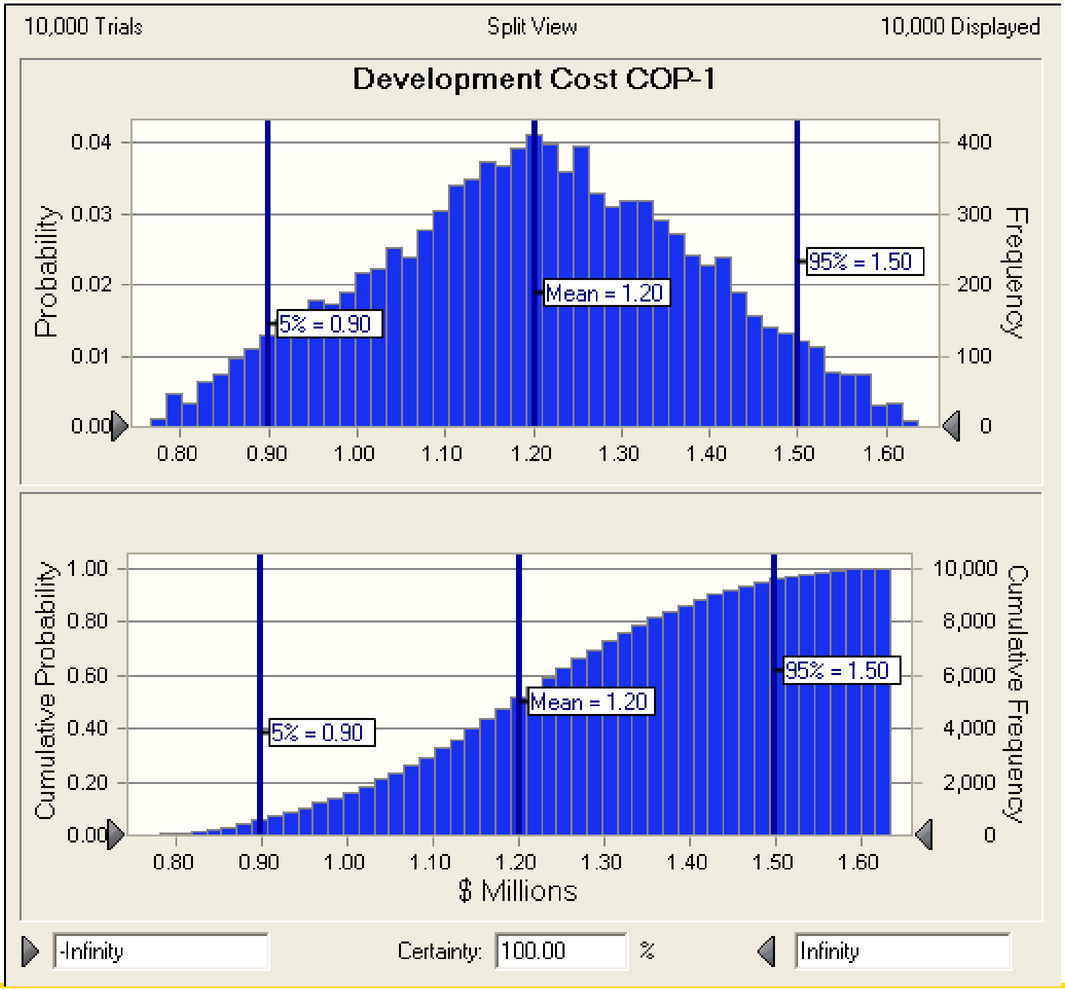
Core Outlet Pipe Matrix of Cases

Case	Design / Initial Operating Parameters				
	ROT	RIT	Power Level	Primary Press.	Mat'ls
	(C)	(C)	(MWt)	(MPa)	
COP-1	<760 / <760*	350	500	9	800H
COP-2	900 / 900	350	500	9	800H
COP-3	950 / <760	350	500	9	Hastelloy
COP-4	950 / 850	350	500	9	Hastelloy
COP-5	950 / 950	350	500	9	Hastelloy

Core Outlet Pipe Development Cost

Case	Development Cost (2008 M$)											
	Design, Codes & Standards			Materials Qualification			Testing and V&V			Test Article Capital & Non Labor		
	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%	5%	Best Est	95%
COP-1	0.9	1.2	1.5	0	0.0	0	0.0	0	0.0	0	0.0	0
COP-2	0.9	1.2	1.8	0	0.0	0	0.0	0	0.0	0	0.0	0
COP-3	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4
COP-4	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4
COP-5	1.2	1.8	2.7	0.9	1.2	1.8	0.9	1.2	1.8	1.5	2.0	4

Development Cost for COP-1 Case



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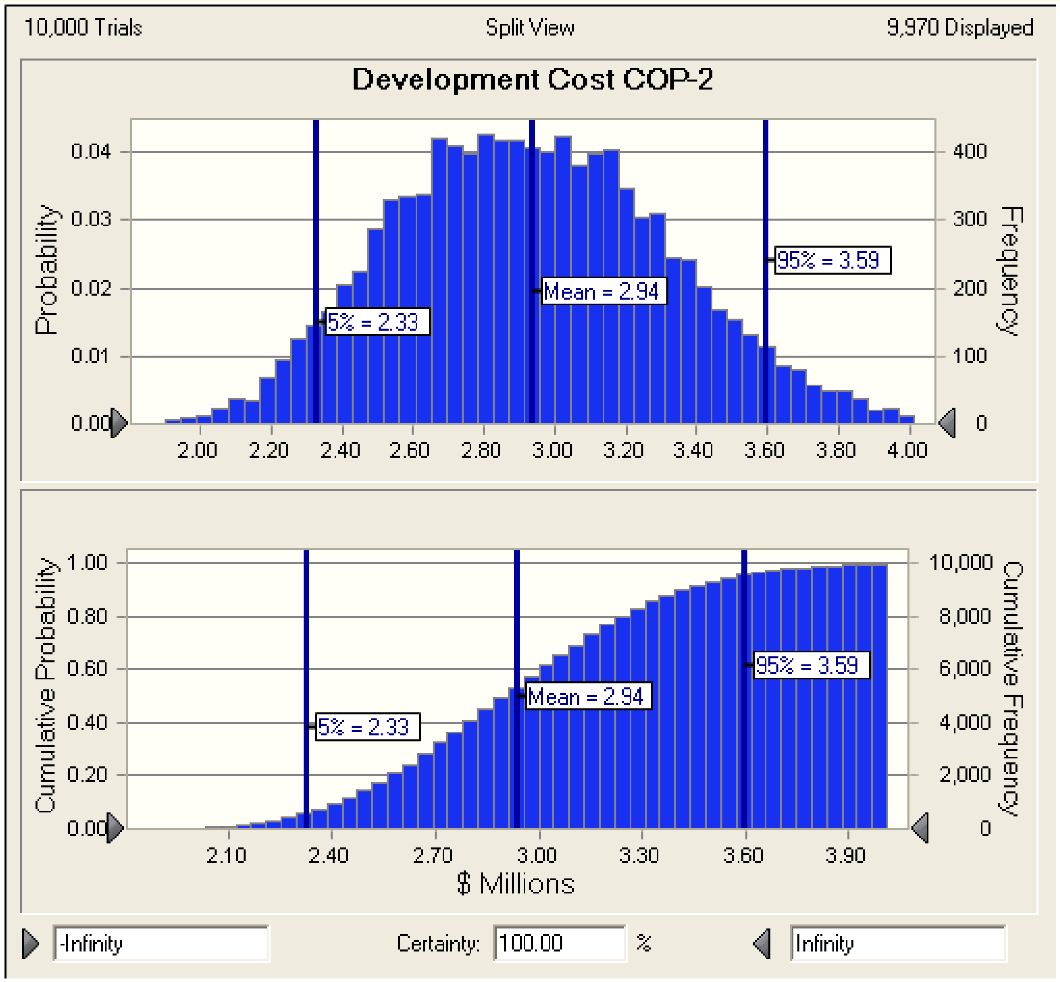
Development Cost for COP-2 Case



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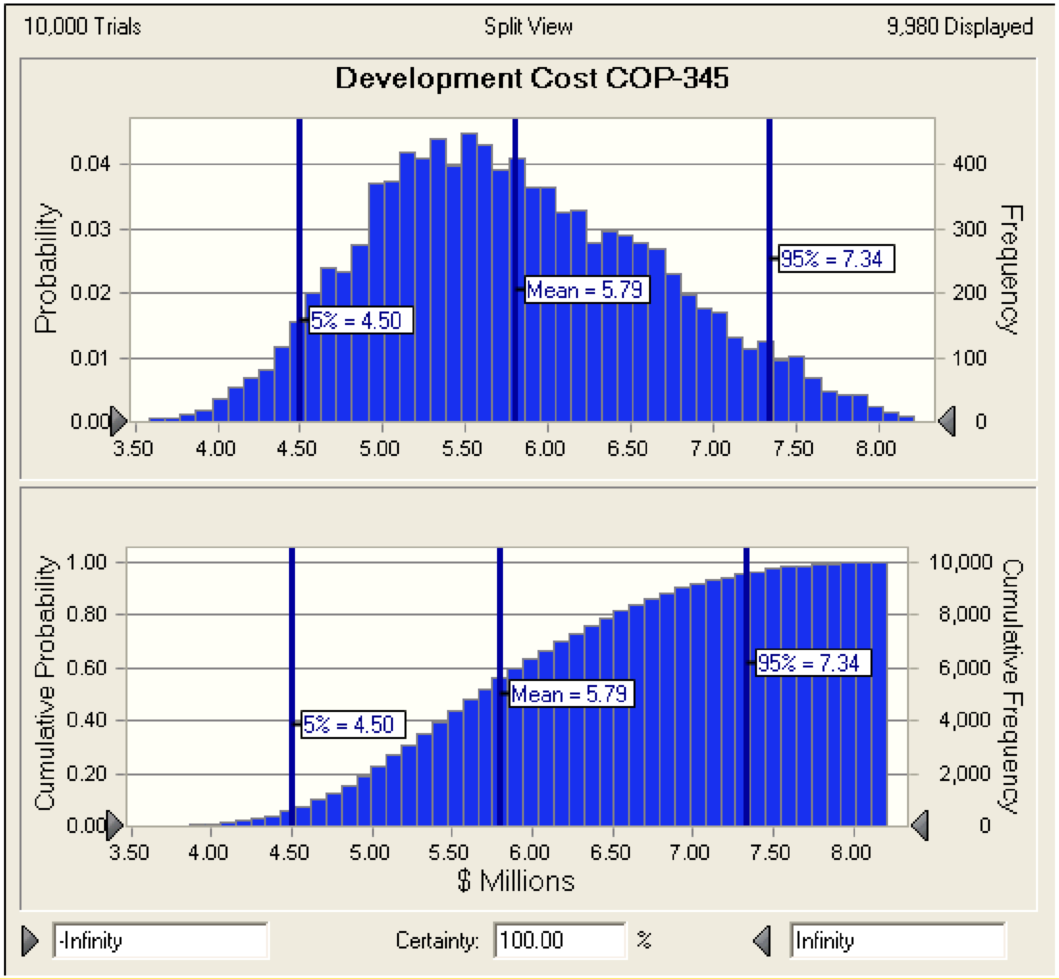
Development Cost for COP-3, 4 and 5 Cases



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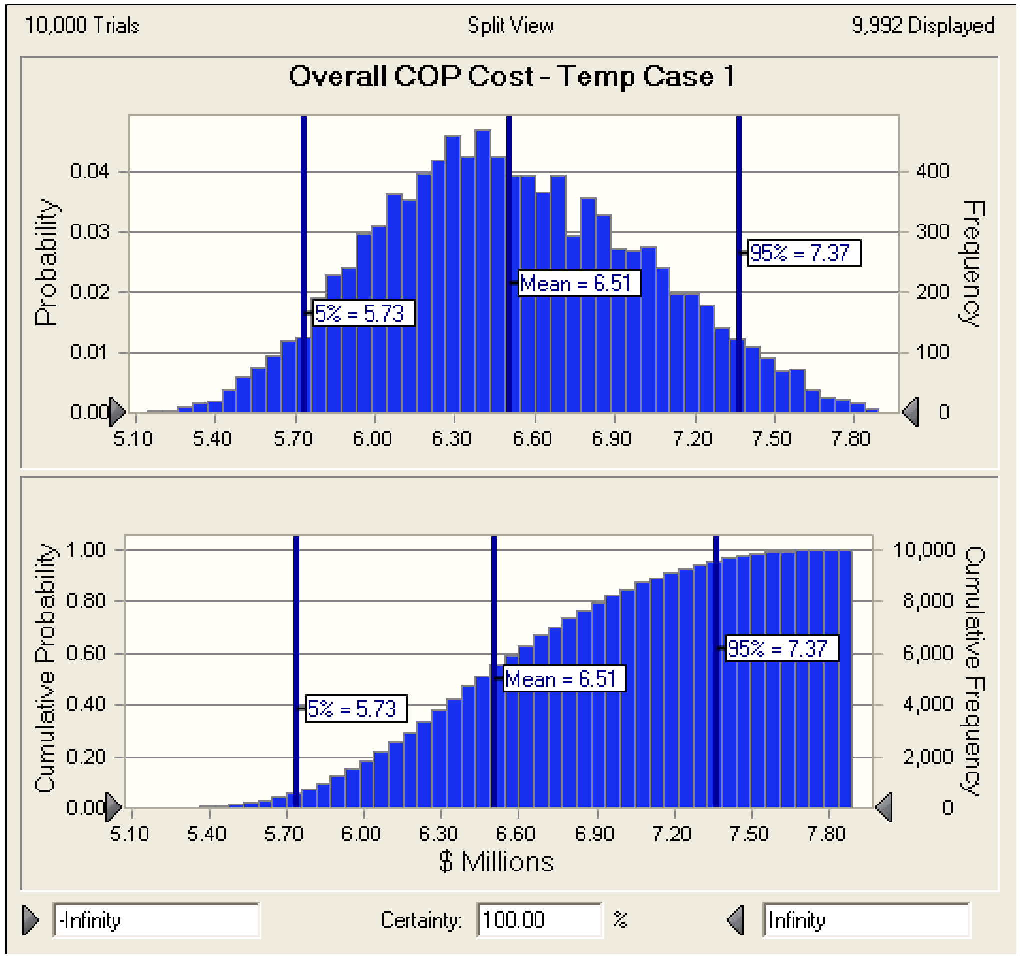
Overall COP-1 Cost
(Development and Capital)



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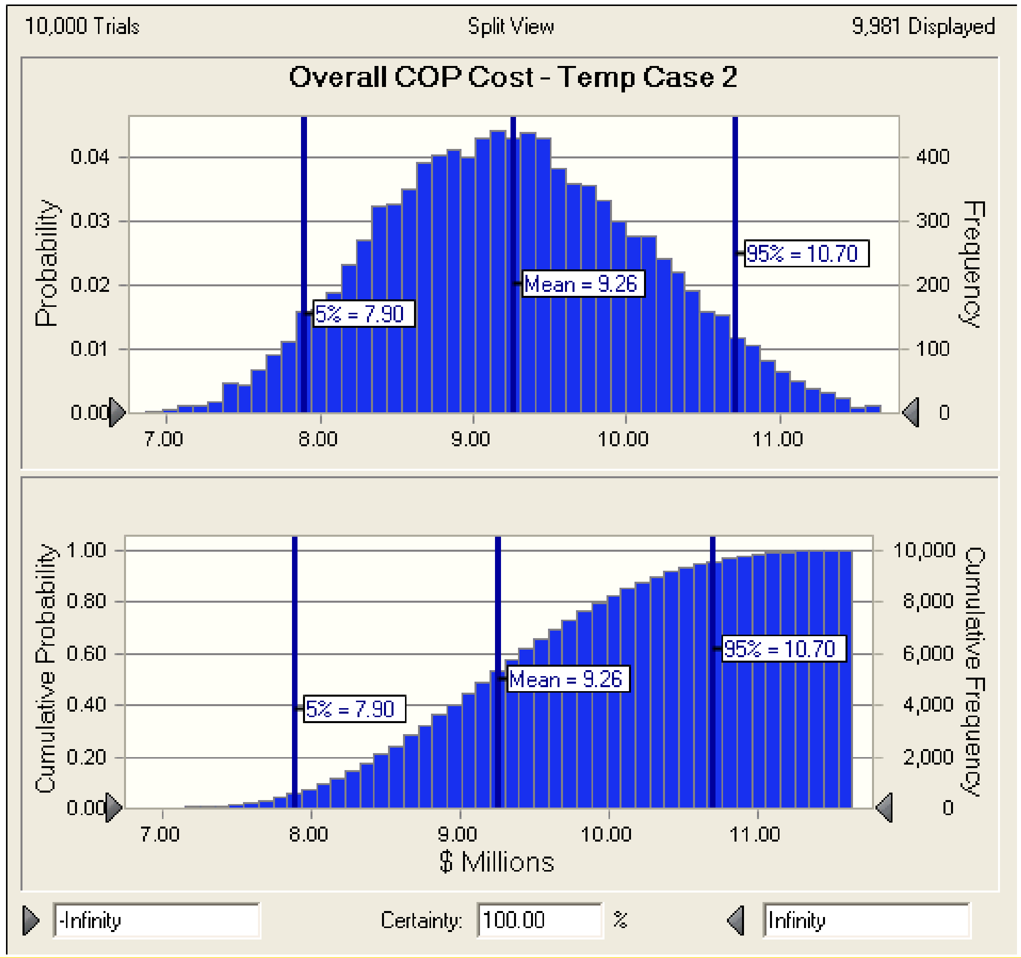
Overall COP-2 Cost
(Development and Capital)



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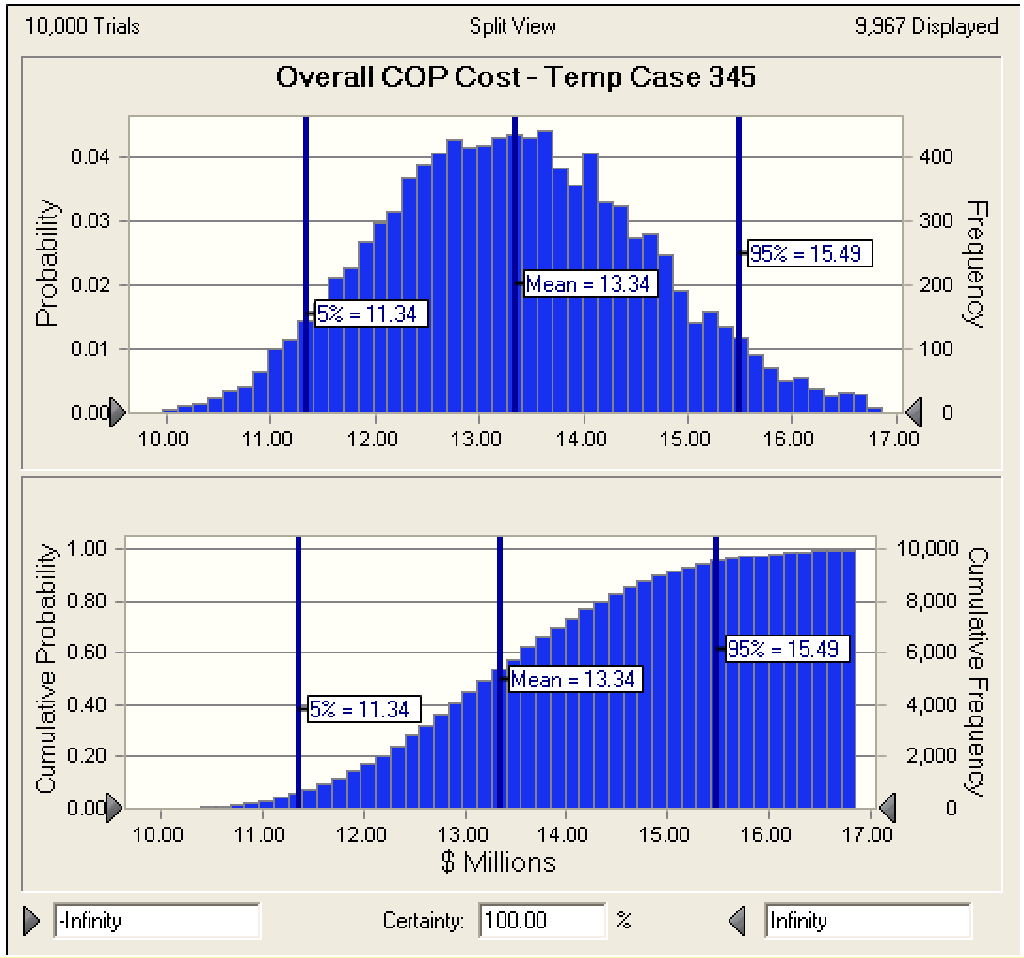
Overall COP-3, 4, and 5 Cost
(Development and Capital)



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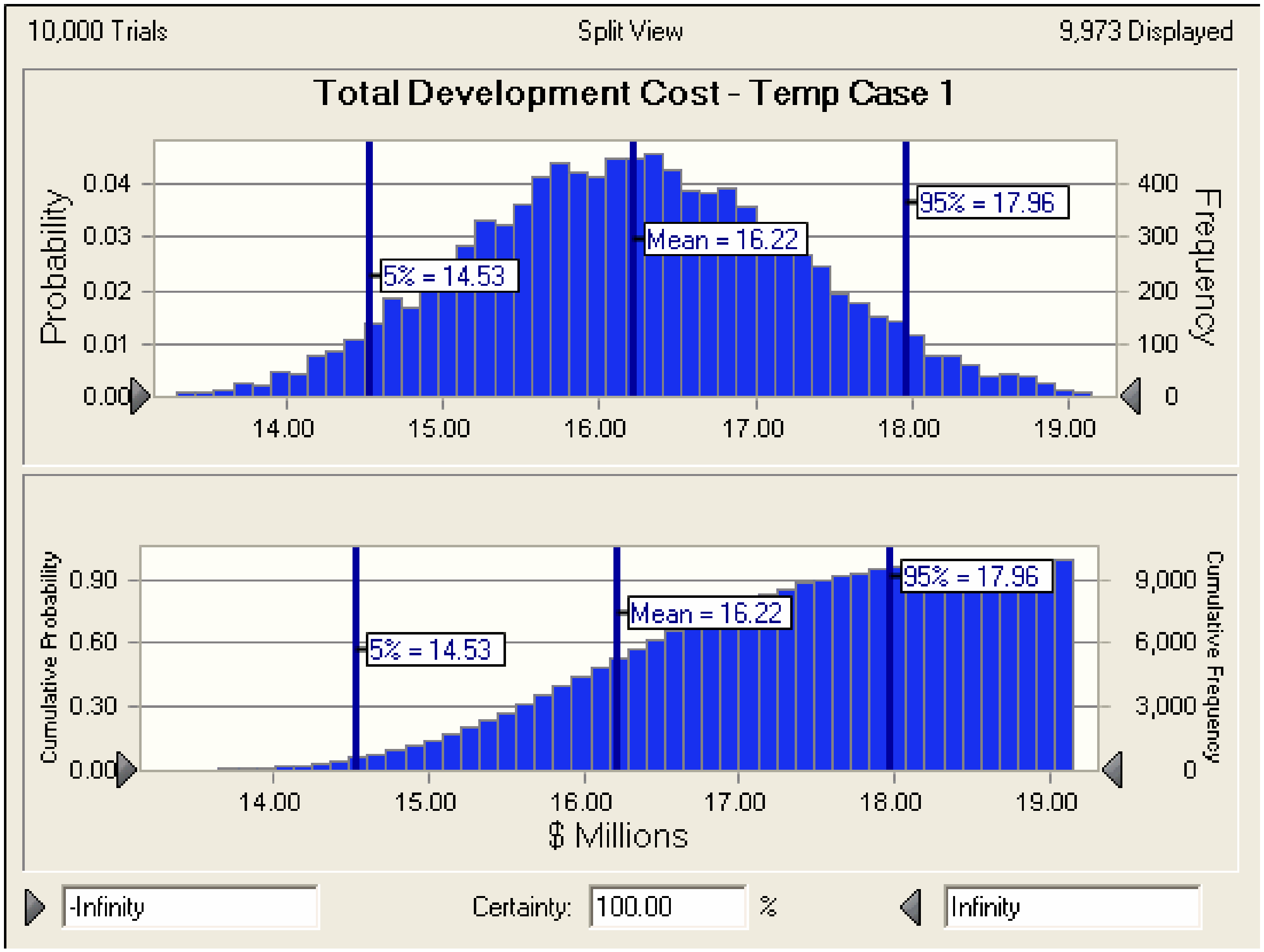
Sensitivity of Reactor Vessel and Core Outlet Pipe Cost to Power Level

Cost Contributor	Impact of 250MWt
Development	Increased costs due to reduced applicability of DPP-based investment
Capital	Total cost savings, unit cost increase (.6 scale factor)
Replacement	NA

Overall Development Cost for <760C Case
(IHX and Vessel, Reactor Vessel, and Core Outlet Pipe)



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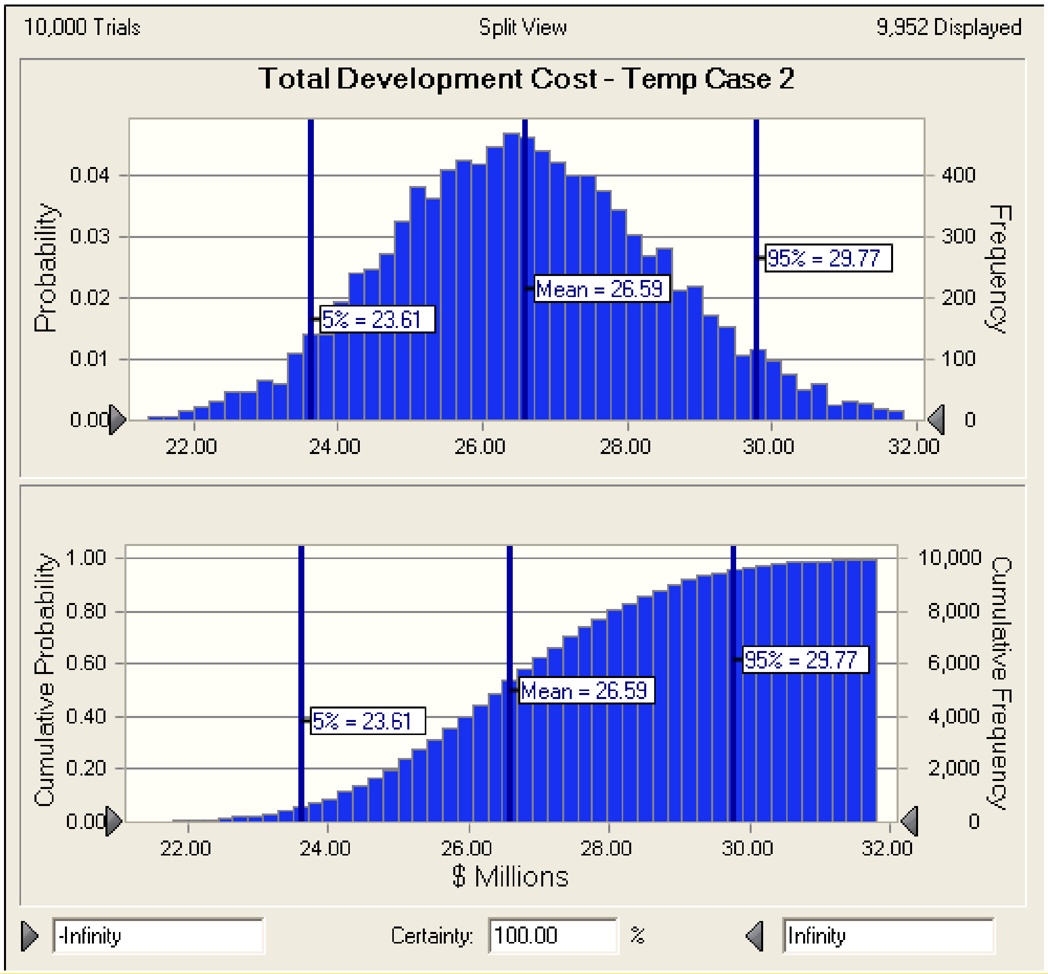
Overall Development Cost for 900C Case
(IHX and Vessel, Reactor Vessel, and Core Outlet Pipe)



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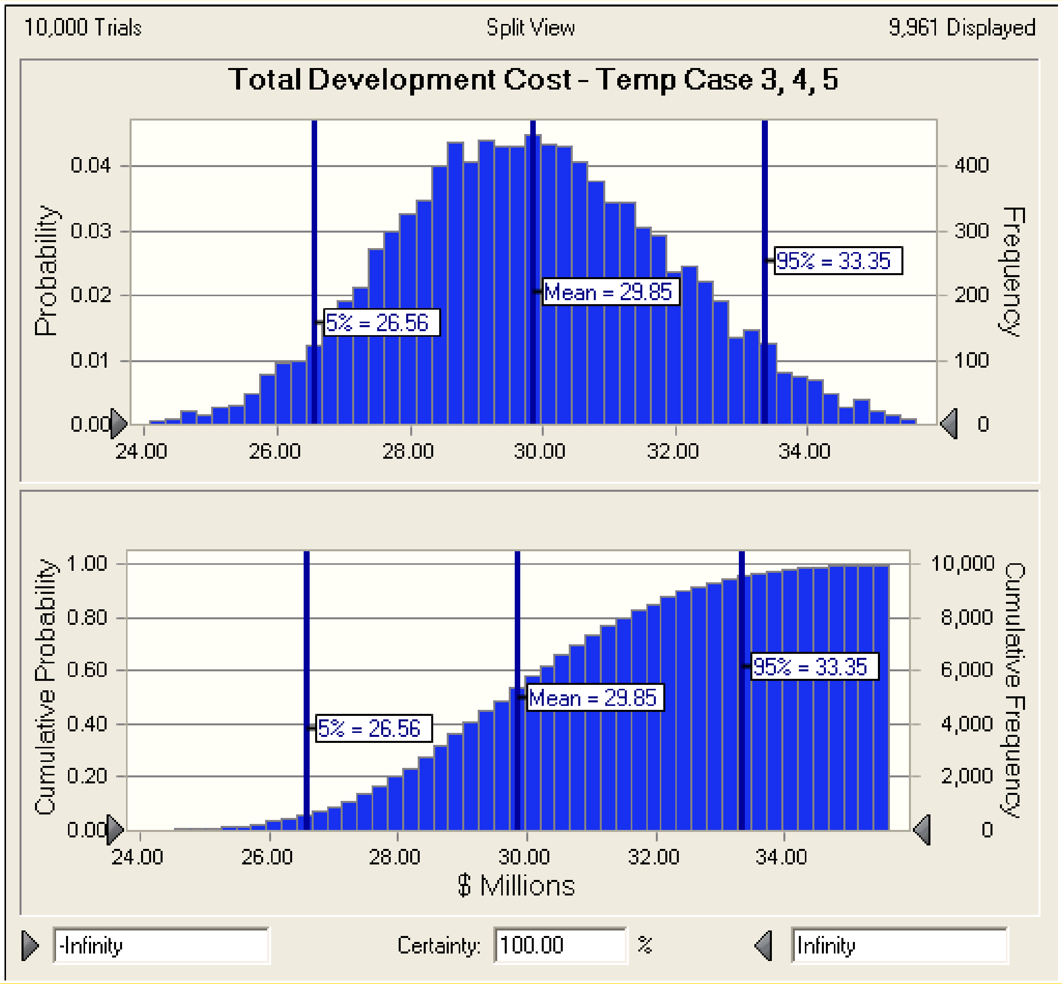
Overall Development Cost for 950C Cases
(IHX and Vessel, Reactor Vessel, and Core Outlet Pipe)



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Observations for Cost Risk Results

- Total IHX + Vessel mean costs for 760C→900C→950C ROT increase from \$46M → \$105M → \$143M
- Replacement IHX + Vessel mean costs for 760C→900C→950C ROT increase from \$0M → \$31M → \$69M
- Impact of reduced operating temperature limited to delaying replacement costs: \$69M → \$59M for 950C/850C ROT (3yr delay) and → \$54M for 950C/760C ROT (5yr delay)
- Total Core Outlet Pipe mean costs for 760C→900C→950C ROT increase from \$6.5M → \$9.3M → \$13.3M
- Total development mean costs for 760C→900C→950C ROT increase from \$16M → \$26.6M → \$29.8M

Summary and Conclusions of Cost Risk Assessment

IHX and Vessel:

- Major cost and risk component
- ROT temperature is major design parameter for the costs
- Lower initial operating temperature for 3 to 5 years has limited effect on cost

Reactor Vessel:

- High cost – relatively low risk
- Initial operating temperature has no effect on cost

Core Outlet Pipe:

- Relatively low cost – risk profile on par with IHX
- Initial operating temperature has no effect on cost

Closing Discussion as Needed