NGNP-CTF MTECH-TDRM-017 **December 2008**
Revision 0

NGNP and Hydrogen Production Conceptual Design Study

NGNP Technology Development Road Mapping Report

Section 17: Integrated Schedule and Cost Estimate

APPROVALS

Function	Printed Name and Signature	Date
Author	Name: Louisa Venter Company: M-Tech Industrial Venter	December 2, 2008
Author	Name: Werner Koekemoer Company: M-Tech Industrial	December 2, 2008
Reviewer	Name: Scott Penfield Company: Technology Insights Scott R. Penfield Jr	December 2, 2008
Reviewer	Name: Dan Allen Company: Technology Insights Daniel J. Allen	December 2, 2008
Reviewer	Name: Michael Correia Company: Pebble Bed Modular Reactor	December 2, 2008
Approval	Name: Jan van Ravenswaay Company: M-Tech Industrial	December 2, 2008

Westinghouse Electric Company LLC
Nuclear Power Plants
Post Office Box 355
Pittsburgh, PA 15230-0355

LIST OF CONTRIBUTORS

Name and Company	Date
Johan Markgraaff (M-Tech Industrial (Pty) Ltd.)	December 2008
Phil Rittenhouse (Technology Insights)	December 2008
George Hayner (Technology Insights)	December 2008
Scott Penfield (Technology Insights)	December 2008
Dan Allen (Technology Insights)	December 2008
Jan van Ravenswaay (M-Tech Industrial (Pty) Ltd.)	December 2008

BACKGROUND INTELLECTUAL PROPERTY CONTENT

Section	Title	Description
N/A		

REVISION HISTORY

RECORD OF CHANGES

Revision No.	Revision Made by	Description	Date
A	Louisa Venter Werner Koekemoer	Initial Review	November 18, 2008
B	Louisa Venter Werner Koekemoer	Formal Review	November 20, 2008
C	Louisa Venter Werner Koekemoer	Document for approval	December 3, 2008
0	Louisa Venter Werner Koekemoer	Document for release to WEC	December 4, 2008

DOCUMENT TRACEABILITY

Created to Support the Following Document(s)	Document Number	Revision
N/A		

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

Acronym	Definition
AI	Inner Annulus (active cooling piping)
AMS	Activity Measurement System
ANL	Argonne National Laboratory
AO	Outer Annulus (active cooling piping)
AOO	Anticipated Operational Occurrence
AS	Automation System
ASME	American Society of Mechanical Engineers
AVR	Arbeitsgemeinschaft Versuchs-Reaktor
BNL	Brookhaven National Laboratory
BOP	Balance of Plant
BUMS	Burn-up Measurement System
CB	Core Barrel
CCS	Core Conditioning System
CEA	Commissariat à l'Énergie Atomique
CFD	Computational Fluid Dynamics
CHE	Compact Heat Exchanger
CIP	Core Inlet Pipe
CO2	Carbon Dioxide
COC	Core Outlet Connection
COP	Core Outlet Pipe
COTS	Commercial Off The Shelf
CRADA	Co-operative Research and Development Agreement
CRD	Control Rod Drive
CSC	Core Structure Ceramics
CSIR	Council for Scientific Industrial Research
CTF	Component Test Facility
CTF	Component Test Facility
CUD	Core Unloading Devices
DAU	Data Acquisition Unit
DBA	Design Base Accident
DBE	Design Base Event
DDN	Design Data Need
DFC	Depressurized Forced Cooling
DLOFC	De-pressurized Loss of Forced Cooling
DOE	Department of Energy
DPP	Demonstration Power Plant
DRL	Design Readiness Level
DWS	Demineralized Water System
ELE	Elecrolyser System
EM	Evaluation Model
EMB	Electomagnetic Bearing
EOFY	End of Fiscal Year
EPCC	Equipment Protection Cooling Circuit

Acronym	Definition
EPCT	Equipment Protection Cooling Tower
F&OR	Functional and Operational Requirements
FHS	Fuel Handling System
FHSS	Fuel Handling and Storage System
FIMA	Fissions per Initial Metal Atoms
FMECA	Failure Modes, Effects and Criticality Analysis
FS	Fuel Spheres
FTA	Fault Tree Analysis
FUS	Feed and Utility System
H2	Hydrogen
H2SO4	Sulfuric Acid
HC	Helium Circulator
He	Helium
HETP	Height Equivalent of the theoretical Plate
HGD	Hot Gas Duct
HI	Hydro-Iodic
HLW	High Level Waste
HPB	Helium Pressure Boundary
HPC	High Pressure Compressor
HPS	Helium Purification System
HPS	Hydrogen Production System
HPT	High Pressure Turbine
HPU	Hydrogen Production Unit
HRS	Heat Removal System
HTF	Helium Test Facility
HTGR	High Temperature Gas-Cooled Reactor
HTR	High Temperature Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HVAC	Heating Ventilation and Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I2	Iodine
ID	Inner Diameter
IHX	Intermediate Heat Exchanger
ILS	Integrated Laboratory Scale
I-NERI	International Nuclear Energy Research Initiative
INL	Idaho National Laboratory
INL	Idaho National Laboratory
IPT	Intermediate Pressure Turbine
ISR	Inner Side Reflector
K-T	Kepner-Tregoe

Acronym	Definition
KTA	German nuclear technical committee
LANL	Los Alamos National Laboratory
LEU	Low Enriched Uranium
LOFC	Loss of Forced Cooling
LPT	Low Pressure Turbine
MES	Membrane-electrode assembly
MTR	Material Test Reactor
NAA	Neutron Activation Analysis
NCS	Nuclear Control System
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
NHS	Nuclear Heat Supply
NHSS	Nuclear Heat Supply System
NNR	National Nuclear Regulator
NRG	Nuclear Research and consultancy Group
NRV	Non-Return Valve
O2	Oxygen
OD	Outer Diameter
ORNL	Oak Ridge National Laboratory
PBMR	Pebble Bed Modular Reactor
PCC	Power Conversion System
PCDR	Pre-Conceptual Design Report
PCHE	Printed Circuit Heat Exchanger
PCHX	Process Coupling Heat Exchanger
PCS	Power Conversion System
PFHE	Plate Fin Heat Exchanger
PHTS	Primary Heat Transport System
PIE	Post-irradiation Examination
PLOFC	Pressurized Loss of Forced Cooling
POC	Power Conversion System
PPM	Parts per million
PPU	Product Purification Unit
PPWC	Primary Pressurized Water Cooler
QA	Quality Assurance
RAMI	Reliability, Availability, Maintainability and Inspectability
RC	Reactor Cavity
RCCS	Reactor Cavity Cooling System
RCS	Reactivity Control System
RCSS	Reactivity Control and Shutdown System
RDM	Rod Drive Mechanism
RIM	Reliability and Integrity Management
RIT	Reactor Inlet Temperature
RM	Road Map
ROT	Reactor Outlet Temperature
RPS	Reactor Protection System

Acronym	Definition
RPT	Report
RPV	Reactor Pressure Vessel
RS	Reactor System
RSS	Reserve Shutdown System
RUS	Reactor Unit System
SAD	Acid Decomposition System
SAR	Safety Analysis Report
SAS	Small Absorber Spheres
SG	Steam Generator
SHTS	Secondary Heat Transport System
S-I	Sulfur Iodine
SiC	Silicon Carbide
SNL	Sandia National Laboratory
SO2	Sulfur Dioxide
SOE	Sulfuric Oxide Electrolyzers
SOEC	Sulfuric Oxide Electrolyzers Cells
SR	Side Reflector
SSC	System Structure Component
SSCs	Systems, Structures and Components
SSE	Safe Shutdown Earthquake
SUD	Software Under Development
TBC	To Be Confirmed
TBD	To Be Determined
TDL	Technology Development Loop (As incorporated in Concept 1)
TDRM	Technology Development Road Map
TER	Test Execution Report
THTR	Thorium High Temperature Reactor
TRISO	Triple Coated Isotropic
TRL	Technology Readiness Level
TRM	Technology Road Map
UCO	Uranium Oxycarbide
UO2	Uranium Dioxide
USA.	United States of America
V&V	Verification and Validation
V&Ved	Verified and Validated
VLE	Vapor-Liquid Equilibrium
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company

SUMMARY AND CONCLUSIONS

In this section, the integrated Technology Development Road Maps (TDRMs) schedule is provided for the WEC NGNP Critical SSCs, together with cost estimates for certain critical Systems, Structures and Components (SSC's).

The cost and schedule of the NGNP evolves continuously as the project progresses due to high uncertainties associated with technology advancements, evolving test plans and schedules, timely availability of resources, etc. Therefore this document presents detailed schedules which include the following:

- Integrated Test Schedule with original TDRM Schedule – Inclusive of the overall NGNP schedule, the original TDRM schedules for critical SSC's as well as the CTF high level schedule.
- Modified TDRM Schedule - The main purpose of the modified TDRM schedule is to move back non-critical tasks in order to relieve pressure on the front end of the schedule. This was done without jeopardizing CTF and NGNP start up dates. Also shown in this schedule is the total estimated cost per specification with possible testing facilities identified.
- Modified CTF Schedule – Schedules of CTF specific tasks were outlined for the 950℃ Reactor Outlet Temperature (ROT) case (inclusive of Small Scale Development Tests (SSDT), Technology Development Loops (TDL), Component Qualification Loops (CQL) and Circulator Test Loop (CTL)) as well as for the 750℃ ROT case. Results and conclusions for the above mentioned scenarios are given in Section 17.1.5.

Cost estimates are provided for certain critical SSCs (notably IHX A (metallic as well as ceramic), IHX B and HTS Piping). Estimates have only been provided only up to a TRL rating of 5. Estimates for higher TRL advancements can only be provided when additional design information (preliminary or final) pertaining to the NGNP and its components becomes available. For some of the SSCs, more design information is required in order to develop reliable cost estimates (notably PHTS Circulator, SHTS Mixing Chamber and Steam Generator). Trade studies (or various trade studies) need to be done to verify and determine the specific combinations of sub-components that will be used in the aforementioned SSCs. There is enough time in the modified schedule to perform the trade studies before the advancement of the TRLs and before possible testing in the CTF will be performed. Costing input relating to the HPS, as noted in the Hydrogen Plant Alternatives Study (HPAS), has also been incorporated into this document.

The bases for all estimates given are noted in Appendix A of this document.

17.1 INTEGRATED TEST SCHEDULE

17.1.1 Introduction

In this section, the integrated schedule for the Technology Development Road Maps (TDRMs) addressing the WEC NGNP Critical SSCs is provided. This schedule, Figure 17-1, is bounded by the CTF schedule [17-2] showing a CTF operational date of 2014 and the WEC Next Generation Nuclear Plant (NGNP) Demonstration Plant schedule [17-1] showing a NGNP start up date of 2021.

The schedule was prepared in Microsoft Project to get an overall impression of the anticipated schedules for the Test Specifications provided in the Technology Development Road Maps.

All of the Test Specifications and their original dates, as stated in Sections 3 to 16, are indicated in the TDRM Schedule Section of the Integrated Test Schedule. This schedule was then modified to accommodate the Small Scale Development Tests (SSDT), an assumed CTF Initial Operational Date of March 2014 (when the first TDL can be assumed to be finished) and the NGNP Initial Operational Date of FY 2021. The resulting modified schedule is given in Figure 17-2.

The CTF schedule with the above mentioned modified Test Specification Schedule incorporated can be seen in Figure 17-3.

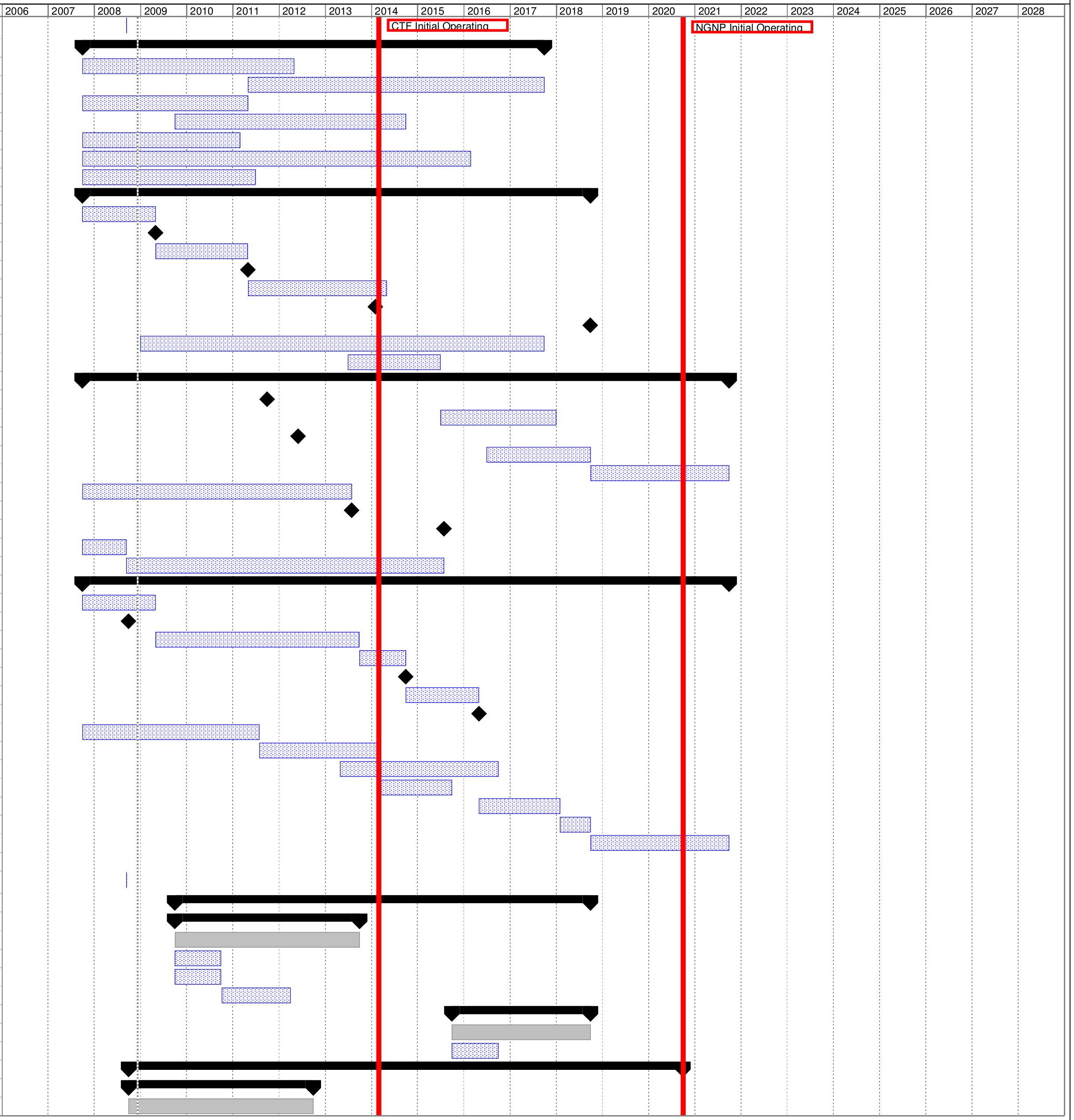
The following Critical SSCs are included in the TDRM schedule:

- PHTS Circulator (including the SHTS Circulator and Valve)
- IHX A – Metallic and Ceramic
- IHX B
- HTS Piping
- SHTS Flow Mixing Chamber
- Hydrogen Production System
- Power Conversion system Steam Generator
- Fuel Elements
- Core Structure Ceramics
- Reserve Shutdown System
- Reactivity Control System
- Core Conditioning System
- Reactor Cavity Cooling System

17.1.2 Integrated Test Schedule with Original TDRM Schedule

The integrated Test Schedule given in Figure 17-1 includes the NGNP Schedule, the original TDRM Schedules, as in Section 3 – Section 16 in the previous report sections, and the CTF High Level Schedule.

ID	Notes	Task Name
1		**A: NGNP Schedule**
2		**Technology Development**
3		Pre-Production Fuel Irradiation Program
4		Production Fuel Irradiation
5		Initial Graphite Irradiation
6		Extended Graphite Irradiation
7		Metallic IHX Development
8		Hydrogen Production Facility
9		Power Conversion Facility
10		**Nuclear Heat Supply Facility, Power Conversion Facility & Balance of Plant**
11		Conceptual Design
12		Completion of NHSF, PCF & BOP Conceptual Design
13		Preliminary Design
14		Completion of NHSF, PCF & BOP Preliminary Design
15		Final Design
16		Approve Start of Construction
17		Completion of NHSF, PCF & BOP Final Design and after receipt of NRD Early Site Permit Decision
18		Acquisition Strategies/ Long lead Procurement
19		Sitework/BOP
20		**Licensing**
21		ESP/LWA Application Submitted
22		Construction (Nuclear)
23		COL Application Submitted
24		Startup & Testing
25		Commercial Operation & Inspection
26		ESP Preparation
27		NRC ESP Review
28		COL Permit Issued
29		COL Application
30		NRC COL Review
31		**Hydrogen Production Facility**
32		Conceptual Design
33		Completion of HPF Conceptual Design
34		Design Support During Tech Development
35		Preliminary Design
36		Completion of HPF "Front End" design package
37		Final Design
38		Successful resolution of DOE comments on HPF "Front End", design package.
39		Component Development
40		Decomposer Pilot Testing
41		Acquisition Strategies/Long Lead Procurement
42		Electrolyzer Pilot Testing
43		Construction
44		Startup & Testing
45		Commercial Operation & Inspection
46		
47		**B: TDRM Road Maps (Original Schedule)**
48		**Circulator**
49		**TRL 6 - TRL 7**
50		Original Schedule in TDRM
51	WEC-TS-CIRC-001	EMBs, catcher bearings Test Specification
52	WEC-TS-CIRC-002	Helium Rotating seals Test Specification
53	WEC-TS-CIRC-003	Partial or Full scale circulator Model Test Specification
54		**TRL 7 - TRL 8**
55		Original Schedule in TDRM
56	WEC-TS-CIRC-004	Prototype circulator Test Specification
57		**IHX A (Metallic)**
58		**TRL 2 - TRL 3**
59		Original Schedule in TDRM

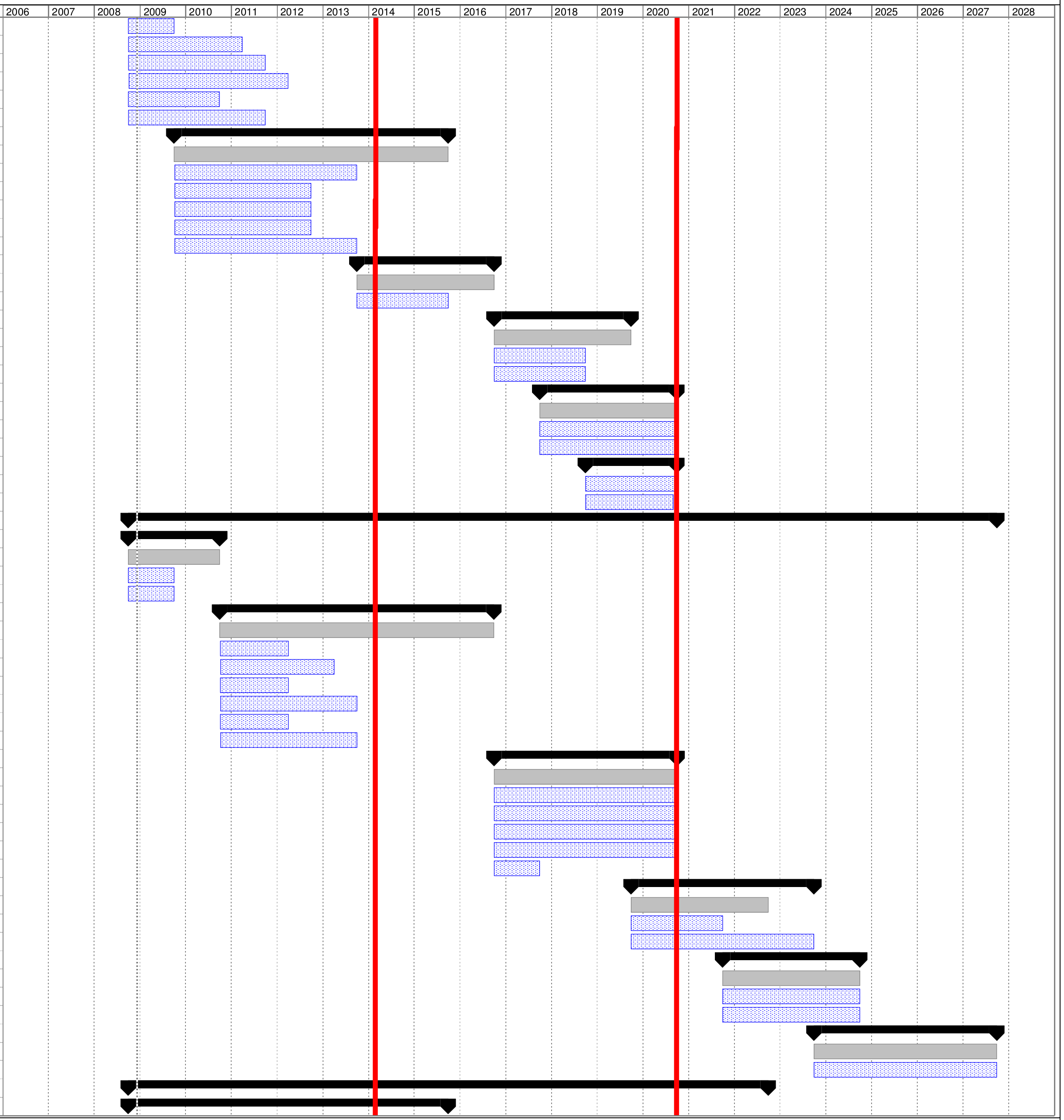


Project: Project1
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-1: Integrated Schedule

ID	Notes	Task Name
60	WEC-TS-IHXA-001	Alloy 617 Material Specification and procurement
61	WEC-TS-IHXA-002	Alloy 617 Joining Technology and Resultant Properties
62	WEC-TS-IHXA-003	Thermal/physical and mechanical properties of Alloy 617
63	WEC-TS-IHXA-004	Effects of thermal Aging and environment on Alloy 617
64	WEC-TS-IHXA-005	Effects of Grain size and selection thickness on Alloy 617 properties
65	WEC-TS-IHXA-006	Corrosion Allowances for Alloy 617
66		**TRL 3 - TRL 4**
67		Original Schedule in TDRM
68	WEC-TS-IHXA-007	ASME section III Code Case for Alloy 617
69	WEC-TS-IHXA-008	Thermal/Fluid Modeling Methods for Metallic IHX A
70	WEC-TS-IHXA-009	Methods for stress/strain modeling of metallic IHX A
71	WEC-TS-IHXA-010	Criteria for structural integrity of IHX A
72	WEC-TS-IHXA-011	Performance Modeling Methods for IHX A
73		**TRL 4 - TRL 5**
74		Original Schedule in TDRM
75	WEC-TS-IHXA-12	Specification of testing of unit cell of compact Heat Exchangers
76		**TRL 5 - TRL 6**
77		Original Schedule in TDRM
78	WEC-TS-IHXA-013	Specification of testing of compact heat exchanger module (1.2MW)
79	WEC-TS-IHXA-014	ASME Section III Code Case for Compact Heat Exchanger Designs
80		**TRL 6 - TRL 7**
81		Original Schedule in TDRM
82	WEC-TS-IHXA-015	Shell Side Flow Distribution and Bypass Leakage Testing
83	WEC-TS-IHXA-016	Multi-module Heat Transfer Testing
84		**TRL 7 - TRL 8**
85		Original Schedule in TDRM
86	WEC-TS-IHXA-017	Specification of testing of a full scale compact Heat Exchangers
87		**IHX A (Ceramic)**
88		**TRL 2 - TRL 3**
89		Original Schedule in TDRM
90	WEC-TS-IHXA-018	Trade study on Candidate Ceramic Material for IHX A
91	WEC-TS-IHXA-019	Trade study on Candidate Ceramic Designs for IHX A
92		**TRL 3 - TRL 4**
93		Original Schedule in TDRM
94	WEC-TS-IHXA-020	Ceramic IHX Detailed Design Data Needs (DDNs)
95	WEC-TS-IHXA-021	Ceramic Materials Specifications and Procurement
96	WEC-TS-IHXA-022	Thermal Physical Properties of Ceramics
97	WEC-TS-IHXA-023	Mechanical Properties of Ceramics
98	WEC-TS-IHXA-024	Compatibility of Ceramic Materials to NGNP He environment
99	WEC-TS-IHXA-025	Manufacturing Technologies for Ceramic Heat Exchangers
100		**TRL 4 - TRL 5**
101		Original Schedule in TDRM
102	WEC-TS-IHXA-026	Ceramic Materials Codes and Standards
103	WEC-TS-IHXA-027	Methods for Thermal/Fluid and Stress/Strain Modeling
104	WEC-TS-IHXA-028	Structural Integrity Criteria for Ceramic Heat Exchangers
105	WEC-TS-IHXA-029	Performance Modeling of Ceramic Heat Exchangers
106	WEC-TS-IHXA-030	Testing of unit cell of Compact Heat Exchanger
107		**TRL 5 - TRL 6**
108		Original Schedule in TDRM
109	WEC-TS-IHXA-031	Specifications of testing of unit cells of compact Heat Exchanger Module (1.2MW)
110	WEC-TS-IHXA-032	ASME Code Case for Ceramic Compact Heat Exchanger Design
111		**TRL 6 - TRL 7**
112		Original Schedule in TDRM
113	WEC-TS-IHXA-033	Shell-side Flow Distribution and Bypass Leakage Testing
114	WEC-TS-IHXA-034	Multi-mode Heat Transfer Testing
115		**TRL 7 - TRL 8**
116		Original Schedule in TDRM
117	WEC-TS-IHXA-035	Specifications of testing of a full scale compact Heat Exchanger
118		**IHX B**
119		**TRL 3 - TRL 4: Alloy 800 H Material Specification and Procurement**

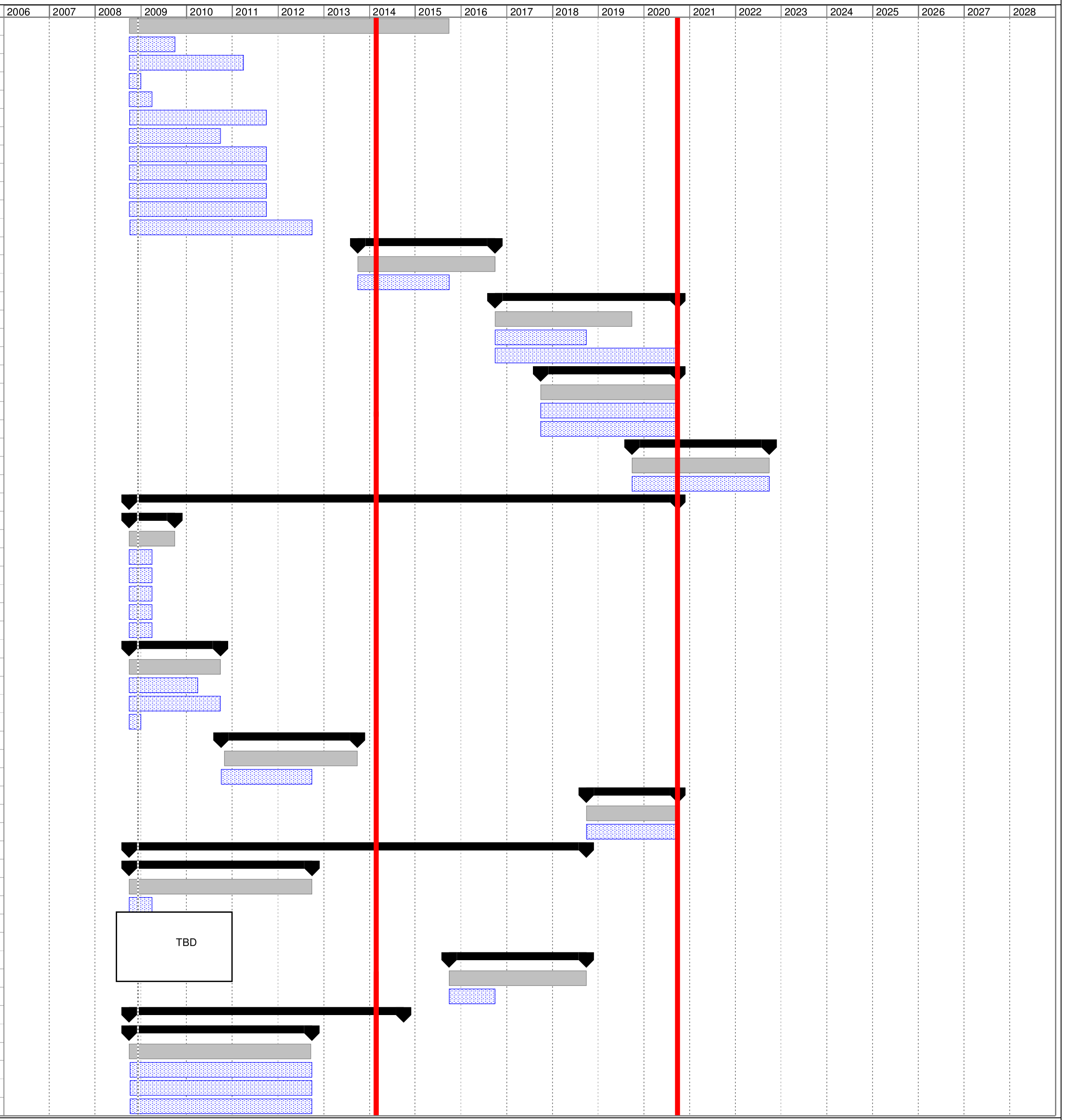


Project: Project1
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-1: Integrated Schedule

ID	Notes	Task Name
120		Original Schedule in TDRM
121	WEC-TS-IHXB-001	Alloy 800H Material Specification and Procurement
122	WEC-TS-IHXB-002	Database for Brazed and Diffusion Bonded Alloy 800H
123	WEC-TS-IHXB-003	Alloy 800H High Temperature Material Properties
124	WEC-TS-IHXB-004	Effects of Thermal Aging and Environment on Alloy 800H Properties
125	WEC-TS-IHXB-005	Effects of Environmental Exposure on Alloy 800H Braze and Diffusion Bonded Joints
126	WEC-TS-IHXB-006	Effects of Grain Size and Section Thickness on Alloy 800H Properties
127	WEC-TS-IHXB-007	Corrosion Allowances for Alloy 800H
128	WEC-TS-IHXB-008	Thermal/Fluid Modeling Methods for IHX B
129	WEC-TS-IHXB-009	Methods for Stress/Strain Modling of IHX B
130	WEC-TS-IHXB-010	Criteria for Structural Intergrity of IHX B
131	WEC-TS-IHXB-011	Performance Modeling Methods for IHX B
132		**TRL 4 - TRL 5: Database for Brazed and Diffusion Bonded Alloy 800H**
133		Original Schedule in TDRM
134	WEC-TS-IHXB-012	Testing of Unit Cell of Compact Heat Exchanger
135		**TRL 5 - TRL 6**
136		Original Schedule in TDRM
137	WEC-TS-IHXB-013	Testing of integrated compact Heat Exchanger
138	WEC-TS-IHXB-014	ASME III Code Case for Meatllic Compact Heat Exchanger Design
139		**TRL 6 - TRL 7**
140		Original Schedule in TDRM
141	WEC-TS-IHXB-015	Shell-side Flow Distribution and Bypass Leakage Testing
142	WEC-TS-IHXB-016	Multi-mode Heat Transfer Testing
143		**TRL 7 - TRL 8**
144		Original Schedule in TDRM
145	WEC-TS-IHXB-017	Testing of full size Compact Heat Exchanger
146		**Piping**
147		**TRL 4 - TRL5**
148		Original Schedule in TDRM
149	WEC-TS-PIP-001	PHTS high-temperature [760°C and 950°C] piping cooling, liner and insulation options trade study
150	WEC-TS-PIP-002	PHTS low-temperature [350°C] piping liner and insulation options trade study
151	WEC-TS-PIP-003	SHTS high-temperature[840°C and 900°C] piping liner and insulation study
152	WEC-TS-PIP-004	SHTS medium-temperature [659°C and 700°C] piping liner and insulation trade study
153	WEC-TS-PIP-005	SHTS low-temperature [<300°C] piping liner and insulation trade study
154		**TRL 5 - TRL 6**
155		Original Schedule in TDRM
156	WEC-TS-PIP-006	Effects of He infiltration on thermal conductivity of insulation material
157	WEC-TS-PIP-007	The effect of fluid impurities on insulation properties
158	WEC-TS-PIP-008	Re-evaluation of needed maturation tasks based on Trade studies
159		**TRL 6 - TRL 7**
160		Original Schedule in TDRM
161	WEC-TS-PIP-009	Performance and environmental testing of prototypical high-temperature and low-temperature piping/insul
162		**TRL 7 - TRL 8**
163		Original Schedule in TDRM
164	WEC-TS-PIP-010	Testing of full size PHTS piping in NGNP
165		**Mixing Chamber**
166		**TRL 6 - TRL 7**
167		Original Schedule in TDRM
168	WEC-TS-MC-001	Enhanced Mixing Devices Test Specification
169	WEC-TS-MC-002	Vibration Damping Devices Test Specification
170	WEC-TS-MC-003	Partial or Full Scale Flow Mixing Chamber Model Test Specification
171		**TRL 7 - TRL 8**
172		Original Schedule in TDRM
173	WEC-TS-MC-004	Prototype Flow Mixing Chamber Test Specification
174		**Steam Generator**
175		**TRL 6 - TRL 7**
176		Original Schedule in TDRM
177	WEC-TS-SG-001	Perform a down selection trade study to determine the preferred conceptual arrangement of the SG
178	WEC-TS-SG-002	Define requirements and design details for the SG in the PCS system context
179	WEC-TS-SG-003	Perform configuration development tests to substantiate the design

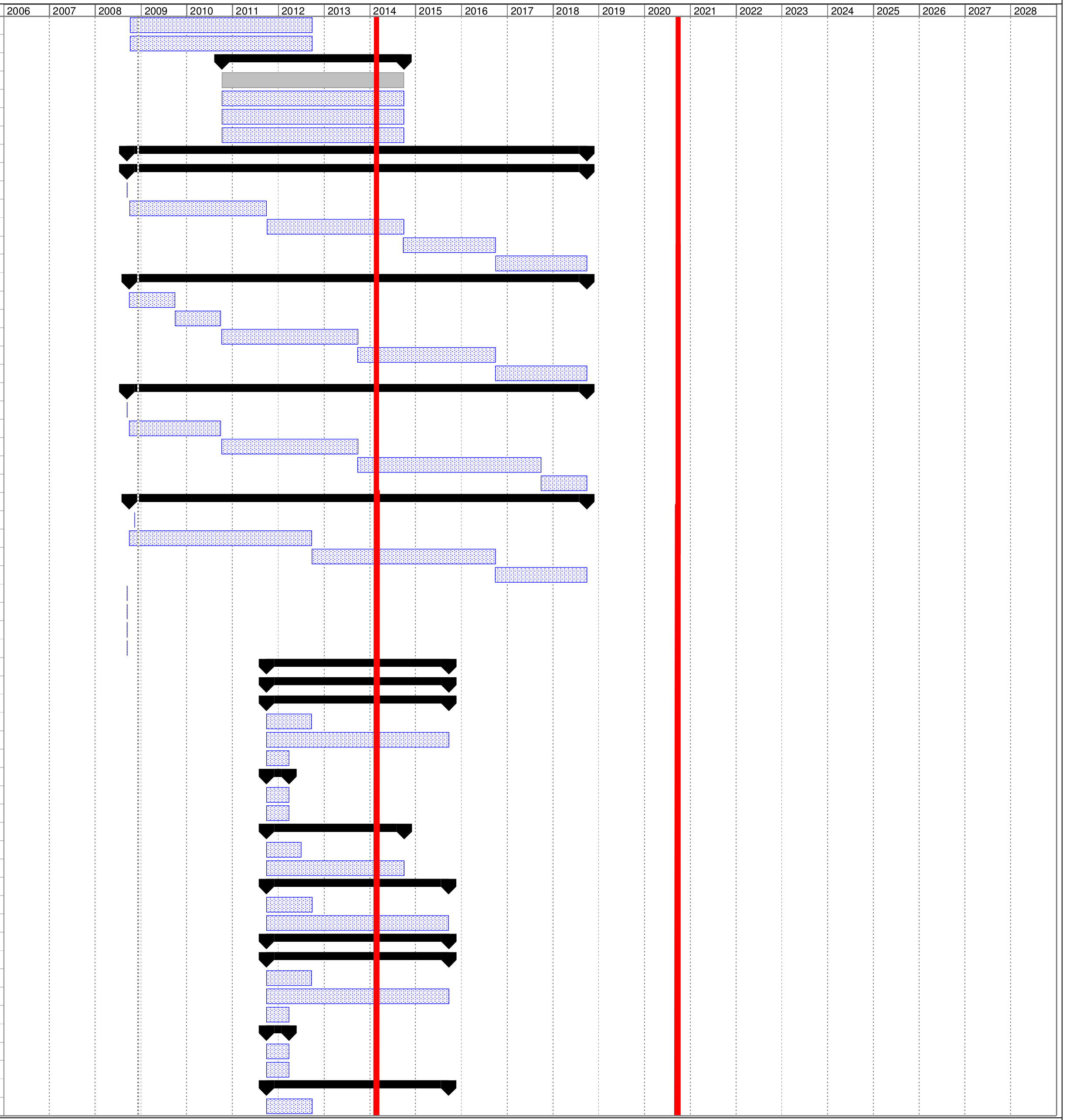


Project: Project1
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▭	Deadline	⇩
Split	⋯⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-1: Integrated Schedule

ID	Notes	Task Name
180	WEC-TS-SG-004	Design and supply a scale prototype for the testing in the CTF
181	WEC-TS-SG-005	Performance testing in CTF
182		**TRL 7 - TRL 8**
183		Original Schedule in TDRM
184	WEC-TS-SG-006	Complete final design of the prototype SG for the NGNP
185	WEC-TS-SG-007	Fabricate and deliver to NGNP to the Site
186	WEC-TS-SG-008	Install and operate
187		**Hydrogen Production System**
188		**Sulfuric Acid Decomposition**
189		Up to completion of S-I ILS
190		Complete analysis, supporting data, materials testing and catalyst choice & tests
191		Pilot test of Decomposer
192		Engineering test of Decomposer
193		Prototype test of Decomposer
194		**Sulfur Dioxide Electrolysis Technology Area**
195		Up to completion of cell demonstration at temperature and pressure
196		HyS ILS and optimized cell demonstration
197		Scale-up cells to 400 cm2 , and Electrolyzer Pilot Test – module
198		Scale-up cells to 1000 cm2 and Engineering test of Electrolyzer
199		Scale-up cells to 1 m2 and Prototype test of Electrolyzer
200		**Bunsen Reaction and HI Decomposistion Technology Area**
201		Up to completion of S-I ILS –Bunsen: TRL
202		HI Section Experimental Test – HI
203		Bunsen and HI Systems Pilot Test
204		Bunsen and HI Systems Engineering Test
205		Prototype HPS Test: Sulfuric Acid, Bunsen & HI Sections
206		**High Temperature Steam Electrolysis Technology Area**
207		Up to completion of ILS
208		Full-scale stack demonstration
209		Pilot Test
210		Prototype HPS Test
211		Sulfuric Acid Decomposition
212		Sulfur Dioxide Electorlysis
213		Bunsen Reaction and HI decomposition
214		High Temperature Steam Electrolysis
215		**Fuel Elements**
216		**TRL 6 - TRL 7**
217	**WEC-TS-FUEL-001**	**Production Fuel Irradiation Tests for Normal Operational Conditions**
218		Irradiation planning & Preparation
219		Irradiation of Pre-Production Fuel
220		PIE and Analysis
221	**WEC-TS-FUEL-002**	**Production Fuel Heat-up Tests at 1600°C and 1800°C.**
222		Physical Heating Test
223		PIE and analysis of Heated Spheres
224	**WEC-TS-FUEL-003**	**Fuel Matrix Graphite Irradiation tests and PIE**
225		Irradiation Planning & Preparation
226		Irradiation and PIE
227	**WEC-TS-FUEL-004**	**Machined Graphite Irradiation tests and PIE**
228		Irradiation Planning & Preparation
229		Irradiation and PIE
230		**TRL 7 - TRL 8**
231	**WEC-TS-FUEL-002**	**Production Fuel Irradiation Tests for NGNP Normal Operational Conditions**
232		Irradiation planning & Preparation
233		Irradiation of Pre-Production Fuel
234		PIE and Analysis
235	**WEC-TS-FUEL-003**	**Production Fuel Heat-up Tests at 1700°C and 1900°C.**
236		Physical Heating Test
237		PIE and analysis of Heated Spheres
238	**WEC-TS-FUEL-004**	**Fuel Matrix Graphite Irradiation tests and PIE**
239		Irradiation Planning & Preparation

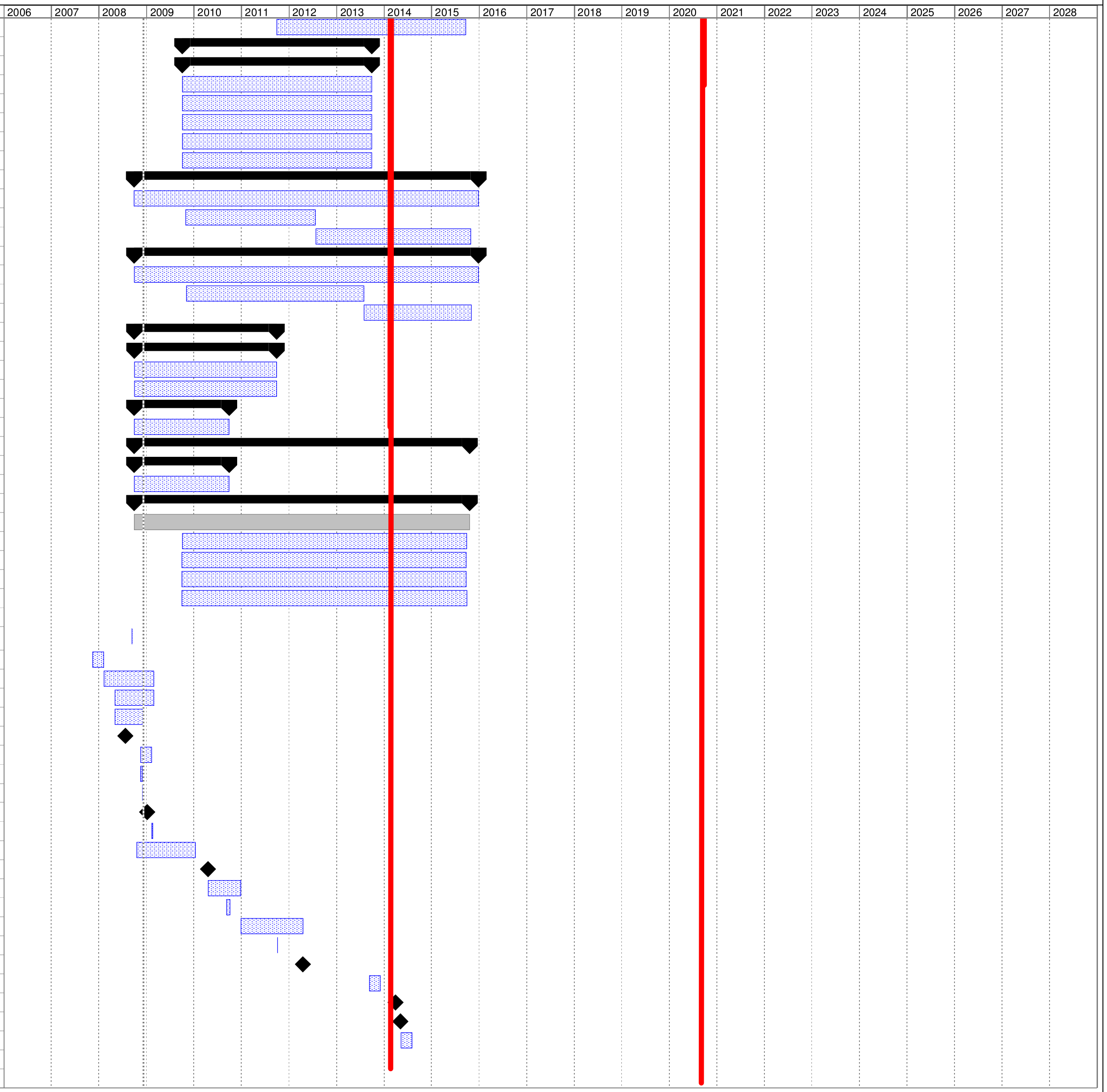


Project: Project1
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▨	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-1: Integrated Schedule

ID	Notes	Task Name
240		Irradiation and PIE
241		**Core Structure Ceramics**
242		**TRL 6 - TRL 7**
243	WEC-TS-CSC-001	PBMR Relevant
244	WEC-TS-CSC-002	Extended Properties of Irradiated Graphite at Low Temperatures
245	WEC-TS-CSC-003	Extended Properties of Irradiated Graphite at High Temperatures
246	WEC-TS-CSC-004	Characterize Race Track Strap and Tie Rod Material
247	WEC-TS-CSC-005	Insulation Material (Unirradiated Data Needed)
248		**Reserve Shutdown System**
249		Anticipated Schedule
250		TRL 6 - TRL 7
251		TRL 7 - TRL 8
252		**Reactivity Control System**
253		Anticipated Schedule
254		TRL 6 - TRL 7
255		TRL 7 - TRL 8
256		**Core Conditioning System**
257		**TRL 6 - TRL 7**
258	WEC-TS-CCS-001	Valves development Test Specification
259	WEC-TS-CCS-002	Blower development Test Specification
260		**TRL 7 - TR8**
261	WEC-TS-CCS-003	CCS Development Test Specification
262		**Reactor Cavity Cooling System**
263		**TRL 6 - TRL 7**
264		No tests defined yet. Advancement to the next TRL only achieved through software analysis.
265		**TRL 7 - TRL 8**
266		Original Schedule in TDRM
267	WEC-TS-RCCS-001	Verify the functioning of the RCCS with respect to maintaining Reactor Cavity concrete below code limits
268	WEC-TS-RCCS-002	Confirm operation of RCCS tank automatic water replenishment function
269	WEC-TS-RCCS-003	Validate analysis of DWS supply and heat sink performances
270	WEC-TS-RCCS-004	Validate theoretical analysis of pump trip effect on RCCS pressure
271		
272		**C: HTGR Component Test Facility**
273		Industry CTF Recommendation Studies
274		Pre-Conceptual Design
275		CTF PCDR
276		Study #1, TDRM and Test Plans for High Temperature SSCs
277		50% ICD Review
278		Prepare CTF PCDR
279		Prepare CTF Pre-Conceptual Test Loop Design
280		PCD 90% Review
281		Pre-Conceptual TDRM & Test Loop Design
282		PCD 90% Review
283		DOE or PPP Issues EPC SOW & RFP
284		Start EPC Contact
285		CTF Preliminary Design
286		Preliminary 90% Design Review
287		CTF Final Design
288		Final Design 90% Review
289		Issue Construction Documents
290		Test & Turnover
291		CTF construction completion
292		CTF Begin Component Installation & Testing
293		Project Transfer



Project: Project1
Date: Fri 08/12/05

Task ▨	Progress ▬	Summary	External Tasks ▨
Split	Milestone ◆	Project Summary	External Milestone ◆

Deadline ⇩

Figure 17-1: Integrated Schedule

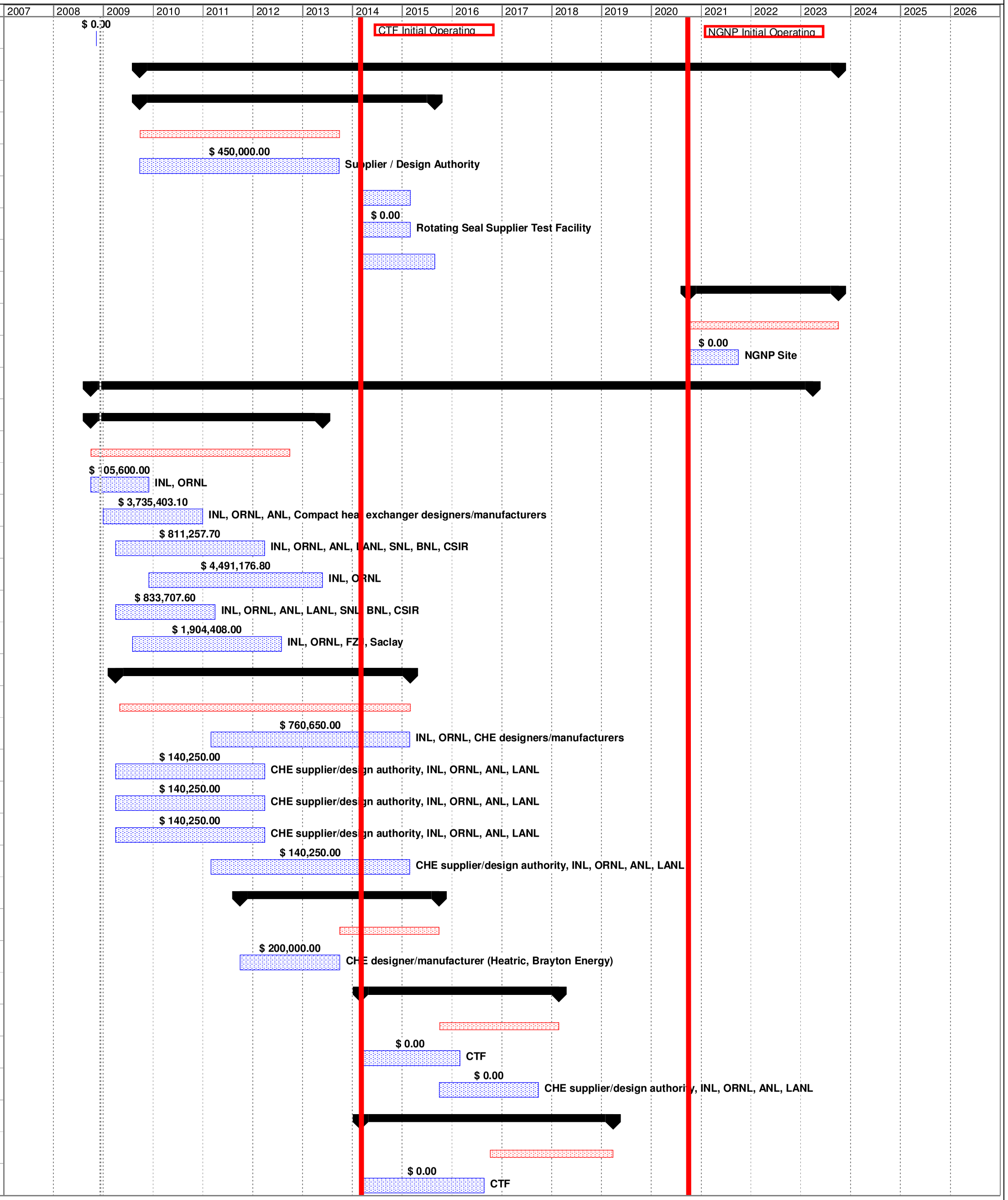
17.1.3 Modified TDRM Schedule

The original integrated TDRM Schedule (Figure 17-1) made the assumption that all work would start in October 2008 (FY2009). In the modified schedule, Figure 17-2, this was changed to relieve the initial pressure on the schedule by moving some of the less critical SSCs to a later starting date, but still within the constraints of the CTF- and NGNP start-up dates noted in the assumptions that follow:

- Small Scale Development Test will start in (October 2011-TBC as part of Phase II).
- CTF Initial Operating Date is March 2014
- NGNP Initial Operation Date is October 2021
- The designs of modules and unit cells are finished and they are fabricated just prior to the start of a test.

SSC specific comments contributing to the starting/end date modification can be seen in Figure 17-2.

ID	Notes	Task Name	Change to Original	Possible testing facility locations
1	**Test Spec Number**	**Modified TDRM Schedule**	**Comments**	
2		**Circulator**		
3		**TRL 6 - TRL 7**		
4		Original Schedule in TDRM		
5		Trade Studies		Supplier / Design Authority
6	WEC-TS-CIRC-001	EMBs, catcher bearings Test Specification	Start date moved: Small Scale Development Test	EMBs Supplier Test Facility
7	WEC-TS-CIRC-002	Helium Rotating seals Test Specification	Start date moved: Small Scale Development Test	Rotating Seal Supplier Test Facility
8	WEC-TS-CIRC-003	Partial or Full scale circulator Model Test Specification	Start date moved to coincide with CTF Starting date: CTL	CTF/Supplier Site
9		**TRL 7 - TRL 8**		
10		Original Schedule in TDRM		
11	WEC-TS-CIRC-004	Prototype circulator Test Specification	Start date moved to coincide with NGNP Initial Operating date	NGNP Site
12		**IHX A (Metallic)**		
13		**TRL 2 - TRL 3**		
14		Original Schedule in TDRM		
15	WEC-TS-IHXA-001	Alloy 617 Material Specification and procurement		INL, ORNL
16	WEC-TS-IHXA-002	Alloy 617 Joining Technology and Resultant Properties	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, Compact heat exchanger designers/manufacturers
17	WEC-TS-IHXA-003	Thermal/physical and mechanical properties of Alloy 617	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, LANL, SNL, BNL, CSIR
18	WEC-TS-IHXA-004	Effects of thermal Aging and environment on Alloy 617	Starting dates moved to more realistic and achievable dates	INL, ORNL
19	WEC-TS-IHXA-005	Effects of Grain size and selection thickness on Alloy 617 properties	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, LANL, SNL, BNL, CSIR
20	WEC-TS-IHXA-006	Corrosion Allowances for Alloy 617	Starting dates moved to more realistic and achievable dates	INL, ORNL, FZJ, Saclay
21		**TRL 3 - TRL 4**		
22		Original Schedule in TDRM		
23	WEC-TS-IHXA-007	ASME section III Code Case for Alloy 617	Starting dates moved to more realistic and achievable dates	INL, ORNL, CHE designers/manufacturers
24	WEC-TS-IHXA-008	Thermal/Fluid Modeling Methods for Metallic IHX A	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
25	WEC-TS-IHXA-009	Methods for stress/strain modeling of metallic IHX A	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
26	WEC-TS-IHXA-010	Criteria for structural integrity of IHX A	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
27	WEC-TS-IHXA-011	Performance Modeling Methods for IHX A	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
28		**TRL 4 - TRL 5**		
29		Original Schedule in TDRM		
30	WEC-TS-IHXA-12	Specification of testing of unit cell of compact Heat Exchangers	Starting dates moved to more realistic and achievable dates	CHE designer/manufacturer (Heatric, Brayton Energy)
31		**TRL 5 - TRL 6**		
32		Original Schedule in TDRM	Assuming 1.2MW Module is designed and Fabricated	
33	WEC-TS-IHXA-013	Specification of testing of compact heat exchanger module (1.2MW)	Starting date moved to coincide with CTF Starting date: TDL	CTF
34	WEC-TS-IHXA-014	ASME Section III Code Case for Compact Heat Exchanger Designs	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
35		**TRL 6 - TRL 7**		
36		Original Schedule in TDRM		
37	WEC-TS-IHXA-015	Shell Side Flow Distribution and Bypass Leakage Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF

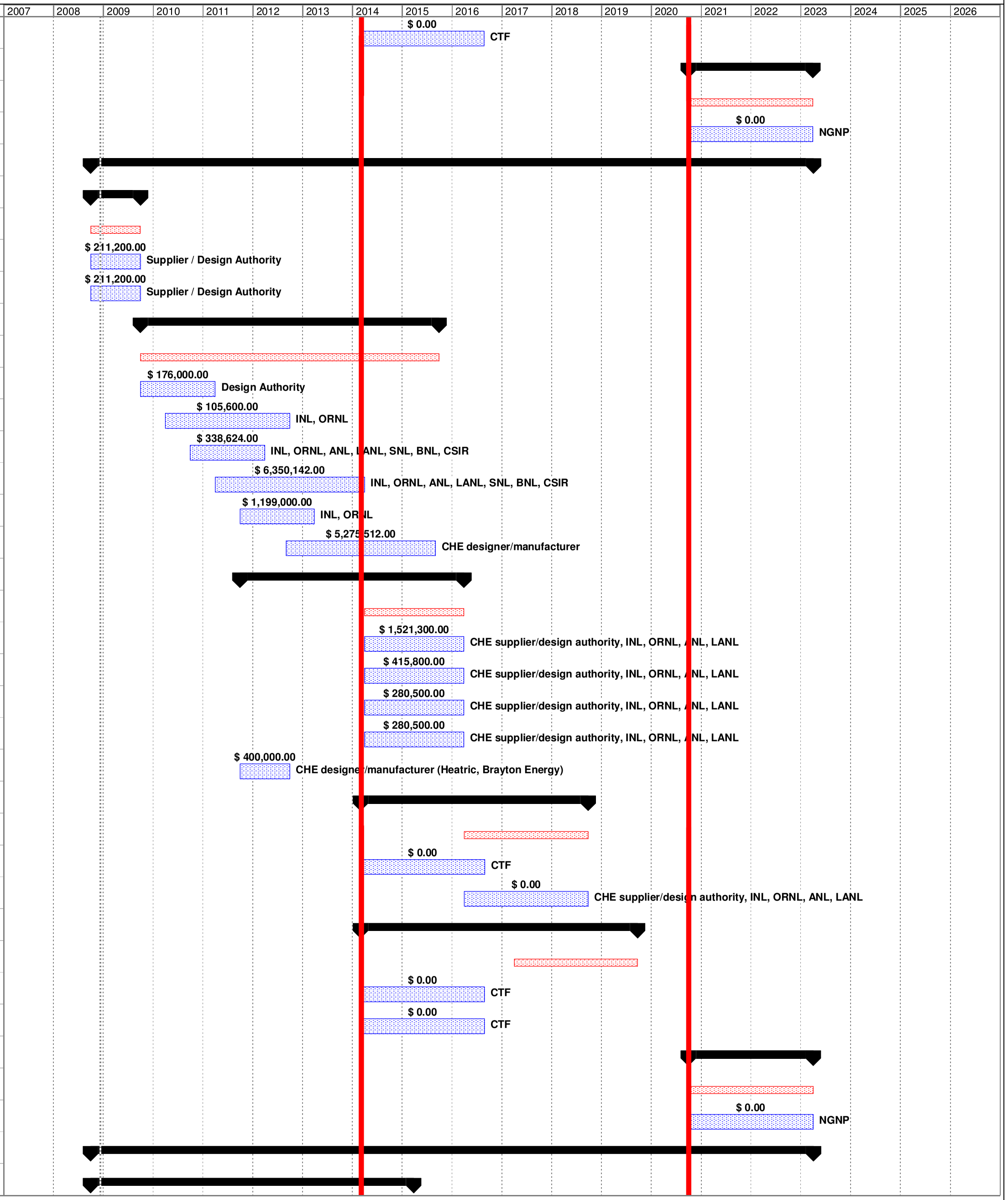


Project: TDRM Schedule_teruggetrek
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▨	Deadline	⇩
Split	....	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-2: Modified TDRM Schedule

ID	Notes	Task Name	Change to Original	Possible testing facility locations
38	WEC-TS-IHXA-016	Multi-module Heat Transfer Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF
39		**TRL 7 - TRL 8**		
40		Original Schedule in TDRM		
41	WEC-TS-IHXA-017	Specification of testing of a full scale compact Heat Exchangers	Start date moved to coincide with NGNP Initial Operating date	NGNP
42		**IHX A (Ceramic)**		
43		**TRL 2 - TRL 3**		
44		Original Schedule in TDRM		
45	WEC-TS-IHXA-018	Trade study on Candidate Ceramic Material for IHX A	Original Date	Supplier / Design Authority
46	WEC-TS-IHXA-019	Trade study on Candidate Ceramic Designs for IHX A	Original Date	Supplier / Design Authority
47		**TRL 3 - TRL 4**		
48		Original Schedule in TDRM		
49	WEC-TS-IHXA-020	Ceramic Detailed Design Data Needs (DDNs)	Starting dates moved to more realistic and achievable dates	Design Authority
50	WEC-TS-IHXA-021	Ceramic Materials Specifications and Procurement	Starting dates moved to more realistic and achievable dates	INL, ORNL
51	WEC-TS-IHXA-022	Thermal Physical Properties of Ceramics	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, LANL, SNL, BNL, CSIR
52	WEC-TS-IHXA-023	Mechanical Properties of Ceramics	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, LANL, SNL, BNL, CSIR
53	WEC-TS-IHXA-024	Compatibility of Ceramic Materials to NGNP He environment	Starting dates moved to more realistic and achievable dates	INL, ORNL
54	WEC-TS-IHXA-025	Manufacturing Technologies for Ceramic Heat Exchangers	Starting dates moved to more realistic and achievable dates	CHE designer/manufacturer
55		**TRL 4 - TRL 5**		
56		Original Schedule in TDRM	Assuming unit cell is designed and Fabricated	
57	WEC-TS-IHXA-026	Ceramic Materials Codes and Standards	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
58	WEC-TS-IHXA-027	Methods for Thermal/Fluid and Stress/Strain Modeling	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
59	WEC-TS-IHXA-028	Structural Integrity Criteria for Ceramic Heat Exchangers	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
60	WEC-TS-IHXA-029	Performance Modeling of Ceramic Heat Exchangers	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
61	WEC-TS-IHXA-030	Testing of unit cell of Compact Heat Exchanger	Start date moved back: Small Scale Development Test	CHE designer/manufacturer (Heatric, Brayton Energy)
62		**TRL 5 - TRL 6**		
63		Original Schedule in TDRM	Assuming 1.2MW Module is designed and Fabricated	
64	WEC-TS-IHXA-031	Specification of testing of compact heat exchanger module (1.2Mw)	Starting date moved to coincide with CTF Starting date: TDL	CTF
65	WEC-TS-IHXA-032	ASME Code Case for Ceramic Compact Heat Exchanger Design	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
66		**TRL 6 - TRL 7**		
67		Original Schedule in TDRM		
68	WEC-TS-IHXA-033	Shell-side Flow Distribution and Bypass Leakage Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF
69	WEC-TS-IHXA-034	Multi-mode Heat Transfer Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF
70		**TRL 7 - TRL 8**		
71		Original Schedule in TDRM		
72	WEC-TS-IHXA-035	Specifications of testing of a full scale compact Heat Exchanger	Start date moved to coincide with NGNP Initial Operating date	NGNP
73		**IHX B**		
74		**TRL 3 - TRL 4**		

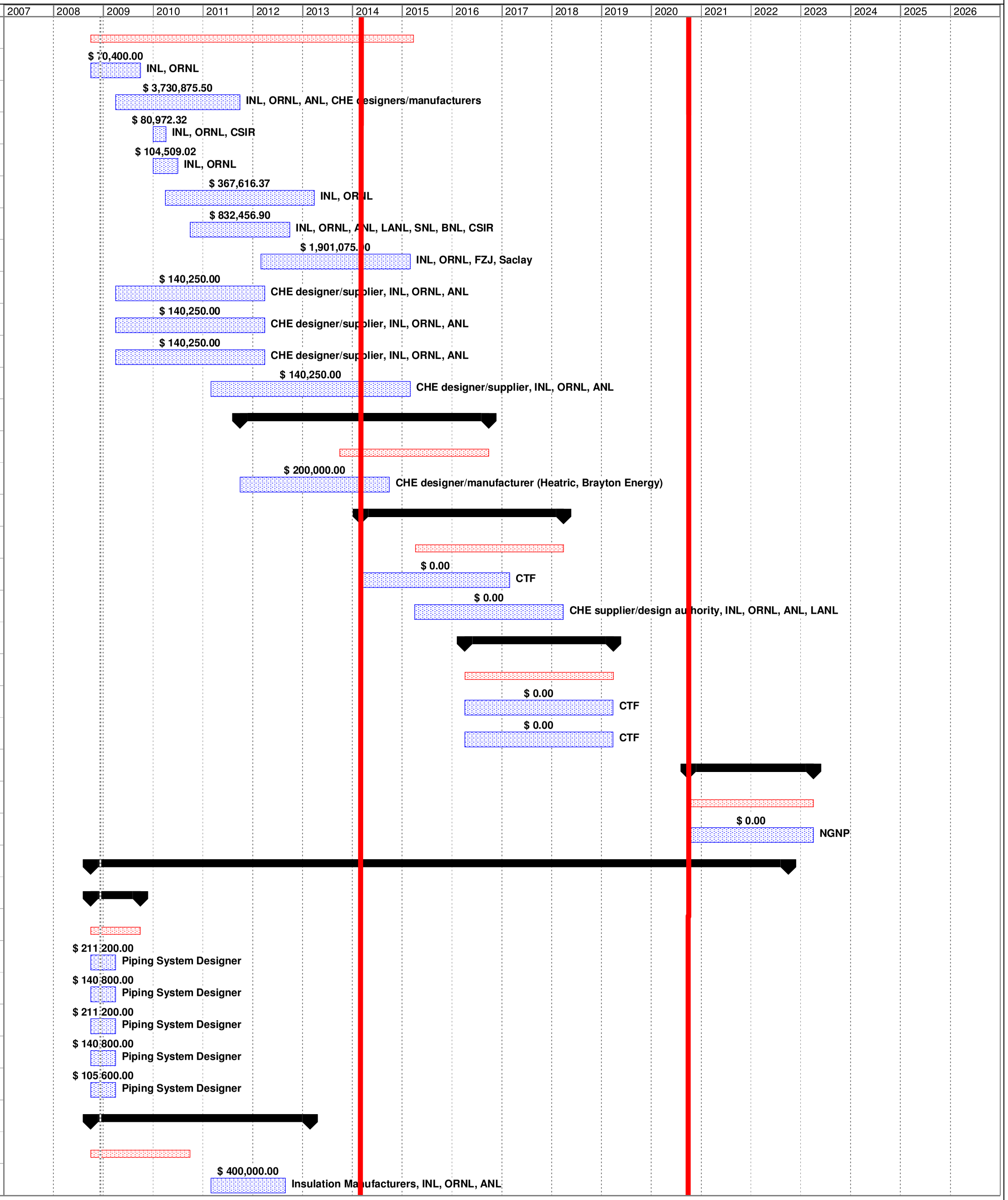


Project: TDRM Schedule_teruggetrek
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-2: Modified TDRM Schedule

ID	Notes	Task Name	Change to Original	Possible testing facility locations
75		Original Schedule in TDRM		
76	WEC-TS-IHXB-001	Alloy 800H Material Specification and Procurement	Starting dates moved to more realistic and achievable dates	INL, ORNL
77	WEC-TS-IHXB-002	Database for Brazed and Diffusion Bonded Alloy 800H	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, CHE designers/manufacturers
78	WEC-TS-IHXB-003	Alloy 800H High Temperature Material Properties	Starting dates moved to more realistic and achievable dates	INL, ORNL, CSIR
79	WEC-TS-IHXB-004	Effects of Thermal Aging and Environment on Alloy 800H Properties	Starting dates moved to more realistic and achievable dates	INL, ORNL
80	WEC-TS-IHXB-005	Effects of Environmental Exposure on Alloy 800H Braze and Diffusion Bonded Joints	Starting dates moved to more realistic and achievable dates	INL, ORNL
81	WEC-TS-IHXB-006	Effects of Grain Size and Section Thickness on Alloy 800H Properties	Starting dates moved to more realistic and achievable dates	INL, ORNL, ANL, LANL, SNL, BNL, CSIR
82	WEC-TS-IHXB-007	Corrosion Allowances for Alloy 800H	Starting dates moved to more realistic and achievable dates	INL, ORNL, FZJ, Saclay
83	WEC-TS-IHXB-008	Thermal/Fluid Modeling Methods for IHX B		CHE designer/supplier, INL, ORNL, ANL
84	WEC-TS-IHXB-009	Methods for Stress/Strain Modling of IHX B	Starting dates moved to more realistic and achievable dates	CHE designer/supplier, INL, ORNL, ANL
85	WEC-TS-IHXB-010	Criteria for Structural Intergrity of IHX B	Starting dates moved to more realistic and achievable dates	CHE designer/supplier, INL, ORNL, ANL
86	WEC-TS-IHXB-011	Performance Modeling Methods for IHX B	Starting dates moved to more realistic and achievable dates	CHE designer/supplier, INL, ORNL, ANL
87		**TRL 4 - TRL 5**		
88		Original Schedule in TDRM	Assuming unit cell is designed and Fabricated	
89	WEC-TS-IHXB-012	Testing of Unit Cell of Compact Heat Exchanger	Start date moved back: Small Scale Development Test	CHE designer/manufacturer (Heatric, Brayton Energy)
90		**TRL 5 - TRL 6**		
91		Original Schedule in TDRM		
92	WEC-TS-IHXB-013	Testing of integrated compact Heat Exchanger	Starting date moved to coincide with CTF Starting date: TDL	CTF
93	WEC-TS-IHXB-014	ASME III Code Case for Meatllic Compact Heat Exchanger Design	Starting dates moved to more realistic and achievable dates	CHE supplier/design authority, INL, ORNL, ANL, LANL
94		**TRL 6 - TRL 7**		
95		Original Schedule in TDRM		
96	WEC-TS-IHXB-015	Shell-side Flow Distribution and Bypass Leakage Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF
97	WEC-TS-IHXB-016	Multi-module Heat Transfer Testing	Starting date moved to coincide with CTF Starting date: TDL	CTF
98		**TRL 7 - TRL 8**		
99		Original Schedule in TDRM		
100	WEC-TS-IHXB-017	Testing of full size Compact Heat Exchanger	Start date moved to coincide with NGNP Initial Operating date	NGNP
101		**Piping**		
102		**TRL 4 - TRL5**		
103		Original Schedule in TDRM		
104	WEC-TS-PIP-001	PHTS high-temperature [760℃ and 950℃] piping cooling, liner& insulation options trade study	Original Date	Piping System Designer
105	WEC-TS-PIP-002	PHTS low-temperature [350℃] piping liner and insulation options trade study	Original Date	Piping System Designer
106	WEC-TS-PIP-003	SHTS high-temperature[840℃ and 900℃] piping liner and insualtion study	Original Date	Piping System Designer
107	WEC-TS-PIP-004	SHTS medium-temperature [659℃ and 700℃] piping liner and insulation trade study	Original Date	Piping System Designer
108	WEC-TS-PIP-005	SHTS low-temperature [<300℃] piping liner and insulation trade study	Original Date	Piping System Designer
109		**TRL 5 - TRL 6**		
110		Original Schedule in TDRM		
111	WEC-TS-PIP-006	Effects of He infiltration on thermal conductivity of insulation material	Start date moved forward: Small Scale Development Test	Insulation Manufacturers, INL, ORNL, ANL

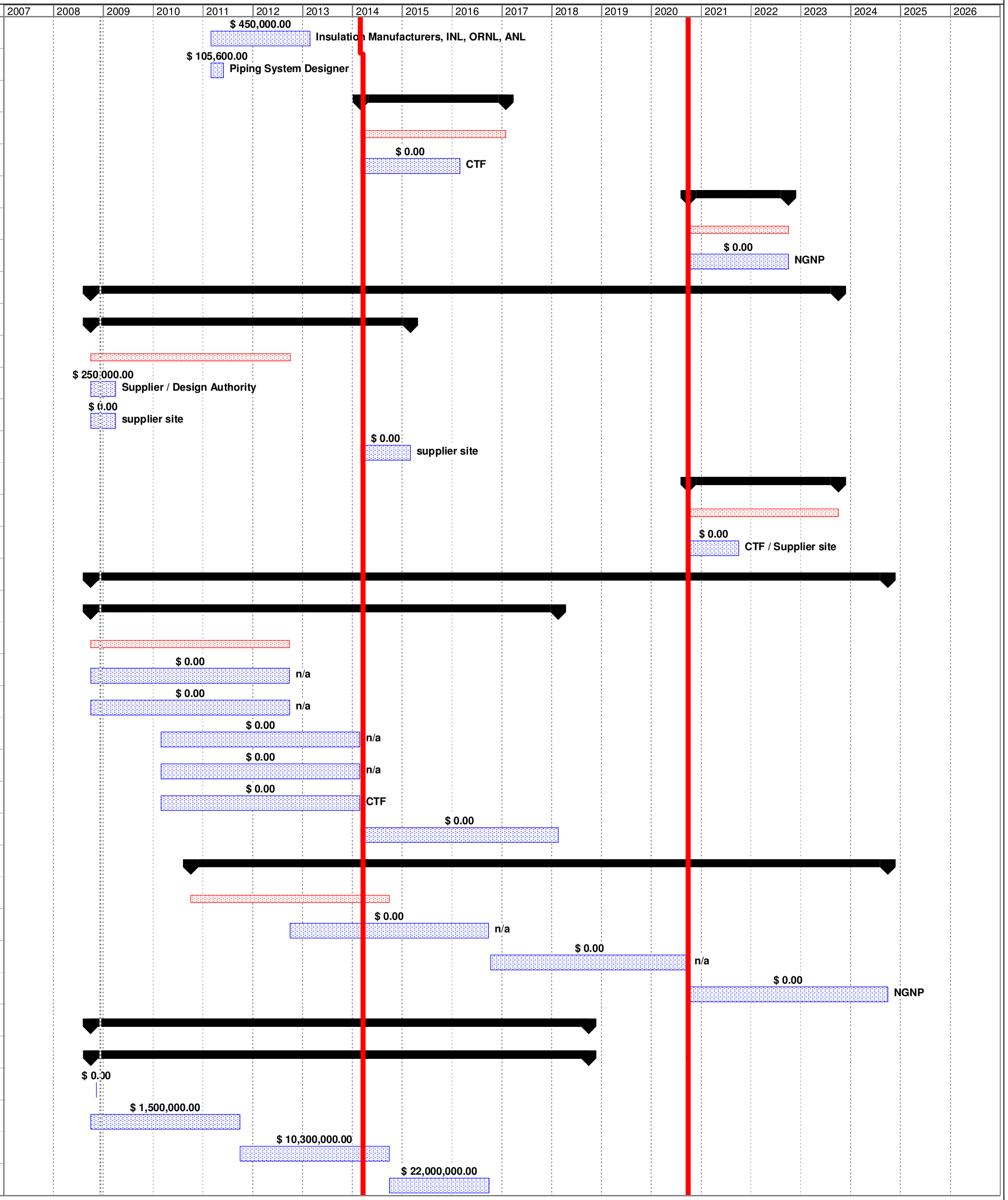


Project: TDRM Schedule_teruggetrek
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	┈	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-2: Modified TDRM Schedule

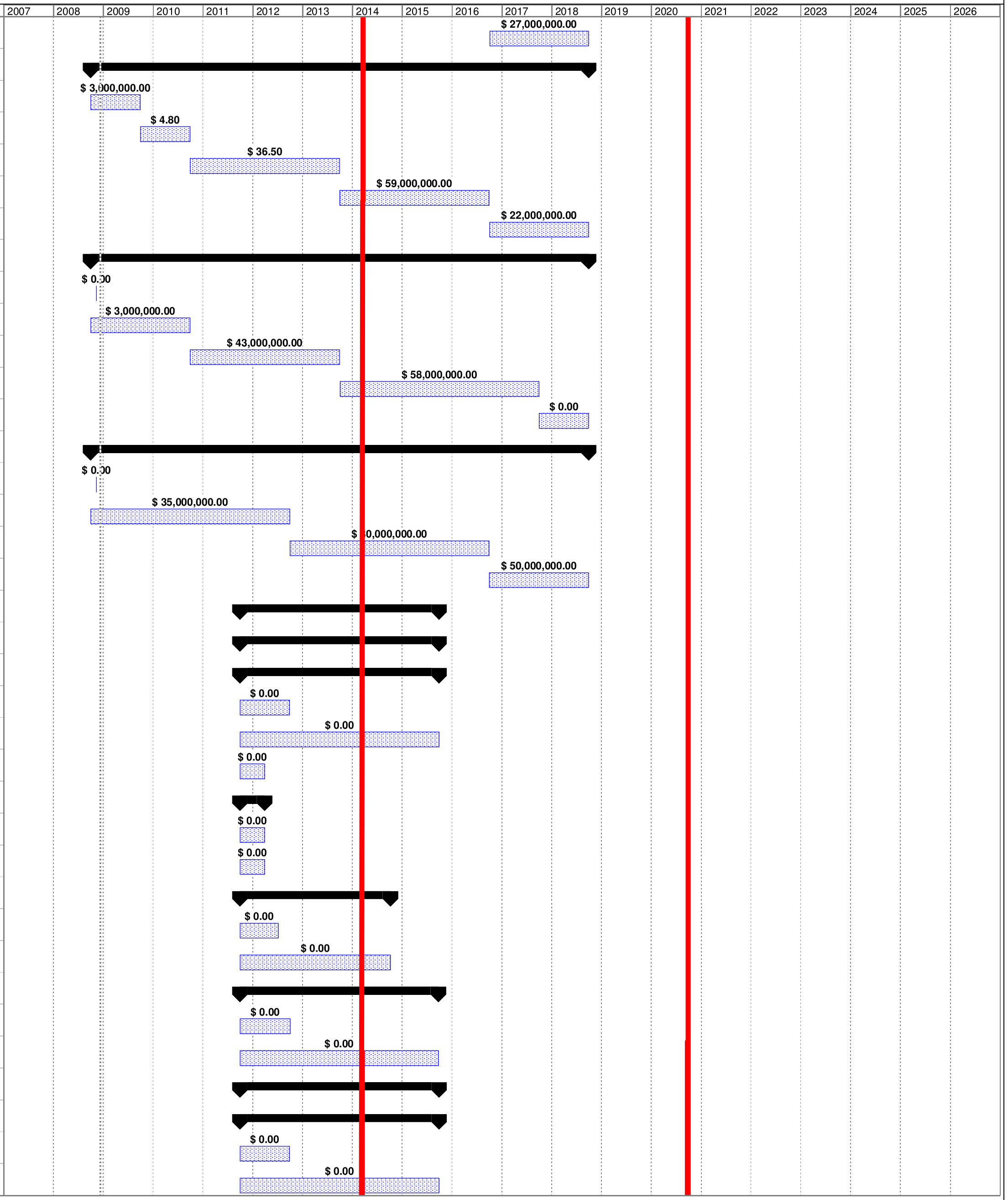
ID	Notes	Task Name	Change to Original	Possible testing facility locations
112	WEC-TS-PIP-007	The effect of fluid impurities on insulation properties	Start date moved forward: Small Scale Development Test	Insulation Manufacturers, INL, ORNL, ANL
113	WEC-TS-PIP-008	Re-evaluation of needed maturation tasks based on Trade studies	Starting dates moved to more realistic and achievable dates	Piping System Designer
114		**TRL 6 - TRL 7**		
115		Original Schedule in TDRM		
116	WEC-TS-PIP-009	Performance&environmental testing:prototypical high-& low-temp piping/insulation system	Starting date moved to coincide with CTF: TDL/CTL	CTF
117		**TRL 7 - TRL 8**		
118		Original Schedule in TDRM		
119	WEC-TS-PIP-010	Testing of full sie PHTS piping in NGNP	Start date moved to coincide with NGNP Initial Operating date	NGNP
120		**Mixing Chamber**		
121		**TRL 6 - TRL 7**		
122		Original Schedule in TDRM		
123	WEC-TS-MC-001	Enhanced Mixing Devices Test Specification	Original Date	Supplier / Design Authority
124	WEC-TS-MC-002	Vibration Damping Devices Test Specification	Original Date	supplier site
125	WEC-TS-MC-003	Partial or Full Scale Flow Mixing Chamber Model Test Specification	Starting date moved to coincide with CTF Starting date: CTL	supplier site
126		**TRL 7 - TRL 8**		
127		Original Schedule in TDRM		
128	WEC-TS-MC-004	Prototype Flow Mixing Chamber Test Specification	Start date moved to coincide with NGNP Initial Operating date	CTF / Supplier site
129		**Steam Generator**		
130		**TRL 6 - TRL 7**		
131		Original Schedule in TDRM		
132		Trade Studies		n/a
133	WEC-TS-SG-001	Down selection trade study:determine the preferred conceptual arrangement of the SG	Original Date	n/a
134	WEC-TS-SG-002	Define requirements and design details for the SG in the PCS system context	To be performed after Trade Study	n/a
135	WEC-TS-SG-003	Perform configuration development tests to substantiate the design	To be performed after Trade Study	n/a
136	WEC-TS-SG-004	Design and supply a scale prototype for the testing in the CTF	Moved to be finished before testing in CTF	CTF
137	WEC-TS-SG-005	Performance testing in CTF	Starting date moved to coincide with CTF Starting date: CTL	
138		**TRL 7 - TRL 8**		
139		Original Schedule in TDRM		
140	WEC-TS-SG-006	Complete final design of the prototype SG for the NGNP	Starting dates moved to more realistic and achievable dates	n/a
141	WEC-TS-SG-007	Fabricate and deliver to NGNP Site	Moved to be finished before testing in CTF	n/a
142	WEC-TS-SG-008	Install and operate	Start date moved to coincide with NGNP Initial Operating date	NGNP
143		**Hydrogen Production System**		
144		**Sulfuric Acid Decomposition**	**Original Date**	**n/a**
145		Up to completion of S-I ILS		
146		Complete analysis, supporting data, materials testing and catalyst choice & tests		
147		Pilot test of Decomposer		
148		Engineering test of Decomposer		



Project: TDRM Schedule_teruggetrek Date: Fri 08/12/05	Task	▨	Progress	■	Summary	▬	External Tasks	▨
	Split	┈	Milestone	◆	Project Summary	▬	External Milestone	◆
	Deadline	⇩						

Figure 17-2: Modified TDRM Schedule

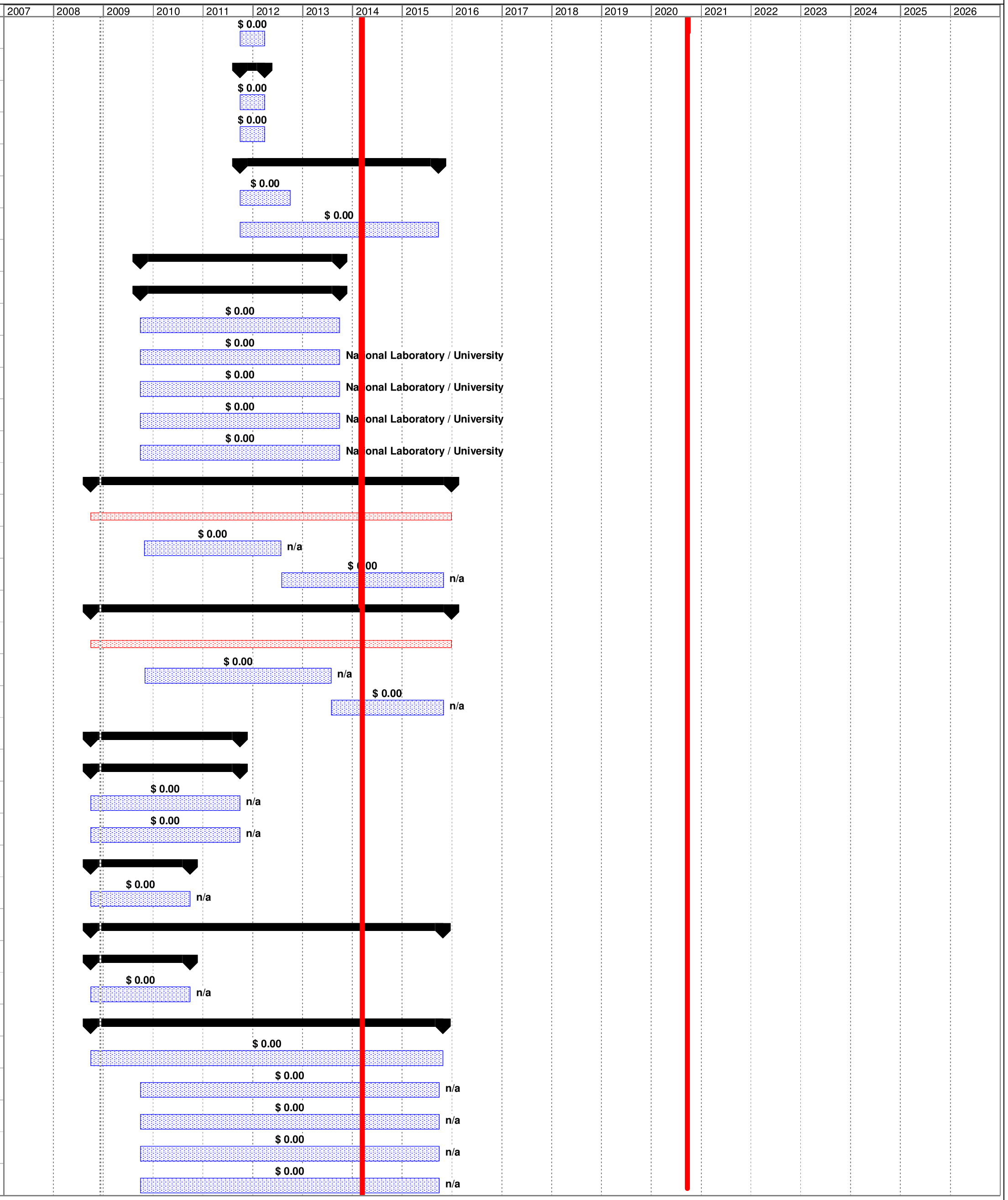
ID	Notes	Task Name	Change to Original	Possible testing facility locations
149		Prototype test of Decomposer		
150		**Sulfur Dioxide Electrolysis Technology Area**		
151		Up to completion of cell demonstration at temperature and pressure		
152		HyS ILS and optimized cell demonstration		
153		Scale-up cells to 400 cm2 , and Electrolyzer Pilot Test – module		
154		Scale-up cells to 1000 cm2 and Engineering test of Electrolyzer		
155		Scale-up cells to 1 m2 and Prototype test of Electrolyzer		
156		**Bunsen Reaction and HI Decomposistion Technology Area**		
157		Up to completion of S-I ILS –Bunsen: TRL		
158		HI Section Experimental Test – HI		
159		Bunsen and HI Systems Pilot Test		
160		Bunsen and HI Systems Engineering Test		
161		Prototype HPS Test: Sulfuric Acid, Bunsen & HI Sections		
162		**High Temperature Steam Electrolysis Technology Area**		
163		Up to completion of ILS		
164		Full-scale stack demonstration		
165		Pilot Test		
166		Prototype HPS Test		
167		**Fuel Elements**		
168		**TRL 6 - TRL 7**		
169	**WEC-TS-FUEL-001**	**Production Fuel Irradiation Tests for Normal Operational Conditions**		**INM Facility**
170		Irradiation planning & Preparation	Original Date	
171		Irradiation of Pre-Production Fuel	Original Date	
172		PIE and Analysis	Original Date	
173	**WEC-TS-FUEL-002**	**Production Fuel Heat-up Tests at 1600°C and 1800°C.**		**INM Facility**
174		Physical Heating Test	Original Date	
175		PIE and analysis of Heated Spheres	Original Date	
176	**WEC-TS-FUEL-003**	**Fuel Matrix Graphite Irradiation tests and PIE**		**IVV-2M Russian Reactor**
177		Irradiation Planning & Preparation	Original Date	
178		Irradiation and PIE	Original Date	
179	**WEC-TS-FUEL-004**	**Machined Graphite Irradiation tests and PIE**		**IVV-2M Russian Reactor**
180		Irradiation Planning & Preparation	Original Date	
181		Irradiation and PIE	Original Date	
182		**TRL 7 - TRL 8**		
183	**WEC-TS-FUEL-005**	**Production Fuel Irradiation Tests for NGNP Normal Operational Conditions**		**Suitable Test Reactor - ATR**
184		Irradiation planning & Preparation	Original Date	
185		Irradiation of Pre-Production Fuel	Original Date	



Task ▨ Progress ▬ Summary
Split Milestone ◆ Project Summary
External Tasks Deadline ⇩
External Milestone ◆

Figure 17-2: Modified TDRM Schedule

ID	Notes	Task Name	Change to Original	Possible testing facility locations
186		PIE and Analysis	Original Date	
187	**WEC-TS-FUEL-006**	**Production Fuel Heat-up Tests at 1700°C and 1900°C.**		**Suitable Test Reactor - ATR**
188		Physical Heating Test	Original Date	
189		PIE and analysis of Heated Spheres	Original Date	
190	**WEC-TS-FUEL-007**	**Fuel Matrix Graphite Irradiation tests and PIE**		**Suitable Test Reactor - ATR**
191		Irradiation Planning & Preparation	Original Date	
192		Irradiation and PIE	Original Date	
193		**Core Structure Ceramics**		
194		**TRL 6 - TRL 7**		
195	WEC-TS-CSC-001	PBMR Relevant	Original Date	
196	WEC-TS-CSC-002	Extended Properties of Irradiated Graphite at Low Temperatures	Original Date	National Laboratory / University
197	WEC-TS-CSC-003	Extended Properties of Irradiated Graphite at High Temperatures	Original Date	National Laboratory / University
198	WEC-TS-CSC-004	Characterize Race Track Strap and Tie Rod Material	Original Date	National Laboratory / University
199	WEC-TS-CSC-005	Insulation Material (Unirradiated Data Needed)	Original Date	National Laboratory / University
200		**Reserve Shutdown System**		
201		Original Schedule in TDRM		
202		TRL 6 - TRL 7	Original Date	n/a
203		TRL 7 - TRL 8	Original Date	n/a
204		**Reactivity Control System**		
205		Original Schedule in TDRM		
206		TRL 6 - TRL 7	Original Date	n/a
207		TRL 7 - TRL 8	Original Date	n/a
208		**Core Conditioning System**		
209		**TRL 6 - TRL 7**		
210	WEC-TS-CCS-001	Valves development Test Specification	Original Date	n/a
211	WEC-TS-CCS-002	Blower development Test Specification	Original Date	n/a
212		**TRL 7 - TR8**		
213	WEC-TS-CCS-003	CCS Development Test Specification	Original Date	n/a
214		**Reactor Cavity Cooling System**		
215		**TRL 6 - TRL 7**		
216		No tests defined.Advancement to next TRL will be achieved through software analysis.	Original Date	n/a
217		**TRL 7 - TRL 8**		
218		Original Schedule in TDRM		
219	WEC-TS-RCCS-001	Verify functioning of RCCS with respect-maintaining Reactor Cavity concrete below code limits	Original Date	n/a
220	WEC-TS-RCCS-002	Confirm operation of RCCS tank automatic water replenishment function	Original Date	n/a
221	WEC-TS-RCCS-003	Validate analysis of DWS supply and heat sink performances	Original Date	n/a
222	WEC-TS-RCCS-004	Validate theoretical analysis of pump trip effect on RCCS pressure	Original Date	n/a



Project: TDRM Schedule_teruggetrek
Date: Fri 08/12/05

Task	▨	Progress	▬	Summary	▬	External Tasks	▭
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone ◆	
Deadline	⇩						

Figure 17-2: Modified TDRM Schedule

17.1.4 Modified CTF Schedule

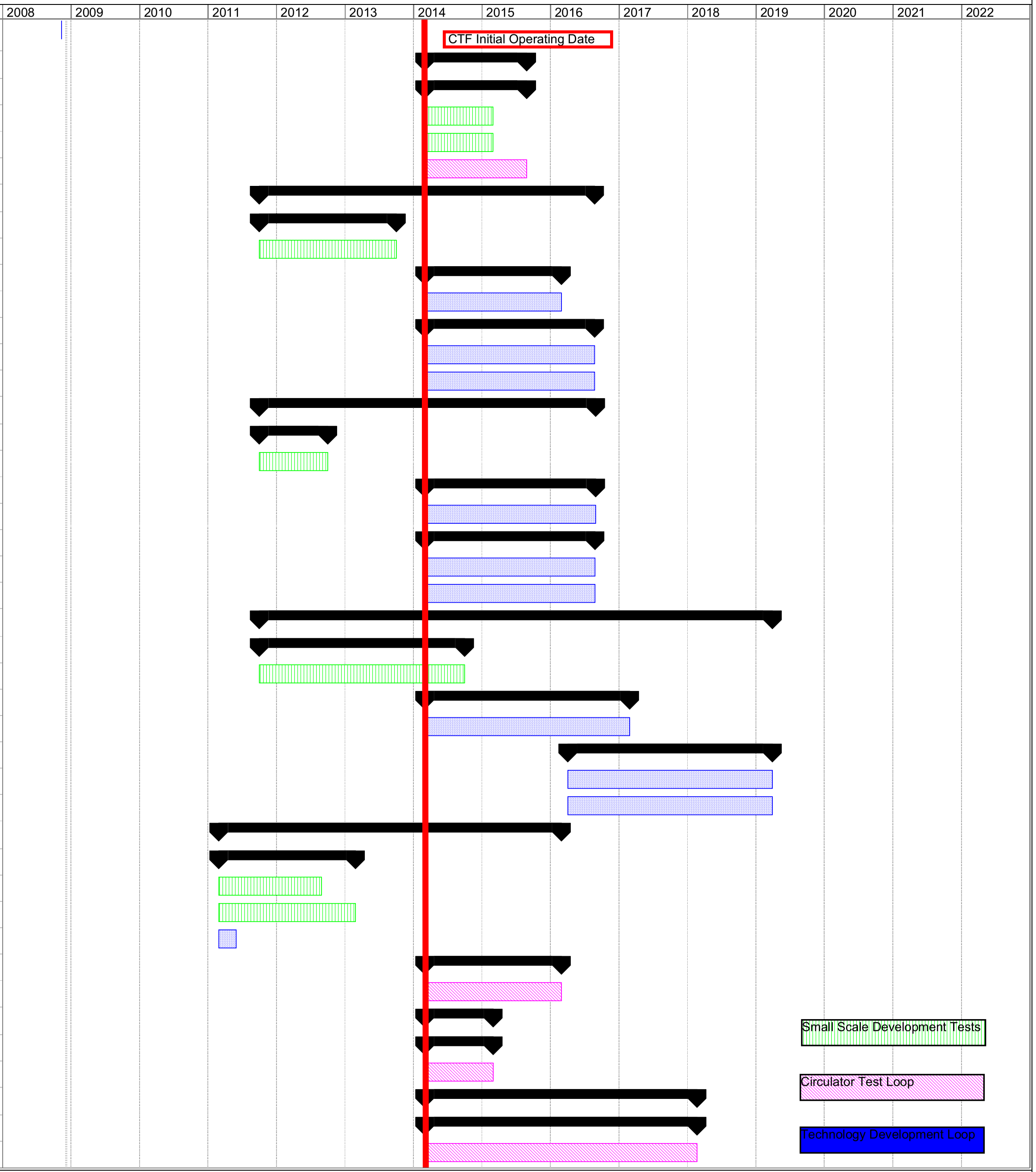
Figure 17-3 shows the test specifications relevant to the CTF only and especially for the 950ºC Reactor Outlet (ROT) Temperature related SSCs. These include Small Scale Development Tests (SSDTs), Technology development Loops (TDLs), Component Qualification Loops and the envisaged Circulator Test Loop (CTL).

The SSDTs are envisaged to incorporate separate and multiple effects tests which are more sophisticated than normal university of laboratory testing. The TDLs are envisaged to be loops with mass flows in the order of 3.6 kg/s at temperature of 950ºC and pressures up to 9 MPa. The CQLs are earmarked for larger component testing and consists of a combination of TDLs linked together to provide higher mass flows and more heating capacity.

For the case in which the NGNP ROT is lowered to 750°C, the test specifications that will still be relevant can be seen in Figure 17-4.

This CTF test schedule is an input to the Test Loop(s) Preconceptual Design and will be updated as the Test Loop(s) Preconceptual Design develops.

ID	Notes	Task Name
1	**Test Spec Number**	**Modified CTF Only 950°C**
2		**Circulator**
3		**TRL 6 - TRL 7**
4	WEC-TS-CIRC-001	EMBs, catcher bearings Test Specification
5	WEC-TS-CIRC-002	Helium Rotating seals Test Specification
6	WEC-TS-CIRC-003	Partial or Full scale circulator Model Test Specification
7		**IHX A (Metallic)**
8		**TRL 4 - TRL 5**
9	WEC-TS-IHXA-12	Specification of testing of unit cell of compact Heat Exchangers
10		**TRL 5 - TRL 6**
11	WEC-TS-IHXA-013	Specification of testing of compact heat exchanger module (1.2MW)
12		**TRL 6 - TRL 7**
13	WEC-TS-IHXA-015	Shell Side Flow Distribution and Bypass Leakage Testing
14	WEC-TS-IHXA-016	Multi-module Heat Transfer Testing
15		**IHX A (Ceramic)**
16		**TRL 4 - TRL 5**
17	WEC-TS-IHXA-030	Testing of unit cell of Compact Heat Exchanger
18		**TRL 5 - TRL 6**
19	WEC-TS-IHXA-031	Specification of testing of compact heat exchanger module (1.2Mw)
20		**TRL 6 - TRL 7**
21	WEC-TS-IHXA-033	Shell-side Flow Distribution and Bypass Leakage Testing
22	WEC-TS-IHXA-034	Multi-module Heat Transfer Testing
23		**IHX B**
24		**TRL 4 - TRL 5**
25	WEC-TS-IHXB-012	Testing of Unit Cell of Compact Heat Exchanger
26		**TRL 5 - TRL 6**
27	WEC-TS-IHXB-013	Testing of integrated compact Heat Exchanger
28		**TRL 6 - TRL 7**
29	WEC-TS-IHXB-015	Shell-side Flow Distribution and Bypass Leakage Testing
30	WEC-TS-IHXB-016	Multi-mode Heat Transfer Testing
31		**Piping**
32		**TRL 5 - TRL 6**
33	WEC-TS-PIP-006	Effects of He infiltration on thermal conductivity of insulation material
34	WEC-TS-PIP-007	The effect of fluid impurities (C) on insulation properties
35	WEC-TS-PIP-008	Re-evaluation of needed maturation tasks based on Trade studies
36		**TRL 6 - TRL 7**
37	WEC-TS-PIP-009	Performance&environmental testing:prototypical high-& low-temp piping/insulation system
38		**Mixing Chamber**
39		**TRL 6 - TRL 7**
40	WEC-TS-MC-003	Partial or Full Scale Flow Mixing Chamber Model Test Specification
41		**Steam Generator**
42		**TRL 6 - TRL 7**
43	WEC-TS-SG-005	Performance testing in CTF

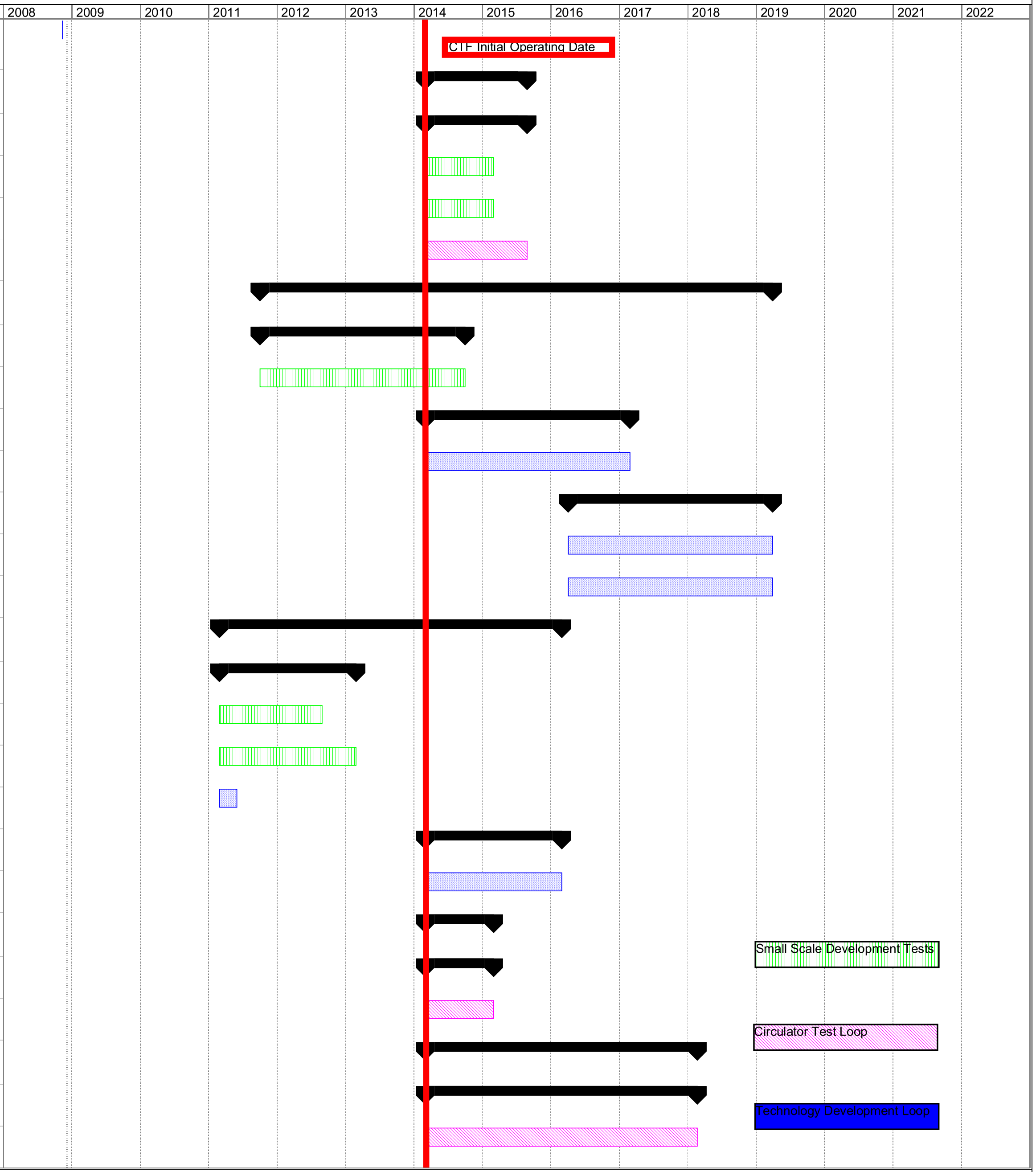


Project: CTF Schedule 950
Date: Thu 08/12/04

Task	▨	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	┈	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 17-3: Modified CTF Schedule - 950°C

ID	Notes	Task Name
1	**Test Spec Number**	**Modified CTF Only 750°C**
2		**Circulator**
3		**TRL 6 - TRL 7**
4	WEC-TS-CIRC-001	EMBs, catcher bearings Test Specification
5	WEC-TS-CIRC-002	Helium Rotating seals Test Specification
6	WEC-TS-CIRC-003	Partial or Full scale circulator Model Test Specification
7		**IHX B**
8		**TRL 4 - TRL 5**
9	WEC-TS-IHXB-012	Testing of Unit Cell of Compact Heat Exchanger
10		**TRL 5 - TRL 6**
11	WEC-TS-IHXB-013	Testing of integrated compact Heat Exchanger
12		**TRL 6 - TRL 7**
13	WEC-TS-IHXB-015	Shell-side Flow Distribution and Bypass Leakage Testing
14	WEC-TS-IHXB-016	Multi-module Heat Transfer Testing
15		**Piping**
16		**TRL 5 - TRL 6**
17	WEC-TS-PIP-006	Effects of He infiltration on thermal conductivity of insulation material
18	WEC-TS-PIP-007	The effect of fluid impurities (C) on insulation properties
19	WEC-TS-PIP-008	Re-evaluation of needed maturation tasks based on Trade studies
20		**TRL 6 - TRL 7**
21	WEC-TS-PIP-009	Performance&environmental testing:prototypical high-& low-temp piping/insulation system
22		**Mixing Chamber**
23		**TRL 6 - TRL 7**
24	WEC-TS-MC-003	Partial or Full Scale Flow Mixing Chamber Model Test Specification
25		**Steam Generator**
26		**TRL 6 - TRL 7**
27	WEC-TS-SG-005	Performance testing in CTF



Project: CTF Schedule 750.mpp
Date: Thu 08/12/04

Task ▨
Split ┈
Progress ▬
Milestone ◆
Summary ▬
Project Summary ▬
External Tasks ▭
External Milestone ◆
Deadline ⇩

Figure 17-4: CTF Schedule 750°C

17.1.5 Conclusion

Pending further schedule enhancements and optimization, the number of loops required in the CTF is forecasted in Table 17.1. (This will be confirmed as part of the Test Loop(s) Preconceptual Design)

Table 17-1: The number of loops required in the CTF

Number of:	**950ºC ROT Related SSCs**	**750ºC ROT Related SSCs**
Technology Development Loops	5-6	2-3
Circulator Test Loops	1	1
CQL-1	1	1

For the 950ºC ROT it is forecasted that five to six TDLs are required, This can be optimized (and will be as part of the Test Loop(s) Preconceptual Design). For instance if the IHX A (Ceramic) tests are conducted after the IHX A (Metallic) testing is completed), two TDLs will fall away. As the methods and software used in the design matures some of the scheduled testing could also be reduced as risks will be mitigated though code verification and validation.

For the 750ºC ROT it is forecasted that two TDLs are required for testing of IHX B. It is forecasted that a CTL will be required to test the circulator as well as some of the piping sections and the mixing chamber.

The Component Qualification Loops (CQL-1) are envisaged for testing of larger components that might be required as the NGNP design progresses and are configured using TDLs.

The number of Small Scale Development Tests will be determined as part of the Test Loop(s) Preconceptual Design.

At the completion of the CTF Preconceptual Design, where the optimum construction and commissioning schedule for the CTF will be determined, the TDRM Schedules will be updated accordingly.

17.2 COST ESTIMATE

17.2.1 Introduction

Cost estimates are provided for certain critical Systems, Structures and Components (SSCs) in this document. These SSCs entail *inter alia* the metallic IHX A, ceramic IHX A and IHX B, as well as the HTS Piping systems. For the purpose of this document, estimates have been provided only up to a TRL rating of 5, due to the high uncertainty that exists in estimating the costs for higher TRL advancements. Estimates for higher TRL advancements can only be provided when additional design information (preliminary or final) of the NGNP and components are available. For some of the SSCs, more design information is required in order to develop reliable cost estimates. These include the PHTS Circulator, SHTS Mixing Chamber and Steam Generator. Trade studies need to be done to progress the designs and to verify and determine the specific combinations of sub-components that will be used. There is enough time as per the modified schedule to perform the trade study before the advancement of the TRL and before possible testing in the CTF will be performed.

The Hydrogen production system cost estimate has been developed as part of the Hydrogen Production Alternatives Study [17-3] and is presented in this document (see Tables 17-3 and 17-4). Estimates for the HPS shown in Table 17-3 (summary cost of original TDRMs) only incorporate total estimates for (i) sulfuric acid decomposition and (ii) sulfur dioxide electrolysis technologies, the respective technologies needed for the Hybrid Sulfur (HyS) hydrogen production system. Although a reference design has not been down selected for the HPS, the HyS process has been selected as the basis for the estimates shown.

Where cost information was not available, the WEC NGNP PCDR costs were used as the basis, i.e., Fuel Elements, Core Structures Ceramics, etc [17-4].

The bulk of estimated costs provided are based on input received/readily available from contributors/institutions conducting similar work in industry. Table 17-4 of this document captures the estimates made for the identified SSCs as well as possible test locations/facilities that were identified and are involved with similar testing programs. The compositions of the estimates made for each test specification are captured in individual specification estimates in Appendix A. The bases used in these sheets will be elaborated upon here after.

17.2.2 Assumptions and Bases of Cost Estimates

The following assumptions and bases are applicable to the estimates shown in Appendix A.

17.1.2.1 Applicability to Schedule

The cost estimates stated in Table 17.4 are based on November 2008 dollar values. No escalation for future years has been incorporated.

17.1.2.2 TRL Advancements

For the purpose of this document, estimates have only been provided up to a TRL rating of 5 due to the high uncertainty that exists in estimating the costs for higher TRL advancements. Estimates for higher TRL advancements can only be provided when additional design information (preliminary or final) is available and the initial technology development has progressed to a more mature point.

17.1.2.3 Contingencies and Uncertainties

Contingencies for the proposed estimates given involve a 10 percent adjustment on resource, testing, materials and other applicable costs stated. This is separate from the adjustment factors applicable to the ceramic IHX A as well as IHX B. The adjustment factors applicable to IHX B are based on IHX A and are shown in Table 17.2. These factors have been used as the basis for the IHX B estimates due to time constraints. The adjustment factors for the ceramic IHX A have been based on a factor of 2 due to various uncertainties that still exist in the estimate process. These factors involve intricacies that exist relating to sample preparation, sample machining as well as the ceramic material that still needs to be identified through relevant trade studies.

Table 17-2: Cost Ratios for Metallic IHX A to IHX B

#	IHX A Test Specification	IHX B Test Specification	Comments	IHX A to IHX B Cost Ratio
1	617 Material Specification and Procure	800H Material Specification and Procure	Adopt existing 800H specification, procure 1 to 2 heats vs. 3 for 617	>2
2	617 Joining Technology and Result Properties	Database for Braze & Diffusion Bond 800H	Equivalent work for both	1
3	Thermal/Physical/ Mech. Prop of 617	800H High Temp Material Properties	Adopt existing 800H database	>10
4	Effects of Thermal Ageing and Environment on 617 Properties	Effects of Thermal Ageing and Environment on 800H	Adopt existing 800H database	>10
5	*Covered in rows 2 and 4 above.*	Effects of Environment Exposure on 800H Braze & Diff Bonds	Equivalent work for 617 and 800H	1
6	Effects of GS and Section Thickness on 617 Properties	Effects of GS and Section Thickness on 800H Properties	Equivalent work for 617 and 800H	1
7	Corrosion Allowance for 617	Corrosion Allowance for 800H	Equivalent work for 617 and 800H but time and cost may be reduced by working in parallel	1
8	ASME Sect III CC for 617	*Existing ASME Section III Code*	No or minimal cost for IHX B	>100

#	IHX A Test Specification	IHX B Test Specification	Comments	IHX A to IHX B Cost Ratio
		Case		
9	Thermal/Fluid Modeling Methods	Thermal/Fluid Modeling Methods	Probably a shared task but with higher temperatures to be considered for IHX A	1
10	Methods for Stress/Strain Modeling	Methods for Stress/Strain Modeling	Probably a shared task but with higher temperatures to be considered for IHX A	1.25
11	Structural Integrity Criteria	Structural Integrity Criteria	Probably a shared task but with higher temperatures to be considered for IHX A	1.25
12	Performance Modeling Methods	Performance Modeling Methods	Probably a shared task but with higher temperatures to be considered for IHX A	1
13	Unit Cell Tests	Unit Cell Tests	Separate and equivalent in cost	1

At a ROT of 950°C, it is important to note that development of both IHX A (metallic or ceramic) and IHX B will be required. At a ROT of 750°C, only the development of an IHX B will be applicable.

The confidence level of the cost estimates at present is +120%/-:60%, which corresponds to an accuracy level of Class 4 as noted in [17-5].

17.1.2.4 General

Other bases for the estimates relating to resources used, testing estimates as well as materials are stated in Appendix A. Aspects lacking an estimate basis will only be updated when additional plant design information is available (preliminary or final). Until this information is readily available, only an allowance for certain identified tasks without a basis can be given.

17.2.3 Summary Cost: Original TDRMs

Table 17.3 shows the sum of cost estimates distributed along a timeline starting in FY2009 and ending in FY2021. The starts and durations of the tasks corresponds to those noted in the original TDRMs. Comments and assumptions applicable to the values shown are given below Table 17.3.

Table 17-3: Summary Cost: Original TDRM

Summary costs: Original TDRMs

SSC [1], [2]	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
Circulator [3]	$450,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$450,000**
IHX A (Metallic)	$4,205,030	$4,464,905	$3,300,971	$1,007,072	$225,225	$100,000	$100,000	$0	$0	$0	$0	$0	$0	**$13,403,203**
IHX A (Ceramic)	$5,482,274	$4,488,666	$3,896,338	$0	$0	$0	$0	$0	$705,925	$705,925	$705,925	$380,325	$400,000	**$16,765,378**
IHX B	$3,107,690	$2,851,809	$1,689,406	$0	$0	$100,000	$100,000	$0	$0	$0	$0	$0	$0	**$7,848,905**
Piping	$1,481,867	$283,333	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$1,765,200**
Mixing Chamber [3]	$0	$0	$1,124,000	$1,124,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$2,248,000**
Steam Generator	$0	$4,092,000	$7,274,000	$7,741,000	$2,814,000	$0	$0	$0	$0	$0	$0	$0	$0	**$21,921,000**
HPS [4]	$3,500,000	$5,300,000	$12,670,000	$15,610,000	$15,610,000	$23,110,000	$30,670,000	$30,670,000	$24,500,000	$24,500,000	$7,800,000	$0	$0	**$193,940,000**
Fuel	$4,500,000	$6,500,000	$6,500,000	$6,500,000	$5,500,000	$3,500,000	$3,500,000	$3,500,000	$4,500,000	$0	$0	$0	$0	**$44,500,000**
CSC	$500,000	$600,000	$800,000	$800,000	$700,000	$900,000	$700,000	$0	$0	$0	$0	$0	$0	**$5,000,000**
RSS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
RCS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
CCS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
RCCS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
TOTAL ($)	**$23,226,861**	**$28,580,714**	**$37,254,714**	**$32,782,072**	**$24,849,225**	**$27,710,000**	**$35,070,000**	**$34,170,000**	**$29,705,925**	**$25,205,925**	**$8,505,925**	**$380,325**	**$400,000**	**$113,901,686**

[1] Estimates noted for some SSC's are those given in NGNP-16-RPT-001 (notably Mixing Chamber, Steam Generator, Fuel, CSC) due to limited design . information

[2] Costing of RSS, RCS, CCS and RCCS make part of PBMR DPP and are not included

[3] For the Circulator, Mixing Chamber as well as the Steam Generator, concept design needs to be progressed further before sensible estimations can be . made

[4] Sum total of HPS reflects totals of sulfuric acid decomposition technology development as well as sulfur dioxide electrolysis technology development [NGNP-CTF MTECH-TDRM-008]. For the purposes of this estimation, estimations reflect costs needed to etablish Hybrid Sulphur hydrogen production system (even though the reference design still has to be selected).

17.2.4 Original TDRM Cost Estimate (Facilities Description and Total Cost Included)

Table 17.4 shows the original TDRM cost estimate for each test specification with associated details regarding possible facilities that have the capabilities of conducting the relevant testing. Costing assumptions have also been listed at the end of the table. Detailed bases for each of the individual test specifications estimates are given in Specification cost estimate sheets shown in Appendix A.

Due to the large number of possible facilities that can conduct similar work to that stated in the test specifications (notably materials qualification actions), only the facility capability is noted in Table 17.4 and not the facility availability. Facilities have been identified in the following areas:

1. Laboratories – These facilities are most common and widely available. Work associated with these facilities involves aspects relating to material qualification actions.
2. Small Scale Testing – Specialized testing on scaled units is required here and can in general be conducted by the relevant supplier or in a small scale development test loop (CTF capability)
3. CTF Testing – Testing of partial or full scaled units at relevant temperatures and pressures.

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
Circulator [1]						**$450,000**
TRL 6 - TRL 7	Trade studies to select reference design	n/a	Supplier / Design Authority	12 Months	FY 2010 - FY 2013	$450,000
	EMBs, Catcher bearings Test Specification	WEC-TS-CIRC-001	EMBs Supplier Test Facility	12 Months	FY 2010 - FY 2013	[-]
	Helium Rotating seals Test Specification	WEC-TS-CIRC-002	Rotating Seal Supplier Test Facility	12 Months	FY 2010 - FY 2013	[-]
	Partial or Full scale circulator Model Test Specification	WEC-TS-CIRC-003	CTF/Supplier Site	18 Months	FY 2010 - FY 2013	[-]
TRL 7 - TRL 8	Prototype circulator Test Specification	WEC-TS-CIRC-004	NGNP Site	3 - 12 Months	FY 2016 - FY 2018	[-]
IHX A (Metallic) [2]						**$13,403,203**
TRL 2 - TRL 3	Alloy 617 Material Specification and procurement	WEC-TS-IHXA-001	INL, ORNL	12 Months	FY 2009 - FY 2012	$105,600
	Alloy 617 Joining Technology and Resultant Properties	WEC-TS-IHXA-002	INL, ORNL, ANL, Compact heat exchanger designers/manufacturers	30 Months	FY 2009 - FY 2012	$3,735,403
	Thermal/physical and mechanical properties of Alloy 617	WEC-TS-IHXA-003	INL, ORNL, ANL, LANL, SNL, BNL, CSIR	36 Months	FY 2009 - FY 2012	$811,258
	Effects of thermal Aging and environment on Alloy 617	WEC-TS-IHXA-004	INL, ORNL	42 Months	FY 2009 - FY 2012	$4,491,177
	Effects of Grain size and selection thickness on Alloy 617 properties	WEC-TS-IHXA-005	INL, ORNL, ANL, LANL, SNL, BNL, CSIR	24 Months	FY 2009 - FY 2012	$833,708
	Corrosion Allowances for Alloy 617	WEC-TS-IHXA-006	INL, ORNL, FZJ, Saclay	36 Months	FY 2009 - FY 2012	$1,904,408

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
TRL 3 - TRL 4	ASME selection III Code Case for Alloy 617	WEC-TS-IHXA-007	INL, ORNL, CHE designers/manufacturers	48 Months	FY 2010 - FY 2015	$760,650
	Thermal/Fluid Modeling Methods for Metallic IHX A	WEC-TS-IHXA-008	CHE supplier/design authority, INL, ORNL, ANL, LANL	36 Months	FY 2010 - FY 2015	$140,250
	Methods for stress/strain modeling of metallic IHX A	WEC-TS-IHXA-009	CHE supplier/design authority, INL, ORNL, ANL, LANL	36 Months	FY 2010 - FY 2015	$140,250
	Criteria for structural integrity of IHX A	WEC-TS-IHXA-010	CHE supplier/design authority, INL, ORNL, ANL, LANL	36 Months	FY 2010 - FY 2015	$140,250
	Performance Modeling Methods for IHX A	WEC-TS-IHXA-011	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2010 - FY 2015	$140,250
TRL 4 - TRL 5	Specification of testing of unit cell of compact Heat Exchangers **[3]**	WEC-TS-IHXA-012	CHE designer/manufacturer (Heatric, Brayton Energy)	24 Months	FY 2014 - FY 2016	$200,000
TRL 5 - TRL 6	Testing of integrated compact heat exchanger module (~1.2MW)	WEC-TS-IHXA-013	CTF	24 Months	FY 2017 - FY 2019	[-]
	ASME III Code Case for Compact Heat Exchanger Designs	WEC-TS-IHXA-014	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2019	[-]
TRL 6 - TRL 7	Shell-side flow distribution and bypass leakage testing	WEC-TS-IHXA-015	CTF		FY 2018 - FY 2020	[-]
	Multi-module heat transfer testing	WEC-TS-IHXA-016	CTF		FY 2018 - FY 2020	[-]
TRL 7 - TRL 8	Testing of full size compact heat exchanger (Full scale NGNP IHX A)	WEC-TS-IHXA-017	NGNP	48 Months	FY 2019 - FY 2020	[-]
IHX A (Ceramic) [4]						**$16,765,378**
TRL 2 - TRL 3	Trade study on Candidate Ceramic Material for IHX A	WEC-TS-IHXA-018	Supplier / Design Authority	12 Months	FY 2009 - FY 2010	$211,200

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
	Trade study on Candidate Ceramic Designs for IHX A	WEC-TS-IHXA-019	Supplier / Design Authority	12 Months	FY 2009 - FY 2010	$211,200
TRL 3 - TRL 4	Caramic HX Detailed Design Data Needs (DDNs)	WEC-TS-IHXA-020	Design Authority	18 Months	FY 2011 - FY 2016	$176,000
	Ceramic Materials Specifications and Procurement	WEC-TS-IHXA-021	INL, ORNL	30 Months	FY 2009 - FY 2011	$105,600
	Thermal Physical Properties of Ceramics	WEC-TS-IHXA-022	INL, ORNL, ANL, LANL, SNL, BNL, CSIR	18 Months	FY 2009 - FY 2011	$338,624
	Mechanical Properties of Ceramics	WEC-TS-IHXA-023	INL, ORNL, ANL, LANL, SNL, BNL, CSIR	36 Months	FY 2009 - FY 2011	$6,350,142
	Compatibility of Ceramic Materials to NGNP He Environment	WEC-TS-IHXA-024	INL, ORNL	18 Months	FY 2009 - FY 2011	$1,199,000
	Manufacturing Technologies for Ceramic Heat Exchangers	WEC-TS-IHXA-025	CHE designer/manufacturer	36 Months	FY 2009 - FY 2011	$5,275,512
TRL 4 - TRL 5	Ceramic Materials Codes and Standards	WEC-TS-IHXA-026	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2020	$1,521,300
	Methods for Thermal/Fluid and Stress/Strain Modeling	WEC-TS-IHXA-027	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2020	$415,800
	Structural Integrity Criteria for Ceramic Heat Exchangers	WEC-TS-IHXA-028	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2020	$280,500
	Performance Modeling of Ceramic Heat Exchangers	WEC-TS-IHXA-029	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2020	$280,500
	Testing of unit cell of compact heat exchanger **[3]**	WEC-TS-IHXA-030	CHE designer/manufacturer (Heatric, Brayton Energy)	12 Months	FY 2017 - FY 2020	$400,000
TRL 5 - TRL 6	Specifications of testing of compact heat exchanger module (~1.2MW)	WEC-TS-IHXA-031	CTF	12 Months	FY 2020 - FY 2022	[-]

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
	ASME III Code Case for Ceramic Compact Heat Exchanger Designs	WEC-TS-IHXA-032	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2020 - FY 2022	[-]
TRL 6 - TRL7	Shell-side flow distribution and bypass leakage tests.	WEC-TS-IHXA-033	CTF		FY 2022 - FY 2024	[-]
	Multi-module heat transfer testing	WEC-TS-IHXA-034	CTF		FY 2022 - FY 2024	[-]
TRL 7 - TRL 8	Testing of full size compact heat exchanger (Full scale NGNP IHX A)	WEC-TS-IHXA-035	NGNP		FY 2024 - FY 2027	[-]
IHX B [5]						**$7,848,905**
TRL 3 - TRL 4	Alloy 800H Material Specification and Procurement	WEC-TS-IHXB-001	INL, ORNL	12 Months	FY 2009 - FY 2015	$70,400
	Database for Brazed and Diffusion Bonded Alloy 800H	WEC-TS-IHXB-002	INL, ORNL, ANL, CHE designers/manufacturers	30 Months	FY 2009 - FY 2015	$3,730,876
	Alloy 800H High Temperature Material Properties	WEC-TS-IHXB-003	INL, ORNL, CSIR	3 Months	FY 2009 - FY 2015	$80,972
	Effects of Thermal Aging and Environment on Alloy 800H Properties	WEC-TS-IHXB-004	INL, ORNL	6 Motnhs	FY 2009 - FY 2015	$104,509
	Effects of Environmental Exposure on Alloy 800H Braze and Diffusion Bonded Joints	WEC-TS-IHXB-005	INL, ORNL	36 Months	FY 2009 - FY 2015	$367,616
	Effects of Grain Size and Section Thickness on Alloy 800H Properties	WEC-TS-IHXB-006	INL, ORNL, ANL, LANL, SNL, BNL, CSIR	24 Months	FY 2009 - FY 2015	$832,457
	Corrosion Allowances for Alloy 800H	WEC-TS-IHXB-007	INL, ORNL, FZJ, Saclay	36 Months	FY 2009 - FY 2015	$1,901,075
	Thermal/Fluid Modeling Methods for IHX B	WEC-TS-IHXB-008	CHE designer/supplier, INL, ORNL, ANL	36 Months	FY 2009 - FY 2015	$140,250

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
	Methods for Stress/Strain Modling of IHX B	WEC-TS-IHXB-009	CHE designer/supplier, INL, ORNL, ANL	36 Months	FY 2009 - FY 2015	$140,250
	Criteria for Structural Intergrity of IHX B	WEC-TS-IHXB-010	CHE designer/supplier, INL, ORNL, ANL	36 Months	FY 2009 - FY 2015	$140,250
	Performance Modeling Methods for IHX B	WEC-TS-IHXB-011	CHE designer/supplier, INL, ORNL, ANL	48 Months	FY 2009 - FY 2015	$140,250
TRL 4 - TRL 5	Specification of testing of Unit Cell of Compact Heat Exchanger **[3]**	WEC-TS-IHXB-012	CHE designer/manufacturer (Heatric, Brayton Energy)	24 Months	FY 2014 - FY2016	$200,000
TRL 5 - TRL 6	Specification of testing of compact heat exchanger module (~1.2MW)	WEC-TS-IHXB-013	CTF	24 Months	FY 2017 - FY 2019	[-]
	ASME Section III Code Case for Compact Heat Exchanger Designs	WEC-TS-IHXB-014	CHE supplier/design authority, INL, ORNL, ANL, LANL	48 Months	FY 2017 - FY 2019	[-]
TRL 6 - TRL 7	Shell-side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXB-015	CTF		FY 2018 - FY 2020	[-]
	Multi-module Heat Transfer Testing	WEC-TS-IHXB-016	CTF		FY 2018 - FY 2020	[-]
TRL 7 - TRL 8	Specification of testing of a full scale compact heat exchanger	WEC-TS-IHXB-017	NGNP	24 Months	FY 2020 - FY 2022	[-]
HTS Piping						**$1,765,200**
TRL 4 - TRL5	PHTS high-temperature [760°C and 950°C] piping cooling, liner and insulation options trade study	WEC-TS-PIP-001	Piping System Designer	6 Months	FY 2009 - FY 2012	$211,200
	PHTS low-temperature [350°C] piping liner and insulation options trade study	WEC-TS-PIP-002	Piping System Designer	6 Months	FY 2009 - FY 2012	$140,800
	SHTS high-temperature[840°C and 900°C] piping liner and insualtion study	WEC-TS-PIP-003	Piping System Designer	6 Months	FY 2009 - FY 2012	$211,200
	SHTS medium-temperature [659°C and 700°C] piping liner and insulation trade study	WEC-TS-PIP-004	Piping System Designer	6 Months	FY 2009 - FY 2012	$140,800

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
	SHTS low-temperature [<300°C] piping liner and insulation trade study	WEC-TS-PIP-005	Piping System Designer	6 Months	FY 2009 - FY 2012	$105,600
TRL 5 - TRL 6	Effects of He infiltration on thermal conductivity of insulation material **[6]**	WEC-TS-PIP-006	Insulation Manufacturers, INL, ORNL, ANL	18 Months	FY 2009 - FY 2012	$400,000
	The effect of fluid impurities on insulation properties **[7]**	WEC-TS-PIP-007	Insulation Manufacturers, INL, ORNL, ANL	18 Months	FY 2009 - FY 2012	$450,000
	Re-evaluation of needed maturation tasks based on Trade studies	WEC-TS-PIP-008	Piping System Designer	3 Months	FY 2009 - FY 2012	$105,600
TRL 6 - TRL 7	Performance and environmental testing of prototypical hegh-temperature and low-temperature piping/insulation system	WEC-TS-PIP-009	CTF	24 Months	FY 2011 - FY 2013	[-]
TRL 7 - TRL 8	Testing of full sie PHTS piping in NGNP	WEC-TS-PIP-010	NGNP	24 Months	FY 2019 - FY 2020	[-]
Mixing Chamber [8]						**$2,498,000**
TRL 6 - TRL 7	Trade studies to select reference design	n/a	Supplier / Design Authority	12 Months	FY 2010 - FY 2013	$250,000
	Specification 1: Enhanced Mixing Devices Test Specification	WEC-TS-MC-001	supplier site	6 Months	FY 2009 - FY 2012	[-]
	Specification 2: Vibration Damping Devices Test Specification	WEC-TS-MC-002	supplier site	6 Months	FY 2009 - FY 2012	[-]
	Partial or Full Scale Flow Mixing Chamber Model Test Specification	WEC-TS-MC-003	CTF / Supplier site	12 Months	FY 2009 - FY 2012	[-]
TRL 7 - TRL 8	Prototype Flow Mixing Chamber Test Specification	WEC-TS-MC-004	NGNP Site	12 Months	FY 2016 - FY2018	[-]
Steam Generator [9]						**$22,500,000**

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
TRL 6 - TRL 7	Perform a down selection trade study to determine the preferred conceptual arrangement of the SG	WEC-TS-SG-001	n/a	48 Months	FY 2009 - FY2012	[-]
	Define requirements and design details for the SG in the PCS system context	WEC-TS-SG-002	n/a	48 Months	FY 2009 - FY2012	[-]
	Perform configuration development tests to substantiate the design	WEC-TS-SG-003	n/a	48 Months	FY 2009 - FY2012	[-]
	Design and supply a scale prototype for the testing in the CTF	WEC-TS-SG-004	n/a	48 Months	FY 2009 - FY2012	[-]
	Performance testing in CTF	WEC-TS-SG-005	CTF	48 Months	FY 2009 - FY2012	[-]
TRL 7 - TRL 8	Complete final design of the prototype SG for the NGNP	WEC-TS-SG-006	n/a	40 - 50 months	FY 2011 - FY2014	[-]
	Fabricate and deliver to NGNP to the Site	WEC-TS-SG-007	n/a	40 - 50 months	FY 2011 - FY2014	[-]
	Install and operate	WEC-TS-SG-008	NGNP	40 - 50 months	FY 2011 - FY2014	[-]
Fuel [10]						**$45,000,000**
TRL 6 - TRL 7	Production Fuel Irradiation Tests for Normal Operational Conditions	WEC-TS-FUEL-001	INM Facility		FY 2012 - 2015	[-]
	Production Fuel Heat-up Tests	WEC-TS-FUEL-002	INM Facility		FY 2012 - 2015	[-]
	Fuel Matrix Graphite Irradiation tests and PIE	WEC-TS-FUEL-003	IVV-2M Russian Reactor		FY 2012 - 2015	[-]
	Machined Graphite Irradiation tests and PIE	WEC-TS-FUEL-004	IVV-2M Russian Reactor		FY 2012 - 2015	[-]

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
TRL 7 - TRL 8	Additional Production Fuel Irradiation Tests for Normal Operational Conditions	WEC-TS-FUEL-005	Suitable Test Reactor - ATR		FY 2012 - 2015	[-]
	Production Fuel Heat-up Tests	WEC-TS-FUEL-006	Suitable Test Reactor - ATR		FY 2012 - 2015	[-]
	Fuel Matrix Graphite Irradiation tests and PIE	WEC-TS-FUEL-007	Suitable Test Reactor - ATR		FY 2012 - 2015	[-]
CSC [11]						**$5,000,000**
TRL 6 - TRL 7	PBMR Relevant	WEC-TS-CSC-001			FY 2009 - FY 2013	[-]
	Extended Properties of Irradiated Graphite at Low Temperatures	WEC-TS-CSC-002	National Laboratory / University		FY 2009 - FY 2013	[-]
	Extended Properties of Irradiated Graphite at High Temperatures	WEC-TS-CSC-003	National Laboratory / University		FY 2009 - FY 2013	[-]
	Characterize Race Track Strap and Tie Rod Material	WEC-TS-CSC-004	National Laboratory / University		FY 2009 - FY 2013	[-]
	Insulation Material (Unirradiated Data Needed)	WEC-TS-CSC-005	National Laboratory / University		FY 2009 - FY 2013	[-]
HPS [12]						**$193,900,000**
Sulfuric Acid Decomposition		n/a	n/a	n/a	n/a	$65,700,000
Sulfur Dioxide Electorlysis		n/a	n/a	n/a	n/a	$128,200,000
Bunsen Reaction and HI decomposition		n/a	n/a	n/a	n/a	$252,100,000

Table 17-4: Original TDRM Cost Estimates (Facility Description and Total Cost Included)

SSC	Test Specification	Test Specification Number	Facility/Supporting Organizations	Duration	Fiscal Year/s	Total ($)
High Temperature Steam Electrolysis		n/a	n/a	n/a	n/a	$128,800,000

[1] Additional design information is required to conduct sensible cost estimates. Trade studies still have to be completed for the Circulator to verify and determine the specific combinations of sub-components that will be used.

[2] For IHX A, estimates have been conducted for three heats. Estimates exclude TRL 5 to TRL 8 advancements due to uncertainties that are still present for later TRL advancements

[3] Total based on discussions with Scott Penfield. Further detail for cost breakdown still required

[4] Equivalent work relating to metallic IHX A have been adjusted by a factor of 2 due to various uncertainties existing with regards to ceramics (sample preparation, materials cost, etc.). Estimates exclude TRL 5 to TRL 8 advancements due to uncertainties that are still present for later TRL advancements

[5] Equivalent work relating to metallic IHX A have been adjusted by factors shown in Table 18.1 in Section 1: Integrated Schedule and Cost Estimate (with Facility Information). Estimates exclude TRL 5 to TRL 8 advancements due to uncertainties that are still present for later TRL advancements

[6] Total based on discussions with Phil Rittenhouse. Further detail for cost breakdown still required

[7] Total based on discussions with Phil Rittenhouse. Further detail for cost breakdown still required

[8] NGNP PCDR Report - Section 16 estimate given - Concept design of plant needs to be progressed before sensible cost estimates can be given.

[9] NGNP PCDR Report - Section 16 estimate given - Concept design of plant needs to be progressed before sensible cost estimates can be given.

[10] NGNP PCDR Report - Section 16 estimate given

[11] NGNP PCDR Report - Section 16 estimate given

[12] Estimates for various process HPS technologies noted in NGNP-CTF MTECH-TDRM-008. Sum total reflects totals of sulfuric acid decomposition technology development as well as sulfur dioxide electrolysis technology development. For the purposes of this estimation, estimations reflect costs needed to etablish Hybrid Sulphur hydrogen production system (even though the reference design still has to be selected).

INL - **Idaho National Laboratory**
ORNL - **Oak Ridge National Laboratory**
ANL - **Argonne National Laboratory**
LANL - **Los Alamos National Laboratory**
SNL - **Sandia National Laboratory**
BNL - **Brookhaven National Laboratory**
CSIR - **Council for Scientific Industrial Research**

17.1.6 Conclusion – Cost Estimates

Cost estimates have been provided for certain critical SSCs (notably IHX A (metallic as well as ceramic), IHX B and HTS Piping). Estimates have only been provided up to a TRL rating of 5. Estimates for higher TRL advancements can only be provided when additional design information (preliminary or final) of the NGNP and components are available.

For some of the SSCs, more design information is required in order to develop reliable cost estimates (notably PHTS Circulator, SHTS Mixing Chamber and Steam Generator). Trade studies (or various trade studies) need to be done to verify and determine the specific combinations of sub-components that will be used in the aforementioned SSC's. There is enough time in the modified schedule to perform the trade studies before the advancement of the TRLs and before possible testing in the CTF will be performed. Costing input relating to the HPS as noted in the Hydrogen Plant Alternatives Study (HPAS) has also been incorporated into this document.

The bases for the estimates given (with the exception of the HPS) have also been noted in Appendix A of this document.

17.2.5 Appendix A: Detailed Cost Estimation Sheets

Basis motivations for cost estimations

1) General

- Guidelines for minimum required number of samples shown in 'sample' sheet

2) Bases for estimations

- Discussions with institutions/available information from institutions conducting similar work (notably ORNL and CSIR) serves partly as basis for these estimations
- Information stipulated in technology maturation plans with an element of engineering judgment also serve as part basis for cost estimations.
- Basis of cost estimation of test equipment costs noted is based on available information for similar work conducted at ORNL
- 10 percent contingency has been built into estimates of individual test specifications
- Material costs have been based on the following:
    a) Alloy 617 - $40/kg, as well as typical sample size needed for relevant testing
    b) Alloy 800H - $35/kg, as well as typical sample size needed for relevant testing
    c) Ceramic - $40/kg (please note that this is subject to change since the down selection still has to be done)
- Other additional bases for testing requirements that are needed are stated in estimate sheets

Crit SSC	Specification number	Specification	Description		Comments
IHX A	WEC-TS-IHXA-001	Alloy 617 Material Specifications and Procurement	Finalize material specifications, develop procurement requirements, procure 3 heats of Alloy 617		N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Compile Alloy 617 procurement specification	Engineer	200	N/A	8	5	4	3	96000	1) Based on time needed to compile procurement specification, inspection during procurement production (production/ rolling/sampling) as well as compiling report.

Total ($)	**96000**
10% contingency ($)	**9600**
Grand total ($)	**105600**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-002	Alloy 617 joining technology and resultant properties	Demonstrate that Alloy617 can be welded, brazed, diffusion bonded and that joint properties are appropriate for this use	N/A

W = Welding
BR = Brazing
DB = Diffusion Bonding

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Weld design/Compiling W-BR-DB specification	Engineer	200		8	5	4	3		96000	Assuming 1 month needed per joining method to compile specification (W/BR/DB)
Welding of joints (W/BR/DB)	Coded welder	100		8	5	46			184000	549 samples to be joined. Due to large uncertainty of of time needed to establish diffusion bonded specimens, assume that 12 samples/week are to be joined (irrespective of joining method).
Conducting testing: Joint properties	Laboratory Technician	80	n/a	8	5	61			195200	Testing will require resources in the form of 1 engineer ($200/hour) as well as 1 laboratory technician
Oversee & Manage	Engineer	200	n/a	8	5	61			488000	(80$/hour). Assuming that 9 samples are tested /week (due to large time uncertainty for fatigue testing).
Total 1 ($)									**963200**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding, pre-testing) [3]										
Cutting, polishing	549		640	351360					351360	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialists.
Observation of metallurgy	549		400	219600					219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour . Estimate made by specialists.
Chemistry profile in joints	549		400	219600					219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour . Estimate made by specialists.
Thermal Physical Mechanical properties of W/BR/DB joints										
Elastic properties [4]	18	7200	350	6300	n/a	n/a	n/a	500	14000	$350-00 per specimen at 950°C (+- 30°C). Based on official quotation to conduct work
Tensile Properties [5]	45	18000	350	15750	n/a	n/a	n/a	500	34250	$350-00 per specimen at 950°C (+- 30°C). Based on official quotation to conduct work
Fatigue Strength (LCF)	135	54000	720	97200	66000	n/a	n/a	1000	218200	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on official quotation to conduct work
Fatigue strength (HCF)	135	54000	800	108000	66000	n/a	n/a	1000	229000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on official quotation to conduct work
Creep strength	144	57600	3500	504000	n/a	n/a	n/a	500	562100	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on official quotation to conduct work
Fracture toughness: CTOD	27	10800	1000	27000	n/a	n/a	n/a	500	38300	Fracture toughness: CTOD - $1000-00 at 650°C per specimen. Based on official quotation to conduct work
Fracture toughness: Kc	27	10800	560	15120	n/a	n/a	n/a	500	26420	Fracture toughness: Kc - $560-00 at 650°C per specimen. Based on official quotation to conduct work
Thermal conductivity	18	7200	100	1800	n/a	n/a	n/a	500	9500	Thermal conductivity to 1000°C: - $95-00 per specimen. Based on official quotation to conduct work
Metallography/Optical/SEM (post-welding,post-testing) [6]										
Cutting, polishing, etching sample	459		640	293760					293760	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialists.
Observation of sample/metallurgy	459		400	183600					183600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialists.
Total 2 ($)		**219600**		**1252530**	**132000**	**0**	**0**	**5000**	**2399690**	

Materials

Materials requirement	Samples				Total ($)	Assumptions/Bases
		Mat.cost/sample	Material cost			
Alloy 617 samples [7]	n/a	n/a	32,931		32,931	Costing based on material price of $40/kg and typical sample size for relevant testing. This does not allow for the cost/development for the weld/braze alloy.
Total 3 ($)					**32931**	

Total ($)	**3395821**
10% contingency ($)	**339582.1**
Grand total ($)	**3735403.1**

[1] See preferred number of samples to be used in 'sample sheet'
[2] Basis for preparation costs - $400/sample
[3] Assuming that all the joined samples to be checked for joint integrity after joining
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Optical/SEM work to be conducted for tesile, fatigue (HCF & LCF) and creep
[7] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-003	Thermal, Physical and Mechanical properties of Alloy 617	Demonstrate that procured Alloy617 will have thermal, physical and mechanical properties appropriate for use in CHE	N/A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing	Laboratory Technician	80	n/a	8	5	21			67200	Testing will require resources in the form of 1 engineer ($200/hour) as well as 1 laboratory technician (80$/hour). Assuming that 9 samples are tested / week (due to large time uncertainty for fatigue testing)
Oversee & Manage	Engineer	200	n/a	8	5	21			168000	
Total 1 ($)									**235200**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis [3]	Reporting		
Thermal Physical Mechanical properties										
Elastic properties [4]	6	2400	350	2100	n/a	n/a	n/a	500	5000	$350-00 per specimen at 950°C (+- 30°C). Based on official quote to conduct work.
Tensile Properties [5]	15	6000	350	5250	n/a	n/a	n/a	500	11750	$350-00 per specimen at 950°C (+- 30°C). Based on official quote to conduct work.
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	9000	1000	126400	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on official quote to conduct work.
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	9000	1000	130000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on official quote to conduct work.
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on official quote to conduct work.
Fracture toughness: CTOD	9	3600	1000	9000	n/a	n/a	1800	500	14900	Fracture toughness: CTOD - $1000-00 at 650°C per specimen. Based on official quote to conduct work.
Fracture toughness: Kc	9	3600	560	5040	n/a	n/a	1800	500	10940	Fracture toughness: Kc - $560-00 at 650°C per specimen. Based on official quote to conduct work.
Thermal conductivity	6	2400	100	600	n/a	n/a	1200	500	4700	Thermal conductivity to 1000°C: - $95-00 per specimen. Based on official quote to conduct work.
SEM Related work										
n/a										
Total 2 ($)		**73200**		**258390**	**132000**	**0**	**22800**	**5000**	**491390**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Alloy 617 samples [6]	n/a	n/a	10,917		10,917	Costing based on material price of $40/kg and typical sample size needed for relevant testing.
Total 3 ($)					**10917**	

Total ($)	**737507**
10% contingency ($)	**73750.7**
Grand total ($)	**811257.7**

[1] See preferred number of samples to be used in 'sample sheet'
[2] Basis for preparation costs - $400/sample
[3] Post test analyses includes possible optical and scanning electron microscopy work and is based engineer/scientist tariff of $200/hour
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-004	Effects of thermal aging and environment on Alloy 617properties	Demonstrate that Alloy 617 and joints can be utilized in NGNP environment (temperature & medium) for long periods without degradation	N/A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Welding of joints (W/BR/DB)	Coded welder	100	n/a	8	5	46			184000	549 samples to be joined. Due to large uncertainty in time needed to establish diffusion bonded specimens, assume that 12 samples/week are to be joined (irrespective of joining method).
Oversee & Manage: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Basis that thermal exposure samples are to be monitored by lab technician every 100h (100 intervals).
Conducting testing: Alloy/Joint properties	Laboratory Technician	80	n/a	8	5	82			262400	Testing will require resources in the form of 1 engineer ($200/hour) as well as 1 laboratory technician (80$/hour).
Oversee & Manage	Engineer	200	n/a	8	5	82			656000	Assuming that 9 samples are tested / week (due to large time uncertainty for fatigue testing)
Total 1 ($)									**1112400**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding, pre-testing) [3]										
Cutting, polishing sample	549	n/a	640	351360		n/a	n/a	n/a	351360	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialist.
Observation of metallurgy	549	n/a	400	219600		n/a	n/a	500	219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Chemistry profile in joints	549	n/a	400	219600		n/a	n/a	500	219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Thermal Physical Mechanical properties of Alloy 617 and W/BR/DB joints										
Elastic properties [4]	24	9600	350	8400	n/a	n/a	n/a	500	18500	$350-00 per specimen at 950℃ (+- 30℃). Based on official quotation to conduct work.
Tensile Properties [5]	60	24000	350	21000	n/a	n/a	n/a	500	45500	$350-00 per specimen at 950℃ (+- 30℃). Based on official quotation to conduct work.
Fatigue Strength (LCF)	180	72000	720	129600	66000	n/a	n/a	1000	268600	Fatigue strength LCF to 1000℃ - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950℃ (+- 30℃). Based on official quotation to conduct work.
Fatigue strength (HCF)	180	72000	800	144000	66000	n/a	n/a	1000	283000	Fatigue strength HCF to 1000℃ - $800-00 up to 1000 000 cycles per specimen at 950℃ (+- 30℃). Based on official quotation to conduct work.
Creep strength	192	76800	3500	672000	n/a	n/a	n/a	500	749300	Creep strength to 1000℃ for 10,000 h - $3500-00 per specimen. Based on official quotation to conduct work.
Fracture toughness: CTOD	36	14400	1000	36000	n/a	n/a	n/a	500	50900	Fracture toughness: CTOD - $1000-00 at 650℃ per specimen. Based on official quotation to conduct work.
Fracture toughness: Kc	36	14400	560	20160	n/a	n/a	n/a	500	35060	Fracture toughness: Kc - $560-00 at 650℃ per specimen. Based on official quotation to conduct work.
Thermal conductivity	24	9600	100	2400	n/a	n/a	n/a	500	12500	Thermal conductivity to 1000℃: - $95-00 per specimen. Based on official quotation to conduct work.
Metallography/SEM (post-welding, post-testing) [6]										
Cutting, polishing, etching sample	612	n/a	640	391680		n/a	n/a	n/a	391680	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialist.
Observation of sample/metallurgy	612	n/a	400	244800		n/a	n/a	500	244800	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Total 2 ($)		**292800**		**2460600**	**132000**	**0**	**0**	**6500**	**2890400**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Alloy 617 samples [7]	n/a	n/a	43,668		43,668	Costing based on material price of $40/kg and typical sample size for relevant testing. This does not allow for the cost/development for the weld/braze alloy.
Total 3 ($)					**43668**	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases
Capital cost - furnaces for thermal aging	3000	3		9000	Costing based on verbal quotation for furnace with required capability sized at 180mm x 180mm x 250mm
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies based on 10% of total capital cost for furnaces
Helium gas for regulating environment	120	156		18,720	156 x 50kg He cylinders to be utilized. Number based on utilization of one cylinder a week for each furnace for 1 year (52 weeks). He gas cost inclusive of impurity gases.
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on personal communication with relevant parties in Mtech.
Total 4 ($)				**36420**	

Total ($)	**4082888**	
10% contingency ($)	**408288.8**	
Grand total ($)	**4491176.8**	

[1] See preferred number of samples to be used in 'sample sheet'
[2] Basis for preparation costs - $400/sample
[3] Assuming that all samples to be checked for joint consistency after joining
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Optical/SEM work to be conducted for tensile, fatigue (HCF, LCF), creep
[7] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-005	Effects of grain size and section thickness on Alloy 617	Demonstrate that slight changes in grain size as well as the section thickness of Alloy 617 has little effect in overall properties of material	N/A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing: Alloy 617 properties	Laboratory Technician	80	n/a	8	5	16			51200	Testing will require resources in the form of 1 engineer ($200/hour) as well as 1 laboratory technician (80$/hour). Assuming that 9 samples/week are tested (due to large time uncertainty for fatigue testing).
Oversee & Manage	Engineer	200	n/a	8	5	16			128000	
Total 1 ($)									179200	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Thermal Physical Mechanical properties of Alloy 617										
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	n/a	1000	117400	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on official quotation to conduct work.
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	n/a	1000	121000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on official quotation to conduct work.
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on official quotation to conduct work.
Metallography/SEM (post-testing) [3]										
Cutting, polishing, etching sample	138		640	88320		n/a	n/a	n/a	88320	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialist.
Observation of sample/metallurgy	138		400	55200		n/a	n/a	500	55200	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Total 2 ($)		55200		379920	132000	0	0	3000	569620	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Alloy 617 samples [4]	n/a	n/a	9,096		9,096	Costing based on material price of $40/kg and typical sample size relevant for testing.Number of samples only relevant to fatigue testing and creep testing
Total 3 ($)					9096	

Total ($)	**757916**
10% contingency ($)	**75791.6**
Grand total ($)	**833707.6**

[1] See preferred number of samples to be used in 'sample sheet'
[2] Basis for preparation costs - $400/sample
[3] Optical/SEM work to be conducted for fatigue and creep samples
[4] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-006	Corrosion allowances for Alloy 617	Demonstrate satisfactory corrosion allowances for Alloy 617 and welded/bonded sections	N/A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Welding of joints (W/BR/DB)	Coded welder	100	n/a	8	5	12			48000	135 samples to be joined. Due to large uncertainty of time needed to establish diffusion bonded specimens, assume that 12 are to be joined (irrespective of joining method).
Oversee & Manage: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Basis that thermal exposure samples are to be monitored by lab technician every 100h (100 intervals).
Oversee & Manage	Engineer	200	n/a	8	5	20			160000	
Total 1 ($)									**218000**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples	Prep (Machining) [1]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding) [2]										
Cutting, polishing sample	135	n/a	640	86400		n/a	n/a	n/a	86400	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialist.
Observation of metallurgy	135	n/a	400	54000		n/a	n/a	500	54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Chemistry profile in joints	135	n/a	400	54000		n/a	n/a	500	54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Thermal Physical Mechanical properties of Alloy 617 and W/BR/DB joints										
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
Metallography/SEM (post-testing)										
Cutting, polishing, etching sample	180	n/a	640	115200		n/a	n/a	n/a	115200	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Estimate made by specialist.
Observation of sample/metallurgy	180	n/a	400	72000		n/a	n/a	500	72000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Depth of internal oxidation	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Depth of depletion of alloy elements (Cr)	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Depth affected bycarburization/ decarburization	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Estimate made by specialist.
Total 2 ($)		0		597600	0	0	0	3000	599100	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Alloy 617 samples [3]	n/a	n/a	12,120		12,120	Costing based on material price of $40/kg and typical sample size relevant for testing. This does not allow for the cost/development for the weld/braze alloy.
Total 3 ($)					**12120**	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases
Capital cost - furnaces for thermal aging	3000	3		9000	Costing based on verbal quotation for furnace with required capability sized at 180mm x 180mm x 250mm
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies based on 10% of total capital cost for furnaces
Helium gas for regulating environment	120	156		18,720	156 x 50kg He cylinders to be utilized. Number based on utilization of one cylinder a week for each furnace for 1 year (52 weeks). He gas cost inclusive of impurity gases.
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on personal communication with relevant parties in Mtech.
Total 4 ($)				**36420**	

Total ($) (Primary side He effects)	**865640**
Secondary side He effects ($)	**865640**
Total (Primary and Secondary effects) ($)	**1731280**
10% contingency ($)	**173128**
Grand total ($)	**1904408**

[1] Basis for preparation costs - $400/sample
[2] Assuming that all joined samples to be checked for joint consistency after joining
[3] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-007	ASME III Code case for Alloy 617	Develop and establish ASME Code case III for	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Preparatory work	Engineers	150	n/a	110				16500	1) Estmation inclusive of interactions with ASME during approval process and provision of additional data requested by ASME.
Draftting code case for Alloy 617	Engineers	150	n/a	4500				675000	Based on discussions with George Hayner.
Total 1 ($)								691500	

Total ($)	**691500**
10% contingency ($)	**69150**
Grand total ($)	**760650**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-008	Thermal/Fluid modelling methods for IHX A	Develop thermal models for IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases
		Hour	Year	Hours	Days	Weeks	Months	Year		
Model generation giving results for mechanical, physical and thermal performance prediction	Group of thermal fluid/modeling specialists		42,500					3	127500	1) Estmation made by M-Tech based on technology maturation plan input- Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work

Total ($)	127500
10% contingency ($)	12750
Grand total ($)	140250

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-009	Methods for stress-strain modelling of IHX A	Develop structural modelling methods for predictive operation for IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases
		Hour	Year	Hours	Days	Weeks	Months	Year		
Structural model generation giving results for predictive operation for IHX B	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech based on technology maturation plan input. Duration of 3 years for work

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-010	Criteria for structural integrity	Establish criteria for structural integrity of CHE's	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases
		Hour	Year	Hours	Days	Weeks	Months	Year		
Structural integrity models of CHE's	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech based on technology maturation plan input. Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-011	Performance modelling methods for IHX A	Develop performance models for predictive operation for IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases
		Hour	Year	Hours	Days	Weeks	Months	Year		
Performance models for IHX	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech based on technology maturation plan input. Duration of 3 years for work

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Material cost details based on preferred number of samples to be tested - Alloy 617 (@ $40/kg)

Sample amount	Per sample cost - 617 Mat.cost	549	IHXA.2	183	IHXA.3	732	IHXA.4	138	IHXA.5	180	IHXA.6
Cost	**($)**	**samples**	**($)**	**samples**	**($)**		**($)**		**($)**		**($)**
Elastic Properties	**1**	18	18	6	6	24	24	0	0	0	0
Tensile Properties	**1**	45	45	15	15	60	60	0	0	0	0
Fatigue strength (LCF)	**100**	135	13500	45	4500	180	18000	45	4500	60	6000
Fatigue strength (HCF)	**100**	135	13500	45	4500	180	18000	45	4500	60	6000
Creep strength	**2**	144	288	48	96	192	384	48	96	60	120
Fracture toughness: CTOD	**100**	27	2700	9	900	36	3600	0	0	0	0
Fracture toughness: Kc	**100**	27	2700	9	900	36	3600	0	0	0	0
Thermal conductivity	**10**	18	180	6	60	24	240	0	0	0	0
Total ($)	**414**		**32931**		**10917**		**43668**		**9096**		**12120**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-018	Trade studies on candidate ceramic materials	Evaluate ceramic materials for use in ceramic CHE's	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate ceramic materials from trade studies	Engineer	200	N/A	8	5	4	6	192000	Based on need of one engineer for duration of 6 months to complete trade studies. Reporting included.

Total ($)	**192000**
10% contingency ($)	**19200**
Grand total ($)	**211200**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-019	Trade studies on candidate ceramic CHE designs	Evaluate ceramic CHE designs for use in ceramic IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate ceramic CHE designs from trade studies	Engineer	200	N/A	8	5	4	6	192000	Based on need of one engineer for duration of 6 months to complete trade studies. Reporting included.

Total ($)	**192000**
10% contingency ($)	**19200**
Grand total ($)	**211200**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-020	Ceramic Heat Exchanger Detailed DDN's	Develop detailed DDN's for the ceramic IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Developing detailed DDN's for ceramic IHX A	Engineer	200	N/A	8	5	4	5	160000	Based on need of one engineer for duration of 6 months to compile DDN's. Reporting included.

Total ($)	**160000**
10% contingency ($)	**16000**
Grand total ($)	**176000**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-021	Ceramic Material Specifications and Procurement	Finalize material specifications, develop procurement requirements	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months		
Ceramic procurement specification	Engineer	200	N/A	8	5	4	3	96000	1) Based on time needed to compile procurement specification, inspection during procurement production as well as compiling report.

Total ($)	**96000**
10% contingency ($)	**9600**
Grand total ($)	**105600**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-022	Thermal, Physical properties of Ceramic	Demonstrate that procured Ceramic will have thermal, physical properties appropriate for use in CHE	N/A

Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing	Laboratory Technician	80	n/a	8	5	2			6400	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	2			16000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor).
Total 1 ($)									**22400**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Thermal Physical properties										
Thermal conductivity	6	2400	100	600	n/a	n/a	1200	500	4700	Thermal conductivity to 1000℃: - $95-00 per specimen. Based on metallic IHX A (see adjustment fac
Coefficient of thermal expansion	6	2400	350	2100	n/a	n/a	n/a	500	5000	Coefficient of thermal expansion test cost based on Tensile/Elastic properties' price.
Thermal shock resistance	6	2400	350	2100	n/a	n/a	1200	500	6200	Thermal shock resistance test cost based on Tensile/Elastic properties' price.
SEM Related work										
n/a										
Total 2 ($)		**7200**		**4800**	**0**	**0**	**2400**	**1500**	**15900**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Ceramic samples [3]	n/a	n/a	180		180	Costing based on material price of $40/kg. Other factors based on metallic IHX A (see adjustment fac
Total 3 ($)					**180**	

Total ($)	**38480**	
Total (4 heats at least) ($)	**153920**	
10% contingency ($)	**15392**	
Grand total ($)	**169312**	
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**	**Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.**
Equivalent costs for ceramic IHX A specification	**338624**	

[1]See preferred number of samples to use in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-023	Mechanical properties of Ceramic	Demonstrate that procured Ceramic will have the mechanical properties appropriate for use in CHE	N/A

Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing	Laboratory Technician	80	n/a	8	5	20			64000	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	20			160000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor).
Total 1 ($)									224000	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis [3]	Reporting		
Thermal Physical Mechanical properties										
Elastic properties [4]	6	2400	350	2100	n/a	n/a	n/a	500	5000	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Tensile Properties [5]	15	6000	350	5250	n/a	n/a	n/a	500	11750	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	9000	1000	126400	Fatigue strength LCF to 1000℃ - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	9000	1000	130000	Fatigue strength HCF to 1000℃ - $800-00 up to 1000 000 cycles per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000℃ for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment fac
Fracture toughness: CTOD	9	3600	1000	9000	n/a	n/a	1800	500	14900	Fracture toughness: CTOD - $1000-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment facto
Fracture toughness: Kc	9	3600	560	5040	n/a	n/a	1800	500	10940	Fracture toughness: Kc - $560-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment factor).
Total 2 ($)		70800		257790	132000	0	21600	4500	486690	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Ceramic samples [6]	n/a	n/a	10,917		10,917	Costing based on material price of $40/kg. Other factors based on metallic IHX A (see adjustment factor).
Total 3 ($)					10917	

Total ($)	721607	
Total (4 heats at least) ($)	2886428	
10% contingency ($)	288643	
Grand total ($)	3175071	
Metallic IHX A to Ceramic IHX A ratio adjustment	0.5	**Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.**
Equivalent costs for ceramic IHX A specification	6350142	

[1]See preferred number of samples to use in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Post test analyses includes possible optical and scanning electron microscopy work and is based on engineer/scientist tariff
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-024	Compatibility of ceramic materials to NGNP He environment	Demonstrate that Ceramic can be utilized in NGNP environment (temperature & medium) for long periods without degradation	N/A

Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases
		Hour	Action	Hours	Days	Weeks	Months	Years		
Testing: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Basis that thermal exposure samples are to be monitored by lab technician every 100h (100 intervals). Based on metallic IHX A (see adjustment factor).
Oversee & Manage	Engineer	200	n/a	8	5	5			40000	Basis of estimate: Resource requirement in the form of one engineer at $200/hour at 9 samples/week Based on metallic IHX A (see adjustment factor).
Total 1 ($)									50000	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples	Prep (Machining) [1]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography/SEM										
Cutting, polishing, etching sample	45	n/a	640	28800		n/a	n/a	n/a	28800	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of sample/metallurgy	45	n/a	400	18000		n/a	n/a	500	18000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Total 2 ($)		0		46800	0	0	0	500	46800	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Ceramic samples [2]	n/a	n/a	3,030		3,030	Costing based on material price of $40/kg. Other factors based on metallic IHX A (see adjustment factor).
Total 3 ($)					3030	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor).)
Capital cost - furnaces for thermal aging	3000	3		9000	Costing based on verbal quotation for furnace with required capability sized at 180mm x 180mm x 250mm
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies based on 10% of total capital cost for furnaces
Helium gas for regulating environment	120	156		18,720	156 x 50kg He cylinders to be utilized. Number based on utilization of one cylinder a week for each furnace for 1 year (52 weeks). He gas cost inclusive of impurity gases.
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on personal communication with relevant parties in Mtech.
Total 4 ($)				36420	

Total ($)	**136250**	
Total (4 heats at least) ($)	**545000**	
10% contingency ($)	**54500**	
Grand total ($)	**599500**	**Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**	
Equivalent costs for ceramic IHX A specification	**1199000**	

[1] Basis for preparation costs - $400/sample

[2] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-025	Manufacturing technology for ceramic CHE's	Ensure that methods and techniques are available and effective in establishing the CHE	N/A

C-C = ceramic to ceramic bond
C-M = ceramic to metallic
C-C comp = C-C composite joints

Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Joint design/Compiling C-C/C-M/C-C comp bond specification	Engineer	200		8	5	4	3		96000	Assuming 1 month needed per joining method to compile specification (c-c/m-c/c-c comp)
Bonding of joints (C-C/C-M/C-C comp) for samples	Coded welder	100		8	5	45			180000	135 samples to be joined. Assume 3 samples/week due to the large uncertainty in time needed to establish ce
Oversee & Manage	Engineer	200	n/a	8	5	15			120000	Oversight and management will require resources in the form of 1 engineer ($200/hour)
Total 1 ($)									396000	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases
	Samples	Prep (Machining) [1]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography/Sample preparation & analyses [2]]										
Sample preparation	135		640	86400					86400	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor)
Observation of metallurgy/optical/SEM	135		400	54000					54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour . Based on metallic IHX A (see adjustment
Chemistry profile in joints	135		400	54000					54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour . Based on metallic IHX A (see adjustment
Total 2 ($)			1440	194400					194400	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Ceramic samples [3]	n/a	n/a	9,090		9,090	Costing based on material price of $40/kg. This does not allow for the cost/development for the weld/braze alloy. Other factors based on metallic IHX A (see adjustment factor)
Total 3 ($)					9090	

Total ($)	**599490**	
Total (4 heats at least) ($)	**2397960**	
10% contingency ($)	**239796**	
Grand total ($)	**2637756**	**Cost will be higher compared to similar metallic IHX A specification due to intricacy of sample preparation, machining and analyses as well as unknown detail regarding the ceramic material to be used.**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**	
Equivalent costs for ceramic IHX A specification	**5275512**	

[1] Basis for preparation costs - $400/sample
[2] Assuming that all the joined samples to be checked for joint integrity after joining
[3] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-026	Ceramic materials codes and standards	Develop and establish ASME code case and ASTM standards	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months		
Preparatory work	Engineers	150	n/a	110				16500	1) Estmation inclusive of interactions with ASME and ASTM during approval process and provision of additional data requested by ASME/ASTM. Basis entails discussions with George Hayner.
Drafting code case and standards for ceramic	Engineers	150	n/a	4500				675000	
Total 1 ($)								691500	

Total ($)	**691500**
10% contingency ($)	**69150**
Grand total ($)	**760650**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**
Equivalent costs for ceramic IHX A specification	**1521300**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-027	Thermal/Fluid and stress-strain modelling methods for ceramic IHX A	Develop thermal-fluid and stress-strain models for ceramic IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor))
		Hour	Year	Hours	Days	Weeks	Months	Year		
Model generation combining thermal-fluid as well as stress-strain models to guide ceramic IHX design	Group of modeling specialists		63,000					3	189000	1) Estmation made by M-Tech - Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work

Total ($)	**189000**
10% contingency ($)	**18900**
Grand total ($)	**207900**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**
Equivalent costs for ceramic IHX A specification	**415800**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-028	Criteria for structural integrity for ceramic IHX A	Establish criteria for structural integrity for ceramic IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor))
		Hour	Year	Hours	Days	Weeks	Months	Year		
Structural integrity models of ceramic IHX A	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech - Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**
Equivalent costs for ceramic IHX A specification	**280500**

Crit SSC	Specification number	Specification	Description	Comments
IHX A	WEC-TS-IHXA-029	Performance modelling methods for ceramic IHX A	Develop performance models for predictive operation for ceramic IHX A	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor))
		Hour	Year	Hours	Days	Weeks	Months	Year		
Performance models for ceramic IHX	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech Duration of 3 years for work

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**
Metallic IHX A to Ceramic IHX A ratio adjustment	**0.5**
Equivalent costs for ceramic IHX A specification	**280500**

Material cost details based on preferred number of samples to be tested - Ceramic [1] (@ $40/kg)

Sample amount [2] Sheet name	Per sample cost - 617 Mat.cost	18	IHXA.22	177	IHXA.23	45	IHXA.24	135	IHXA.25
Cost	($)	samples	($)	samples	($)		($)		($)
Elastic Properties	**1**	0	0	6	6	0	0	0	0
Tensile Properties	**1**	0	0	15	15	0	0	0	0
Fatigue strength (LCF)	**100**	0	0	45	4500	15	1500	45	4500
Fatigue strength (HCF)	**100**	0	0	45	4500	15	1500	45	4500
Creep strength	**2**	0	0	48	96	15	30	45	90
Fracture toughness: CTOD	**100**	0	0	9	900	0	0	0	0
Fracture toughness: Kc	**100**	0	0	9	900	0	0	0	0
Thermal conductivity	**10**	18	180	0	0	0	0	0	0
Total ($)	414		180		10917		3030		9090

[1] Down selection of the ceramic material still has to be done and this value is subject to change

[2] Sample amount needed based on Metallic IHX A Samples required

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-001	Alloy 800H Material Specifications and Procurement	Finalize material specifications, develop procurement requirements, procure 1/2 heats of Alloy 800H	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months		
Alloy 800H procurement specification	Engineer	200	N/A	8	5	8		64000	1) Based on time needed to compile procurement specification, inspection during procurement production (production/rolling/sampling) as well as compiling report.

Total ($)	64000
10% contingency ($)	6400
Grand total ($)	70400

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-002	Alloy 800H joining technology and resultant properties	Demonstrate that Alloy800H can be brazed, diffusion bonded and that joint properties are appropriate for this use	N/A

W = Welding
BR = Brazing
DB = Diffusion Bonding **Same equivalent of work needed as for metallic IHX A specification**

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Weld design/Compiling W-BR-DB specification	Engineer	200		8	5	4	3		96000	Assuming 1 month needed per joining method to compile specification (W/BR/DB)
Welding of joints (W/BR/DB)	Coded welder	100		8	5	46			184000	549 samples to be joined. Due to large uncertainty of the time needed to establish diffusion bonded specimens, assume that 12 samples/week are to be joined (irrespective of joining method).
Conducting testing: Joint properties	Laboratory Technician	80	n/a	8	5	61			195200	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	61			488000	as well as 1 laboratory technician (80$/hour). Assuming that 9 samples/week are tested
Total 1 ($)									**963200**	(due to large time uncertainty for fatigue testing)

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding, pre-testing) [3]										
Cutting, polishing	549		640	351360					351360	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor)
Observation of metallurgy	549		400	219600					219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor)
Chemistry profile in joints	549		400	219600					219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor)
Thermal Physical Mechanical properties of W/BR/DB joints										
Elastic properties [4]	18	7200	350	6300	n/a	n/a	n/a	500	14000	$350-00 per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Tensile Properties [5]	45	18000	350	15750	n/a	n/a	n/a	500	34250	$350-00 per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Fatigue Strength (LCF)	135	54000	720	97200	66000	n/a	n/a	1000	218200	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Fatigue strength (HCF)	135	54000	800	108000	66000	n/a	n/a	1000	229000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Creep strength	144	57600	3500	504000	n/a	n/a	n/a	500	562100	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: CTOD	27	10800	1000	27000	n/a	n/a	n/a	500	38300	Fracture toughness: CTOD - $1000-00 at 650°C per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: Kc	27	10800	560	15120	n/a	n/a	n/a	500	26420	Fracture toughness: Kc - $560-00 at 650°C per specimen. Based on metallic IHX A (see adjustment factor)
Thermal conductivity	18	7200	100	1800	n/a	n/a	n/a	500	9500	Thermal conductivity to 1000°C: - $95-00 per specimen. Based on metallic IHX A (see adjustment factor)
Metallography/Optical/SEM (post-welding,post-testing) [6]										
Cutting, polishing, etching sample	459		640	293760					293760	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor)
Observation of sample/metallurgy	459		400	183600					183600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour . Based on metallic IHX A (see adjustment factor)
Total 2 ($)		**219600**		**1252530**	**132000**	**0**	**0**	**5000**	**2399690**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
Alloy 800H samples [7]	n/a	n/a	28,815		28,815	Costing based on material price of $35/kg. This does not allow for the cost/development for the weld/braze alloy. Other aspects based on metallic IHX A (see adjustment factor)
Total 3 ($)					**28815**	

Total ($)	**3391705**	
10% contingency ($)	**339170**	
Grand total ($)	**3730875**	
IHX A to IHX B ratio adjustment	**1**	**Same estimates for IHX B relating to IHX A** **Same equivalent of work needed as for metallic IHX A specification**
Equivalent costs for IHX B specification	**3730875**	

[1] See preferred number of samples to be used in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Assuming that all the joined samples to be checked for joint integrity after joining
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Optical/SEM work to be conducted for tesile, fatigue (HCF & LCF) and creep
[7] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-003	Thermal, Physical and Mechanical properties of Alloy 800H	Demonstrate that procured Alloy800H will have thermal, physical and mechanical properties appropriate for use in CHE	N/A

Cost will be lower compared to similar metallic IHX A specification due to the existing Alloy 800H database that can be adopted

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing	Laboratory Technician	80	n/a	8	5	21			67200	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	21			168000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor)
Total 1 ($)									**235200**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis [3]	Reporting		
Thermal Physical Mechanical properties										
Elastic properties [4]	6	2400	350	2100	n/a	n/a	n/a	500	5000	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor)
Tensile Properties [5]	15	6000	350	5250	n/a	n/a	n/a	500	11750	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor)
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	9000	1000	126400	Fatigue strength LCF to 1000℃ - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor)
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	9000	1000	130000	Fatigue strength HCF to 1000℃ - $800-00 up to 1000 000 cycles per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor)
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000℃ for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: CTOD	9	3600	1000	9000	n/a	n/a	1800	500	14900	Fracture toughness: CTOD - $1000-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: Kc	9	3600	560	5040	n/a	n/a	1800	500	10940	Fracture toughness: Kc - $560-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment factor)
Thermal conductivity	6	2400	100	600	n/a	n/a	1200	500	4700	Thermal conductivity to 1000℃: - $95-00 per specimen. Based on metallic IHX A (see adjustment factor)
SEM Related work										
n/a										
Total 2 ($)		**73200**		**258390**	**132000**	**0**	**22800**	**5000**	**491390**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
Alloy 800H samples [6]	n/a	n/a	9,552		9,552	Costing based on material price of $35/kg. Other factots based on metallic IHX A (see adjustment factor)
Total 3 ($)					**9552**	

Total ($)	**736142**	
10% contingency ($)	**73614**	
Grand total ($)	**809757**	
IHX A to IHX B ratio adjustment	**10**	**Cost will be lower compared to similar metallic IHX A specification due to the existing Alloy 800H database that can be adopted**
Equivalent costs for IHX B specification	**80976**	

[1] See preferred number of samples to be used in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Post test analyses includes possible optical and scanning electron microscopy work and is based engineer/scientist tariff of $200/hour
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-004	Effects of thermal aging and environment on Alloy 800Hproperties	Demonstrate that Alloy 800H can be utilized in NGNP environment (temperature & medium) for long periods without degradation	N/A

Cost will be lower compared to similar metallic IHX A specification due to the existing Alloy 800H database that can be adopted

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Welding of joints (W/BR/DB)	Coded welder	n/a	n/a	n/a	n/a	n/a			0	
Oversee & Manage: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Thermal exposure monitored by lab technician every 100h (100 intervals). Based on metallic IHX A (see adjustment factor)
Conducting testing: Alloy properties	Laboratory Technician	80	n/a	8	5	21			67200	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	21			168000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor)
Total 1 ($)									**245200**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding, pre-testing) [3]										
Cutting, polishing sample	n/a	n/a	640	0		n/a	n/a	n/a	0	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor)
Observation of metallurgy	n/a	n/a	400	0		n/a	n/a	500	0	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor)
Chemistry profile in joints	n/a	n/a	400	0		n/a	n/a	500	0	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor)
Thermal Physical Mechanical properties										
of Alloy 800H and W/BR/DB joints										
Elastic properties [4]	6	2400	350	2100	n/a	n/a	n/a	500	5000	$350-00 per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Tensile Properties [5]	15	6000	350	5250	n/a	n/a	n/a	500	11750	$350-00 per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	n/a	1000	117400	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	n/a	1000	121000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor)
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: CTOD	9	3600	1000	9000	n/a	n/a	n/a	500	13100	Fracture toughness: CTOD - $1000-00 at 650°C per specimen. Based on metallic IHX A (see adjustment factor)
Fracture toughness: Kc	9	3600	560	5040	n/a	n/a	n/a	500	9140	Fracture toughness: Kc - $560-00 at 650°C per specimen. Based on metallic IHX A (see adjustment factor)
Thermal conductivity	6	2400	100	600	n/a	n/a	n/a	500	3500	Thermal conductivity to 1000°C: - $95-00 per specimen. Based on metallic IHX A (see adjustment factor)
Metallography/SEM (post-welding, post-testing) [6]										
Cutting, polishing, etching sample	183	n/a	640	117120		n/a	n/a	n/a	117120	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor)
Observation of sample/metallurgy	183	n/a	400	73200		n/a	n/a	500	73200	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor)
Total 2 ($)		**73200**		**448710**	**132000**	**0**	**0**	**6500**	**658910**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases
Alloy 800H samples [7]	n/a	n/a	9,552		9,552	Costing based on material price of $35/kg. This does not allow for the cost/development for the weld/braze alloy. Other aspects based on metallic IHX A (see adjustment factor)
Total 3 ($)					**9552.375**	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases
Capital cost - furnaces for thermal aging	3000	3		9000	Furnace with required capability sized at 180mm x 180mm x 250mm. Based on metallic IHX A (see adjustment factor)
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies make up 10% of total capital cost for furnaces. Based on metallic IHX A (see adjustment factor)
Helium gas for regulating environment	120	156		18,720	156 50kg x He cylinders to be utilized. One cylinder a week for each furnace (52 weeks in total). He gas cost inclusive of impurity gases. Based on metallic IHX A (see adjustment factor)
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on metallic IHX A (see adjustment factor)
Total 4 ($)				**36420**	

Total ($)	**950082.38**	
10% contingency ($)	**95008.238**	
Grand total ($)	**1045091**	
IHX A to IHX B ratio adjustment	**10**	**Cost will be lower compared to similar metallic IHX A specification due to the existing Alloy 800H database that can be adopted**
Equivalent costs for IHX B specification	**104509**	

[1] See preferred number of samples to be used in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Assuming that all samples to be checked for joint consistency after joining
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Optical/SEM work to be conducted for tensile, fatigue (HCF, LCF), creep
[7] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-005	Effects of environment on Alloy 800H joints	Demonstrate that Alloy 800H joints can be utilized in NGNP environment (temperature & medium) for long periods without degradation	N/A

Existing Alloy 800H database can be utilized

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Welding of joints (W/BR/DB)	Coded welder	100	n/a	8	5	46			184000	549 samples to be joined. Assume 12 samples/week. Based on metallic IHX A (see adjustment factor).
Oversee & Manage: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Thermal exposure monitored by lab technician every 100h (100 intervals). Based on metallic IHX A (see adjustment fac
Conducting testing: Alloy/Joint properties	Laboratory Technician	80	n/a	8	5	61			195200	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	61			488000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor).
Total 1 ($)									**877200**	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor).)
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding, pre-testing) [3]										
Cutting, polishing sample	549	n/a	640	351360		n/a	n/a	n/a	351360	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of metallurgy	549	n/a	400	219600		n/a	n/a	500	219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Chemistry profile in joints	549	n/a	400	219600		n/a	n/a	500	219600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Thermal Physical Mechanical properties of Alloy 800H and W/BR/DB joints										
Elastic properties [4]	18	7200	350	6300	n/a	n/a	n/a	500	14000	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Tensile Properties [5]	45	18000	350	15750	n/a	n/a	n/a	500	34250	$350-00 per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Fatigue Strength (LCF)	135	54000	720	97200	66000	n/a	n/a	1000	218200	Fatigue strength LCF to 1000℃ - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Fatigue strength (HCF)	135	54000	800	108000	66000	n/a	n/a	1000	229000	Fatigue strength HCF to 1000℃ - $800-00 up to 1000 000 cycles per specimen at 950℃ (+- 30℃). Based on metallic IHX A (see adjustment factor).
Creep strength	144	57600	3500	504000	n/a	n/a	n/a	500	562100	Creep strength to 1000℃ for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment factor).
Fracture toughness: CTOD	27	10800	1000	27000	n/a	n/a	n/a	500	38300	Fracture toughness: CTOD - $1000-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment factor).
Fracture toughness: Kc	27	10800	560	15120	n/a	n/a	n/a	500	26420	Fracture toughness: Kc - $560-00 at 650℃ per specimen. Based on metallic IHX A (see adjustment factor).
Thermal conductivity	18	7200	100	1800	n/a	n/a	n/a	500	9500	Thermal conductivity to 1000℃: - $95-00 per specimen. Based on metallic IHX A (see adjustment factor).
Metallography/SEM (post-welding, post-testing) [6]										
Cutting, polishing, etching sample	459	n/a	640	293760		n/a	n/a	n/a	293760	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of sample/metallurgy	459	n/a	400	183600		n/a	n/a	500	183600	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Total 2 ($)		**219600**		**2043090**	**132000**	**0**	**0**	**6500**	**2399690**	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor).)
Alloy 800H samples [7]	n/a	n/a	28,657		28,657	Costing based on material price of $35/kg. This does not allow for the cost/development for the weld/braze alloy. Other aspects based on metallic IHX A (see adjustment factor).
Total 3 ($)					**28657.125**	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor).)
Capital cost - furnaces for thermal aging	3000	3		9000	Furnace with required capability sized at 180mm x 180mm x 250mm. Based on metallic IHX A (see adjustment factor).
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies make up 10% of total capital cost for furnaces. Based on metallic IHX A (see adjustment factor)
Helium gas for regulating environment	120	156		18,720	156 x 50kg He cylinders to be utilized. One cylinder a week for each furnace. He gas cost inclusive of impurity gases. Based on metallic IHX A (see adjustment factor).
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on metallic IHX A (see adjustment factor).
Total 4 ($)				**36420**	

Total ($)	**3341967.1**	
10% contingency ($)	**334196.71**	
Grand total ($)	**3676164**	
IHX A to IHX B ratio adjustment	**10**	**Existing Alloy 800H database can be utilized**
Equivalent costs for IHX B specification	**367616**	

[1] See preferred number of samples to be used in 'sample' sheet
[2] Basis for preparation costs - $400/sample
[3] Assuming that all samples to be checked for joint consistency after joining
[4] Determination by way of mechanical testing not advised. Determination should be based on natural vibrational methods
[5] Tensile properties (yield strength, tensile strength, elongation, and RA)
[6] Optical/SEM work to be conducted for tensile, fatigue (HCF, LCF), creep
[7] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-006	Effects of grain size and section thickness on Alloy 800H	Demonstrate that slight changes in grain size as well as the section thickness of Alloy 800H has little effect in overall properties of material	N/A

Work stated is equivalent to similar work stated in metallic IHX A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Conducting testing: Alloy 800H properties	Laboratory Technician	80	n/a	8	5	16			51200	Testing will require resources in the form of 1 engineer ($200/hour)
Oversee & Manage	Engineer	200	n/a	8	5	16			128000	as well as 1 laboratory technician (80$/hour). Based on metallic IHX A (see adjustment factor).
Total 1 ($)									179200	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
	Samples [1]	Prep (Machining) [2]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Thermal Physical Mechanical properties of Alloy 800H										
Fatigue Strength (LCF)	45	18000	720	32400	66000	n/a	n/a	1000	117400	Fatigue strength LCF to 1000°C - $720-00 up to 80 000 cycles + $20-00/hour there after per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor).
Fatigue strength (HCF)	45	18000	800	36000	66000	n/a	n/a	1000	121000	Fatigue strength HCF to 1000°C - $800-00 up to 1000 000 cycles per specimen at 950°C (+- 30°C). Based on metallic IHX A (see adjustment factor).
Creep strength	48	19200	3500	168000	n/a	n/a	n/a	500	187700	Creep strength to 1000°C for 10,000 h - $3500-00 per specimen. Based on metallic IHX A (see adjustment factor
Metallography/SEM (post-testing) [3]										
Cutting, polishing, etching sample	138		640	88320		n/a	n/a	n/a	88320	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of sample/metallurgy	138		400	55200		n/a	n/a	500	55200	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment fac
Total 2 ($)		55200		379920	132000	0	0	3000	569620	

Materials

Materials requirement	Samples				Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Mat.cost/sample	Material cost			
Alloy 800H samples [4]	n/a	n/a	7,959		7,959	Costing based on material price of $35/kg. Number of samples only relevant to fatigue testing and creep testing. Based on metallic IHX A (see adjustment factor).
Total 3 ($)					7959	

Total ($)	**756779**	
10% contingency ($)	**75677.9**	
Grand total ($)	**832456.9**	
IHX A to IHX B ratio adjustment	**1**	**Same estimates for IHX B relating to IHX A** **Work stated is equivalent to similar work stated in metallic IHX A**
Equivalent costs for IHX B specification	**832456.9**	

[1] See preferred number of samples to be used in 'sample' sheet

[2] Basis for preparation costs - $400/sample

[3] Optical/SEM work to be conducted for fatigue and creep samples

[4] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-007	Corrosion allowances for Alloy 800H	Demonstrate satisfactory corrosion allowances for Alloy 800H and welded/bonded sections	N/A

Work stated is equivalent to that stated in metallic IHX A

Resources

Resource requirement	Action to be performed by	Tariff ($)		Duration					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Action	Hours	Days	Weeks	Months	Years		
Welding of joints (W/BR/DB)	Coded welder	100	n/a	8	5	12			48000	135 samples to be joined. Assume 12 samples/week. Based on metallic IHX A (see adjustment factor).
Oversee & Manage: Thermal exposure of samples - 10,000h	Laboratory Technician	100	n/a	100					10000	Thermal exposure monitored by lab technician every 100h (100 intervals). Based on metallic IHX A (see adjustment factor).
Oversee & Manage	Engineer	200	n/a	8	5	20			160000	
Total 1 ($)									218000	

Testing

Task requirement	Testing								Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
	Samples	Prep (Machining) [1]	Test cost/sample	Testing Costs	Eq. setup	Post test sample prep	Post test analysis	Reporting		
Metallography (post welding/bonding) [2]										
Cutting, polishing sample	135	n/a	640	86400		n/a	n/a	n/a	86400	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of metallurgy	135	n/a	400	54000		n/a	n/a	500	54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Chemistry profile in joints	135	n/a	400	54000		n/a	n/a	500	54000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Thermal Physical Mechanical properties of Alloy 800H and W/BR/DB joints										
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
Metallography/SEM (post-testing)										
Cutting, polishing, etching sample	180	n/a	640	115200		n/a	n/a	n/a	115200	Taking into account that laboratory technician will need 8 hours for sample preparation at $80/hour. Based on metallic IHX A (see adjustment factor).
Observation of sample/metallurgy	180	n/a	400	72000		n/a	n/a	500	72000	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Depth of internal oxidation	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Depth of depletion of alloy elements (Cr)	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Depth affected bycarburization/ decarburization	180	n/a	400	72000				500	72500	Inclusive of 1) Analyses cost (inclusive of operator and machine costs) at $200/hour and 2) Scientist/Engineering input at $200/hour. Based on metallic IHX A (see adjustment factor).
Total 2 ($)		0		597600	0	0	0	3000	599100	

Materials

Materials requirement	Samples	Mat.cost/sample	Material cost		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
Alloy 800H samples [3]	n/a	n/a	10,605		10,605	Costing based on material price of $35/kg. This does not allow for the cost/development for the weld/braze alloy. Based on metallic IHX A (see adjustment factor).
Total 3 ($)					10605	

Other

Additional requirements	Unit price ($)	Quantity		Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
Capital cost - furnaces for thermal aging	3000	3		9000	Furnace with required capability sized at 180mm x 180mm x 250mm. Based on metallic IHX A (see adjustment factor).
Contingencies (power consumption, element replacement)	900	1		900	Furnace contingencies make up 10% of total capital cost for furnaces. Based on metallic IHX A (see adjustment factor).
Helium gas for regulating environment	120	156		18,720	156 x 50kg He cylinders to be utilized. One cylinder a week for each furnace. He gas cost inclusive of impurity gases. Based on metallic IHX A (see adjustment factor).
Sampling gas analyses	150	52		7,800	Sampling of furnace testing environment done once a week by external institution. Collective sampling from 3 furnaces add up to $150/week. Based on metallic IHX A (see adjustment factor).
Total 4 ($)				36420	

Total ($) (Primary side He effects)	**864125**	
Secondary side He effects ($)	**864125**	
Total (Primary and secondary effects) ($)	**1728250**	
10% contingency ($)	**172825**	
Grand total ($)	**1901075**	
IHX A to IHX B ratio adjustment	**1**	**Work stated is equivalent to that stated in metallic IHX A**
Equivalent costs for IHX B specification	**1901075**	

[1] Basis for preparation costs - $400/sample

[2] Assuming that all joined samples to be checked for joint consistency after joining

[3] Refer to 'material cost' sheet for material costing aspects

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-008	Thermal/Fluid modelling methods for IHX B	Develop thermal models for IHX B	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor))
		Hour	Year	Hours	Days	Weeks	Months	Year		
Model generation giving results for mechanical, physical and thermal performance prediction	Group of thermal fluid/modeling specialists		42,500					3	127500	1) Estmation made by M-Tech - Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work. Based on metallic IHX A (see adjustment factor)

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-009	Methods for stress-strain modelling of IHX B	Develop structural modelling methods for predictive operation for IHX B	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Year	Hours	Days	Weeks	Months	Year		
Structural model generation giving results for predictive operation for IHX B	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech Duration of 3 years for work. Based on metallic IHX A (see adjustment factor)

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-010	Criteria for structural integrity	Establish criteria for structural integrity of CHE's	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Year	Hours	Days	Weeks	Months	Year		
Structural integrity models of CHE's	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech - Duration and cost is greatly dependant on the data supplied by suppliers (transfer coefficients). Duration of 3 years for work. Based on metallic IHX A (see adjustment factor)

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Crit SSC	Specification number	Specification	Description	Comments
IHX B	WEC-TS-IHXB-011	Performance modelling methods for IHX B	Develop performance models for predictive operation for IHX B	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed					Total ($)	Assumptions/Bases (Based on metallic IHX A (see adjustment factor)).
		Hour	Year	Hours	Days	Weeks	Months	Year		
Performance models for IHX	Group of modeling specialists		42,500					3	127500	1) Estmation made by M-Tech Duration of 3 years for work. Based on metallic IHX A (see adjustment factor)

Total ($)	**127500**
10% contingency ($)	**12750**
Grand total ($)	**140250**

Material cost details based on preferred number of samples to be tested - Alloy 800H (@ $35/kg)

Sample amount	Per sample cost - 800H Mat.cost	549	IHXB.2	183	IHXB.3	183	IHXB.4	549	IHXB.5	138	IHXB.6	180	IHXB.7
Cost	**($)**	**samples**	**($)**	**samples**	**($)**		**($)**		**($)**		**($)**		**($)**
Elastic Properties	**0.875**	18	15.75	6	5.25	6	5.25	18	15.75	0	0	0	0
Tensile Properties	**0.875**	45	39.375	15	13.125	15	13.125	45	39.375	0	0	0	0
Fatigue strength (LCF)	**87.5**	135	11812.5	45	3937.5	45	3937.5	135	11812.5	45	3937.5	60	5250
Fatigue strength (HCF)	**87.5**	135	11812.5	45	3937.5	45	3937.5	135	11812.5	45	3937.5	60	5250
Creep strength	**1.75**	144	252	48	84	48	84	144	252	48	84	60	105
Fracture toughness: CTOD	**87.5**	27	2362.5	9	787.5	9	787.5	27	2362.5	0	0	0	0
Fracture toughness: Kc	**87.5**	27	2362.5	9	787.5	9	787.5	27	2362.5	0	0	0	0
Thermal conductivity	**8.75**	18	157.5	6	52.5	6	52.5	18	157.5	0	0	0	0
Total ($)	**362**		**28815**		**9552**		**9552**		**28657**		**7959**		**10605**

Crit SSC	Specification number	Specification	Description	Comments
HTS Piping	WEC-TS-PIP-001	PHTS High temperature trade study	Assess design options for high temperature PHTS piping	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate design options from trade studies	Engineer	200	N/A	8	5	4	6	192000	Based on need for one engineer for duration of 6 months. Includes reporting.

Total ($)	**192000**
10% contingency ($)	**19200**
Grand total ($)	**211200**

Crit SSC	Specification number	Specification	Description	Comments
HTS Piping	WEC-TS-PIP-002	PHTS Low temperature trade study	Assess design options for low temperature PHTS piping	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate design options from trade studies	Engineer	200	N/A	8	5	4	4	128000	Based on need for one engineer for duration of 6 months. Includes reporting.

Total ($)	**128000**
10% contingency ($)	**12800**
Grand total ($)	**140800**

Crit SSC	Specification number	Specification	Description	Comments
HTS Piping	WEC-TS-PIP-003	SHTS High temperature trade study	Assess design options for high temperature SHTS piping	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate design options from trade studies	Engineer	200	N/A	8	5	4	6	192000	Based on need for one engineer for duration of 6 months. Includes reporting.

Total ($)	**192000**
10% contingency ($)	**19200**
Grand total ($)	**211200**

Crit SSC	Specification number	Specification	Description	Comments
HTS Piping	WEC-TS-PIP-004	SHTS Medium temperature trade study	Assess design options for medium temperature PHTS piping	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate design options from trade studies	Engineer	200	N/A	8	5	4	4	128000	Based on need for one engineer for duration of 6 months. Includes reporting.

Total ($)	**128000**
10% contingency ($)	**12800**
Grand total ($)	**140800**

Crit SSC	Specification number	Specification	Description	Comments
HTS Piping	WEC-TS-PIP-005	SHTS Low temperature trade study	Assess design options for low temperature SHTS piping	N/A

Tasks required	Action to be performed by	Tariff ($)		Time needed				Total ($)	Assumptions
		Hour	Action	Hours	Days	Weeks	Months		
Evaluate and identify candidate design options from trade studies	Engineer	200	N/A	8	5	4	3	96000	Based on need for one engineer for duration of 6 months. Includes reporting.

Total ($)	**96000**
10% contingency ($)	**9600**
Grand total ($)	**105600**

Additional notes on preferred number of testing samples - Alloy 617 / Alloy 800H

1) General
- Samples representative of the three heats to be tested for all thermal, physical and mechanical tests

2) Elastic properties
- At least 2 samples for each heat should be tested assuming the vibrational methods permit testing of a single specimen at multiple temperatures

3) Tensile properties
- As a minimum, testing should be conducted on 15 samples (5 temperatures for each heat)
- Noted testing does not include any duplicates

4) Fatigue tests
- As a minimum, LCF testing should be conducted on 45 samples [3 heats x 5 temperatures x 3 strain ranges]
- As a minimum, HCF testing should be conducted on 45 samples [3 heats x 5 temperatures x 3 cycle rates]

5) Creep strength
- As a minimum, testing should be conducted on 48 samples [3 heats x 4 temperatures x 4 stress levels]

6) Fracture Toughness
- As a minimum, testing for fracture toughness [CTOD] should be conducted on 9 samples [3 heats x 3 temperatures]
- As a minimum, testing for fracture toughness [Kc] should be conducted on 9 samples [3 heats x 3 temperatures]

7) Thermal conductivity
- As a minimum, testing should be conducted on 6 samples, 2 for each heat, as the complete temperature range can be covered with a single specimen

8) Coefficient of thermal expansion
- As a minimum, testing should be conducted on 6 samples, 2 for each heat, as the complete temperature range can be covered with a single specimen

9) Stress rupture
- As a minimum, stress rupture testing should be conducted on 48 samples [3 heats x 4 temperatures x 4 stress levels]

17.2.6 Appendix B: References

[17-1] “NGNP and Hydrogen Production Pre-conceptual Design Report - SECTION 18: NGNP PROJECT SCHEDULE “,NGNP-18-RPT-001, Rev 0, May 2007

[17-2] CTF Schedule per e-mail from BEA

[17-3] HPS.000.S01 (WBS Element Code Level) - Hydrogen Plant Alternatives Study

[17-4] NGNP-16-RPT-001 – NGNP and Hydrogen Production Pre-conceptual Design Report – Technology Development

[17-5] AACE International Recommended Practice No. 17R-97 TCM Framework; 7.3-Cost Estimating and Budgeting (as supplied by BEA)