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NGNP CTF Test Loop Preconceptual Design Report

Section 10: System Integration

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
ABC	Activity Based Costing
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CEPSI	Chemical Engineering Plant Costing Index
CES	Control Emulation System
CFE	Capacity-Factored Estimates
CFR	Code of Federal Regulations
CH	Cold Header
CHE	Compact Heat Exchanger
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelve (Commercial Grade Items)
CPI	Chemical Process Industries
CPU	Central Processing Unit
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1

Abbreviation or Acronym	Definition
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
CWS	Cooling Water System
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DFC	Direct Field Cost
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
ECC	Engineering, Construction and Commission
ED&I	Engineering design and Inspection
EFE	Equipment Factor Estimation
EDMS	Engineering Data Management System
I	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES	Engineering Simulator
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements

Abbreviation or Acronym	Definition
H_2	Hydrogen Production Test (Specifically referring to H_2SO_4 Decomposition Reactor Test)
H_2SO_4	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface
HOC	Home Office Costs
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature G–s –Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
IC	Initial Conditions
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Intermediate Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B

Abbreviation or Acronym	Definition
IChemE	Institution of Chemical Engineers
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
IS	Instructor/Engineering Station
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
KD	Key Decision
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MC	Mixing Chambers
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
MW_{th}	Megawatt Thermal
N	Rotational Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities

Abbreviation or Acronym	Definition
NRC	Nuclear Regulatory Commission
OC	Operating Costs
OPC	Other Project Costs
OSHA	Occupational Safety and Health Administration
OTS	Operator Training Simulator
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
PS	Plant Simulator
psig	Pound per square inch gauge
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
ROT	Reactor Outlet Temperature
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
R&D	Research and Development
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System

Abbreviation or Acronym	Definition
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBC	To be Confirmed
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEC	Total Equipment Cost
TEC	Total Estimated Cost
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association
TIC	Total Installed Costs
TPC	Total Plant Cost
TPC	Total Project Cost
TRL	Technology Readiness Level
TS	Training Simulator
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor

Abbreviation or Acronym	Definition
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ε	Strain

SUMMARY AND CONCLUSIONS

This section of the NGNP CTF Test Loop PCDR outlines possibilities as to the different, interrelated Technology Development Paths anticipated for the CTF. The current scope of work requires a facility that can test components for a full 950 °C NGNP Reactor Outlet Temperature (ROT).

Opting for the correct CTF Engineering, Construction and Commissioning (ECC) as well as Operational Development Paths will be challenging seeing that it is primarily linked to the paths outlined by the Technology Development Roadmapping Report [10-1] over and above the NGNP design. The challenge lies therein to coordinate these different development paths altogether in optimally utilizing the CTF. In doing so, a persevering "Road to Hydrogen Production" remains indisputable, which is the principal purpose of the NGNP.

Distinctive and logical scenarios of system integration, derived from the reference designs, are suggested within this section, taking the total duration into account of each system's project lifecycle. The duration for each system is split into an ECC phase and a testing phase, each accompanied with its associated cost.

Due to uncertainties surrounding an accurate prediction of the Hydrogen Development Path, the CTF preconceptual design strategically encompasses a design philosophy of modularity as far as initial CTF deployment and afterward expansion is concerned. Thus, a concept of commencing with Small Scale Development Tests (SSDTs) earlier on in the process is also proposed, specifically so that experimental data and lessons learned from these test setups can be incorporated into the successive Technology Development Loop (TDL) design and operations.

The specific challenges of meeting the NGNP deadlines are rooted in the CTF's ability in successfully meeting test schedule demands and the manner in which the CTF systems are integrated physically and timeously. It therefore has been deemed necessary to combine the different systems'- and test requirements (SSDTs, TDLs, CTL and CQLs) into an integrated schedule in which the approach followed makes use of a principle of concurrent testing with combinations of integrated systems. These different system integration approaches are classed as Moderate, Aggressive and Very Aggressive, each classification denoting the level of need to complete the heat transfer component test schedules. These three approaches relate to the schedule of the testing phases only and not to the ECC phases.

A schedule-dependent costing was also done, based on Equipment Factored Estimates (EFEs) for all three approaches, which also forms part of this document.

Each approach caters for a 950 °C NGNP ROT Development Path. A 750 °C NGNP ROT Development Path has been added for information purposes only, should it be considered. A 750 °C NGNP ROT growth path approach could by any means be followed should technical challenges surface during NGNP design. A 750 °C ROT growth path approach will however, not affect the 950 °C, 9MPa CTF design; it will only influence the preference of test schedules during the operational phase.

The three approaches are summarized as follows:

A. Moderate Approach:
   - Integrated CTF Utilizing 1 x TDL for a 950 °C NGNP ROT Development Path.

B. Aggressive Approach:
   - Integrated CTF Utilizing 2 x TDLs for a 950 °C NGNP ROT Development Path.

C. Very Aggressive Approach:
   - Integrated CTF Utilizing 3 x TDLs for a 950 °C NGNP ROT Development Path.

The strategic advantage of using the modular TDL approach is that after test completion, the HGD outlets of two TDLs could be coupled allowing helium to pass through headers to initiate CQL1 testing. CQL1 testing capability could only be put into effect pending finalization of the Steam Generator and H_2SO_4 Decomposition Reactor proto-typical designs.

CQL2 is a larger proposed helium test facility, which, similar to CQL1 preferably should be considered once the modular TDLs have fulfilled their role. The decision for either CQL (CQL1 or CQL2) is to be made prior to TDL test completion dates, as indicated by the key decision mileposts in the graphs depicted in Paragraph 10.7 and in Appendix F. At the writing of this report, in anticipation of the expected proto-typical designs, no single CQL is yet made allowance for in terms of pinpointing commencement of CQL ECC and follow-up operation.

Effective and assertive system integration is necessary to meet the 2021 NGNP operational deadline. An immediate commencement of Small Scale Development Tests upfront of TDL acquisition is necessary to pave the road for successful larger scale testing of heat transfer components expected to be available by 2015. Given the tight NGNP schedule, which is to be updated after the NGNP Conceptual Design Planning (early 2009), a Very Aggressive approach i.e. utilization of three TDLs will be the preeminent choice for the CTF. Yet, this Very Aggressive approach results in a completion date of TDL-based tests by 2019, which is on the doorstep of 2021.

On the whole the CTF has built-in expandability since it is based on a modular design. Higher degrees of technological usefulness with regards to high temperature heat transfer testing capability are strived for within this CTF system integration concept.

10. SYSTEM INTEGRATION

10.1 Introduction – NGNP Background, CTF Need and Modularity

A large-scale helium test facility is intended [10-2] to address specific NGNP-related component testing in order to advance the Technology Readiness Levels (TRLs) of NGNP-identified components or parts thereof, of which IHX-related testing is the most prominent of all. In order to achieve NGNP Technology Readiness, different CTF Test Loops (i.e. SSDTs, TDL, CTL and CQLs) have been suggested, which were initially accounted for in a feasibility study and are currently reported on within this PCDR [10-3]. These component testing systems, which all make up the CTF, were consciously fragmentized in order to allow uncomplicated expansion of the CTF-NGNP Development Path. This chapter focuses on recommending a few different system-integrated options with subsequent costing and scheduling thereof. All these options are applicable to a 950 °C NGNP ROT. Should the need arise to test components related to a 750 °C NGNP ROT Development Path, it can be done without disrupting CTF operation. Time constraints could be addressed by adding development loops to expand the installed testing capability of the CTF. In such a way the concurrent testing methodology i.e. simultaneous testing between different systems, could be amplified. Test loop systems could be added at any stage of the CTF project lifecycle.

Henceforth, the different approaches as regards to system integration will be referred to as either being Moderate, Aggressive or Very Aggressive, which in essence, are all TDL dependent. At the outset, CQLs do not form part of these three integrated approaches due to uncertainties still to be addressed concerning the proto-typical designs of both the Steam Generator and the H_2SO_4 Decomposition Reactor Units Under Test (UUTs).

Once TDL tests have been completed, subsequent engagement of two TDLs can bring CQL1 into play. CQL2 is, just as CQL1, to be added to the rear-end project lifecycle of the CTF upon completion of TDL testing. In such an instance, the possibility exists that TDLs could be reconfigured into CQL2, if the need thereto arises. Such an option will imply some re-engineering. As stated earlier, the choice for either CQL1 or CQL2 will depend on the outcome of the mentioned proto-typical UUT designs.

As regards to the TDL modular line of attack, all three approaches have the same number of fixed systems i.e. one SSDT1, one SSDT2, one SSDT3 and one CTL. The variable systems are related to the number of TDLs and possible consecutive CQL1 testing. For the Moderate approach one TDL is proposed, followed by two TDLs for the Aggressive approach and three TDLs for the Very Aggressive approach.

Owing to the existing challenging economic climate and a very demanding research and development NGNP schedule, built-in engineering resiliency is essential for the successful operation of any of the proposed CTF system integrations. The system integration proposals are to help plan a facility suited to stand up to the demand of the lingering component tests to benefit all future CTF design and operational phases. Critical parameters for aiding the design path further on are directly related to the Technology Readiness Levels of each component designated

for CTF testing where an eventual TRL rating of 8 is to be acquired. In addition to achieving the target TRL rating of each component designated for CTF testing, a reliable cost estimate package including the technical scope and schedule is necessary to ensure a sound basis for completing the CTF project lifecycle. As far as costs are concerned, direct and indirect costs have been estimated using appropriate methods (discussed later) where necessary. The capital cost estimate is the pioneering work of this total cost estimate. Indirect Field Costs (IFC), Home Office Costs (HOC), costs put aside for commissioning and contingencies, which are all invaluable to attain a respectable cost estimation, supplemented by incurring Operating and Maintenance (O&M) costs ultimately reconciles the total cost estimate.

Several factors have lead to accurately select a well planned and well-structured system integration philosophy. These typically include front-end development risks and costs which are related to the technology readiness of all units designated for testing. These factors also add to complexities associated with the initial Phase I CTF design, construction and subsequent CTF developments. A reliable and well thought-through cost estimate package is essential in determining the CTF system integration path henceforth although several different options and strategies exist regarding a modular building-block approach. This built-in modularity is seen as a strategic advantage in terms of adapting the CTF as per the NGNP Development Path requirements. The modular approach comprises several smaller test loops and some larger loops that could eventually result in a larger system. Any of the mentioned three approaches comprise of Small Scale Development Tests (SSDTs) as precursor for either option. The SSDTs are indispensable for CTF design developments as will be seen later on in this section.

The integration options presented in Paragraph 10.7 are to be seen as distinctive options indicating different overall test completion closing dates by allowing a modular building approach to be followed. The main plant constraint, currently fixed at 50 MW electrical supply, is at all times to be taken into account irrespective of the eventual system integration option selected.

10.2 Reference Technology Development Systems

From the test specifications presented in the CTF Test Loop Preconceptual Design Report (PCDR) Section 4: System Requirement Manual, reference [10-4], preconceptual design systems have evolved based on test specific information as well as engineering judgment. This list of tests has been derived from the Technology Development Road Mapping Report, reference [10-1]. These systems are dealt with in more technical detail in Sections 5 through 9 of this same PCDR [10-3] and include the following:

- Small Scale Development Tests (SSDTs)
- Technology Development Loops (TDLs)
- Component Qualification Loop 1 (CQL1)
- Component Qualification Loop 2 (CQL2)
- Circulator Test Loop (CTL)

They are given a brief rundown in the following paragraphs (paragraphs 10.2.1 through 10.2.5).

10.2.1 Small Scale Development Test (SSDT) Capabilities

The SSDTs originated from a collection of tests that do not require significant volume flow rates or large amounts of heat transfer when compared to TDL testing capability [10-5]. Most of the tests are performed in a helium environment of 950 °C and 9 MPa. The tests designated for SSDTs comprise of IHX A (Metallic & Ceramic) and IHX B (Metallic) joint integrity, creep lifetimes, fatigue lifetimes and corrosion allowances for both alloys 617 and 800H. Additional SSDTs are specifically related to piping and insulation i.e. to determine insulation performance on sudden depressurization and impurities (i.e. carbon infiltration). Other tests are circulator-specific i.e. tests related to catcher bearings and rotating seals. Most of the anticipated tests related to SSDTs lie on a TRL rating of 4 and lower, the only exception being the tests designated for insulation performance testing (TRL 5), and effects of sudden depressurization on insulation properties (TRL 6).

The abovementioned tests are mostly related to SSDT1 and SSDT2. As the CTF Test Loop PCDR has progressed, a new SSDT capability has been proposed by the design team, i.e. SSDT3. SSDT3 is a new and innovative concept that has since evolved from the initial writing of this report. It is therefore not dealt with the same level of technical detail as SSDT1 and SSDT2.

The three anticipated SSDT systems thus are:

- SSDT1 – High temperature tests (mainly creep tests) in a high pressure helium environment with no-flow conditions (refer to Figure 10-1).
- SSDT2 – High temperature tests (mainly fatigue tests) in a high pressure helium environment with very little flow conditions (refer to Figure 10-2).
- SSDT3 – High temperature tests in a primary loop high pressure helium environment, with a helium flow in the order of 1.2 kg/s (refer to Figure 10-3).

SSDT3 has evolved from ideas being exchanged between members of the design team to allow testing capability of an NGNP environment at a heat duty that is lower than the TDL's. SSDT3 could be implemented at lower cost and will have a much shorter ECC project lifecycle than a TDL. For a cost and ECC duration comparison between the different systems, refer to Paragraph 10.7. It is important to note that most of the prominent CTF-specified tests are IHX related, thus justifying the naissance of a small-scale testing capability such as the SSDT3.

As any testing facility is results-driven, a rational path would entail advancing the TRL ratings of the relevant listed critical SSCs from the onset of 2009. Small-scale heat transfer testing capabilities compared to larger scale testing capabilities would be beneficial due to its lower capital cost accompanied with lower operational cost. The latter could be achieved by employing SSDTs before advancing too soon with surplus plant furnished for higher TRL developments. The SSDTs will act as a stepping stone for TDLs, which in turn are to be used for possible CQL1 or CQL2 operation. The tests specified for the TDLs could eventually also be conducted concurrently with SSDTs opening up the possibilities of optimizing system integration options as experimental data is generated.

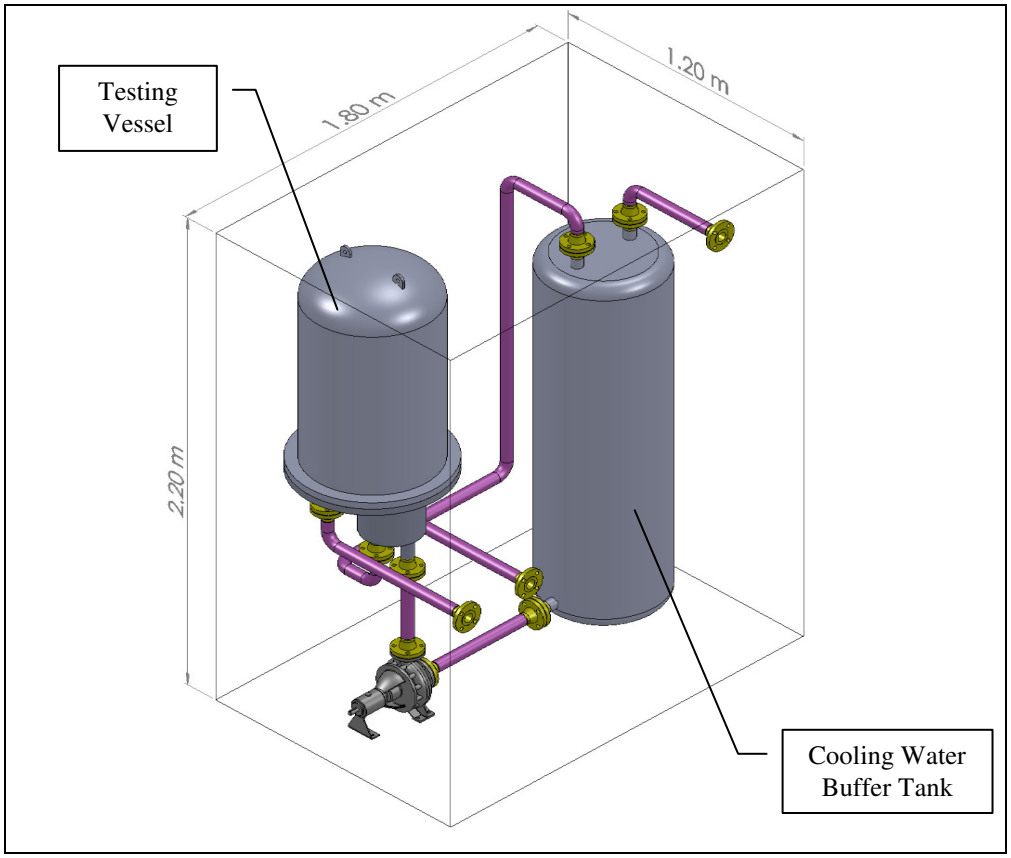


Figure 10-1: Isometric view of SSDT1

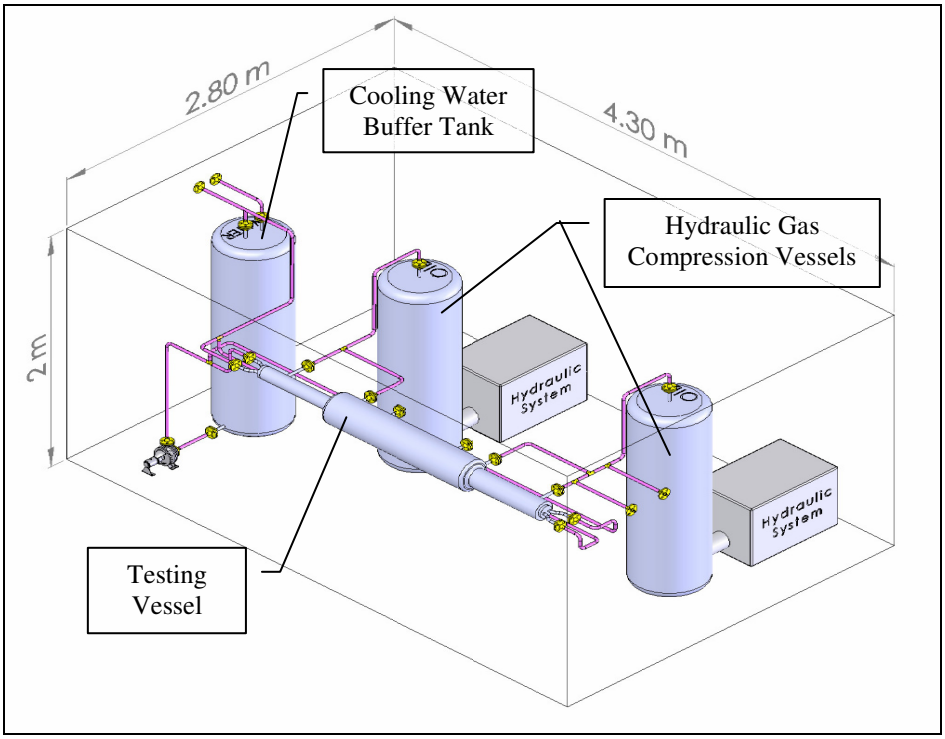


Figure 10-2: Isometric view of SSDT2

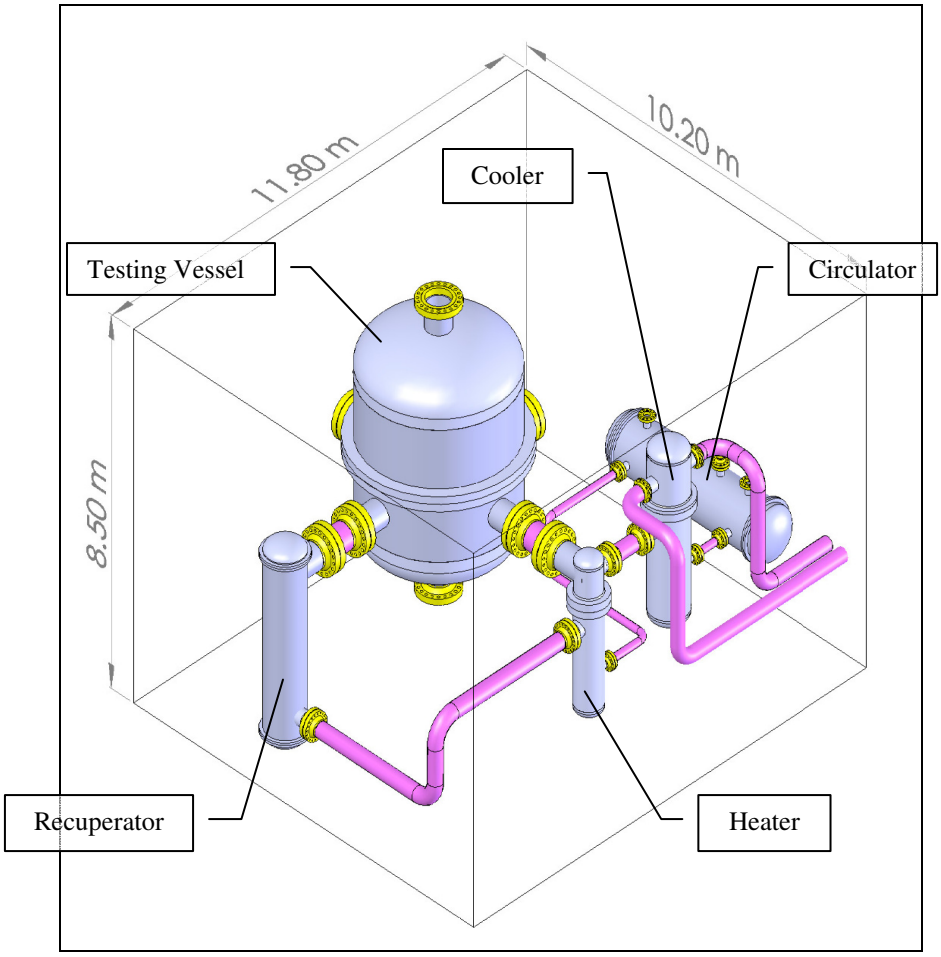


Figure 10-3: Isometric view of the newly proposed SSDT3

Due to less complexity associated with the smaller-sized SSDTs compared to TDLs or CQLs, it is possible to commence with the design and subsequent manufacturing of these units during the CTF Pre-Title I phase (see Figure 10-7). The line of thinking remains that utilization of SSDTs will be essential in obtaining valuable information designated as input for component testing within TDLs or CQLs. All SSDT experimental data will be used as input into any of the TDL, CQL and CTL designs.

A conclusive decision regarding the commencement of the SSDTs' project lifecycles is to be based upon the techno-economic objective of the CTF project as a whole. The SSDTs are perceived as forerunner, lower-risk testing facilities of the later planned CTF developments, thus playing an important role in progressively achieving test results.

10.2.2 Technology Development Loop (TDL)

The idea of a Technology Development Loop (TDL) originated from a collection of tests that require volume flow rates in a helium environment of 950 °C and 9.0 MPa. The mass flow rate

of a TDL is designed at 3.65 kg/s, which is 2.3 percent of the anticipated maximum NGNP flow. The TDL provides a means of measuring the performance of anticipated component testing where the technology readiness of such components has reached levels of 6 or 7. Robust Commercial-off-the-Shelf (COTS) components are anticipated to be used to drive the TDLs thereby mitigating risks associated with technology development of these components itself. Two conditioning loops make up a TDL, hence providing a means for component tests within a testing vessel (i.e. IHX A or IHX B tests) or matching up flanges for complete units anticipated for testing (i.e. mixing chamber and hot-gas-duct tests). The main feature of the TDL is that it is designed to allow flexibility in terms of component testing and should the need arise, more than one TDL could be deployed. In the extreme it is possible to allow up to four TDLs, which would in fact comprise a very accommodating CTF, although three TDLs are expected to be the practical limit, considering the 50 MW electrical supply constraint. Should the electrical supply be increased, more than three TDLs would be feasible.

The TDL size was driven by the IHX test requirements since limited information regarding the mass flow and thermal heat transfer for the Hot Gas Duct (HGD) and mixing chamber tests are available. It was therefore decided to base the TDL design mass flow on the mass flow required for multi-module (3 x 1.2 MW) heat transfer testing for IHX A. With this mass flow as basis (3.65 kg/s), the TDL component sizes could be calculated to provide the desired mass flows, pressures and temperatures for the test requirements as specified in CTF Test Loop Preconceptual Design Report (PCDR) Section 6: Technology Development Loop, reference [10-6]. These same TDL component sizes are used for the cost estimation exercise.

It is worth mentioning that the TDL layout, as shown in Figure 10-4 and Figure 10-5 has been modified slightly from the layout depicted in Section 6 of this PCDR [10-6] in that the main equipment comprising the TDL has been re-arranged to cut down HGD lengths. This modified TDL layout, as well as all other system layouts will evolve during further design.

Not all TDLs need to be equipped with secondary heaters. If more than one TDL is installed, only one of them will require a secondary heater since it would be sufficient to carry out the anticipated Mixing Chamber test(s).

From the schematic view given in Figure 10-5 it is noticeable that the HGDs linking up with the main components are more sensibly arranged than previously depicted in Section 6 of this PCDR [10-6]. With inside HGD temperatures reaching 950 °C (HGD situated between the heater and the testing vessel) further design is necessary to ensure HGD mechanical stability.

10.2.3 Component Qualification Loop (CQL1)

From the initial TDL design concept, the Component Qualification Loop (CQL1) came into being whereby at least two TDL's individual mass flows are combined to provide larger mass flow capability for anticipated Steam Generator (SG) and H_2SO_4 Decomposition Reactor testing. Although designs for both the SG and the H_2SO_4 Decomposition Reactor are still remaining, it was anticipated that these two Units Under Test (UUTs) would have heat duties in the order of 10 to 12 MW for the former and 8 to 9 MW for the latter. CQL1 is thus only an

extension of the TDLs' testing environment, combining the separate but equal mass flows at a general Hot Header (HH) from where it departs into a common manifold. The exit stream from CQL1 test station runs into a Cold Header (CH) from where it departs into separate but equal mass flows back to the TDLs from where the loops started out. CQL1 forms part of the overall CTF system integration (following key decision discriminating criteria) as discussed in the different system integration options in Paragraph 10.7.

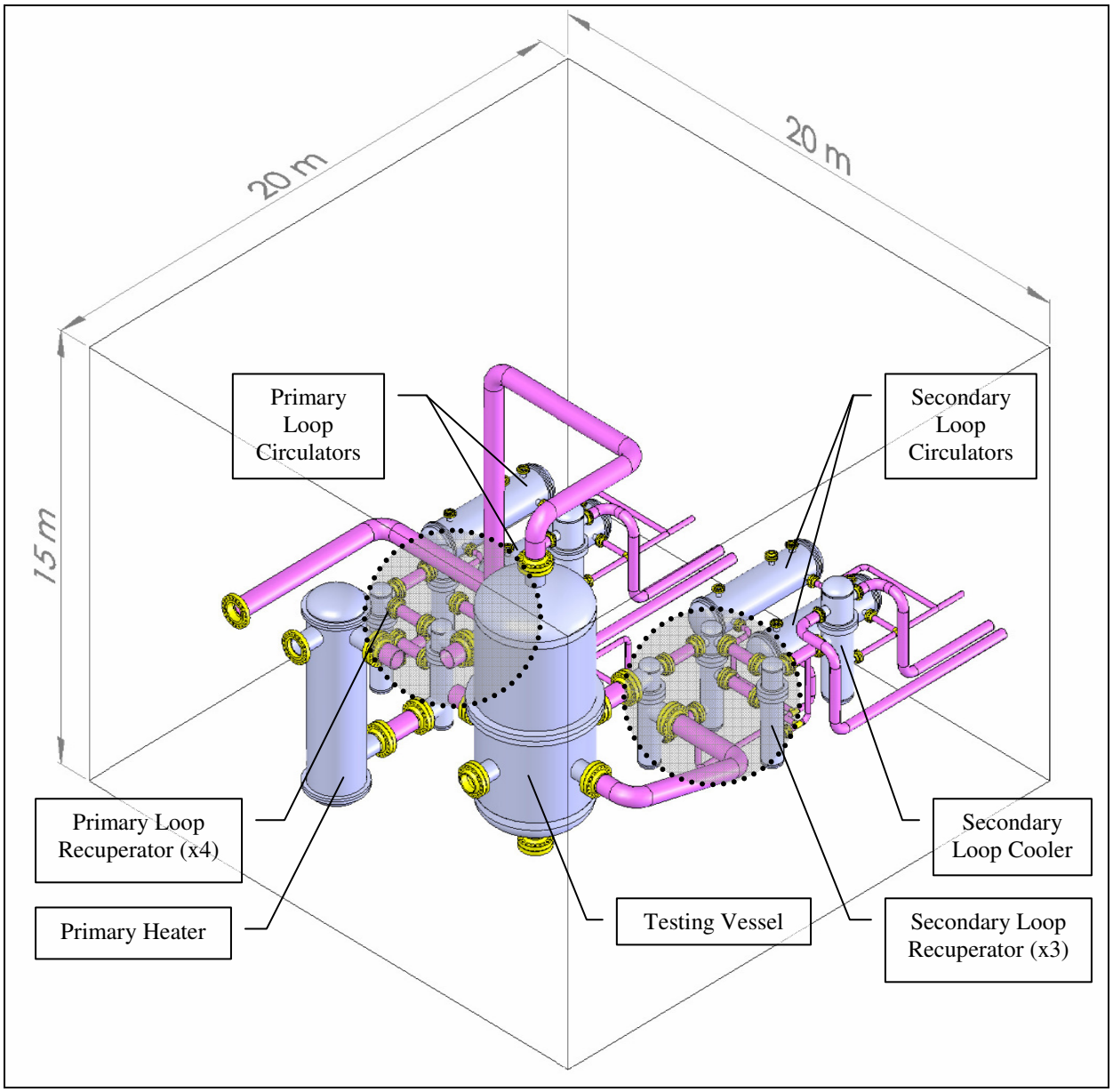


Figure 10-4: Isometric view of a Modified TDL

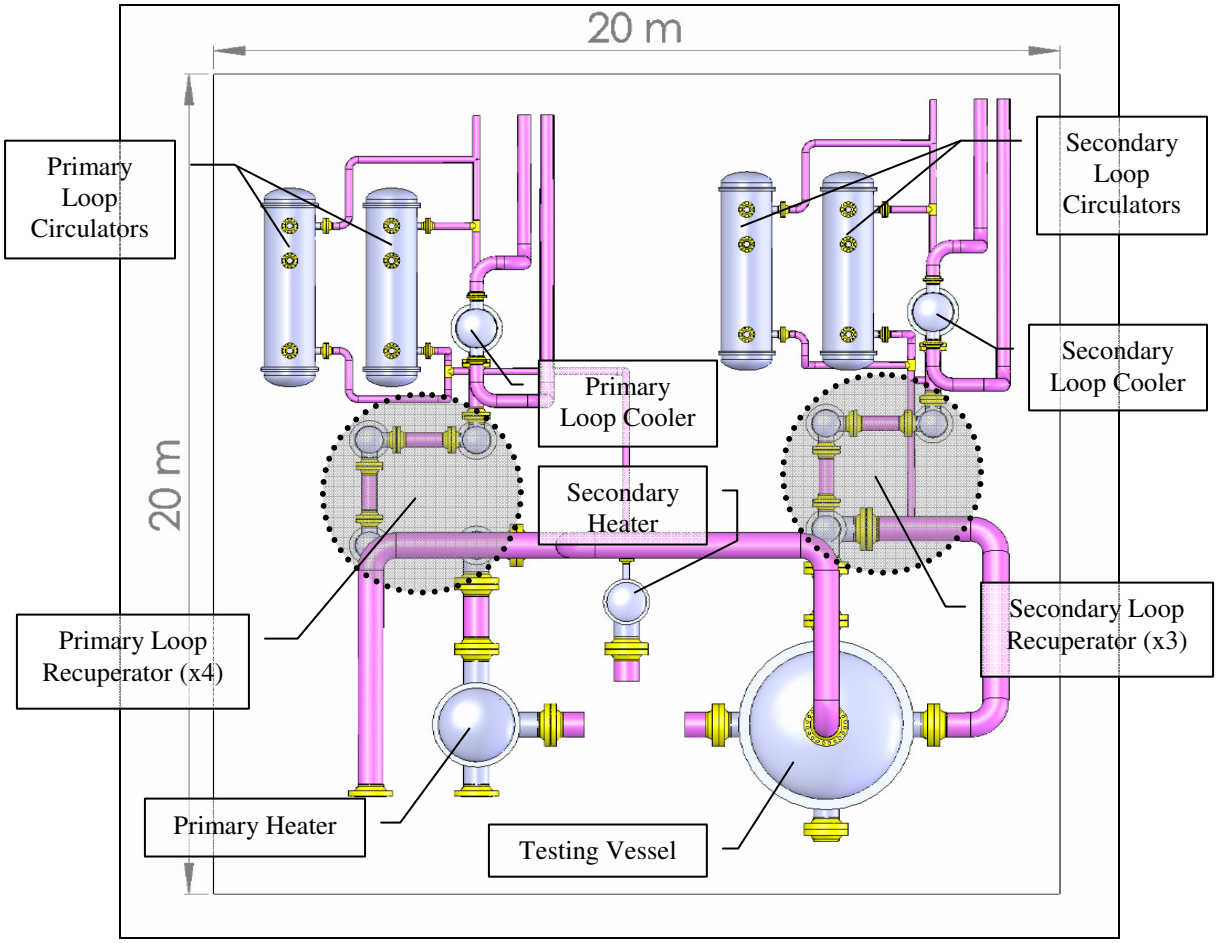


Figure 10-5: Top view of a Modified TDL

The costs associated with CQL1 are only related to the HGDs up until the flanged connections interfacing with the UUTs. The thermal hydraulic calculations with listed assumptions for these two anticipated tests are discussed in more detail in the CTF Test Loop Preconceptual Design Report (PCDR) Section 7: Component Qualification Loop (CQL1), reference [10-7].

Emphasis has to be placed on the fact that both the Steam Generator (SG) and the H_2SO_4 Decomposition Reactor are considered UUTs. Proto-typical designs on both these units are outstanding at writing. Accordingly, the rationale behind this PCDR was to draw a line as far as CQL1 is concerned i.e. CQL1 does not include any of the mentioned UUTs. No cost has been allocated for either of these two units as they are considered to be treated as part of the utilities, once their designs have been finalized.

10.2.4 Component Qualification Loop (CQL2)

CQL2 has been described in detail in the CTF Test Loop Preconceptual Design Report (PCDR) Section 8: Component Qualification Loop 2 (CQL2), reference [10-8].

CQL2 is referred to as Concept 2 in the NGNP CTF Feasibility and Recommendation Study, reference [10-2]. CQL2 makes use of larger mass flows i.e. 25 kg/s, which accounts to approximately 15 percent of the anticipated PBMR-based NGNP maximum mass flow, using helium as fluid with similar process conditions as described for the TDLs i.e. 950 °C and 9.0 MPa. CQL2 makes provision for the testing of a wide spectrum of high temperature reactor system components, all by using a two-loop flow system that simulates NGNP demonstration plant primary and secondary loops. CQL2 can be configured into seven different configurations which provide necessary flexibility for testing different main components under stated process conditions.

The CQL2 design basis caters for the development and qualification of critical heat transfer products, systems and subsystems for commercially sized equipment. The capacity of the CQL2 test loop provides in some defined cases for development, testing and qualification of full-scale components. The CQL2 hot-to-hot and hot-to-cold manifolds can be physically divided into sections to facilitate in anticipated experiments. It is also possible to isolate experimental set-ups for specific reasons like rebuilding, maintenance, re-configuration and end of tests.

The primary loop provides high-temperature helium flow, but it is possible to create intermediate temperatures by making use of mixing devices (mixing of hot helium with cold helium downstream of the blowers). The specific flow control devices for the different streams will need special design attention.

CQL2 is preferably to be added to the rear-end of the CTF NGNP Development Path. When added to the rear-end of the CTF project lifecycle, the suggested modular TDL-approach is preferred as precursor to CQL2 that could be constructed and reconfigured using a number of the existing TDL components. Obviously, during the TDL operational phase, a decision will have to be made to either proceed with CQL1 or CQL2. CQL1 will imply coupling of existing TDLs. CQL2 will imply some reconfiguration of components, obviously including a large amount of add-on components where applicable. All these key decision mileposts are indicated in the time-based graphs illustrated in paragraph 10.7 as well as in the time-based graphs illustrated in Appendix F. Should CQL1 be preferred, the need for CQL2 would probably be superfluous and *vice versa*. The decision for opting for CQL1 or the larger CQL2 can only be made in future, pending the Steam Generator (SG) and the H_2SO_4 Decomposition Reactor proto-typical designs and further advancements. It is therefore recommended that if CQL2 be selected, it be utilized once the TDLs have played their role. This modular approach of first making the most of smaller modular TDLs could mitigate technological risks associated to either of the CQLs.

Incorporation of CQL2 into the CTF will have to be based on the techno-economic objective of the CTF project as it progresses in accordance to the NGNP Technology Development needs.

10.2.5 Circulator Test Loop (CTL)

The Circulator Test Loop (CTL) comprises a Test Station for a full-scale circulator for the NGNP. The CTL is to be operated at 160 kg/s helium flow rate, at a maximum temperature of 350°C and a pressure of 9MPa. Due to the availability of a high flow rate of helium at a high pressure drop (450 kPa total), several other tests can also be conducted in the CTL. These tests have been classified as:

- flow meter calibration as per full-scale NGNP;
- flow-induced vibration testing in the full-scale Heat Transport System (HTS) piping (also referred to as HGDs);
- vibration damping device testing in the mixing chamber;
- determination of the pressure drop coefficient of a full-scale check valve.

The Test Loop is heated by means of the Circulator energy input into the fluid, while temperature control is obtained by utilizing a controlled water cooler.

The CTL's ECC is dependent upon the Blower Development, which could advance by utilizing SSDTs.

10.3 Constraints and Limitations

Considering the CTF system integration as a whole, the following constraints and limitations need to be taken into account:

- From a design point-of-view, the main plant constraint is the 50 MW electricity supply. The TDLs make use of an 8.9 MW primary heater (over-designed by 30 percent due to the envisaged 40 year CTF operation) thus placing a restriction on the number of TDLs that could be incorporated for CTF usage (preferably limited to three at this stage). Concerning the CQL2 design, 25 MW has been made available for heating.

- The CTF will initially be used for technology development support of NGNP high temperature, high pressure heat applications. All heaters are designed to deliver helium at 950 °C, which is in alignment with NGNP requirements. The system pressure is 9.0 MPa in the primary loops of each proposed large-scale helium test facility. Technology development of the technologies designated for hydrogen production is crucial to comply with the CTF's installed capacity. In this regard, specific component manufacturing techniques for some of the equipment designated for hydrogen production (i.e. proto-typical H_2SO_4 Decomposition Reactor and all its sub-assemblies) are not fully developed and therefore require specific attention to ensure technology readiness by 2021. These manufacturing techniques must be demonstrated to provide assurance for commercial acceptance.

- To assure that the CTF facility is in alignment with industry standards for industrial facilities, International Building Codes and National Electric Codes shall be adhered to.

- In terms of environmental related requirements, all DOE orders shall be governed according to the "General Environmental Protection Program", as provided in DOE Order 5400.1, as referenced in [10-10].

- All vendors participating in prototype testing at the facility shall be safeguarded in such a way to ensure that intellectual property is protected. The I&C philosophy has been written as such to ensure strict security during concurrent prototype component testing. Distinction should be made between vendors participating in high-temperature heat application component testing and CTF operational and maintenance fleet.

- INL is to demonstrate electricity (process steam) and hydrogen production from HTGR technology by the year 2021. The CTF will be a crucial stepping stone to perform technology development in time to successfully mitigate current and future risks. Central to understanding the CTF Engineering, Construction and

Commissioning (ECC) life cycle, the following development paths are highlighted that need to be integrated to reach the NGNP Hydrogen Production goal.

- 950 °C NGNP ROT Development Path
- 750 °C NGNP ROT Development Path
- TDRM Report
- CTF Project Lifecycle
    - SSDT Project Lifecycle proposed to commence during Pre-Title I CTF Lifecycle.
    - Further TDL acquisition to follow SSDT testing.
    - CTF systems integration.

It is anticipated that the TDL ECC phase could be completed by 2015, ready and equipped to handle 950 °C NGNP ROT-based tests. However, 750 °C NGNP ROT-based tests could easily be accomplished if the need thereto would arise.

Funds dedicated to the CTF in whole will determine eventual CTF requirements attainability. General considerations toward CTF System Integration are underscored in paragraph 10.4, whilst the cost estimate approach for the CTF is given in paragraph 10.5.

10.4 General Considerations toward System Integration

10.4.1 CTF Project Lifecycle

Figure 10-6 below shows a simple schematic of the total CTF project phase, which begins with Pre-Title I design, currently being the phase of the CTF project at the writing of this report. Pre-Title I design is followed by Title I and Title II design stages alternatively referred to as basic and detail design stages, respectively.

The Procurement, Plant Construction and Supervision & Quality Control (QC) phases (collectively known as the Title III design phase) follow the Title II design stage, where after Commissioning and Start-Up commences. Subsequent operation is ensued upon following successful commissioning.

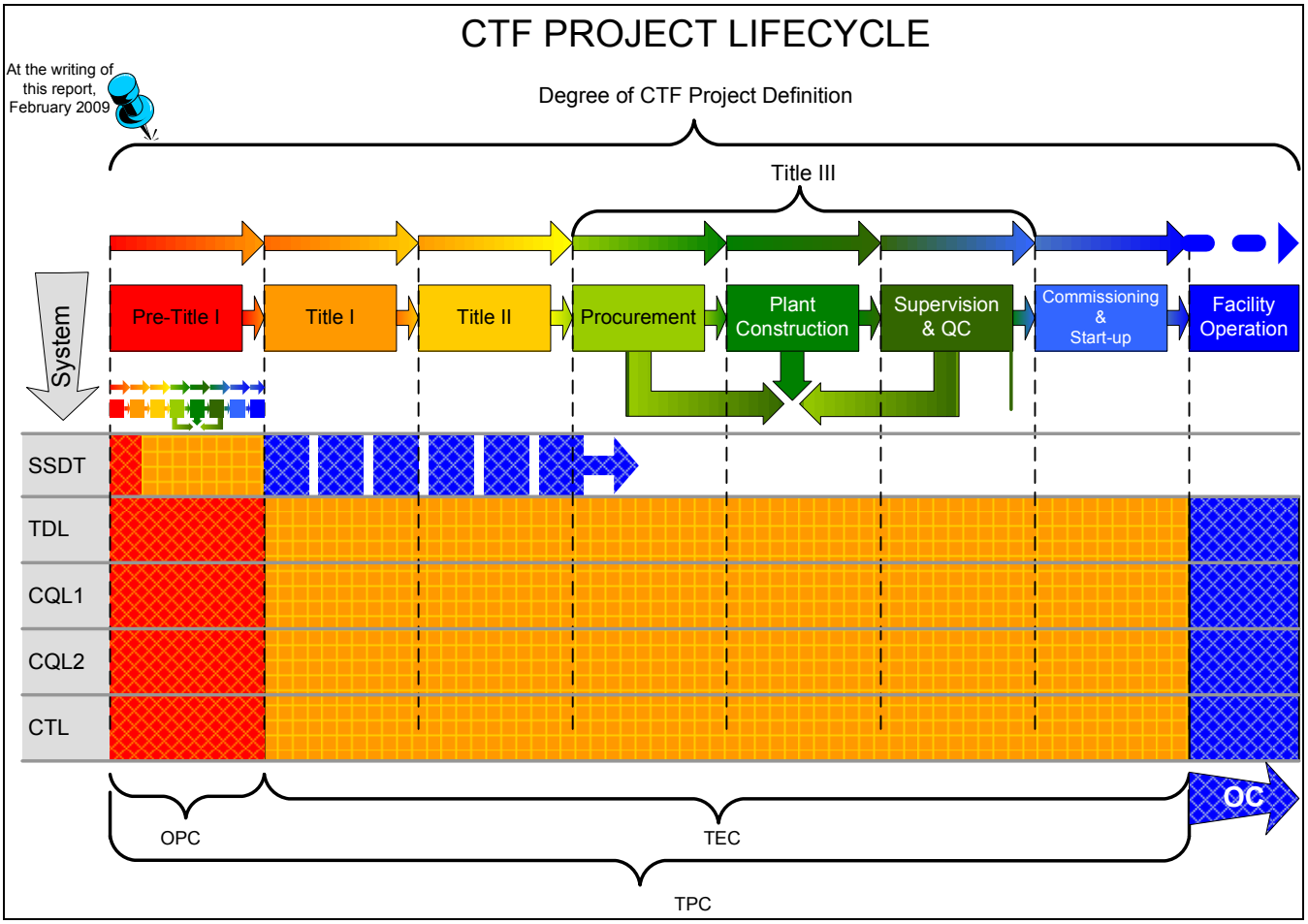


Figure 10-6: Schematic illustration of the CTF Project Lifecycle Phases.

The cost-related nomenclature used in Figure 10-6 is defined as follows:

- OPC = Other Project Costs
- TEC = Total Estimate Costs
- TPC = Total Project Costs
- OC = Operating Costs

Figure 10-6 above schematically illustrates the interdependent system project progression. This schematic, as well as the two follow-up figures (Figure 10-7 and Figure 10-8) are not based on specific time periods. Moreover, the abscissas in Figure 10-6 through Figure 10-8 is indicative of nonspecific time only.

From Figure 10-6 it is noticed that the SSDT phase requires less design than other CTF project phases (TDL, CQL1, CQL2 and CTL).

It is advised that the SSDTs' designs commence during the CTF Pre-Title I phase. Such an approach will remove some of the obstacles (i.e. technology readiness of components due for

CTF testing) associated with establishing the way forward on the other planned CTF systems and the integration thereof.

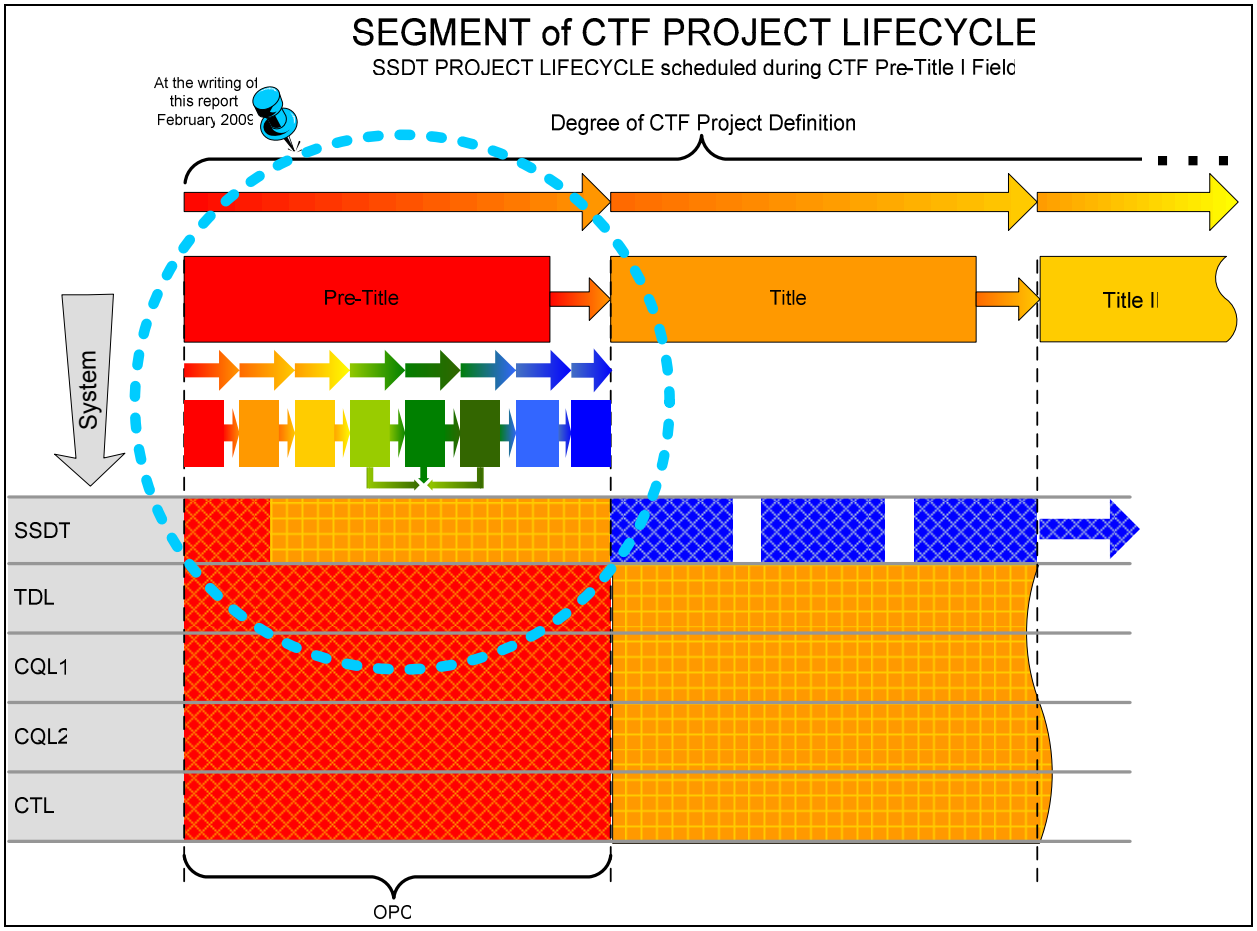


Figure 10-7: Schematic of SSDT design phase and subsequent construction activities

Evidently, during the SSDT project phase, the same sequence of events (Pre-Title I through Operations) are applicable as per CTF design. The SSDT project phases are referred to as "Degree of SSDT Project Definition", whereas the CTF project phases are referred to as "Degree of CTF Project Definition" – see Figure 10-8 below.

The purpose of commencing with SSDT design during the CTF Pre-Title I phase will be sensible from a cost point-of-view. Early SSDT operation will also provide valuable information for future CTF (TDL or CQL) design.

Following, is a discussion on different scheduling considerations and cost estimation methodologies eventually leading to the cost estimation approach used in this System Integration section.

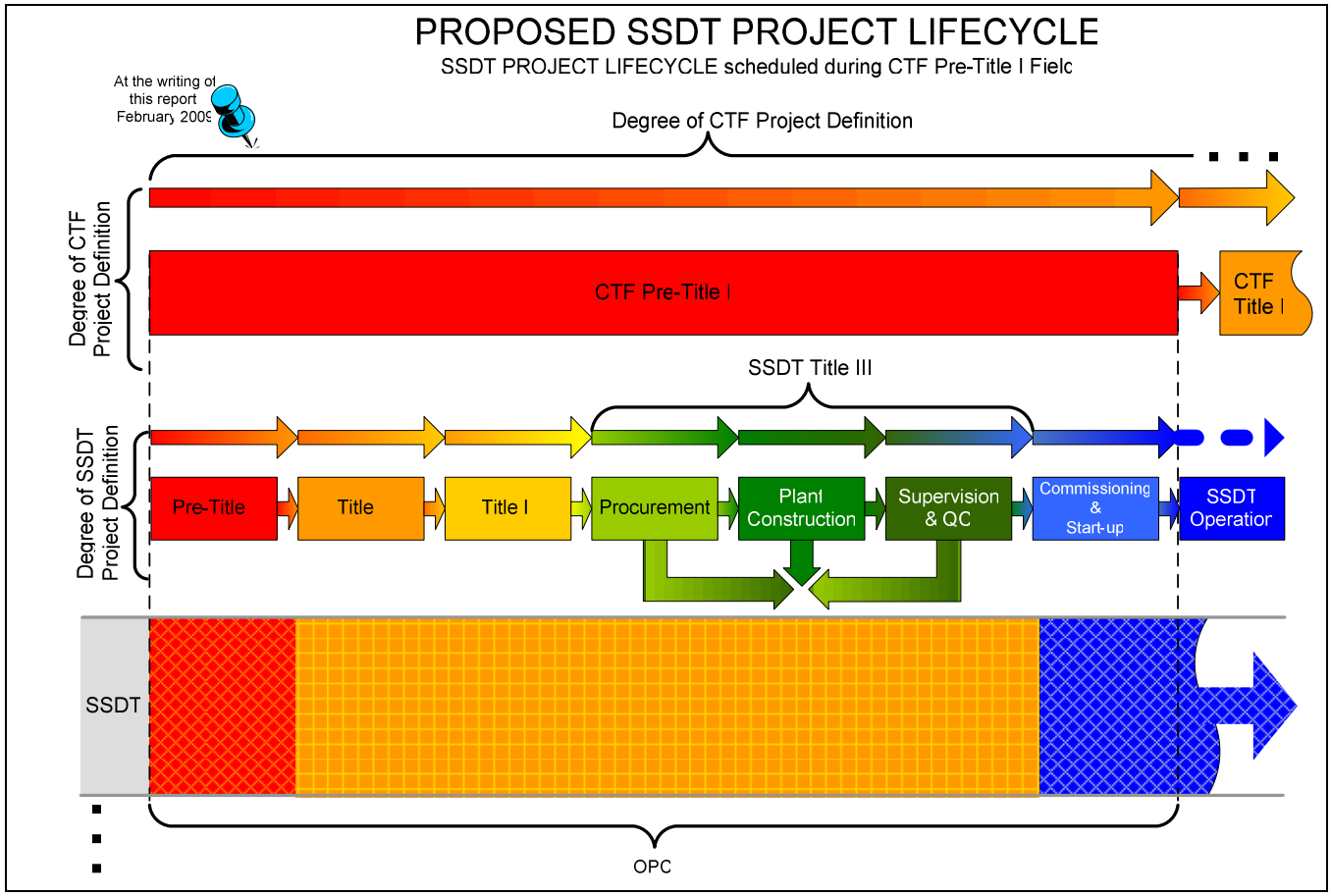


Figure 10-8: SSDT Project phase to ensue during CTF Pre-Title I project phase.

10.4.2 Schedule

Three different CTF System Integration approaches are suggested. The three approaches are:

- Moderate Approach (One TDL used as reference.)
- Aggressive Approach (Two TDLs used as reference.)
- Very Aggressive Approach (Three TDLs used as reference.)

A complete Gant Chart schedule is provided for the Very Aggressive Approach for the 950 °C NGNP ROT (refer to Appendix A).

10.4.3 Costing Methodology

10.4.3.1 General Approach

Any estimating methodology could be categorized as being either stochastic or deterministic. For the former, independent costing variables involve factoring, based on

statistical relationships between costs and other design related factors such as Capacity-Factored Estimates (CFEs). CFEs provide a prompt and satisfactorily accurate means of determining whether a proposed project could be sustained. The CFE approach is adequate for deriving the cost of a new plant from the cost of a comparable plant of known capacity. In view of a facility such as the CTF, this approach has too many uncertainties. The CFE approach is not employed for this report due to uncertainties in comparing "capacities" of the proposed CTF *vs.* a similar previously operated component testing facility. Besides, the CFE approach is mostly used as cost estimate methodology during feasibility phases, which is part of the past considering the current CTF project lifecycle phase (Preconceptual Design).

When a deterministic methodology is used, independent variables are a direct measure of each item being estimated, which requires detailed quantities and pricing. The deterministic approach is normally put into practice as the level of project definition increases, which will be more appropriate as the CTF design progresses. The CTF's project lifecycle is at the closing stages of the Preconceptual Design phase and at the dawning stages of the Title I phase.

The dominant cost estimation methodology dealt with in this report is the Equipment-Factored Estimate (EFE) methodology, which is typically prepared during the Pre-Title I to Title I stage of a project, when engineering is between 1 and 15 percent complete – reference [10-11].

The EFE methodology in combination with proven factorized cost estimation of indirect costs as well as sound engineering judgment and previous costing experience can lead to very accurate cost estimates. Most of the participants of the current M-Tech design team have had the privilege of partaking in the Engineering, Construction and Commissioning (ECC) of similar, but smaller component testing facilities. Thus, the EFE approach has been followed for this CTF costing exercise, taking into consideration the degrees of project definition as stipulated in Figure 10-6 above. EFEs make use of the straightforward principle that cost elements are expressed as factors of purchased equipment.

EFEs are generally used during an Estimate Class 4 (classes ranging from 5, which is the lowest level of project definition to 1, which is the highest level of project maturity) to justify further funding required to complete additional engineering design and subsequent related activities [10-11]. An EFE can be relatively accurate if equipment factors are properly made use of and process equipment is somewhat comprehensive and accurate, which relies on examination of the equipment list and comparing it to PFDs and P&IDs. It is worth mentioning that the equipment list in any Pre-Title I phase of a project lifecycle is still in a preliminary stage and therefore it is imperative that although major equipment have been identified, it will be necessary to assume a cost percentage for auxiliary equipment that has not yet been identified. Due to the envisaged 40 year operation of the CTF, size verification is crucial at this stage and the over-sizing fraction will have to be confirmed by current and future design teams and compared alongside INL's procedures and guidelines. Paragraph 10.5 provides more detail regarding the factored approach used as basis for cost estimation of the proposed CTF.

Part and parcel of an EFE is to obtain decent equipment purchase costs, since material costs of equipment can represent 20 to 40 percent of the total project costs for process plants [10-11]. An article by Uppal mentions that equipment cost alone can typically represent 20 to 35

percent of total capital expenditures [10-12]. It is thus prudent that appropriate escalation of historical purchase data be taken into account for more precise equipment estimates, where applicable. Once the equipment cost has been ascertained, appropriate equipment factors need to be applied taking into consideration adjustments be made in terms of equipment size, material designated for use as well as operating conditions. For example, factors for foundations and steel support structures including embedment depths for large components will have to be adjusted when the proposed process industry is situated within an active seismic zone. Such information can be obtained from geotechnical investigations. With reference to this specific example, according to the CTF Site Selection Study, INL is located in an a-seismic area and therefore the "Minimize Impact from Potential Earthquakes"-criteria has been removed from the Final "Want" Criteria in the abovementioned Site Selection Study. Thus the factor to be used in the EFEs for foundations and steel support structures are adjusted accordingly.

The EFE methodology thus uses the equipment cost, multiplied by an appropriate factor to arrive at the installed Direct Field Cost (DFC). Hans Lang [10-11] used a simplified approach for cost estimates in where the Total Plant Cost (TPC) amounted to the Total Equipment Cost (TEC) multiplied by the equipment factor, nowadays called the Lang Factor. Lang proposed three different process dependent factors, of which for a process plant running on fluids alone, he used an overall equipment factor of 4.74. It should be noted that Lang's equipment factor covers the Total Installed Cost (TIC) of a plant i.e. the ratio of the complete plant cost to the sum of the purchased cost of all equipment, typically ranging between 3 and 5.

A rather invigorated approach has evolved from Lang's work where different factors may apply to Total Installed Costs (TIC) or to Direct Field Costs (DFC). Typical equipment factors, based on W E Hand's work [10-11] who elaborated on Lang's work by categorizing equipment factors as component-specific rather than process-specific, ranges between 2.4 to 4.3 including instrumentation.

In addition to Hand, there is Happel's method [10-13], which includes estimated Labor necessary for installation, extra material and labor for piping, insulation, overheads, engineering fees and contingencies leading to a total investment cost. The EFE method is also described by IchemE, commonly referred to as the method of IchemE "Blue Book" [10-14].

The cost estimation methodology dealt with in this report, has resulted from the Equipment Factor Estimate (EFE) methodology, which is used as corner stone for the capital cost estimation. The EFE estimate used in this report was calibrated using equipment factors by Brennan and Golonka [10-14] together with engineering judgment, actual costing estimates and comparative costing of comparable technology from other test facilities, where applicable.

10.5 CTF Cost Estimate Approach

10.5.1 Introduction

The CTF is intended to qualify newly developed components for the Next Generation Nuclear Reactor, which is still in the preconceptual phase. However, the scale of the project is such that the budget for the test facility also has to be approved by Congress. The approval of the budget for the project is referred to by the DOE Guidelines (DOE G 430.1-1) [10-15] as "Key Decision 1". The phases and main events during the execution of a project within the DOE framework are shown in Figure 10-9.

10.5.2 Type and purpose of this estimate

This report documents a conceptual design estimate, referred to at point (2) in Figure 10-9. The DOE guideline recommends that the degree of accuracy should be plus or minus 30 percent for such an estimate, which is comprehensible with the degree of project definition at current. The purpose of the comprehensive cost estimate of which this one will form part, is to request congressional authorization for funding, referred to as *Key Decision 1* in Figure 10-9.

Furthermore, this cost estimate serves the following purposes:

- to ensure project feasibility and attainable performance levels;
- to develop a reliable project cost estimate consistent with realistic schedules;
- to use it to establish baseline project definitions, schedules, and costs.

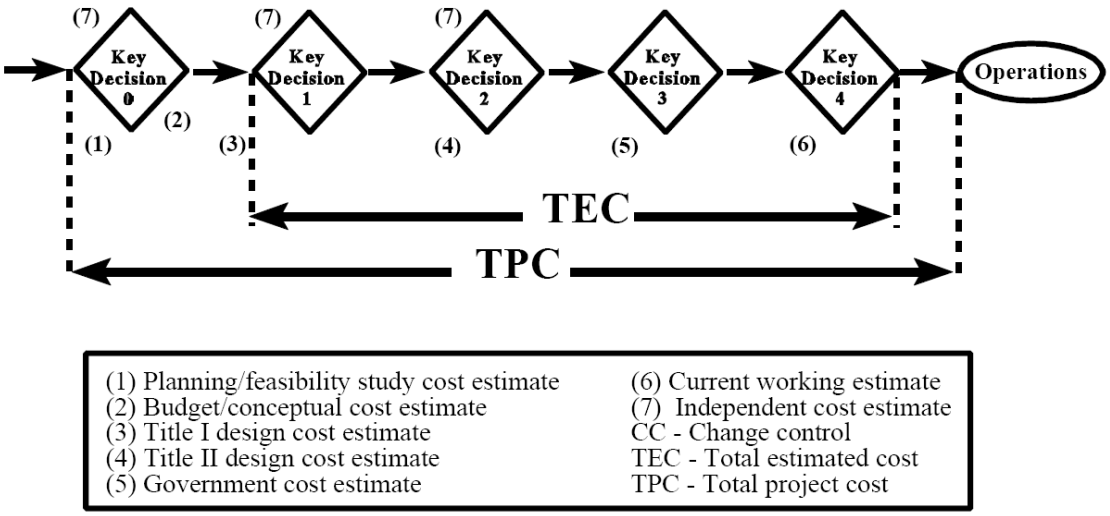


Figure 10-9: Phases and main events in a project within the DOE framework, from DOE G 430.1-1.

10.5.3 Scope of Work

This cost estimate covers the equipment that is directly involved for testing of NGNP components, the so-called test loops. Utilities, civil works and buildings have been considered by utilizing a factored approach and it should be noted that these could vary depending on the fact whether these test loops will be constructed on the CTF premises and whether they will be having dedicated or shared auxiliary usage. No quotations have been obtained for utilities, civil works and buildings.

As vendors other than Westinghouse Electric Company (WEC) will also submit proposals of test loops, the CTF building and utilities may also in future have to cater for test loops from more than one vendor. This is illustrated in Figure 10-10.

The WEC proposal consists of the following systems:

- Small-Scale Development Tests (SSDTs)
- Technology Development Loops (TDLs, essentially Heat Exchanger Test Loops)
- Component Qualification Loops (CQL1 and CQL2)
- Circulator Test Loop (CTL)

The technical details of these systems, as documented in Sections 5 through 9 of this PCDR [10-3], serve as input to this cost estimate.

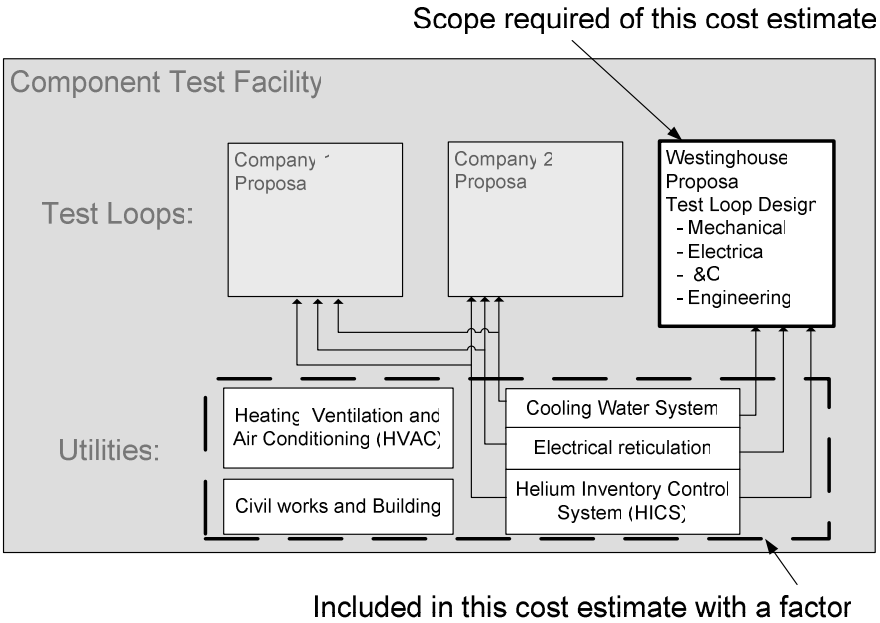


Figure 10-10: Indication of the scope of this cost estimate in the context of the CTF project.

These systems are all only at a preconceptual design level, so that, in order to reflect the actual cost, the Total Project Cost estimate will have to cover the whole engineering

development process. This development process for a project is broken down into the following phases by the DOE Guide [10-15]:

- Pre-Title I activities (i.e. part of Other Project Costs (OPC))
- Title I – Preliminary Design
- Title II – Detail Design
- Title III – Construction
- Commissioning and Start-up
- Operation

As shown in Figure 10-9, Total Estimated Cost (TEC) includes only the phases from Title I (Preliminary Design) to Commissioning and Start-up. It is also required to give an indication of some of the Other Project Cost (OPC), which includes Pre-Title I activities. Over and above the Total Project Cost (TPC = OPC + TEC), the estimated initial Operating Cost for the Westinghouse test loops is furthermore required. The above scope of work is shown schematically in Figure 10-11.

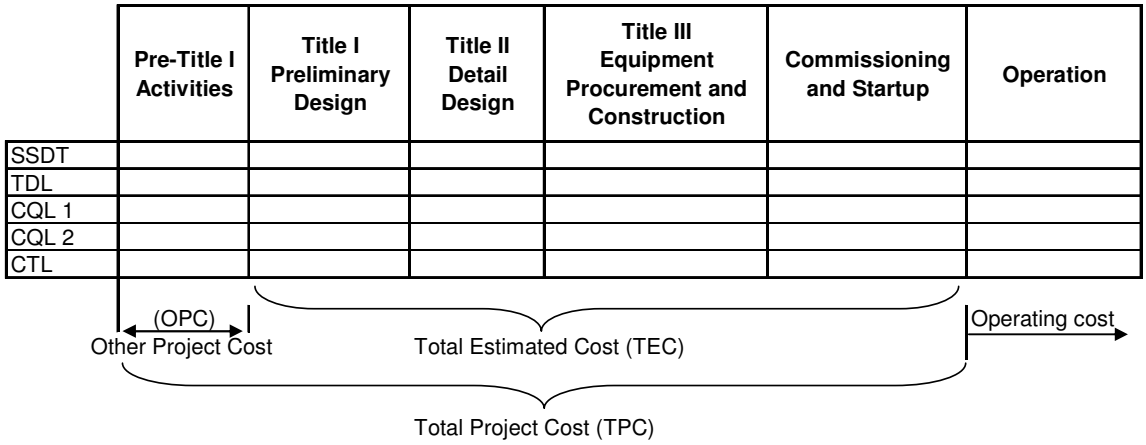


Figure 10-11: High-level breakdown of this cost estimate according to system and project phase.

10.5.4 Costing Limitations and Exclusions

As stated in the previous paragraph, utilities, civil works and buildings have been considered by utilizing a factored approach. These utilities, shown in Figure 10-10, include the following systems:

- Heating, Ventilation and Air Conditioning (HVAC)
- Helium Inventory Control System (HICS)
- Cooling Water System (CWS)
- Electrical reticulation and transformers
- Civil works and building

10.5.5 Assumptions

The following assumptions were made in the creation of this cost estimate, done for the 1st quarter, 2009.

- **Electrical reticulation**

It is assumed that electricity will be available at the required voltage at every power-using component and that the interface with the facility is a manual isolating switch. Electrical equipment that is unique to a specific test loop, such as a heater thyristor controller or a VSD for the circulator motors, are included in this cost estimate.

- **Helium Inventory Control System (HICS)**

It is assumed that Helium will be available at the required pressure (up to 9.6 MPa) for each of the SSDT, TDL, CQL and CTL systems.

- **Cooling Water System (CWS)**

It is assumed that cooling water will be available at the required pressure (up to 500 kPa) and temperature (20 °C) for each of the SSDT, TDL, CQL and CTL systems. The return temperature from each of the process plants' coolers is limited to 45 °C.

- **Heating, Ventilation and Air Conditioning (HVAC) System**

It is assumed that HVAC will be available as per the Client's requirements.

10.5.6 Approaches for cost estimation according to phase

As mentioned earlier, for this phase of the CTF project, with the amount of available design detail, the most appropriate method was considered the Equipment Factor Estimation (EFE) method. This method relates all phases and expenses of a plant to the cost of the purchased equipment, which include all process equipment such as pressure vessels, coolers and heat exchangers. In this study, the purchased equipment cost was determined by means of budget quotations from suppliers.

In order to cross-check the EFE, a high-level Activity Based Costing (ABC) was also done. ABC consists of an estimation of the number of man-hours for each activity in each phase. Factored cost estimate results were double checked against previous plant experience and their associated ABC.

A confidence factor has been incorporated into the spreadsheet which indicates the level of assurance of the equipment cost estimates. These confidence levels has however not been linked to the contingency and had no effect on the overall costing.

10.5.7 Establishment of EFE factors

As pointed out earlier, the basis for this method was laid by Lang [10-11], who related the total plant cost to purchased equipment cost. From a survey of fluid processing plants (such as the CTF), he found this factor to be 4.74 on average. Later investigators have found that the variation in this overall plant factor to be the most accurate of the all the various factors used to estimate total plant costs.

Lang's method was expanded by Hand [10-11], who broke down Lang`s plant factor into cost for design phases and separate equipment. The IChemE expanded and formalized this EFE method in a publication, the so-called "Blue Book" [10-14], so that this method is also commonly referred to as the method of the IChemE "Blue Book" (Brennan and Golonka).

For this investigation, equipment factors published by Brennan and Golonka (2002) were used.

When using the EFE method, the following has to be kept in mind:

1. The cost factor is dependent on the size of the equipment it is based on. This makes sense as many of the equipment and tasks stay the same, regardless of the size of the equipment, such as walkways alongside a pressure vessel or instrumentation on the vessel.
2. The material of construction has to be taken into account. Material and manufacturing costs for nickel- and chromium-containing alloys are higher than for carbon steels, while the surrounding equipment cost stays the same.
3. To a certain extent, equipment and plant factors are industry-specific. For instance, the typical cost factor for plant piping on a refinery is not at all applicable to the HGDs encountered on High-Temperature Gas Cooled Reactors or on the CTF.

For this investigation, one set of factors have been used for all Test Loop cost estimates except for the SSDT's. Due to the abovementioned scale effects, the costs calculated with the general EFE method for the SSDTs were not realistic. In the case of the SSDTs, another set of factors were derived from previous experience on similar sized projects.

10.5.7.1 Sources of Equipment factors

The set of factors used for the CTF cost estimate was derived from the following sources:

1. A paper by Brennan and Golonka (2002) explaining factors for capital cost estimation in evolving process designs [10-14].

2. Previous experience of M-Tech Industrial with the complete engineering, construction, commissioning and operation of high-pressure, high-temperature experimental plants. These projects were done over the past six years.
3. Guide to Capital Cost Estimating authored by A.M. Gerrard [10-16].
4. A paper by Larry Dysert (2001) titled "Sharpen Your Capital-Cost-Estimation Skills", referenced in [10-11].

The cost breakdown of all the above sources differ so that is was not possible to directly compare cost factors for each of the segments making out the Total Installed Cost (TIC) of each component. Combination and rearrangement of the information from the above sources resulted in the cost breakdown and factors described in more detail in Appendix E of this same section (Section 10 – Appendix E).

The above costs are related to the capital expenditure of a plant. Following are the costs associated with Commissioning and Start-up and the Operational Cost.

10.5.8 Commissioning and Start-up

Commissioning and start-up costs have been based on 15 percent of the raw equipment costs. At this stage of the CTF's project lifecycle it is still based on the factored approach.

10.5.9 Operational Cost

In order to acquire operational cost estimations for operating either one of the SSDTs, TDLs, CQL1 or the CTL, an independent hourly rate was calculated for each of these systems. This calculation was based on DOE [10-15] guide lines and previous experience gained with other test facilities in South Africa. The operating cost estimation is done within similar confines stipulated for the proposed CTF, as previously dictated by the technical design within Section 5 through 9 of this PCDR [10-3]. It thus excludes all auxiliary equipment facilities such as the HVAC, HICS, HPS and cooling water.

Considering CQL2, operational costs have been omitted due to the uncertainty of the exact tests for this system at this point in time.

10.5.9.1 Time Allocation

The total test duration (total time allocated to use the test facility) was divided into:

- Setup time (real time used for experimental setup, excluding post-testing maintenance)
- Testing time (real time used for actual testing purposes).

In addition to the total test duration, provision was made for downtime which includes unforeseen plant failures as well as regular maintenance to the conditioning equipment. It is

foreseen that an experimental plant of such caliber should be running on a Reliability Factor (RF) of 95 percent and higher. A simple definition of reliability is:

Reliability Factor (RF) = (Available Operational Plant Time minus (–) Downtime due to Incidents) / Available Operational Plant Time.

Utilization Factor (UF) = Available Operational Plant Time (i.e. includes Total Available Time minus (–) Downtime due to scheduled maintenance and Downtime arising from all incidents).

Scheduled downtime is not considered as Incident Downtime and therefore only influences the Available Operational Time. The less the scheduled maintenance, the better the chance of achieving higher available operational plant time i.e. Utilization Factor (UF). Obviously, scheduled maintenance is not to be underestimated.

10.5.9.2 Setup Time Cost ($/h)

To accommodate and facilitate possible complex component testing configurations, set-up time was also incorporated into the cost estimate. These costs typically include utility costs, labor costs and support service costs. It is assumed that 10 percent of the total time allocated for testing (total test duration) is designated for proper setting-up of equipment. It is also assumed that during this setup time period only day shifts (8-hour shifts) will be required, thus eliminating afternoon and night shifts. Setup time will also be utilized for test configuration changes and may include some pre-test engineering.

- **Utility costs**

Utility costs include all costs associated with heating and cooling the facility as well as all additional costs necessary for providing electricity, cooling water, compressed air, steam and other consumables where applicable. Since most of the auxiliary supply systems fall outside the costing boundary, and electricity cost is a minimum during setup time, utility costs within the costing boundary are assumed to be negligible during the setup time phase.

- **Labor costs**

Labor costs during the setup time phase are allotted to a project manager, test engineers and artisans (millwrights), assuming an 8 hour day shift. Hourly Labor rates are based on the Monthly Labor Review (MLR), published by the U.S. Department of Labor's Bureau of Labor Statistics (BLS) [10-17].

10.5.9.3 Testing Time Cost ($/h)

Costs related to testing time once more includes utility costs, labor costs and support service costs. It is assumed that 90 percent of the total test duration is to be spent on testing time. It is also assumed that testing would be conducted 24 hours per day comprising three shifts per day.

- **Utility Costs**

Utility costs include all costs associated with heating and cooling of the facility as well as costs for providing electricity, cooling water, compressed air, steam and other consumables where applicable. Since most of the auxiliary supply systems fall outside the costing boundary, only electricity, helium and "other" utility costs, which are assumed to be 20 percent of the electricity cost, are included during testing time.

An additional helium inventory cost was calculated. This is based on a leak rate of 0.28 percent (per day) of the inventory [10-18].

- **Labor Costs**

Labor costs are distributed between a project manager, test engineers and artisans (millwrights), assuming testing personnel would be available 24 hours a day, working in shifts spanning 8 hours each. It is assumed that there would be four shift teams in total. Three shift teams would be active over a week-period running three 8-hour shifts per day, whilst the fourth team could be utilized for training purposes. Hourly Labor rates are based on the Monthly Labor Review (MLR), published by the U.S. Department of Labor's Bureau of Labor Statistics (BLS) [10-17].

10.5.9.4 Proportional Total Cost ($/h)

The proportional total cost per hour was calculated by adding the setup time cost and testing time cost proportionally to the time allocated to each of these activities.

10.5.9.5 Downtime Allowance Cost ($/h)

Downtime allowance includes downtime due to unforeseen conditioning loop failure (unplanned incidents) as well as general plant maintenance (planned downtime). This is however not related to setup time activities. It is assumed that 90 percent of the total time is allocated to the total test duration and 10 percent of the total time to downtime allowance. Downtime allowance cost is calculated from the total hourly rate (excluding downtime allowance).

10.5.9.6 Capital Recovery Cost ($/h)

The CTF is a dedicated testing facility. No capital recovery cost is catered for in this estimate.

10.5.9.7 Maintenance Cost ($/h)

The maintenance cost was calculated by multiplying the total capital investment by 2.5 percent [10-19]. According to reference [10-19] this factor varies from 1 to 2.5 percent.

10.5.9.8 Laboratory cost ($/h)

Laboratory cost is associated with laboratory analyses required for process monitoring and quality control. This cost is based on 20 to 30 percent of the operating labor cost [10-20]; a 25 percent cost was assumed for the purpose of this report.

10.5.9.9 Plant overheads ($/h)

Plant overheads can be categorized as general costs associated with the plant, such as general management, plant security, medical expenses and canteen services. Costs are based on 50 to 100 percent of the labor cost [10-20]; a weight of 75 percent of the labor cost was assumed for the purpose of this report.

10.5.9.10 Support services ($/h)

Support services include drinking water, sanitation and waste disposal. Costs related to support services were allocated percentage-wise to each of the test facilities. A base support service cost of $20 000 per month was assumed for the CTF facility.

10.5.9.11 Total Hourly Rate ($/h)

The total hourly rate could then be calculated by summation of the proportional total cost, downtime allowance cost, maintenance cost, laboratory cost, plant overheads and costs related to support services.

10.5.10 Costing methods for various components

10.5.10.1 Pressure vessels, Coolers, Heat exchangers

Quotes for these components were obtained from several fabricators.

10.5.10.2Transport

Three freight classes were defined according to weight, with the assumption that for a certain volume, the tonnage capacity of the truck will be adequate. For each class, the running cost per kilometer was determined and used as basis for estimating transport costs.

10.5.10.3Method for remainder

All other component costs were obtained by means of quotations from suppliers.

10.5.11 Overall plant cost and benchmarking

Once the overall plant cost is calculated, the ratios between various parts of the plant are calculated and compared with industry-standard ratios in order to check that the estimates are within the expected price ranges.

The costing as presented does not include any travel or subsistence costs. It neither includes any spare parts for any of the mentioned systems.

10.5.12 Regulatory drivers

The regulatory drivers and design criteria requirements are discussed in Section 3 of this PCDR, Reference [10-21].

10.6 Available Test Specifications

All the test specifications as per the Technology Development Roadmapping (TDRM) report [10-1] are condensed in the tables given below as well as in the schedule for the Very Aggressive approach – refer to Appendix A for the complete schedule.

The tables give a summary of the tests designated for each of the different systems.

Note that some of the tests given in the tables below are based on engineering judgment and that not all of these tests are derived from the TDRM report. These engineering judgment specifications are based on experience gained from PBMR test facilities.

Some tests have been earmarked for Laboratory testing to lessen the impact of total testing time on CTF system integration. The colors in the bars on the left hand side of each table are similar to the colored sections in the graphs depicted in Paragraph 10.7 below. Only a few tests could be run concurrently per system, which also shortens total testing duration. These anticipated concurrent tests (per system) are identified in the "Remarks" column of the tables below.

Please note that all tests, as indicated in the tables below (Table 10-1 through Table 10-6), are applicable for the 950 °C NGNP ROT Development Path. A 750 °C NGNP ROT Development Path could easily be implemented should the need arise.

Total testing times are reflected in the "Total Duration" rows of each table below i.e. there is a "Total Duration" for the 950 °C NGNP ROT as well as for the 750 °C NGNP ROT. Due to the fact that the 750 °C NGNP ROT TDRM report has not been completed yet, the total duration times of the 750 °C NGNP ROT tests are based on the assumption of exclusion of all IHX A as well as all Mixing Chamber tests. The reduced time-loads due to a 750 °C NGNP ROT is given for information purposes only. The scope of the CTF remains to conduct tests related to the 950 °C NGNP ROT.

Test durations for CQL1 are anticipated to extend over three years for both anticipated Steam Generator and H_2SO_4 Decomposition Reactor tests. Durations for the High Temperature Steam Electrolysis (HTSE) tests have not been specified yet due to limited information.

Table 10-1: All tests related to SSDT1.

	SSDT1 Tests (No Flow)	TRL Advancement	Duration (Months)	Remarks
IHX A (Met.)	IHX A (Metallic): Corrosion allowances for Alloy 617	2-3	~~27~~*	Could be tested in a suitable Laboratory.
	IHX A (Metallic): Testing of Unit Cell of Compact Heat Exchanger • IHX Joint Integrity • Creep lifetime tests @ 1000 °C	4-5	24	As per test specification in NGNP-CTF MTECH-TLDR-0005, test number WEC-TS-IHXA-012.
	Subtotal (Duration)		**24**	950 °C NGNP ROT based tests.
IHX A (Cer.)	IHX A (Metallic): Testing of Unit Cell of Compact Heat Exchanger • IHX Joint Integrity • Creep lifetime tests @ 1000 °C	4-5	12	As per test specification in NGNP-CTF MTECH-TLDR-0005, test number WEC-TS-IHXA-030.
	Subtotal (Duration)		**12**	950 °C NGNP ROT based tests.
IHX B	IHX B (Metallic): Corrosion allowances for Alloy 800H	3-4	~~27~~*	IHX B related to 750 °C NGNP operational temperature. Could be tested in a suitable Laboratory.
	IHX B (Metallic): Testing of Unit Cell of Compact Heat Exchanger • IHX Joint Integrity • Creep lifetime tests @ 1000 °C	4-5	24	IHX B related to 750 °C NGNP operational temperature. As per test specification in NGNP-CTF MTECH-TLDR-0005, test number WEC-TS-IHXB-012.
	Subtotal (Duration)		**24**	750 °C NGNP ROT based tests. Also applicable to the 950 °C NGNP ROT schedule.
E R	Piping: • Effects of He infiltration on thermal conductivity	5-6	18	As per test specifications in NGNP-CTF MTECH-TLDR-0005, test numbers WEC-TS-PIP-006_1 and WEC-TS-PIP-006_2.

* The 27 months time allocation is crossed out in this table to indicate that it will not influence SSDT operational time. This specific test could be performed in a laboratory.

	SSDT1 Tests (No Flow)	TRL Advancement	Duration (Months)	Remarks
	of insulation material • Effects of sudden depressurization on insulation at 9 MPa, 950 °C			
	Piping: Effects of impurities (C) on material insulation properties • Instruments: o Determine impact of temperature on strain gauges o Determine impact of helium on strain gauges o Determine methods to measure leak flow • Material: o Elevated temperature testing in He with no self-welding • Lubricants: o Testing of lubricants for high temperature environment	5-6	18	Possibility of performing the effect of impurities on material insulation properties test concurrently with IHX A creep test. As per test specification in NGNP-CTF MTECH-TLDR-0005, test number WEC-TS-PIP-007. • Impact of temperature on strain gauges could be tested in a suitable Laboratory. • The impact of He on strain gauges to be tested in a High Pressure environment. • Methods to measure leak flow to be treated as separate study. • Elevated temperature testing in He environment with no self-welding could also be tested in a suitable Laboratory.
	Subtotal (Duration)		**36**	950 °C NGNP ROT based tests. Also applicable to the 750 °C NGNP ROT schedule.
	Total Duration (750 °C ROT Integrated Option)		**60**	Excludes all IHX A tests' duration (assumption).
	Total Duration (950 °C ROT Integrated Option)		**96**	Includes all tests' duration.

Table 10-2: All tests related to SSDT2.

	SSDT2 Tests (Low Flow)	TRL Advancement	Duration (Months)	Remarks
	IHX A (Metallic): Unit Cell Fatigue Life Test	2-3	24	As per test specification in NGNP-CTF MTECH-TLDR-0005, test number WEC-TS-IHXA-012_3.
	IHX A (Ceramic): Fatigue testing of unit cell of compact IHX	4-5	12	
	IHX B (Metallic): Fatigue testing of unit cell of compact IHX	4-5	24	
	Subtotal (Duration)		**60**	950 °C NGNP ROT based tests.
	Total Duration (750 °C ROT Integrated Option)		**24**	Excludes all IHX A tests' duration (assumption).
	Total Duration (950 °C ROT Integrated Option)		**60**	Includes all tests' duration.

Table 10-3: All anticipated tests related to SSDT3.

	SSDT3 Tests (Higher Flow)	TRL Advancement	Duration (Months)	Remarks
	IHX A (Metallic): Heat Transfer Capacity	4-5	12	Performance at nominal conditions.
	IHX A (Ceramic): Heat Transfer Capacity	4-5	12	Performance at nominal conditions.
	IHX B (Metallic): Heat Transfer Capacity	4-5	12	Performance at nominal conditions.
	Blower Development: Expected Lifetime Evaluation	[TBD]	12	Could include destructive testing. Will determine boundaries for TDL operation.
	Transient Tests: Possible Temperature Transient Tests	4-5	9	Possible temperature transients ranging from 300 to 900 °C.
	Subtotal (Duration)		**57**	
	Total Duration (750 °C ROT Integrated Option)		**33**	Excludes all IHX A tests' duration (assumption).
	Total Duration (950 °C ROT Integrated Option)		**57**	Includes all tests' duration.

Table 10-4: All tests related to the TDL system.

	TDL Tests	TRL Advancement	Duration (Months)	Remarks
IHX A (Metallic)	IHX A (Metallic): Corrosion allowances for Alloy 617	2-3	~~27~~*	Could be tested in a suitable Laboratory. Equipment testing independent of other TDL tests.
	IHX A (Metallic): Testing of compact IHX module • Operating performance in typical steady state pressure & temperature environment • Operating performance in typical pressure transient environment • Operating performance in typical temperature transient environment • Compact IHX module tests at varying process parameters	5-6	24	Test specifications to be finalized prior to CTF testing.
	IHX A (Metallic): Shell side flow distribution & Bypass leakage testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX A (Metallic) multi-module heat transfer test.
	IHX A (Metallic): Multi-module heat transfer testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX A (Metallic) shell side flow distribution & bypass leakage test.
	Subtotal (Duration)		**45**	950 °C NGNP ROT based tests.
IHX A (Ceramic)	IHX A (Ceramic): Testing of compact IHX module • Operating performance in typical steady state pressure & temperature environment • Operating performance in typical pressure transient environment • Operating performance in typical temperature transient environment • Compact IHX module tests at varying process parameters	5-6	24	Test specifications to be finalized prior to CTF testing.

* The 27 months time allocation is crossed out in this table to indicate that it will not influence TDL operational time. This specific test could be performed in a laboratory.

	TDL Tests	TRL Advancement	Duration (Months)	Remarks
	IHX A (Ceramic): Shell side flow distribution & Bypass leakage testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX A (Ceramic) multi-module heat transfer test.
	IHX A (Ceramic): Multi-module heat transfer testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX A (Ceramic) shell side flow distribution & bypass leakage test.
	Subtotal (Duration)		**45**	950 °C NGNP ROT based tests.
IHX B (Metallic)	IHX B (Metallic): Corrosion allowances for Alloy 617	2-3	~~27~~	Could be tested in a suitable Laboratory.
IHX B (Metallic)	IHX B (Metallic): Testing of compact IHX module • Operating performance in typical steady state pressure & temperature environment • Operating performance in typical pressure transient environment • Operating performance in typical temperature transient environment • Compact IHX module tests at varying process parameters	5-6	24	Test specifications to be finalized prior to CTF testing.
IHX B (Metallic)	IHX B (Metallic): Shell side flow distribution & Bypass leakage testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX B (Metallic) multi-module heat transfer test.
IHX B (Metallic)	IHX B (Metallic): Multi-module heat transfer testing	6-7	21	Test specification to be finalized prior to CTF testing. This test could be run concurrently with the IHX B (Metallic) shell side flow distribution & bypass leakage test.
IHX B (Metallic)	**Subtotal (Duration)**		**45**	750 °C NGNP ROT based tests. Also applicable to the 950 °C NGNP ROT schedule.
OTHER Tests	Piping: Performance & Environmental testing on prototypical piping / insulation system • Performance & Environmental testing – typical steady state pressure and temperature	6-7	24	

	TDL Tests	TRL Advancement	Duration (Months)	Remarks
	environment • Performance & Environmental testing – typical pressure transient environment • Performance & Environmental testing – typical temperature transient environment			
	Mixing Chamber: Enhanced mixing devices	6-7	6	Not applicable to the 750 °C NGNP ROT schedule.
	Mixing Chamber: Vibration damping devices	6-7	6	Not applicable to the 750 °C NGNP ROT schedule.
	Material: Elevated temperature testing in helium with no self-welding	6-7	4	
	Lubricants: Testing of lubricants for high temperature environment	6-7	4	
	Subtotal (Duration)		**44**	950 °C NGNP ROT based tests. All tests except the Mixing Chamber tests also applicable to the 750 °C NGNP ROT schedule.
	Total Duration (750 °C ROT Integrated Option)		**77**	Excludes all IHX A tests' duration as well as Mixing Chamber tests' duration.
	Total Duration (950 °C ROT Integrated Option)		**179**	Includes all tests' duration.

Table 10-5: All tests related to CQL1.

	CQL1 Tests	TRL Advancement	Duration (Months)	Remarks
CQL1 Tests	SG Test: Performance testing of proto-typical Steam Generator.	6-7	36	Performance testing of steam generator considered as Unit Under Test (UUT). In need of steam generator proto-typical design prior to CTF performance testing.
	H_2SO_4 Decomposition Reactor Test: Performance testing of H_2SO_4 proto-typical Decomposition Reactor	6-7	36	Performance testing of H_2SO_4 Decomposition Reactor considered as Unit Under Test (UUT). In need of H_2SO_4 Decomposition Reactor proto-typical design prior to CTF performance testing.
	Subtotal (Duration)		**72**	950 °C NGNP ROT based tests
	Total Duration (750 °C ROT Integrated Option)		**-**	At the writing of this report, only applicable to 950 °C integrated CTF option.
	Total Duration (950 °C ROT Integrated Option)		**72**	Includes all tests' duration.

Table 10-6: All tests related to the CTL system.

	CTL Tests	TRL Advancement	Duration (Months)	Remarks
CTL Tests	Circulator: Partial or full-scale circulator Model Test	6-7	18	
	Piping - Performance and Environmental testing: Proto-typical high temperature piping/insulation system tested at low temperatures.	6-7	24	To be tested concurrently with low temperature piping/insulation system.
	Piping - Performance and Environmental testing: Proto-typical low temperature piping/insulation system tested at low temperatures.	6-7		To be tested concurrently with high temperature piping/insulation system.
	Mixing Chamber: Enhanced mixing devices	6-7	3	Dependent on NGNP design prior to CTL testing.
	Mixing Chamber: Vibration damping devices	6-7	9	Dependent on NGNP design prior to CTL testing.
	Subtotal (Duration)		**54**	
	Total Duration (750 °C ROT Integrated Option)		**42**	Independent of 750 °C integrated CTF option, except for the Mixing Chamber tests' duration.
	Total Duration (950 °C ROT Integrated Option)		**54**	Independent of 950 °C integrated CTF option.

10.7 CTF System Integration

10.7.1 System Integration Description

Three different CTF System Integrated approaches are represented in this section. The approaches have already been introduced and classed as Moderate, Aggressive and Very Aggressive. The terminology used for each of the different approaches points to the level of insistence to complete the high temperature heat transfer component tests. These proposed approaches are all TDL dependent, thus, each approach has the same fixed systems, which are:

- 1 x SSDT1
- 1 x SSDT2
- 1 x SSDT3
- 1 x CTL

The TDL count, being the varying component of the CTF system ranges from 1 x TDL for the Moderate approach, 2 x TDLs for the Aggressive approach and 3 x TDLs for the Very Aggressive approach.

All three approaches relate to the operational phase and not to the ECC phase. Each approach caters for the 950 °C NGNP ROT Development Path as outlined below:

A. Moderate Approach:
   - Integrated CTF with fixed systems; furthermore utilizing 1 x TDL

B. Aggressive Approach:
   - Integrated CTF with fixed systems; furthermore utilizing 2 x TDLs

C. Very Aggressive Approach:
   - Integrated CTF with fixed systems; furthermore utilizing 3 x TDLs

All SSDTs are designated for earlier project lifecycle development than any of the other mentioned Test Loops. They needn't be represented within the CTF. For example, SSDT1, SSDT2 and SSDT3 could be designated as Laboratory-scale testing facilities (especially SSDT1 and SSDT2), thereby leaving behind a possible SSDT3 and TDLs, a CTL and CQLs (either CQL1 or CQL2) designated for the CTF. Nothing forbids SSDT operation to take place remotely from the CTF site. Compared to the dimensions of the proposed CTF building, the SSDTs do not occupy a large footprint. They are indicated as block-footprints in the system integrated schematics illustrated later on (paragraph 10.7.2.3, paragraph 10.7.3.3 and paragraph 10.7.4.3).

The number of systems necessary for component testing, including the SSDTs are related to the test durations obtained from the Technology Development Roadmapping Report [10-1]. From these durations and from the test specifications set out in the NGNP-CTF

Preconceptual Design Report (PCDR), it can be seen from the graphs represented within this section, that only one of each of the SSDTs and one CTL is sufficient to complete most of the required tests related to each of these systems before the TDL testing commencement date (FY 2015) kicks in.

On the other hand, not one but three TDLs are necessary to shorten TDL test duration ahead of 2021. Utilizing only one TDL will extend its test completion date to far beyond the NGNP start-up date of 2021. It is recommended that the Very Aggressive approach, utilizing three TDLs be considered.

A phased approach could be considered where the CTF can be expanded i.e. through appending additional TDLs to an existing one. These key decisions need to be made in view of the dependency existing between the NGNP design and related technology and design maturity obtained from future component designs and tests.

It is necessary to say again that commencement of CQL testing (both CQL1 and CQL2) is dependent on the prototypical designs for both the Steam Generator (SG) and the H_2SO_4 Decomposition Reactor as well as all their sub assemblies, components and systems. At the writing of this report, CQL testing schedules are handled with less certainty and key decisions can only be made once more information regarding the abovementioned UUTs is available.

Assuming TDL operation can commence beginning 2015, the following TDL completion test-dates are foreseen (taking the listed assumptions into account – refer to Paragraph 10.7.1.1 below):

Approach	Test Completion Date:
• Moderate approach (1 x TDL):	2026
• Aggressive approach (2 x TDLs):	2022
• Very Aggressive approach (3 x TDLs):	2019

The milestone for reaching completion of TDRM-listed tests by 2019 is viable assuming unlimited resources for design and construction of all systems designated for CTF operation i.e. SSDT acquisition and testing, followed by acquisition of three TDLs and acquisition of one CTL. For these schedules, test durations are as per the Technology Roadmapping Report [10-1]. It is assumed that these test durations include both set-up- and post-testing dismantling -time, thus implying total test duration.

The above completion test dates do not include any large-scale tests for the Steam Generator (SG) and the H_2SO_4 Decomposition Reactor.

The graphs depicted below represent ECC and Test durations for each CTF system. The proposed NGNP schedule (i.e. design path) is also included on each graph. This NGNP schedule is to be updated following NGNP Conceptual Design (CD) Planning.

Graphs illustrating the ECC and Test durations of the SSDTs and the CTL are represented independently from and prior to those illustrating the ECC and Test durations of the three different TDL-dependent approaches.

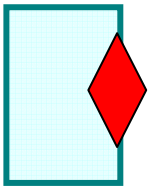
10.7.1.1 CTF Systems' ECC and Test Durations: Assumptions

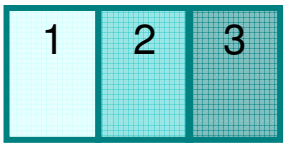
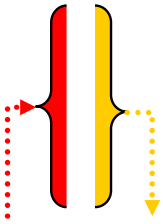
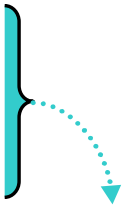
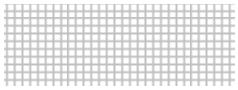
- SSDTs' Title I design assumed to commence during April 2009.
- All TDL-related tests assumed to commence at end of TDL ECC i.e. January 2015. At the writing of this report, the CTF project Lifecycle is in Pre-Title I phase.
- Unlimited resources for design and construction of TDLs designated for CTF operation.
- Testing time for each of the IHX tests i.e. IHX A (Metallic), IHX A (Ceramic) and IHX B (Metallic) span a duration of 45 months each (refer to Table 10-4).
- All other tests, i.e. HGD-related and Mixing Chamber tests span a duration of 44 months (refer to Table 10-4).

10.7.1.2 Chart Nomenclature

Nomenclature used in the graphs in this section as well as in Appendix F is given in Table 10-7 below.

Table 10-7: Chart Nomenclature, Abbreviations and Acronyms

Symbol / Abbreviation	Color (If applicable)	Description
Color Red (SSDTs and TDLs)		IHX A (Metallic) Tests
Color Blue (SSDTs and TDLs)		IHX B (Metallic) Tests
Color Orange (SSDTs and TDLs)		IHX A (Ceramic) Tests
Color Green (SSDTs and TDLs)		Other Tests i.e. Piping (HGD), Mixing Chamber etc.
Color Light Blue: ECC		Engineering Commissioning & Construction
Color Teal Blue: Eng		Engineering
Color Light Blue: CC		Commissioning & Construction
CD		Conceptual Design
	=	Indicates Commencement of Tests (Operation). Commencement date of TDLs and CTL assumed to be January 2015. SSDTs could be operational by 2012. SSDTs needn't be part of the CTF.
	=	Symbol for representing initiation of any of the tests listed below. Due to non-concurrent testing per system, an OR logic needs to be followed i.e. only one of the following will be feasible for testing: **Red Arrow = IHX A (Metallic) Test or,** **Blue Arrow = IHX B (Metallic) Test or,** **Green Arrow = Other Test(s) or,** **Orange Arrow = IHX A (Ceramic) Test**
	=	Anticipated IHX A (Ceramic) Testing. These IHX A (Ceramic) Test durations are superimposed by the 4-Arrowed symbol (see symbol above) to indicate that any of the other 3 tests mentioned above could take preference above the IHX A (Ceramic) tests.
	=	Anticipated 1 year phase prior to making a Key Decision for proceeding with CQL ECC. Dependent on applicability of anticipated CQL operation as per NGNP Technology Development requirements. Red Milestone = latest decision date to commence with CQL ECC. Above decisions are dependent on outcome of prototypical SG and H_2SO_4 Decomposition Reactor designs.

Symbol / Abbreviation	Color (If applicable)	Description
	=	CQL Development Path stretching from: 1. CQL ECC Key Decision Phase 2. CQL ECC 3. CQL Operation
	=	Current NGNP design path. NGNP design path is to be updated following the NGNP Conceptual Design (CD) Planning.
	=	Red and Yellow Brackets signify the dependency between NGNP Design and Component Testing data. Red dotted line: NGNP design inputs - essential for component testing design and operation. Yellow Dotted Line: Experimental data obtained from component testing used to substantiate NGNP design.
	=	Blue Bracket indicates possibility of commencing with CQL1 testing.
	=	Green broken line indicates completion dates of TDL testing. The duration of tests are specified as per Table 10-4.
	=	Phase prior to CTL ECC to indicate Blower Development.
Pre-Title I	=	Preconceptual Design and Planning Phase
Title I	=	Basic Design
Title II	=	Detail Design
Title III	=	Construction Phase

Note:

- The NGNP design path (bottom yellow-arrowed bar on all graphs) illustrates the current NGNP ECC. This NGNP ECC is to be updated following Conceptual Design (CD) Planning.
- Colors on CTL testing are not related to any of the tests described in Table 10-7.

The next two graphs depict the ECC and Test durations for both the SSDT (Figure 10-12) and the CTL project lifecycles (Figure 10-13). Paragraph 10.7.2 follows, describing the moderate CTF system integrated approach, later on followed by the Aggressive and Very Aggressive CTF system integrated approaches.

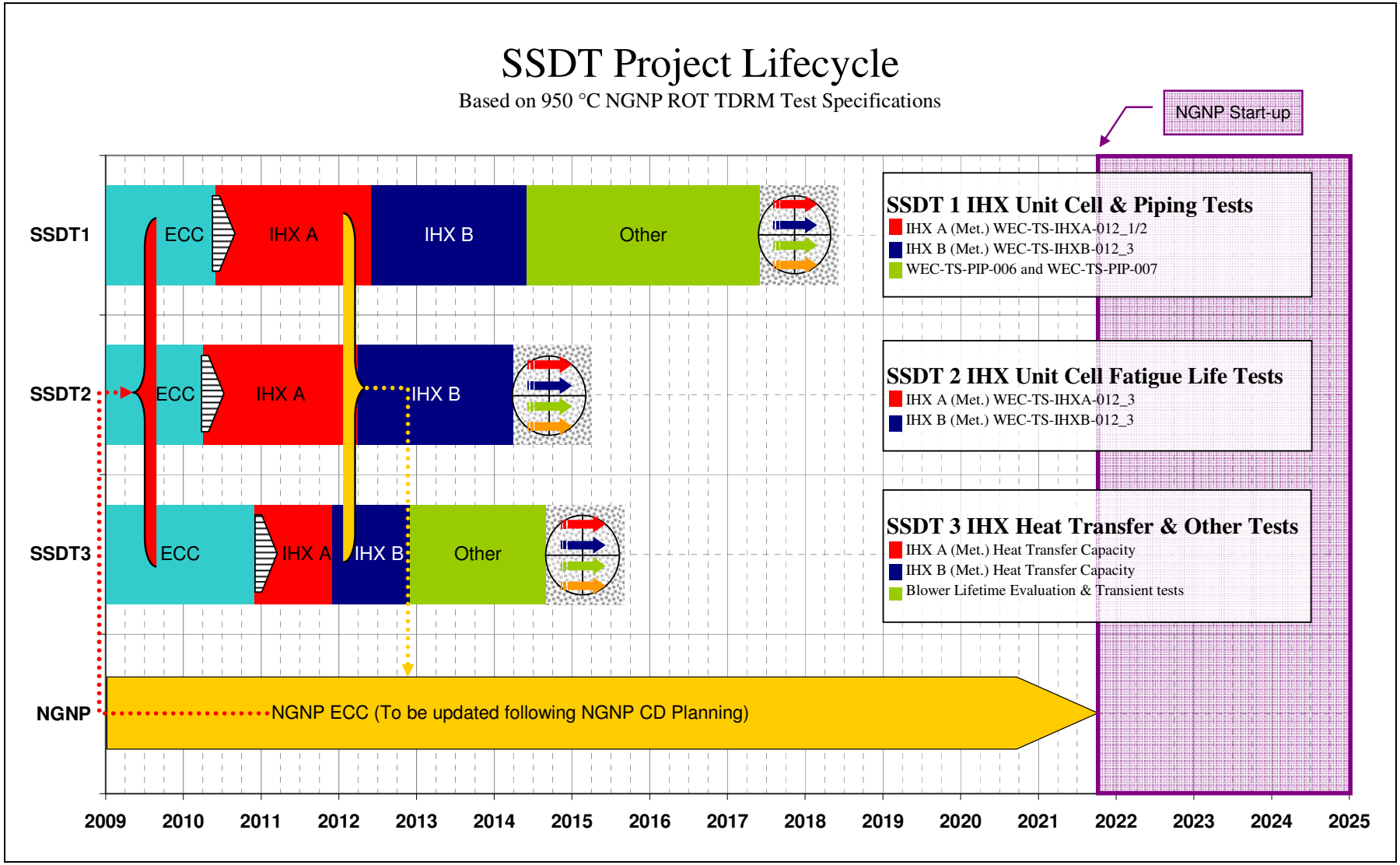


Figure 10-12: ECC and Test durations of the three different SSDTs for the 950 °C NGNP ROT Development Path.

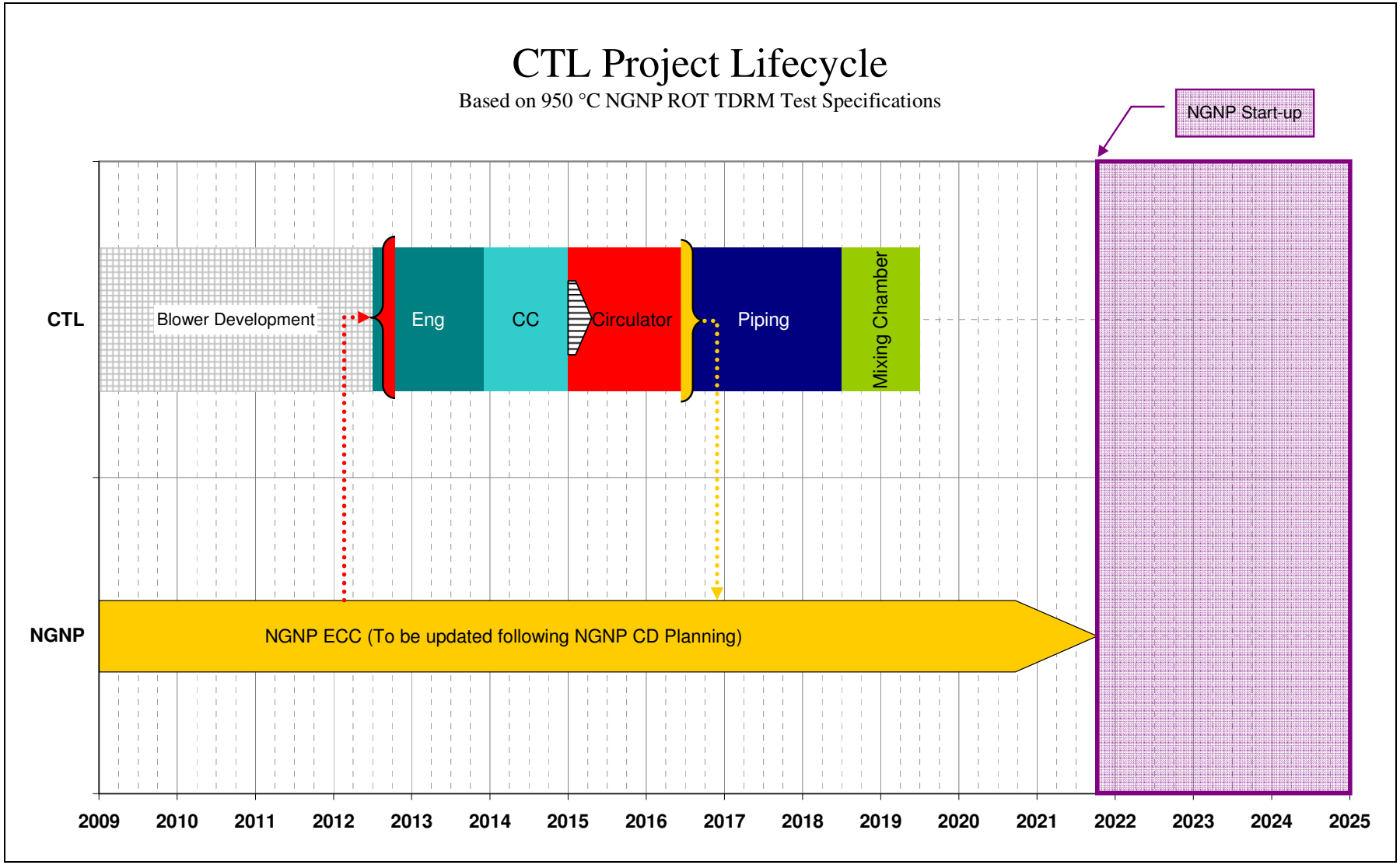


Figure 10-13: ECC and Test durations of one CTL for the 950 °C NGNP ROT Development Path.

10.7.2 Moderate CTF System Integrated Approach

10.7.2.1 System Description

The Moderate CTF System Integrated approach utilizes the following systems:

Fixed or Basic Test Loops:

- 1 x SSDT1
- 1 x SSDT2
- 1 x SSDT3
- 1 x CTL
- 1 x TDL

Expandable Test Loops:

- 1 x TDL (necessary for CQL1 operation)
- Possible CQL expansion

Considering the Moderate approach, completion of TDL tests for the 950 °C NGNP ROT Development Path is beyond 2026, which nullifies the use of one TDL only. The ECC and Test durations for this option are shown in paragraph 10.7.2.5 below.

10.7.2.2 Interfacing

The interface requirements include the following auxiliaries: HVAC, Electrical, HICS, Cooling Water, Steam and Air. The interface requirements are restricted to the SSDTs, TDLs and one CTL and do not include the requirements of the auxiliary systems.

For the purpose of the combined interface requirements, neither CQL1 nor CQL2 is included.

Table 10-8: Auxiliary Interface Requirements for Moderate Approach

Moderate Approach	Electricity	HVAC	HICS (Storage)	HICS (Flow)	Cooling Water	Steam (HTSE)	Air (HTSE)
Units	kW	kW	kg	kg/s	kg/s	kg/s	kg/s
SSDT (x 3)	700	33	26	0.0006	4.5	-	-
TDL (x 1)	14 300	989	1 218	0.169	125.4	0.62	0.76
CTL (x 1)	13 000	100	604	0.169	155	-	-
Total	**28 000**	**1 122**	**1 848**	**0.339**	**284.9**	**0.62**	**0.76**

10.7.2.3 System layout

The proposed system layout for the Moderate Approach is shown in a top-view schematic below, indicating one TDL only. The second TDL space is laid down as it is foreseen that a second TDL will be necessary for CQL1 testing.

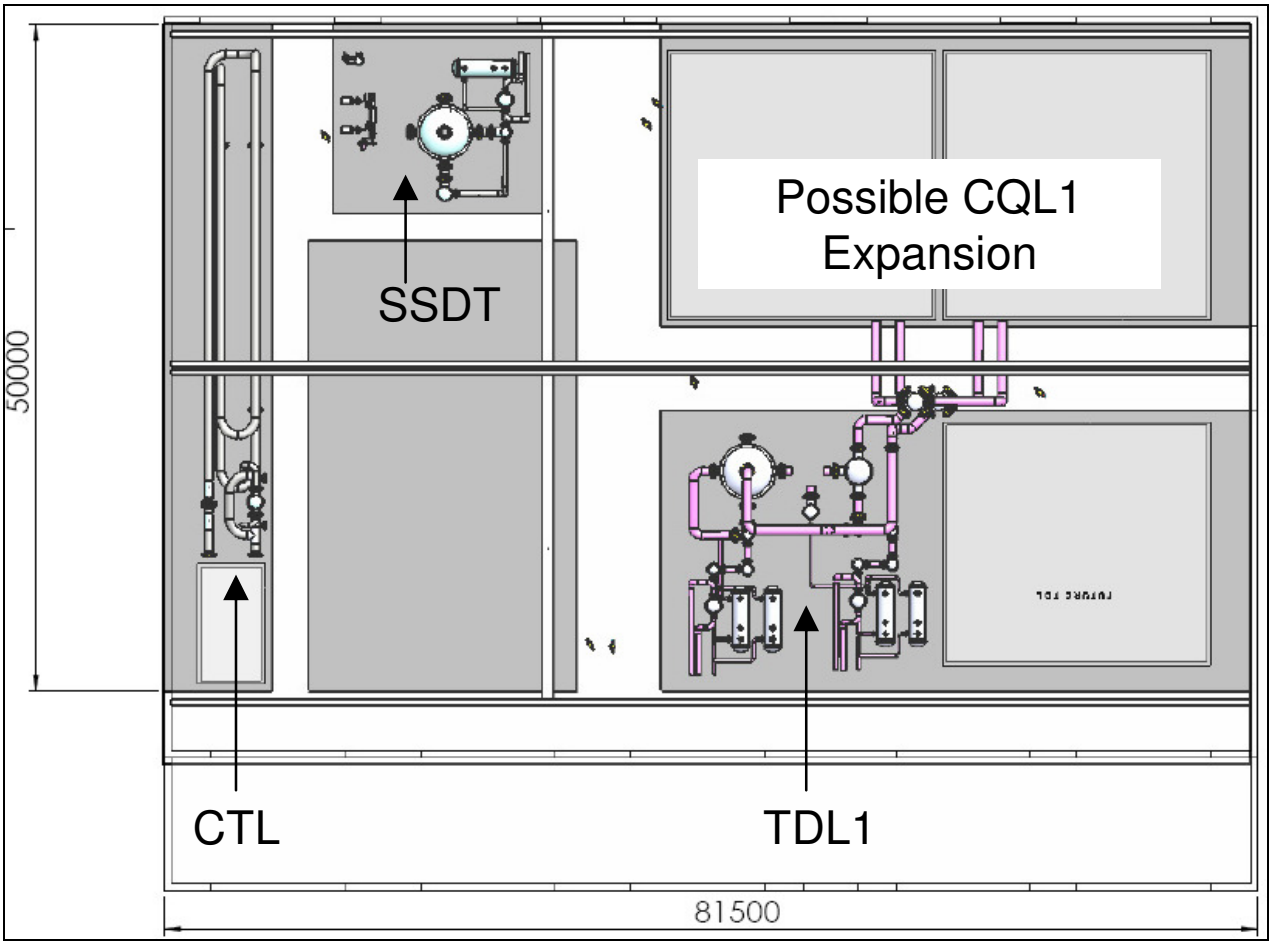


Figure 10-14: Proposed System Integration Layout for the Moderate Approach.

10.7.2.4 Cost Estimate

The total cost for the basic systems for the Moderate approach amounts to ~ $ 57M.

The basic systems consist of the SSDTs, the CTL and one TDL as outlined in Table 10-9 below.

Table 10-9: Summary of the Total Capital Cost Estimation for the Basic Set of Test Loops (Moderate Approach)

Moderate option	Test Loops	Total ECC*	Operating cost per hour
Basic set of test loops	SSDT1: Creep&static test	$ 1,819,543	$ 290
	SSDT2: Thermal fatigue	$ 1,886,672	$ -
	SSDT3: Heat transfer	$ 8,057,696	$ -
	TDL1	$ 37,933,351	$ 800
	CTL	$ 7,078,786	$ 1,110
	TOTAL FOR BASIC	**$ 56,776,048**	**$ 2,200**

* Includes 30% Contingency

In order to allow CQL1 testing another TDL will have to be included and therefore allowance is made for a second TDL in the expansion systems, as shown in Table 10-10 below.

The total ECC cost for CQL1 accounts for HGDs and not for its intended UUTs, as mentioned earlier in this report.

Table 10-10: Summary of the Total Capital Cost Estimation for Basic- and Expansion Set of Test Loops (Moderate Approach)

Expansion of Moderate option	Test Loops	Total ECC*	Operating cost per hour
	TDL2 (necessary for CQL1)	$ 34,983,222	$ 800
	CQL1	$ 3,947,073	$ 1,330
	CQL2	$ 280,486,814	$ -
	TOTAL FOR EXPANSION	**$ 319,417,109**	**$ 2,130**
	TOTAL AFTER EXPANSION	**$ 376,193,157**	**$ 4,330**

* Includes 30% Contingency

10.7.2.5 High Level Scheduling

The ECC and Test durations for the Moderate approach are represented in Figure 10-15 and Figure 10-16 below. The graphs illustrate the duration of each of the proposed test loops for the Moderate approach.

The following is to be noted:

- SSDT Engineering, Construction and Commissioning (ECC) is assumed to commence in April 2009. Early SSDT ECC can lead to experimental data that could favorably be incorporated into the TDL design.
- TDL Operation is assumed to commence in January 2015.
- Design of a second TDL will only encompass ~ 10 percent of the design cost compared to that of the first TDL.

[A-1]Moderate Approach for the Integrated CTF utilizing one TDL for a 950 °C NGNP ROT Development Path.

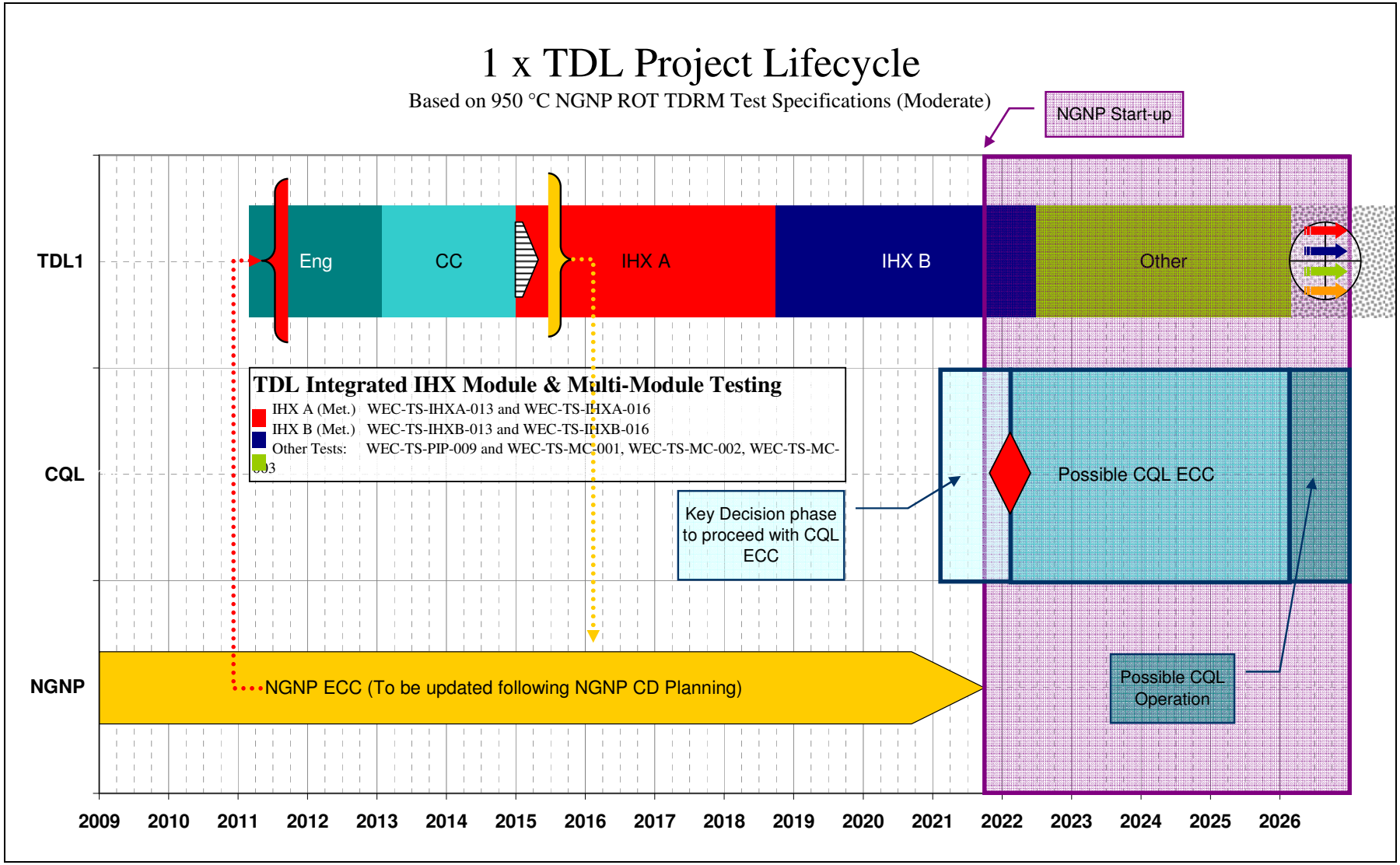


Figure 10-15: ECC and Test durations of one TDL for the 950 °C NGNP ROT Development Path.

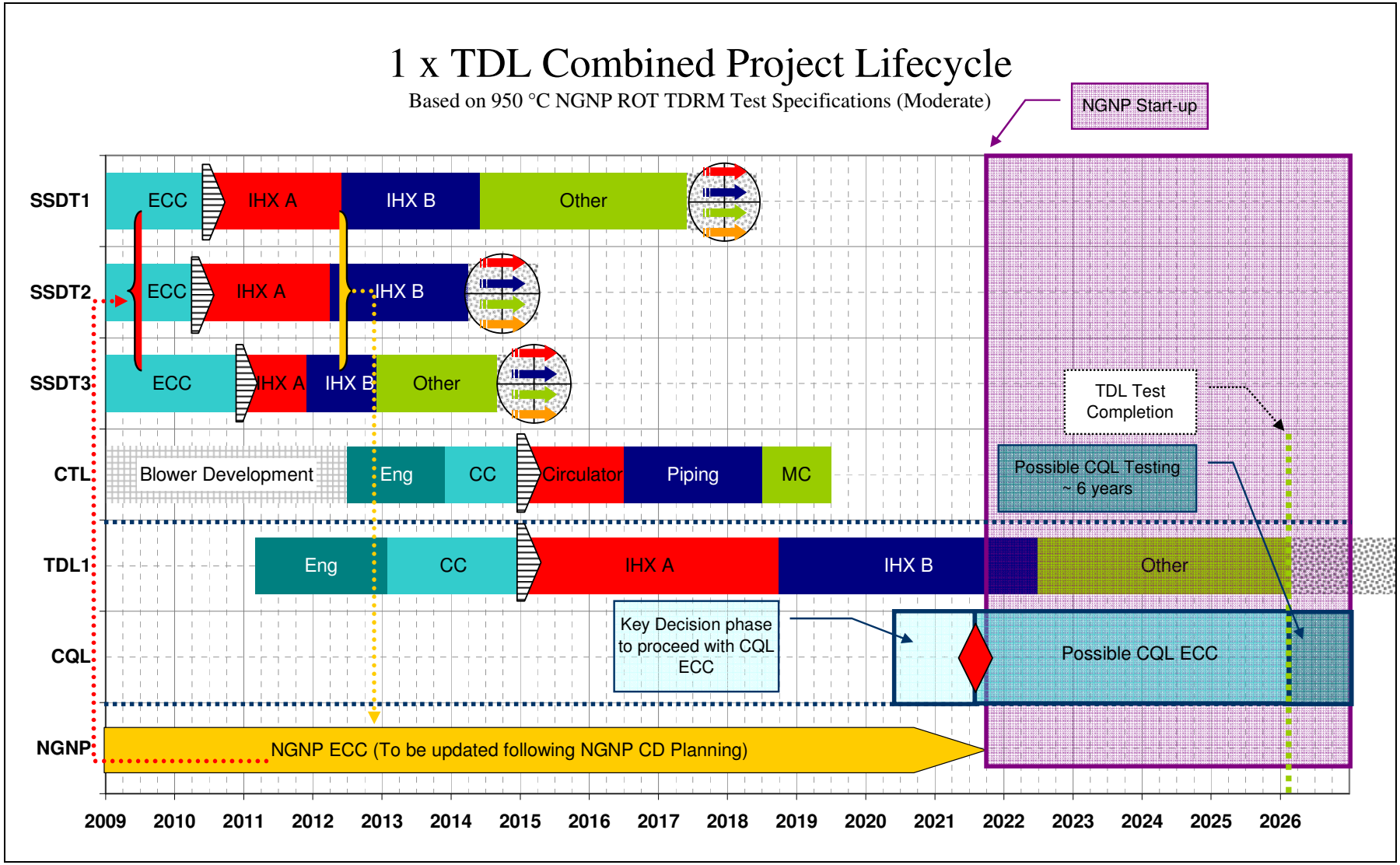


Figure 10-16: ECC and Test durations of one TDL and other fixed systems for the 950 °C NGNP ROT Development Path.

10.7.3 Aggressive CTF System Integrated Approach

10.7.3.1 System Description

The Aggressive CTF System Integrated approach utilizes the following systems:

Fixed or Basic Test Loops:

- 1 x SSDT1
- 1 x SSDT2
- 1 x SSDT3
- 1 x CTL
- 2 x TDLs

Expandable Test Loops

- Possible CQL expansion
- Possible TDL expansion

Considering the Aggressive Approach, completion of TDL tests for the 950 °C NGNP ROT Development Path is beyond 2022, which is also at the rear of the proposed NGNP schedule. The ECC and Test durations for this option are shown in paragraph 10.7.3.5 below.

10.7.3.2 Interfacing

The interface requirements include the following auxiliaries: HVAC, Electrical, HICS, Cooling Water, Steam and Air. The interface requirements are restricted to the SSDTs, TDLs and one CTL and do not include the requirements of the auxiliary systems.

For the purpose of the combined interface requirements, neither CQL1 nor CQL2 is included.

Table 10-11: Interface requirements for auxiliaries for the Aggressive Approach

Aggressive Approach	Electricity	HVAC	HICS (Storage)	HICS (Flow)	Cooling Water	Steam (HTSE)	Air (HTSE)
Units	kW	kW	kg	kg/s	kg/s	kg/s	kg/s
SSDT (x 3)	700	33	26	0.0006	4.5	-	-
TDL (x 2)	28 600	1 978	2 436	0.338	250.8	1.24	1.52
CTL (x 1)	13 000	100	604	0.169	155	-	-
Total	**42 300**	**2 111**	**3 066**	**0.508**	**410.3**	**1.24**	**1.52**

10.7.3.3 System layout

The proposed system layout for the Aggressive Approach is shown in a top-view schematic below. It is similar to the system layout of the Moderate approach, except for the additional TDL. These TDLs are mirrored towards each other in order to optimize HGD lengths headed for the CQL1 testing area.

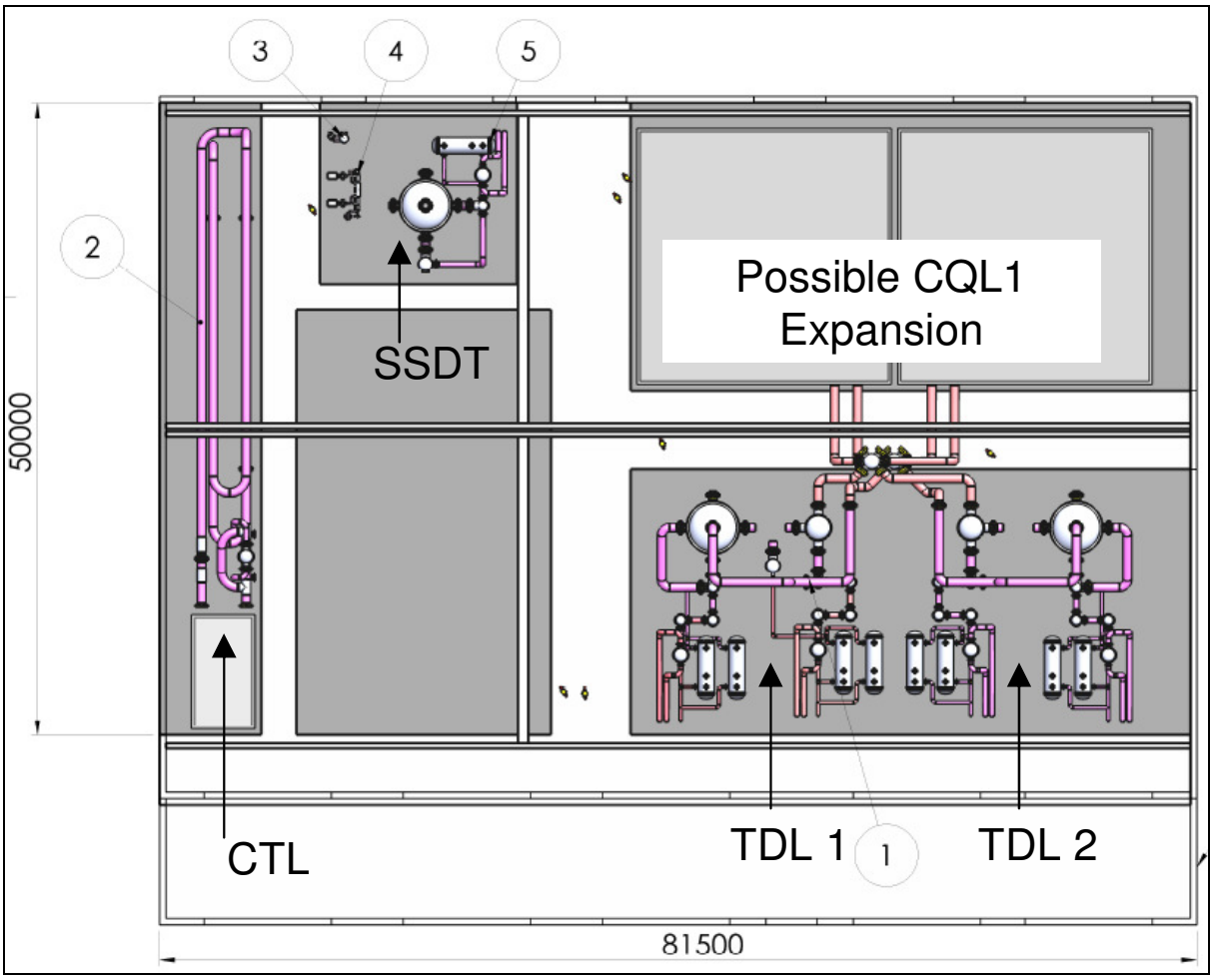


Figure 10-17: Proposed System Integration Layout for the Aggressive Approach.

10.7.3.4 Cost Estimate

The total cost for the basic systems for the Aggressive approach amounts to ~ $ 92 M.

The basic systems consist of the SSDTs, the CTL and two TDLs as outlined in Table 10-12 below.

Table 10-12: Summary of the Total Capital Cost Estimation for the Basic Set of Test Loops (Aggressive Approach)

Aggressive	Test Loops	Total ECC*	Operating cost per hour
Basic set of test loops	SSDT1: Creep&static test	$ 1,819,543	$ 290
	SSDT2: Thermal fatigue	$ 1,886,672	$ -
	SSDT3: Heat transfer	$ 8,057,696	$ -
	TDL1	$ 37,933,351	$ 800
	TDL2	$ 34,983,222	$ 800
	CTL	$ 7,078,786	$ 1,110
	TOTAL FOR BASIC	**$ 91,759,270**	**$ 3,000**

* Includes 30% Contingency

The two TDLs will allow CQL1 testing.

The total ECC cost for CQL1 accounts for HGDs and not for its intended UUTs, as mentioned earlier in this report.

Table 10-13: Summary of the Total Capital Cost Estimation for Basic- and Expansion Set of Test Loops (Aggressive Approach)

Expansion of Aggressive option	Test Loops	Total ECC*	Operating cost per hour
	CQL1	$ 3,947,073	$ 1,330
	CQL2	$ 280,486,814	$ -
	TOTAL FOR EXPANSION	**$ 284,433,887**	**$ 1,330**
	TOTAL AFTER EXPANSION	**$ 376,193,157**	**$ 4,330**

* Includes 30% Contingency

10.7.3.5 High Level Scheduling

The ECC and Test durations for the Aggressive approach are represented below. Making use of two TDLs extends completion of TDL-related tests to beyond 2022. The duration of all the basic set of test loops are shown in Figure 10-18 and Figure 10-19 below.

The following is to be noted:

- SSDT Engineering, Construction and Commissioning (ECC) is assumed to commence in April 2009. Early SSDT ECC can lead to experimental data that could favorably be incorporated into the TDL design.
- TDL Operation is assumed to commence in January 2015.
- Design of the second TDL will only encompass ~ 10 percent of the design cost compared to that of the first TDL.

[B-1] Aggressive Approach for the Integrated CTF utilizing two TDLs for a 950 °C NGNP ROT Development Path.

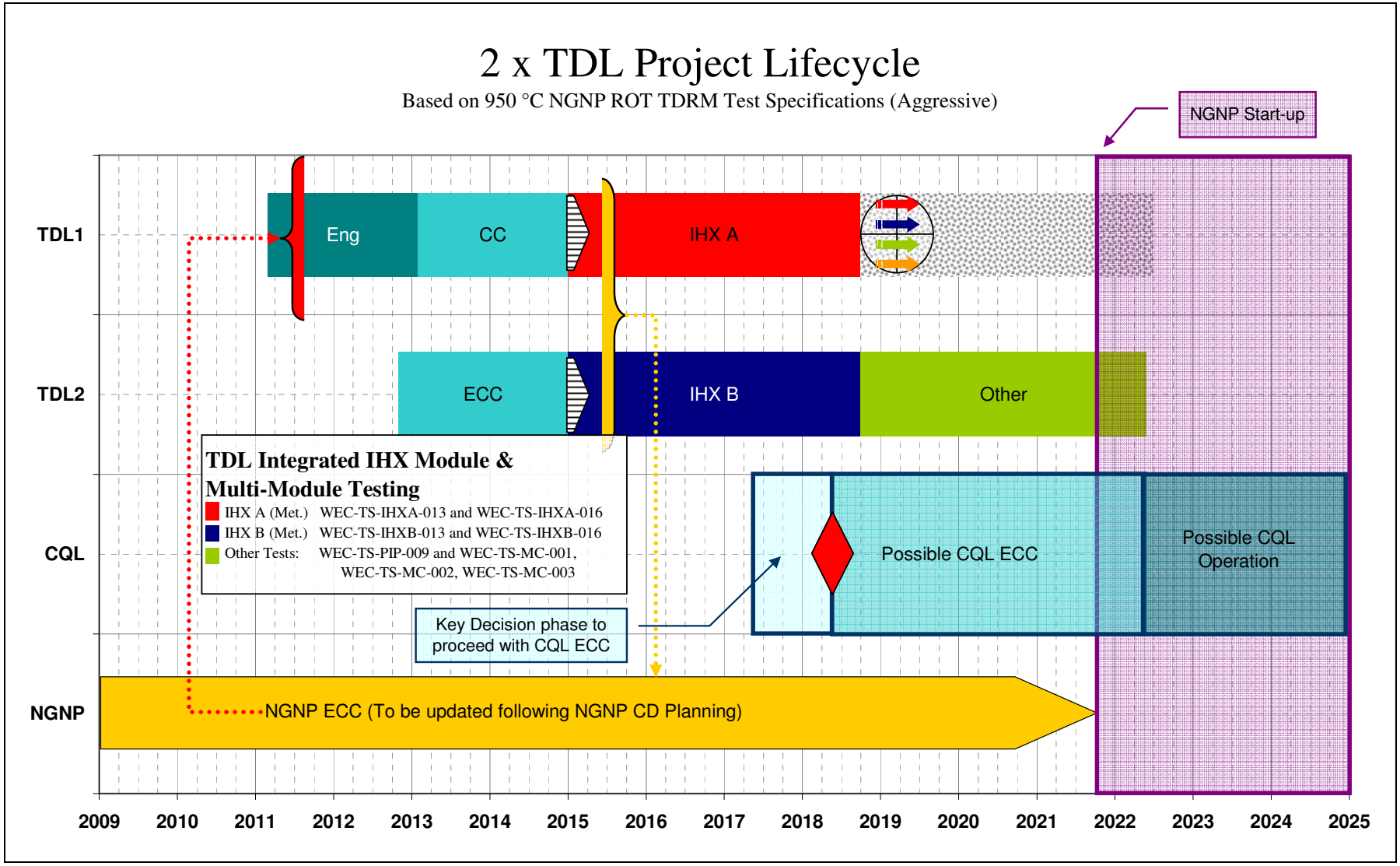


Figure 10-18: ECC and Test durations of two TDLs for the 950 °C NGNP ROT Development Path.

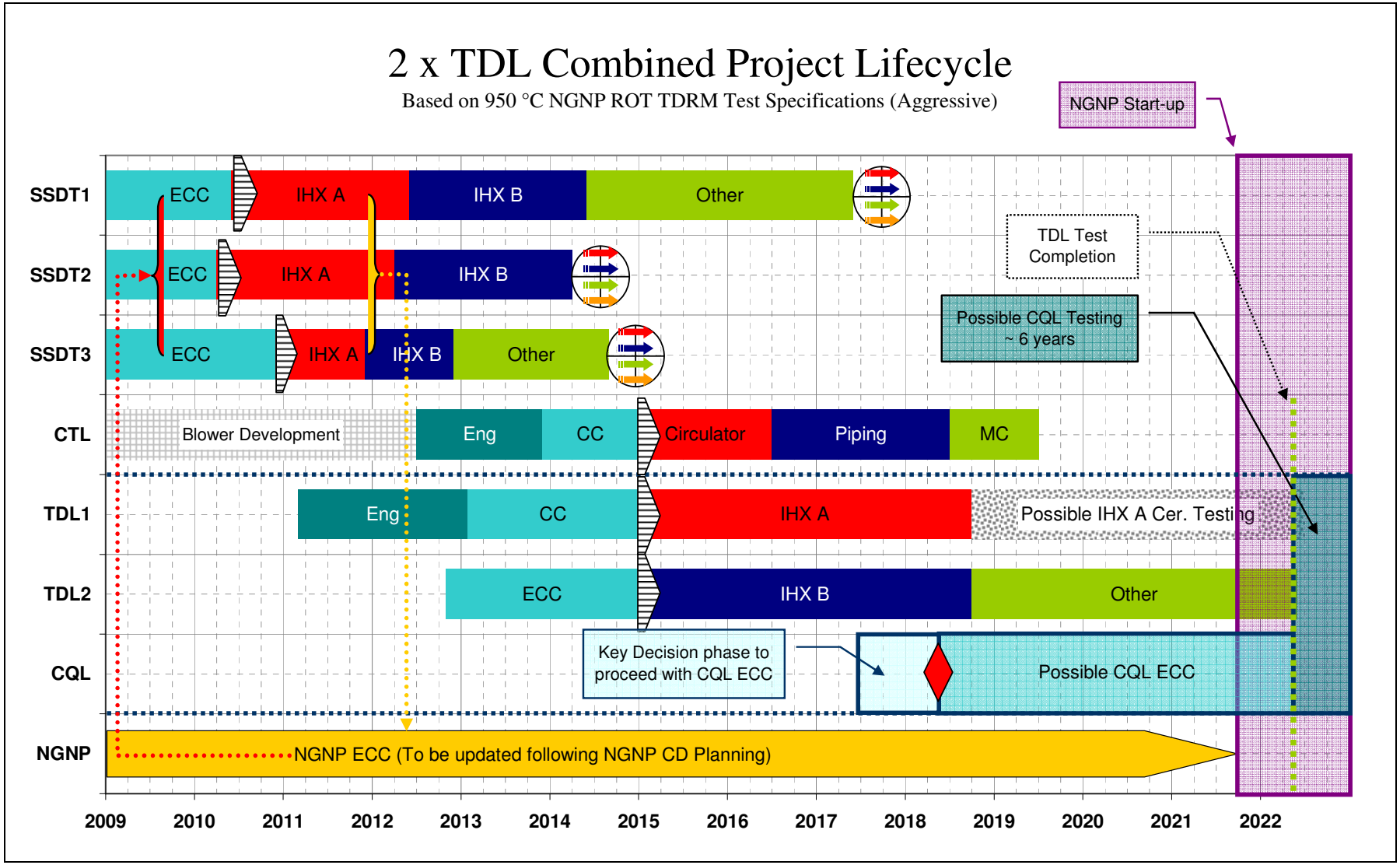


Figure 10-19: ECC and Test durations of two TDLs and other fixed systems for the 950 °C NGNP ROT Development Path.

10.7.4 Very Aggressive CTF System Integrated Approach

10.7.4.1 System Description

The Very Aggressive CTF System Integrated approach utilizes the following systems:

Fixed or Basic Test Loops:

- 1 x SSDT1
- 1 x SSDT2
- 1 x SSDT3
- 1 x CTL
- 3 x TDLs

Expandable Test Loops:

- Possible CQL expansion

Considering the Very Aggressive Approach, completion of TDL tests for the 950 °C NGNP ROT Development Path could be achieved by 2019. The ECC and Test durations for this option are shown in paragraph 10.7.4.5 below.

10.7.4.2 Interfacing

The interface requirements include the following auxiliaries: HVAC, Electrical, HICS, Cooling water, Steam and Air. The interface requirements are restricted to the SSDT, TDL, CTL, CQL1 and CQL2 systems themselves and do not include the requirements of the auxiliary systems.

The Very Aggressive Approach includes three SSDTs, three TDLs and one CTL. For the purpose of the combined interface requirements, neither CQL1 nor CQL2 is included.

Table 10-14: Interface requirements for auxiliaries for the Very Aggressive Approach

Very Aggressive Approach	Electricity	HVAC	HICS (Storage)	HICS (Flow)	Cooling Water	Steam (HTSE)	Air (HTSE)
Units	kW	kW	kg	kg/s	kg/s	kg/s	kg/s
SSDT (x 3)	700	33	26	0.0006	4.5	-	-
TDL (x 3)	42 900	2 967	3 654	0.507	376.2	1.86	2.28
CTL (x 1)	13 000	100	604	0.169	155	-	-
Total	**56 600**	**3 100**	**4 284**	**0.677**	**535.7**	**1.86**	**2.28**

10.7.4.3 System layout

The proposed system layout for the Very Aggressive Approach is shown in a top-view schematic below.

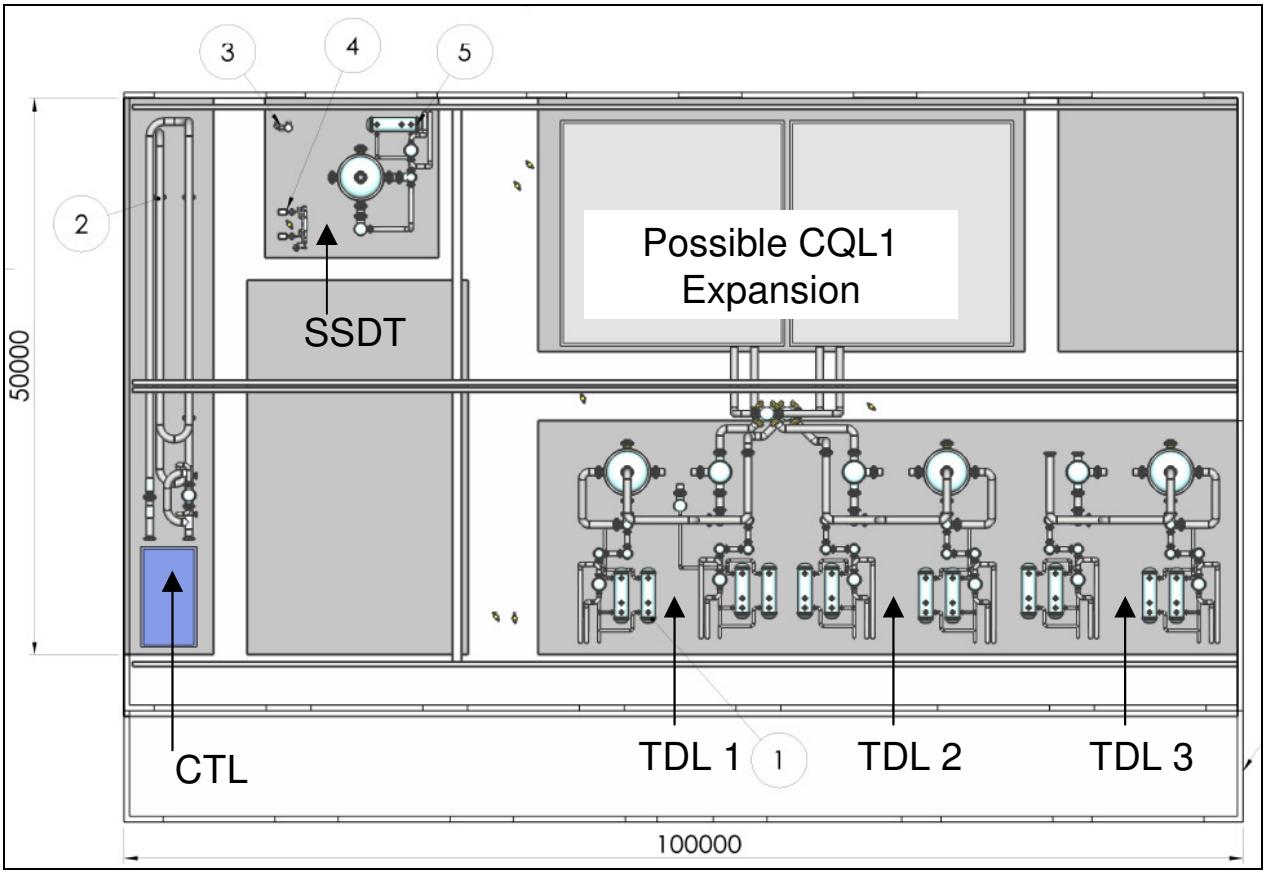


Figure 10-20: Proposed System Integration Layout for the Very Aggressive Approach.

10.7.4.4 Cost Estimate

The total cost for the basic systems for the Very Aggressive approach amounts to ~ $ 127 M.

The basic systems consist of the SSDTs, the CTL and three TDLs as outlined in Table 10-15 below.

Table 10-15: Summary of the Total Capital Cost Estimation for the Basic Set of Test Loops (Very Aggressive Approach)

Very Aggressive	Test Loops	Total ECC*	Operating cost per hour
Basic set of test loops	SSDT1: Creep&static test	$ 1,819,543	$ 290
	SSDT2: Thermal fatigue	$ 1,886,672	$ -
	SSDT3: Heat transfer	$ 8,057,696	$ -
	TDL1	$ 37,933,351	$ 800
	TDL2	$ 34,983,222	$ 800
	TDL3	$ 34,983,222	$ 800
	CTL	$ 7,078,786	$ 1,110
	TOTAL FOR BASIC	**$ 126,742,492**	**$ 3,800**

* Includes 30% Contingency

CQL1 testing will be possible since provision is made for three TDLs within this approach.

The total ECC cost for CQL1 only accounts for HGDs and not for its intended UUTs, as mentioned earlier in this report.

Table 10-16: Summary of the Total Capital Cost Estimation for Basic- and Expansion Set of Test Loops (Very Aggressive Approach)

Expansion of Very Aggressive option	Test Loops	Total ECC*	Operating cost per hour
	CQL1	$ 3,947,073	$ 1,330
	CQL2	$ 280,486,814	$ -
	TOTAL FOR EXPANSION	**$ 284,433,887**	**$ 1,330**
	TOTAL AFTER EXPANSION	**$ 411,176,379**	**$ 5,130**

* Includes 30% Contingency

The funding profile for the basic set of test loops for the Very Aggressive approach is given in Figure 10-21**Error! Reference source not found.** below. This funding profile provides information as regards to accumulated expenditure over time.

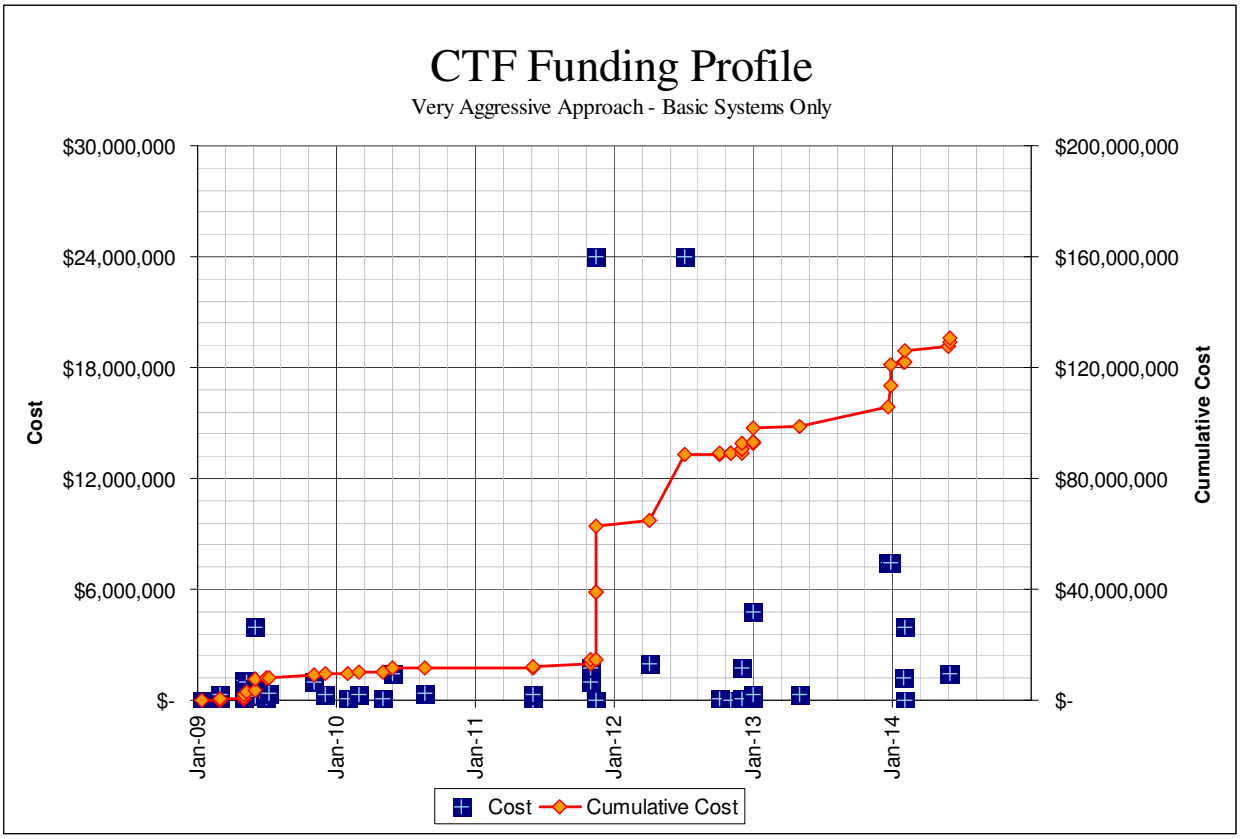


Figure 10-21: CTF Funding profile for the Very Aggressive option – Basic systems Only; (Expansion systems not included).

10.7.4.5 High Level Scheduling

The graphs for the Very Aggressive approach are represented below. By making use of three TDLs pulls completion of TDL-related test specifications to within 2019. The test durations of all the basic set of test loops are shown in Figure 10-22 and Figure 10-23 below.

The following is to be noted:

- SSDT Engineering, Construction and Commissioning (ECC) is assumed to commence in April 2009. Early SSDT ECC can lead to experimental data that could favorably be incorporated into the TDL design.
- TDL Operation is assumed to commence in January 2015.
- The second and third TDLs will both only encompass ~ 10 percent of the design cost compared to that of the first TDL.

It is to be noted that upon completion of the TDL-related test specifications, two primary loop TDLs could be coupled to initiate CQL1 testing. Over and above the coupling of the primary TDL loops, the two secondary loops of these TDLs could be modified i.e. by adding heaters to both secondary loops. This re-configuration of secondary loops will enable additional CQL1 operating capacity. In such a case, the third TDL will then still be available for TDL-related test specifications, such as IHX A Ceramic testing.

This specific option of re-configuring the secondary loops has been catered for in neither the costing nor the schedule. This option needs further investigation.

[C-1] Very Aggressive Approach for the Integrated CTF utilizing three TDLs for a 950 °C NGNP ROT Development Path.

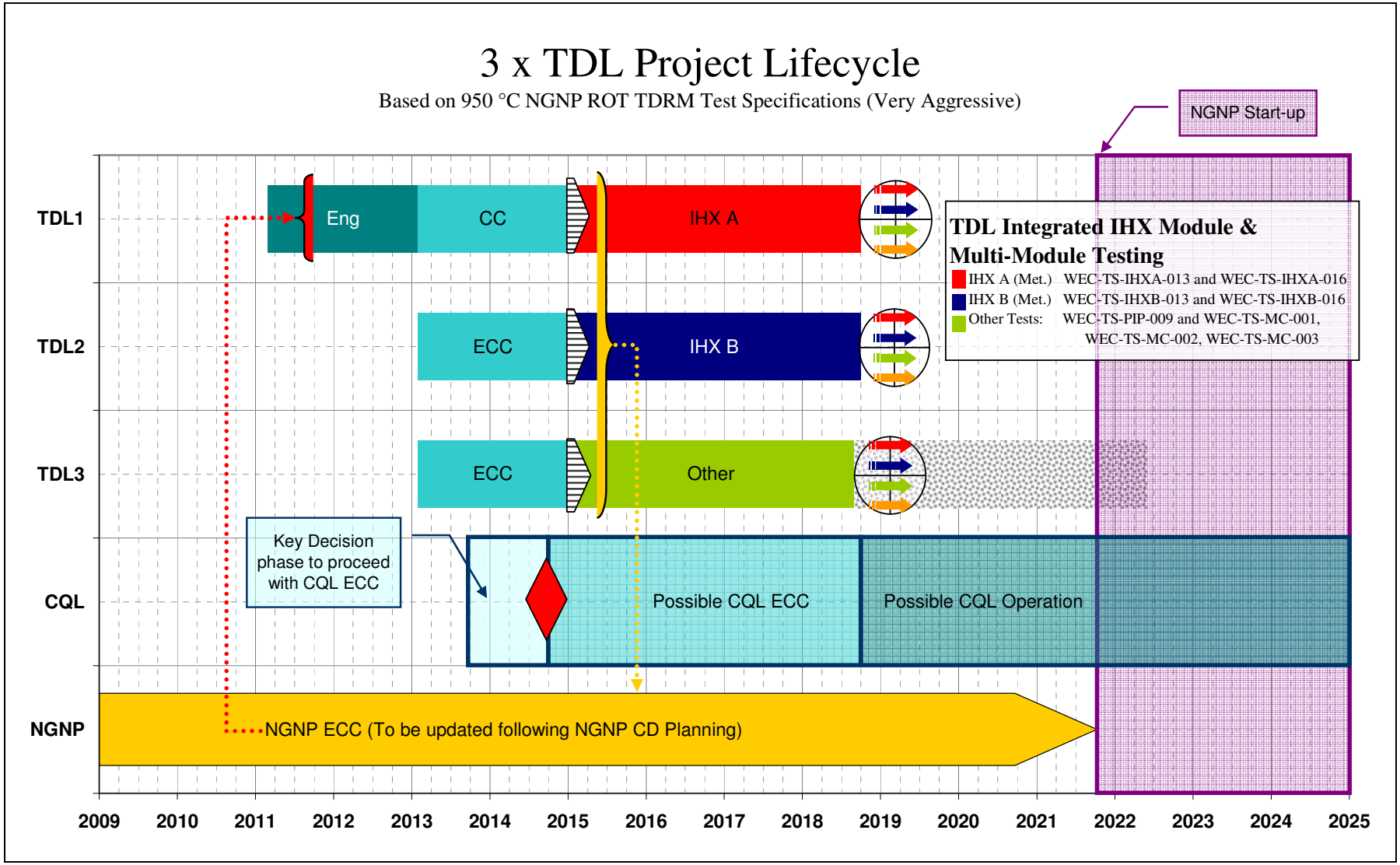


Figure 10-22: ECC and Test durations of three TDLs for the 950 °C NGNP ROT Development Path.

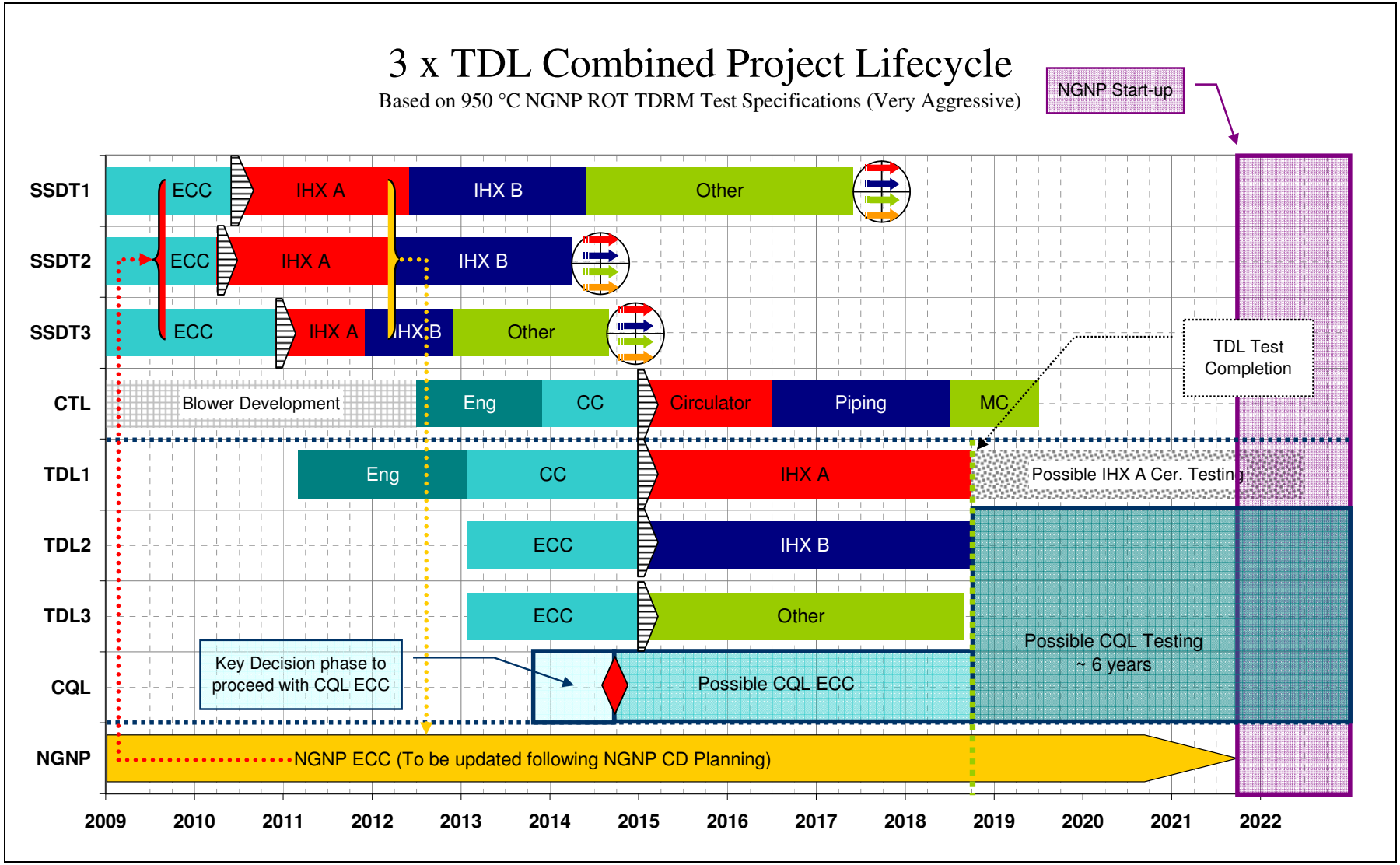


Figure 10-23: ECC and Test durations of three TDLs and other systems for the 950 °C NGNP ROT Development Path.

10.8 Recommendations

In order to accomplish the required technology development as required for the NGNP, a number of different system integration options are illustrated in Paragraph 10.7. These options all utilized the systems as presented in sections 5 through 9 of this PCDR, which form the basic building blocks for the proposed CTF.

The Very Aggressive option remains the preeminent choice to allow completion of TDL tests by 2019 as illustrated in Figure 10-23.

The decision to implement a CQL for the Very Aggressive Approach (assuming an ECC of 4 years) will have to be made by end 2014, to allow for simultaneous TDL and CQL operation.

The Moderate approach (1 x TDL) stretches TDL-related tests to beyond 2026, which nullifies this option. The Moderate approach is only viable if it is expanded to an Aggressive or Very Aggressive approach before 2016. Such expansion would imply an additional TDL or two.

Although the Aggressive approach (2 x TDLs) will complete TDL-related tests ahead of 2022, it wouldn't suffice to meet the current NGNP start-up date. This option could also be expanded by adding another TDL, which would shorten this approach's overall test duration.

The Very Aggressive approach (3 x TDLs) will complete TDL-related test specifications ahead of 2019, which makes it the best choice of all three system integration approaches. Taking into account that two of the three TDLs deliver enough mass flow for CQL1 operation and that additional heaters, if installed into the secondary loops of these same TDLs could provide sufficient mass flow for a second CQL1, makes this option even more attractive.

Overall CQL testing is pending the outcome of the proto-typical designs of the Steam Generator and the H_2SO_4 Decomposition Reactor. Both CQLs make provision for testing components with larger thermal heat duties. Each of the graphs containing TDL-CQL durations show a milestone, which indicates the final CQL ECC commencement date to allow optimum TDL-CQL utilization. At this point in time until further information is given as regards to the designs of the mentioned UUTs, the ultimatum (for the Very Aggressive approach) to commence with CQL ECC is set at October 2014, be it CQL1 or CQL2.

Similar graphs as illustrated in Paragraph 10.7 are also represented in Appendix F for a 750 °C NGNP ROT Development Path. The 750 °C NGNP ROT Development Path is not recommended for the current scope of work. It is nevertheless added for information purposes, should NGNP design momentarily digress along that path.

10.9 Future Work

Due to the preconceptual nature of the design a number of risks still exist. This could typically be addressed in follow-on design phases as well as possible trade studies.

Among these are aspects such as:

- High pressure and -temperature vessel protrusions.
- A more detail trade-off between active and passive cooling for HGDs and internal insulated vessel liners.
- Inventory control methods such as storage management.
- Flow liner design for the HGDs due to thermal expansion and stresses.

10.10 References

[10-1] "NGNP Technology Development Road Mapping Report" NGNP-CTF MTECH-TDRM, dated December 2008.

[10-2] "HTGR Component Test Facility (CTF) Feasibility and Recommendations," NGNP and Hydrogen Production Facility, dated February 2008.

[10-3] "NGNP-CTF-MTECH-TLDR. NGNP CTF Test Loop Pre-Conceptual Design Report", dated December 2008.

[10-4] "NGNP-CTF-MTECH-TLDR-0004. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 4: System Requirement Manual", dated December 2008.

[10-5] "NGNP-CTF-MTECH-TLDR-0005. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 5: Small Scale Development Tests", dated December 2008.

[10-6] "NGNP-CTF-MTECH-TLDR-0006. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 6: Technology Development Loop", dated December 2008.

[10-7] "NGNP-CTF-MTECH-TLDR-0007. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 7: Component Qualification Loop 1 (CQL1)", dated December 2008.

[10-8] "NGNP-CTF-MTECH-TLDR-0008. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 8: Component Qualification Loop 2 (CQL2)", dated December 2008.

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[10-10] "High Level Requirements; High Temperature Gas Reactor (HTGR) - Component Test Facility (CTF)," INL/MIS-08-14156, dated April 2008

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[10-13] Microsoft PowerPoint Presentation on the Laboratory for Analysis and Synthesis of Chemical Systems website, http://www.lassc.ulg.ac.be/webCheng00/ CHIM0054/ Part_3.pdf

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[10-16] "Guide to Capital Cost Estimating," IChemE (Paperback). A.M. Gerrard (Editor). Fourth Edition (2000).

[10-17] Monthly Labor Review (MLR) published by the U.S. Dept. of Labor's Bureau of Labor statistics (BLS).

[10-18] "Present status of the High Temperature engineering Test Reactor (HTTR)", Shusaku Shiozawa; Japan Atomic Energy Research Institute (JAERI).

[10-19] "How to estimate operating costs," William M. Vatavuk, Chemical Engineering, pp. 33-37, July 2005.

[10-20] Coulson JM, JF Richardson, Chemical Engineering Volume 6, Pargamon Press, pp 197 – pp 198.\

[10-21] "NGNP-CTF-MTECH-TLDR-0003. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 3: Design Criteria Document", dated December 2008.

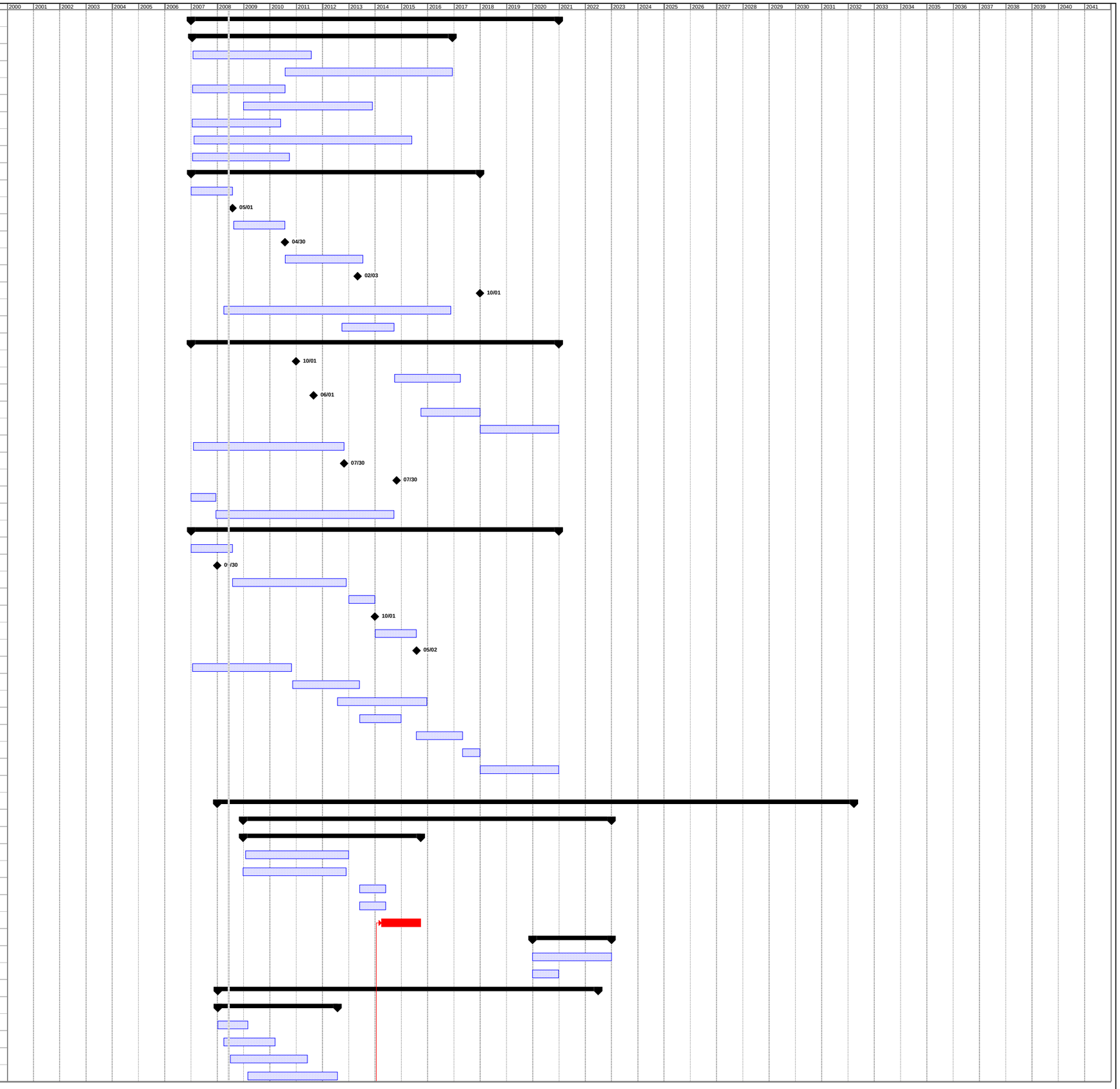
10.11 Appendices

Appendix A:	Schedule for the 950 °C NGNP ROT-based Tests (Very Aggressive Option)
Appendix B:	3D System Layout for the 950 °C NGNP ROT-based Tests (Very Aggressive Option)
Appendix C:	Electrical one-line drawings (Very Aggressive Option)
Appendix D:	Typical content of a Test Procedure Template
Appendix E:	Description of the cost breakdown
Appendix F:	Graphs of System Integration Schedules Illustrated for 750 °C NGNP ROT-based Tests.

Appendix A

Schedule for the 950 °C NGNP ROT-based Tests (Very Aggressive Option)

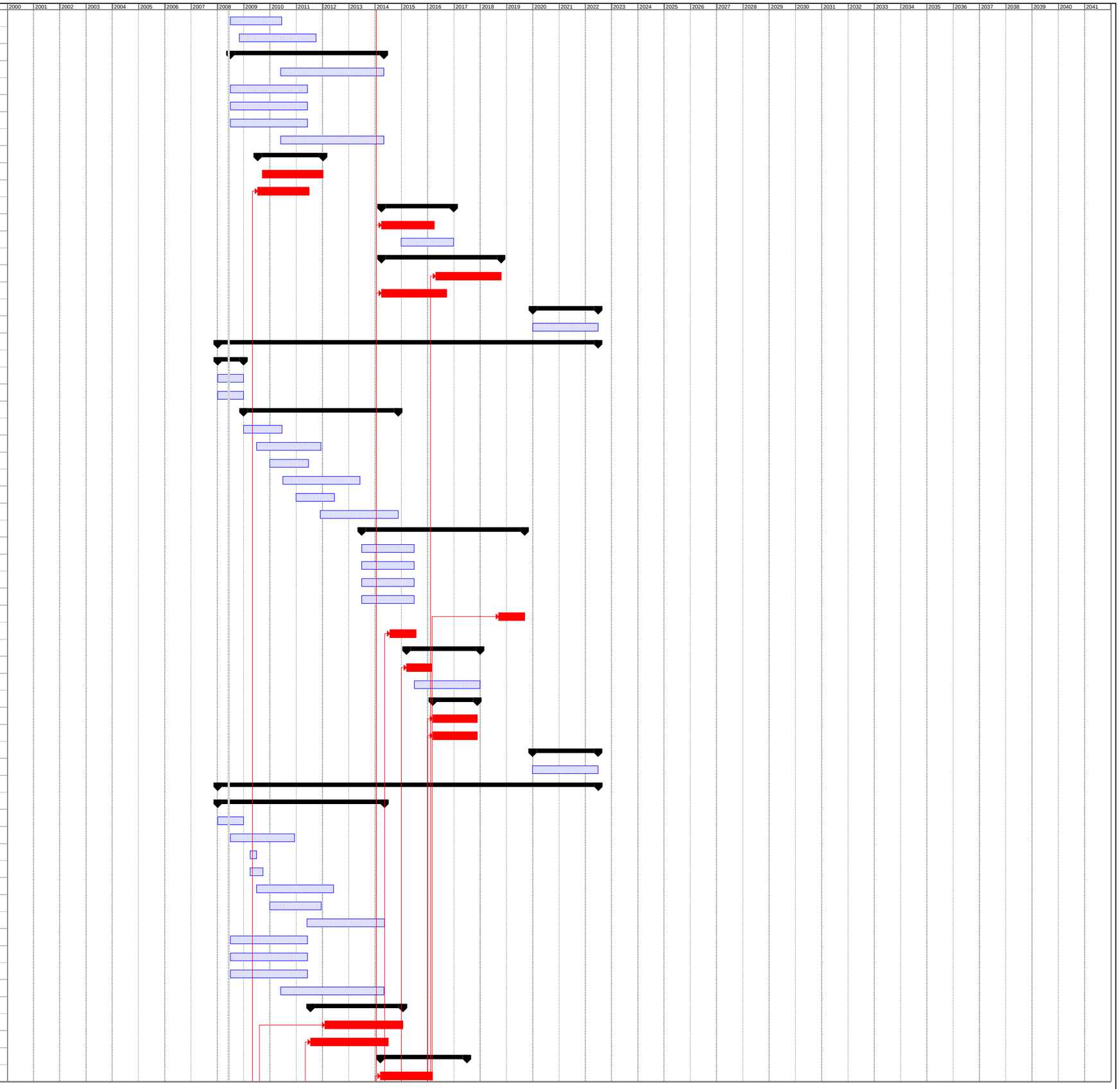
ID	Task Name	Start	Finish	Predecessors
1	**A: BEA NGNP 950°C Schedule [NGNP-18-RPT-001]**	**Tue 07/10/02**	**Thu 21/09/30**	
2	**Technology Development**	**Fri 07/10/19**	**Tue 17/09/12**	
3	Pre-Production Fuel Irradiation Program	Mon 07/10/29	Mon 12/04/30	
4	Production Fuel Irradiation	Mon 11/05/02	Tue 17/09/12	
5	Initial Graphite Irradiation	Wed 07/10/24	Mon 11/05/02	
6	Extended Graphite Irradiation	Thu 09/10/01	Thu 14/08/28	
7	Metallic IHX Development	Fri 07/10/19	Mon 11/02/28	
8	Hydrogen Production Facility	Mon 07/11/12	Fri 16/02/26	
9	Power Conversion Facility	Wed 07/10/24	Thu 11/06/30	
10	**Nuclear Heat Supply Facility, Power Conversion Facility & Balance of Plant**	**Thu 07/10/04**	**Mon 18/10/01**	
11	Conceptual Design	Thu 07/10/04	Thu 09/04/30	
12	Completion of NHST, PCF & BOP Conceptual Design	Fri 09/05/01	Fri 09/05/01	
13	Preliminary Design	Mon 09/05/18	Fri 11/04/29	
14	Completion of NHST, PCF & BOP Preliminary Design	Sat 11/04/30	Sat 11/04/30	
15	Final Design	Tue 11/05/03	Thu 14/04/17	
16	Approve Start of Construction	Mon 14/02/03	Mon 14/02/03	
17	Completion of NHSF, PCF & BOP Final Design and after receipt op NRD Early Site Permit Decision	Mon 18/10/01	Mon 18/10/01	
18	Acquisition Strategies/ Long lead Procurement	Thu 09/01/01	Mon 17/08/21	
19	Site work/BOP	Mon 13/07/01	Thu 15/06/25	
20	**Licensing**	**Tue 07/10/02**	**Thu 21/09/30**	
21	ESP/LWA Application Submitted	Sat 11/10/01	Sat 11/10/01	
22	Construction (Nuclear)	Thu 15/07/02	Mon 18/01/01	
23	COL Application Submitted	Fri 12/06/01	Fri 12/06/01	
24	Startup & Testing	Fri 16/07/01	Tue 18/10/02	
25	Commercial Operation & Inspection	Fri 18/10/05	Thu 21/09/30	
26	ESP Preparation	Mon 07/11/05	Tue 13/07/30	
27	NRC ESP Review	Tue 13/07/30	Tue 13/07/30	
28	COL Permit Issued	Thu 15/07/30	Thu 15/07/30	
29	COL Application	Tue 07/10/02	Fri 08/09/12	
30	NRC COL Review	Fri 08/09/12	Mon 15/06/22	
31	**Hydrogen Production Facility**	**Thu 07/10/04**	**Thu 21/09/30**	
32	Conceptual Design	Thu 07/10/04	Thu 09/04/30	
33	Completion of HPF Conceptual Design	Tue 08/09/30	Tue 13/08/27	
34	Design Support During Tech Development	Fri 09/05/01	Thu 13/08/29	
35	Preliminary Design	Thu 13/10/03	Tue 14/09/30	
36	Completion of HPF "Front End" design package	Wed 14/10/01	Wed 14/10/01	
37	Final Design	Mon 14/10/06	Fri 16/04/29	
38	Successful resolution of DOE comments on HPF "Front End", design package.	Mon 16/05/02	Mon 16/05/02	
39	Component Development	Wed 07/10/24	Fri 11/07/29	
40	Decomposer Pilot Testing	Mon 11/08/15	Fri 14/02/28	
41	Acquisition Strategies/Long Lead Procurement	Tue 13/04/30	Thu 16/09/22	
42	Electrolyzer Pilot Testing	Wed 14/03/05	Wed 15/09/30	
43	Construction	Fri 16/04/29	Wed 18/01/31	
44	Startup & Testing	Wed 18/01/31	Sun 18/09/30	
45	Commercial Operation & Inspection	Fri 18/10/05	Thu 21/09/30	
46				
47	**B: Modified TDRM Schedule [NGNP-CTF MTECH-TDRM-017]**	**Tue 08/09/30**	**Thu 32/12/23**	
48	**Circulator**	**Fri 09/09/25**	**Tue 23/10/03**	
49	**TRL 6 - TRL 7**	**Fri 09/09/25**	**Wed 16/06/29**	
50	Original Schedule in TDRM	Fri 09/10/30	Mon 13/09/30	
51	Trade Studies	Fri 09/09/25	Tue 13/08/27	
52	EMBs, catcher bearings Test Specification	Mon 14/03/03	Fri 15/02/27	
53	Helium Rotating seals Test Specification	Mon 14/03/03	Fri 15/02/27	
54	Partial or Full scale circulator Model Test Specification	Thu 15/01/01	Wed 16/06/29	605SS
55	**TRL 7 - TRL 8**	**Thu 20/10/01**	**Tue 23/10/03**	
56	Original Schedule in TDRM	Thu 20/10/01	Tue 23/10/03	
57	Prototype circulator Test Specification	Thu 20/10/01	Wed 21/09/29	
58	**IHX A (Metallic)**	**Thu 08/10/09**	**Fri 23/03/31**	
59	**TRL 2 - TRL 3**	**Thu 08/10/09**	**Mon 13/04/29**	
60	Alloy 617 Material Specification and procurement	Thu 08/10/09	Tue 09/12/01	
61	Alloy 617 Joining Technology and Resultant Properties	Thu 09/01/01	Mon 10/12/13	
62	Thermal/physical and mechanical properties of Alloy 617	Wed 09/04/01	Tue 12/03/06	
63	Effects of thermal Aging and environment on Alloy 617	Tue 09/12/01	Mon 13/04/29	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

ID	Task Name	Start	Finish	Predecessors
64	Effects of Grain size and selection thickness on Alloy 617 properties	Wed 09/04/01	Wed 11/03/16	
65	Corrosion Allowances for Alloy 617	Mon 09/08/03	Thu 12/07/05	
66	**TRL 3 - TRL 4**	**Wed 09/04/01**	**Mon 15/02/02**	
67	ASME selection III Code Case for Alloy 617	Tue 11/03/01	Mon 15/02/02	
68	Thermal/Fluid Modeling Methods for Metallic IHX A	Wed 09/04/01	Wed 12/03/07	
69	Methods for stress/strain modeling of metallic IHX A	Wed 09/04/01	Wed 12/03/07	
70	Criteria for structural integrity of IHX A	Wed 09/04/01	Wed 12/03/07	
71	Performance Modeling Methods for IHX A	Tue 11/03/01	Mon 15/02/02	
72	**TRL 4 - TRL 5**	**Fri 10/04/16**	**Thu 12/10/11**	
73	Testing of unit cell of compact Heat Exchangers	Fri 10/06/18	Thu 12/10/11	
74	Unit Cell Fatigue Life Test	Fri 10/04/16	Sun 12/04/01	340SS
75	**TRL 5 - TRL 6**	**Thu 15/01/01**	**Fri 17/09/29**	
76	Specification of testing of compact heat exchanger module (1.2MW)	Thu 15/01/01	Wed 17/01/04	445SS
77	ASME Section III Code Case for Compact Heat Exchanger Designs	Thu 15/10/01	Fri 17/09/29	
78	**TRL 6 - TRL 7**	**Thu 15/01/01**	**Mon 19/07/22**	
79	Shell Side Flow Distribution and Bypass Leakage Testing	Tue 17/01/24	Mon 19/07/22	447SS
80	Multi-module Heat Transfer Testing	Thu 15/01/01	Mon 17/06/26	448SS
81	**TRL 7 - TRL 8**	**Mon 20/10/05**	**Fri 23/03/31**	
82	Specification of testing of a full scale compact Heat Exchangers	Mon 20/10/05	Fri 23/03/31	
83	**IHX A (Ceramic)**	**Tue 08/10/07**	**Thu 23/03/30**	
84	**TRL 2 - TRL 3**	**Tue 08/10/07**	**Thu 09/10/01**	
85	Trade study on Candidate Ceramic Material for IHX A	Tue 08/10/07	Thu 09/10/01	
86	Trade study on Candidate Ceramic Designs for IHX A	Tue 08/10/07	Thu 09/10/01	
87	**TRL 3 - TRL 4**	**Thu 09/10/01**	**Fri 15/08/21**	
88	Ceramic Detailed Design Data Needs (DDNs)	Thu 09/10/01	Mon 11/03/21	
89	Ceramic Materials Specifications and Procurement	Thu 10/04/01	Tue 12/09/11	
90	Thermal Physical Properties of Ceramics	Fri 10/10/01	Wed 12/03/21	
91	Mechanical Properties of Ceramics	Fri 11/04/01	Fri 14/03/07	
92	Compatibility of Ceramic Materials to NGNP He environment	Sat 11/10/01	Mon 13/03/18	
93	Manufacturing Technologies for Ceramic Heat Exchangers	Mon 12/09/03	Fri 15/08/21	
94	**TRL 4 - TRL 5**	**Tue 14/04/01**	**Fri 20/06/12**	
95	Ceramic Materials Codes and Standards	Tue 14/04/01	Tue 16/03/29	
96	Methods for Thermal/Fluid and Stress/Strain Modeling	Tue 14/04/01	Tue 16/03/29	
97	Structural Integrity Criteria for Ceramic Heat Exchangers	Tue 14/04/01	Tue 16/03/29	
98	Performance Modeling of Ceramic Heat Exchangers	Tue 14/04/01	Tue 16/03/29	
99	Testing of unit cell of Compact Heat Exchanger	Mon 19/06/17	Fri 20/06/12	293SS
100	Fatigue testing of unit cell of compact Compact Heat Exchanger	Tue 15/04/28	Tue 16/04/26	344SS
101	**TRL 5 - TRL 6**	**Tue 15/12/15**	**Tue 18/10/02**	
102	Specification of testing of compact heat exchanger module (1.2Mw)	Tue 15/12/15	Fri 16/11/25	450SS
103	ASME Code Case for Ceramic Compact Heat Exchanger Design	Fri 16/04/01	Tue 18/10/02	
104	**TRL 6 - TRL 7**	**Wed 16/12/14**	**Fri 18/08/24**	
105	Shell-side Flow Distribution and Bypass Leakage Testing	Wed 16/12/14	Fri 18/08/24	452SS
106	Multi-mode Heat Transfer Testing	Wed 16/12/14	Fri 18/08/24	453SS
107	**TRL 7 - TRL 8**	**Thu 20/10/01**	**Thu 23/03/30**	
108	Specifications of testing of a full scale compact Heat Exchanger	Thu 20/10/01	Thu 23/03/30	
109	**IHX B**	**Tue 08/10/07**	**Mon 23/04/03**	
110	**TRL 3 - TRL 4**	**Tue 08/10/07**	**Thu 15/02/12**	
111	Alloy 800H Material Specification and Procurement	Tue 08/10/07	Thu 09/10/01	
112	Database for Brazed and Diffusion Bonded Alloy 800H	Wed 09/04/01	Fri 11/09/09	
113	Alloy 800H High Temperature Material Properties	Fri 10/01/01	Wed 10/03/31	
114	Effects of Thermal Aging and Environment on Alloy 800H Properties	Fri 10/01/01	Mon 10/06/28	
115	Effects of Environmental Exposure on Alloy 800H Braze and Diffusion Bonded Joints	Thu 10/04/01	Tue 13/03/05	
116	Effects of Grain Size and Section Thickness on Alloy 800H Properties	Fri 10/10/01	Fri 12/09/14	
117	Corrosion Allowances for Alloy 800H	Thu 12/03/01	Thu 15/02/12	
118	Thermal/Fluid Modeling Methods for IHX B	Wed 09/04/01	Wed 12/03/07	
119	Methods for Stress/Strain Modeling of IHX B	Wed 09/04/01	Wed 12/03/07	
120	Criteria for Structural Integrity of IHX B	Wed 09/04/01	Wed 12/03/07	
121	Performance Modeling Methods for IHX B	Tue 11/03/01	Wed 15/02/04	
122	**TRL 4 - TRL 5**	**Thu 12/04/19**	**Mon 15/10/26**	
123	Testing of Unit Cell of Compact Heat Exchanger	Mon 12/11/05	Mon 15/10/26	287SS
124	IHX B: Fatigue Testing of unit cell of Compact Heat Exchanger	Thu 12/04/19	Mon 15/04/06	342SS
125	**TRL 5 - TRL 6**	**Tue 14/12/16**	**Mon 18/04/02**	
126	Testing of integrated compact Heat Exchanger	Tue 14/12/16	Fri 16/12/09	500SS



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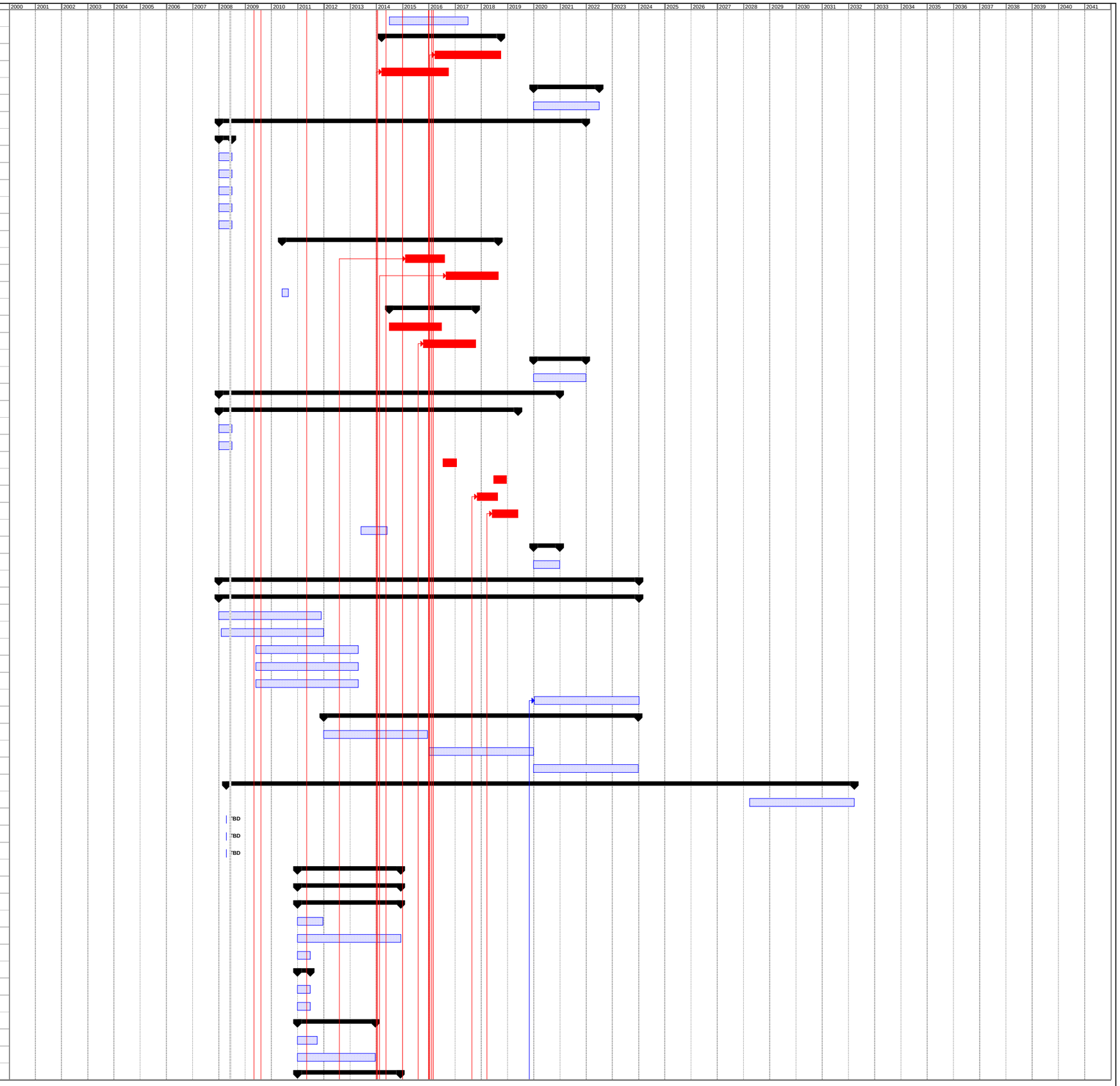
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

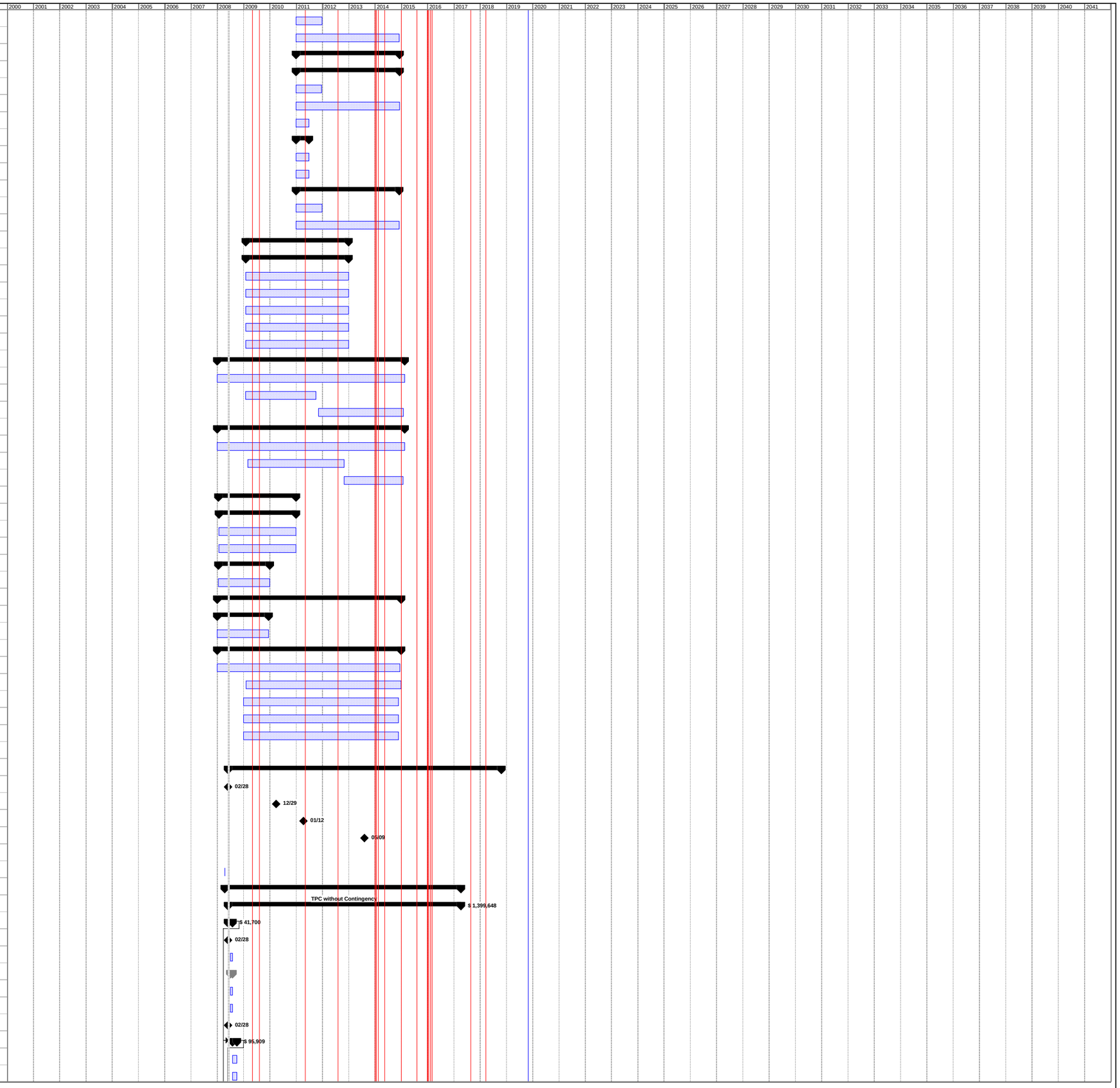
ID	Task Name	Start	Finish	Predecessors
127	ASME III Code Case for Metallic Compact Heat Exchanger Design	Fri 15/04/03	Mon 18/04/02	
128	**TRL 6 - TRL 7**	**Tue 14/12/16**	**Wed 19/07/03**	
129	Shell-side Flow Distribution and Bypass Leakage Testing	Wed 16/12/28	Wed 19/07/03	502SS
130	Multi-mode Heat Transfer Testing	Tue 14/12/16	Tue 17/07/04	503SS
131	**TRL 7 - TRL 8**	**Thu 20/10/01**	**Mon 23/04/03**	
132	Testing of full size Compact Heat Exchanger	Thu 20/10/01	Mon 23/04/03	
133	**Piping**	**Fri 08/10/03**	**Thu 22/09/29**	
134	**TRL 4 - TRL5**	**Fri 08/10/03**	**Wed 09/04/01**	
135	PHTS high-temperature [760°C and 950°C] piping cooling, liner& insulation options trade study	Fri 08/10/03	Wed 09/04/01	
136	PHTS low-temperature [350°C] piping liner and insulation options trade study	Fri 08/10/03	Wed 09/04/01	
137	SHTS high-temperature[840°C and 900°C] piping liner and insulation study	Fri 08/10/03	Wed 09/04/01	
138	SHTS medium-temperature [659°C and 700°C] piping liner and insulation trade study	Fri 08/10/03	Wed 09/04/01	
139	SHTS low-temperature [<300°C] piping liner and insulation trade study	Fri 08/10/03	Wed 09/04/01	
140	**TRL 5 - TRL 6**	**Tue 11/03/01**	**Wed 19/05/29**	
141	Effects of He infiltration on thermal conductivity of insulation material	Thu 15/11/12	Wed 17/05/10	289SS
142	The effect of fluid impurities © on insulation properties	Tue 17/05/30	Wed 19/05/29	291SS
143	Re-evaluation of needed maturation tasks based on Trade studies	Tue 11/03/01	Fri 11/05/27	
144	**TRL 6 - TRL 7**	**Wed 15/04/01**	**Wed 18/07/18**	
145	Piping: Performance&environmental testing: prototypical high-& low-temp piping/insulation system	Wed 15/04/01	Wed 17/03/29	
146	Piping: Performance and environmental testing	Tue 16/07/19	Wed 18/07/18	607SS
147	**TRL 7 - TRL 8**	**Thu 20/10/01**	**Thu 22/09/29**	
148	Testing of full size PHTS piping in NGNP	Thu 20/10/01	Thu 22/09/29	
149	**Mixing Chamber**	**Fri 08/10/03**	**Thu 21/09/30**	
150	**TRL 6 - TRL 7**	**Fri 08/10/03**	**Thu 20/02/27**	
151	Enhanced Mixing Devices Test Specification	Fri 08/10/03	Wed 09/04/01	
152	Vibration Damping Devices Test Specification	Fri 08/10/03	Wed 09/04/01	
153	Mixing Chamber: Enhanced Mixing Devices Test Specification	Tue 17/04/18	Tue 17/10/24	
154	Mixing Chamber: Vibration Damping Devices Test Specification	Mon 19/03/25	Fri 19/09/20	
155	Mixing Chamber: Vibration Damping Devices Test Specification (CL)	Tue 18/08/07	Wed 19/05/15	609SS
156	Partial or Full Scale Flow Mixing Chamber Model Test Specification	Mon 19/03/04	Thu 20/02/27	611SS
157	Partial or Full Scale Flow Mixing Chamber Model Test Specification	Mon 14/03/03	Mon 15/03/02	
158	**TRL 7 - TRL 8**	**Thu 20/10/01**	**Thu 21/09/30**	
159	Prototype Flow Mixing Chamber Test Specification	Thu 20/10/01	Thu 21/09/30	
160	**Steam Generator**	**Wed 08/10/01**	**Tue 24/10/08**	
161	**TRL 6 - TRL 7**	**Wed 08/10/01**	**Tue 24/10/08**	
162	Trade Studies	Wed 08/10/01	Mon 12/08/27	
163	Down selection trade study: determine the preferred conceptual arrangement of the SG	Tue 08/11/04	Fri 12/09/28	
164	Define requirements and design details for the SG in the PCS system context	Mon 10/03/01	Fri 14/01/24	
165	Perform configuration development tests to substantiate the design	Mon 10/03/01	Fri 14/01/24	
166	Design and supply a scale prototype for the testing in the CTF	Mon 10/03/01	Fri 14/01/24	
167	Performance testing in CTF	Tue 20/10/13	Tue 24/10/08	673SS
168	**TRL 7 - TRL 8**	**Mon 12/10/01**	**Fri 24/09/27**	
169	Complete final design of the prototype SG for the NGNP	Mon 12/10/01	Thu 16/09/15	
170	Fabricate and deliver to NGNP to the Site	Wed 16/10/05	Wed 20/09/30	
171	Install and operate	Thu 20/10/01	Fri 24/09/27	
172	**Hydrogen Production System**	**Tue 09/01/13**	**Thu 32/12/23**	
173	Sulfuric Acid Decomposition	Tue 28/12/26	Thu 32/12/23	
174	Sulfur Dioxide Electrolysis	Tue 09/01/13	Tue 09/01/13	
175	Bunsen Reaction and HI decomposition	Tue 09/01/13	Tue 09/01/13	
176	High Temperature Steam Electrolysis	Tue 09/01/13	Tue 09/01/13	
177	**Fuel Elements**	**Sat 11/10/01**	**Wed 15/09/09**	
178	**TRL 6 - TRL 7**	**Sat 11/10/01**	**Wed 15/09/09**	
179	**Production Fuel Irradiation Tests for Normal Operational Conditions**	**Sat 11/10/01**	**Wed 15/09/09**	
180	Irradiation planning & Preparation	Sat 11/10/01	Wed 12/09/19	
181	Irradiation of Pre-Production Fuel	Sat 11/10/01	Wed 15/09/09	
182	PIE and Analysis	Sat 11/10/01	Tue 12/03/27	
183	**Production Fuel Heat-up Tests at 1600°C and 1800°C.**	**Sat 11/10/01**	**Tue 12/03/27**	
184	Physical Heating Test	Sat 11/10/01	Tue 12/03/27	
185	PIE and analysis of Heated Spheres	Sat 11/10/01	Tue 12/03/27	
186	**Fuel Matrix Graphite Irradiation tests and PIE**	**Sat 11/10/01**	**Fri 14/09/19**	
187	Irradiation Planning & Preparation	Sat 11/10/01	Sun 12/07/01	
188	Irradiation and PIE	Sat 11/10/01	Fri 14/09/19	
189	**Machined Graphite Irradiation tests and PIE**	**Sat 11/10/01**	**Fri 15/09/04**	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

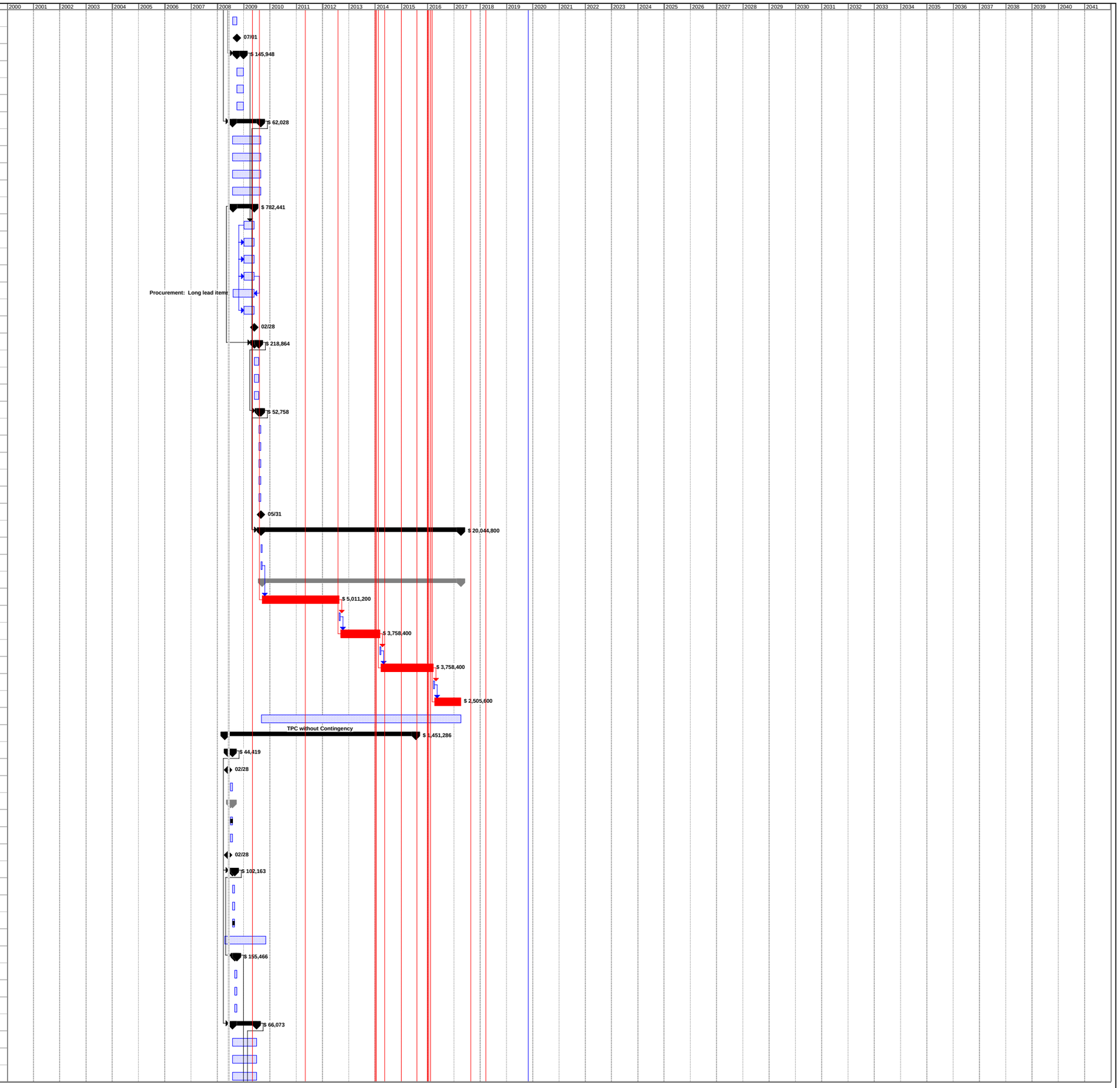
ID	Task Name	Start	Finish	Predecessors
190	Irradiation Planning & Preparation	Sat 11/10/01	Wed 12/09/26	
191	Irradiation and PIE	Sat 11/10/01	Fri 15/09/04	
192	**TRL 7 - TRL 8**	**Sat 11/10/01**	**Wed 15/09/09**	
193	**Production Fuel Irradiation Tests for NGNP Normal Operational Conditions**	**Sat 11/10/01**	**Wed 15/09/09**	
194	Irradiation planning & Preparation	Sat 11/10/01	Wed 12/09/19	
195	Irradiation of Pre-Production Fuel	Sat 11/10/01	Wed 15/09/09	
196	PIE and Analysis	Sat 11/10/01	Tue 12/03/27	
197	**Production Fuel Heat-up Tests at 1700°C and 1900°C.**	**Sat 11/10/01**	**Tue 12/03/27**	
198	Physical Heating Test	Sat 11/10/01	Tue 12/03/27	
199	PIE and analysis of Heated Spheres	Sat 11/10/01	Tue 12/03/27	
200	**Fuel Matrix Graphite Irradiation tests and PIE**	**Sat 11/10/01**	**Fri 15/09/04**	
201	Irradiation Planning & Preparation	Sat 11/10/01	Wed 12/09/26	
202	Irradiation and PIE	Sat 11/10/01	Fri 15/09/04	
203	**Core Structure Ceramics**	**Sun 09/11/01**	**Mon 13/09/30**	
204	**TRL 6 - TRL 7**	**Sun 09/11/01**	**Mon 13/09/30**	
205	PBMR Relevant	Sun 09/11/01	Mon 13/09/30	
206	Extended Properties of Irradiated Graphite at Low Temperatures	Sun 09/11/01	Mon 13/09/30	
207	Extended Properties of Irradiated Graphite at High Temperatures	Sun 09/11/01	Mon 13/09/30	
208	Characterize Race Track Strap and Tie Rod Material	Sun 09/11/01	Mon 13/09/30	
209	Insulation Material (Unirradiated Data Needed)	Sun 09/11/01	Mon 13/09/30	
210	**Reserve Shutdown System**	**Tue 08/09/30**	**Wed 15/11/18**	
211	Original Schedule in TDRM	Tue 08/09/30	Wed 15/11/18	
212	TRL 6 - TRL 7	Fri 09/10/30	Tue 12/07/03	
213	TRL 7 - TRL 8	Thu 12/08/09	Sat 15/10/31	
214	**Reactivity Control System**	**Wed 08/10/01**	**Wed 15/11/18**	
215	Original Schedule in TDRM	Wed 08/10/01	Wed 15/11/18	
216	TRL 6 - TRL 7	Tue 09/12/01	Tue 13/07/30	
217	TRL 7 - TRL 8	Wed 13/07/31	Wed 15/10/28	
218	**Core Conditioning System**	**Fri 08/10/17**	**Fri 11/09/30**	
219	**TRL 6 - TRL 7**	**Fri 08/10/24**	**Fri 11/09/30**	
220	Valves development Test Specification	Fri 08/10/24	Fri 11/09/30	
221	Blower development Test Specification	Fri 08/10/24	Fri 11/09/30	
222	**TRL 7 - TR8**	**Fri 08/10/17**	**Thu 10/09/30**	
223	CCS Development Test Specification	Fri 08/10/17	Thu 10/09/30	
224	**Reactor Cavity Cooling System**	**Wed 08/10/01**	**Wed 15/09/30**	
225	**TRL 6 - TRL 7**	**Wed 08/10/01**	**Tue 10/09/14**	
226	No tests defined.Advancement to next TRL will be achieved through software analysis.	Wed 08/10/01	Tue 10/09/14	
227	**TRL 7 - TRL 8**	**Wed 08/10/01**	**Wed 15/09/30**	
228	Original Schedule in TDRM	Wed 08/10/01	Mon 15/09/14	
229	Verify functioning of RCCS with respect-maintaining Reactor Cavity concrete below code limits	Thu 09/11/05	Wed 15/09/30	
230	Confirm operation of RCCS tank automatic water replenishment function	Thu 09/10/01	Mon 15/08/24	
231	Validate analysis of DWS supply and heat sink performances	Thu 09/10/01	Mon 15/08/24	
232	Validate theoretical analysis of pump trip effect on RCCS pressure	Thu 09/10/01	Mon 15/08/24	
233				
234	**C: CTF Critical Decisions Original as per BEA CTF Schedule**	**Sat 09/02/28**	**Thu 19/07/25**	
235	**Critical Decision 1 (CD-1) - Approval to Commence Preliminary Design**	Sat 09/02/28	Thu 19/07/25	
236	**Critical Decision 2 (CD-2) - Approval to Commence Final / Detailed Design**	Wed 10/12/29	Wed 10/12/29	
237	**Critical Decision 3(CD-3) - Approval to Commence Construction or Enter Full-Scale Development**	Thu 12/01/12	Fri 12/11/30	
238	**Critical Decision 4 (CD-4) - Approval to Commence Operation Testing**	Fri 14/05/09	Fri 14/05/09	
239				
240	**E: TLDR Schedule**	Tue 09/01/13	Tue 09/01/13	
241	**Small Scale Development Tests (SSDT)**	**Tue 09/01/13**	**Mon 18/01/08**	
242	**SSDT/Separate Effects Test 1 (No Flow - Creep Test Module)**	**Sat 09/02/28**	**Mon 18/01/08**	
243	**A) Pre-Title I Activities**	**Sat 09/02/28**	**Thu 09/04/30**	
244	Preconceptual Design and Relevant Activities	Sat 09/02/28	Sat 09/02/28	
245	Concept Refinement	Wed 09/04/01	Thu 09/04/30	
246	**Research and Development**	**Wed 09/04/01**	**Thu 09/04/30**	
247	Completion of UUT Detailed Test Specification	Wed 09/04/01	Thu 09/04/30	
248	Software Development/Code V&V	Wed 09/04/01	Thu 09/04/30	
249	**Approval to Commence Preliminary Design (SSDT 1 Critical Decision 1)**	Sat 09/02/28	Sat 09/02/28	
250	**B) Preliminary Design**	**Fri 09/05/01**	**Tue 09/06/30**	243
251	Preliminary Design Activities	Fri 09/05/01	Mon 09/06/29	
252	Supporting Activities	Fri 09/05/01	Mon 09/06/29	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

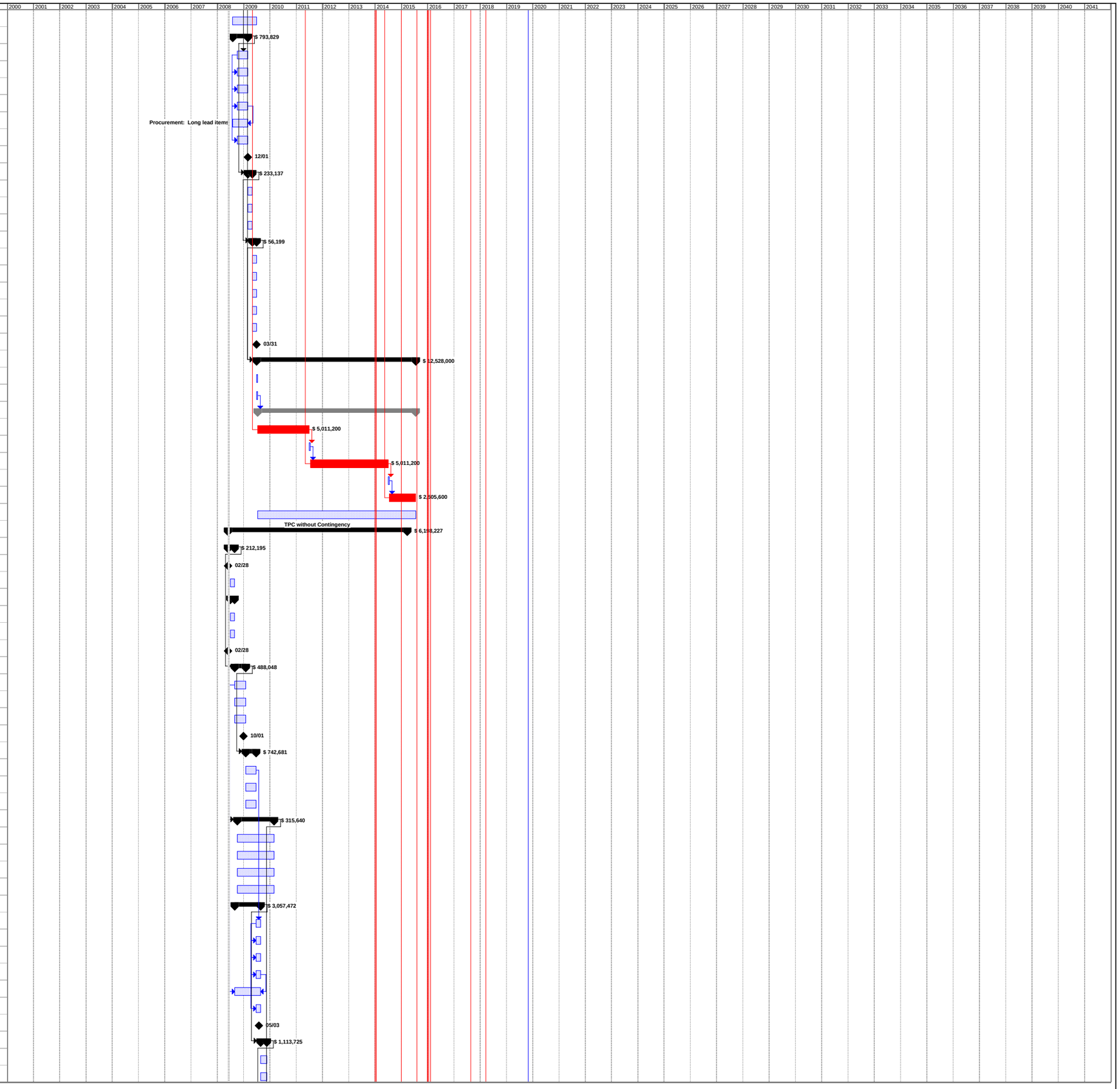
ID	Task Name	Start	Finish	Predecessors
253	Software Development/Code V&V	Mon 09/05/04	Tue 09/06/30	
254	**Approval to Commence Final / Detailed Design (SSDT 1 Critical Decision 2)**	Wed 09/07/01	Mon 10/12/27	
255	**C) Detail Design**	**Wed 09/07/01**	**Wed 09/09/30**	**250**
256	Detail Design and Relevant Activities	Wed 09/07/01	Wed 09/09/30	
257	Supporting Activities	Wed 09/07/01	Wed 09/09/30	
258	Software Development/Code V&V	Wed 09/07/01	Wed 09/09/30	
259	**D) Construction Supervision & QC**	**Fri 09/05/01**	**Fri 10/05/28**	**250SS**
260	Final budget proposal	Fri 09/05/01	Fri 10/05/28	
261	Approval	Fri 09/05/01	Fri 10/05/28	
262	Other Documentation	Fri 09/05/01	Fri 10/05/28	
263	Supporting Activities	Fri 09/05/01	Fri 10/05/28	
264	**E) Hardware Procurement**	**Fri 09/05/08**	**Fri 10/02/26**	
265	Final budget proposal	Wed 09/10/07	Fri 10/02/26	255
266	Approval	Wed 09/10/07	Fri 10/02/26	265SS
267	Other Documentation	Wed 09/10/07	Fri 10/02/26	266SS
268	Equipment procurement	Wed 09/10/07	Fri 10/02/26	267SS
269	Long Lead Items	Fri 09/05/08	Fri 10/02/26	268FF
270	Supporting Activities	Wed 09/10/07	Fri 10/02/26	268SS
271	**Approval to Commence Construction or Enter Full-Scale Development (SSDT 1 Critical Decision 3)**	Sun 10/02/28	Mon 12/11/26	
272	**F) Construction**	**Mon 10/03/01**	**Fri 10/04/30**	**264SS**
273	Project Management	Mon 10/03/01	Fri 10/04/30	
274	Construction contracts	Mon 10/03/01	Fri 10/04/30	
275	Supporting Activities	Mon 10/03/01	Fri 10/04/30	
276	**G) Commissioning & Start-up**	**Mon 10/05/03**	**Fri 10/05/28**	**272**
277	General Activities	Mon 10/05/03	Fri 10/05/28	
278	Discipline Related Activities	Mon 10/05/03	Fri 10/05/28	
279	Supporting Activities	Mon 10/05/03	Fri 10/05/28	
280	Start-up Coordination, Material and Supplies	Mon 10/05/03	Fri 10/05/28	
281	Correction of Design/Construction Deficiencies	Mon 10/05/03	Fri 10/05/28	
282	**Approval to Commence Operation Testing (SSDT 1 Critical Decision 4)**	Mon 10/05/31	Tue 14/04/29	
283	**H) Operation**	**Tue 10/06/01**	**Mon 18/01/08**	**276,259**
284	Pre Testing Activities (Set-up time)	Tue 10/06/01	Wed 10/06/16	
285	Re-Engineering/Re-configuration	Tue 10/06/01	Wed 10/06/16	
286	**Testing Activities (Per TDRM Test Spec)**	**Thu 10/06/17**	**Mon 18/01/08**	
287	IHX B: Testing of unit cell of compact Heat Exchangers	Thu 10/06/17	Tue 13/05/21	285
288	Re-Engineering/Re-configuration (Set-up Time)	Wed 13/05/22	Thu 13/06/06	287
289	Piping: Effects of He infiltration on thermal conductivity of insulation material and the Effect of sudden depressurization at 9 Mpa, 950°C	Thu 13/06/13	Mon 14/12/08	288
290	Re-Engineering/Re-configuration (Set-up Time)	Tue 14/12/09	Wed 14/12/24	289
291	Piping: The effect of fluid impurities (C) on insulation properties	Thu 14/12/25	Wed 16/12/21	290
292	Re-Engineering/Re-configuration (Set-up Time)	Thu 16/12/22	Fri 17/01/06	291
293	IHX A (Ceramic): Testing of unit cell of Compact Heat Exchanger	Mon 17/01/09	Mon 18/01/08	292
294	Software Development/Code V&V	Mon 10/06/07	Mon 18/01/08	
295	**SSDT/Separate Effects Test 2 (Low Flow - Fatigue Test Module)**	**Tue 09/01/13**	**Fri 16/04/22**	
296	**A) Pre-Title I Activities**	**Sat 09/02/28**	**Thu 09/04/30**	
297	Conceptual Design and Relevant Activities	Sat 09/02/28	Thu 09/04/30	
298	Concept Refinement	Wed 09/04/01	Thu 09/04/30	
299	**Research and Development**	**Wed 09/04/01**	**Thu 09/04/30**	
300	Completion of UUT Detailed Test Specification	Wed 09/04/01	Thu 09/04/30	
301	Software Development/Code V&V	Wed 09/04/01	Thu 09/04/30	
302	**Approval to Commence Preliminary Design (SSDT 2 Critical Decision 1)**	Sat 09/02/28	Sat 09/02/28	
303	**B) Preliminary Design**	**Fri 09/05/01**	**Sun 09/05/31**	**296**
304	Preliminary Design Activities	Fri 09/05/01	Fri 09/05/29	
305	Supporting Activities	Fri 09/05/01	Sun 09/05/31	
306	Software Development/Code V&V	Fri 09/05/01	Fri 09/05/29	
307	**Approval to Commence Final / Detailed Design (SSDT 2 Critical Decision 2)**	Tue 09/01/13	Fri 10/08/06	
308	**C) Detail Design**	**Tue 09/06/02**	**Tue 09/06/30**	**303**
309	Detail Design and Relevant Activities	Tue 09/06/02	Tue 09/06/30	
310	Supporting Activities	Tue 09/06/02	Tue 09/06/30	
311	Software Development/Code V&V	Tue 09/06/02	Tue 09/06/30	
312	**D) Construction Supervision & QC**	**Fri 09/05/01**	**Wed 10/03/31**	**303SS**
313	Final budget proposal	Fri 09/05/01	Wed 10/03/31	
314	Approval	Fri 09/05/01	Wed 10/03/31	
315	Other Documentation	Fri 09/05/01	Wed 10/03/31	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

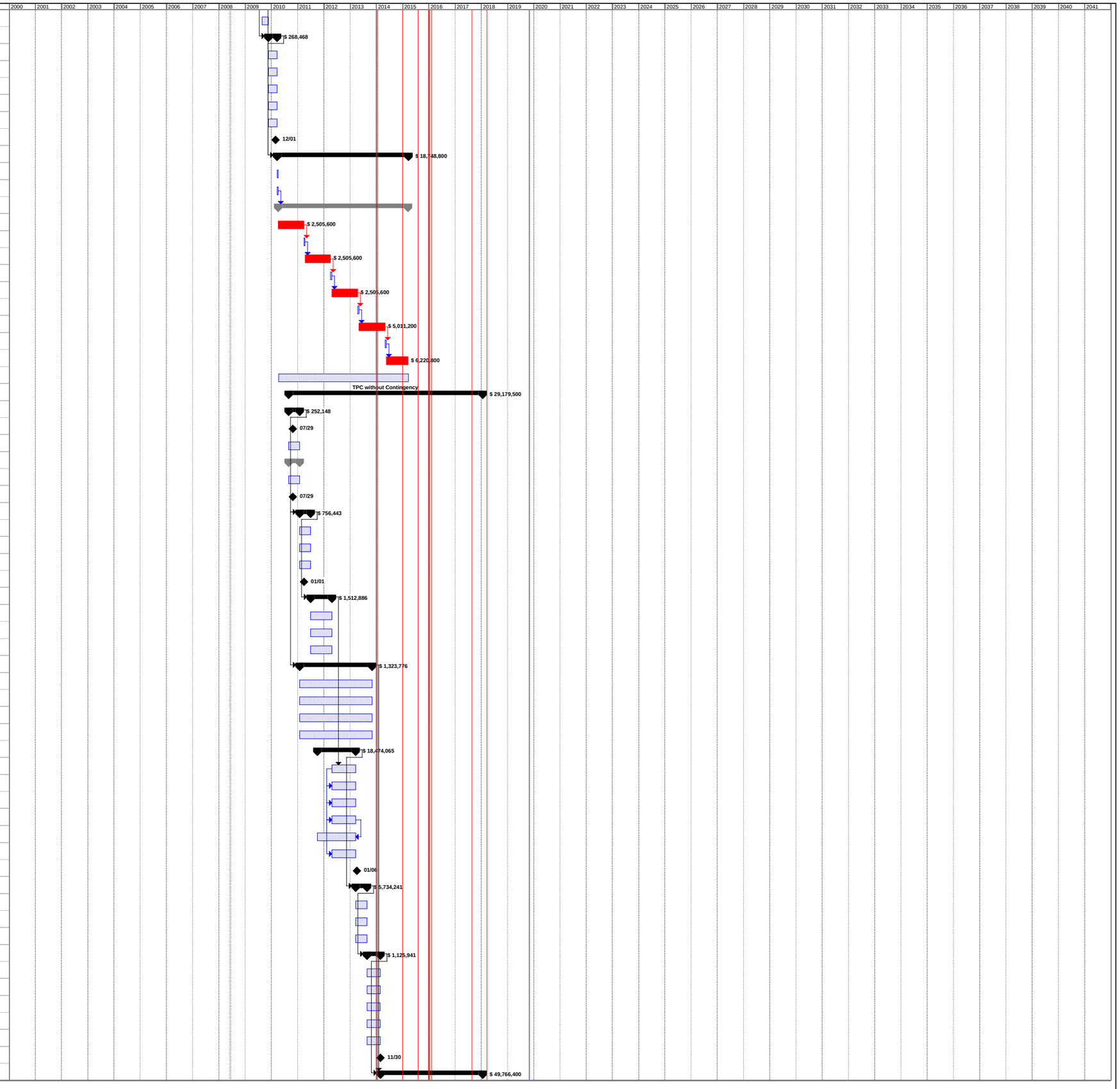
ID	Task Name	Start	Finish	Predecessors
316	Supporting Activities	Fri 09/05/01	Wed 10/03/31	
317	**E) Hardware Procurement**	**Mon 09/05/04**	**Tue 09/12/01**	
318	Final budget proposal	Mon 09/07/06	Tue 09/12/01	308
319	Approval	Mon 09/07/06	Tue 09/12/01	318SS
320	Other Documentation	Mon 09/07/06	Tue 09/12/01	319SS
321	Equipment procurement	Mon 09/07/06	Tue 09/12/01	320SS
322	Long lead Items	Mon 09/05/04	Tue 09/12/01	321FF
323	Supporting Activities	Mon 09/07/06	Mon 09/11/30	321SS
324	**Approval to Commence Construction or Enter Full-Scale Development (SSDT 2 Critical Decision 3)**	Tue 09/12/01	Mon 10/04/26	
325	**F) Construction**	**Tue 09/12/01**	**Sat 10/01/30**	**317**
326	Project Management	Tue 09/12/01	Sat 10/01/30	
327	Construction contracts	Tue 09/12/01	Sat 10/01/30	
328	Supporting Activities	Tue 09/12/01	Sat 10/01/30	
329	**G) Commissioning & Start-up**	**Mon 10/02/01**	**Wed 10/03/31**	**325**
330	General Activities	Mon 10/02/01	Wed 10/03/31	
331	Discipline Related Activities	Mon 10/02/01	Wed 10/03/31	
332	Supporting Activities	Tue 10/02/02	Wed 10/03/31	
333	Start-up Coordination, Material and Supplies	Mon 10/02/01	Wed 10/03/31	
334	Correction of Design/Construction Deficiencies	Mon 10/02/01	Wed 10/03/31	
335	**Approval to Commence Operation Testing (SSDT 2 Critical Decision 4)**	Wed 10/03/31	Tue 14/04/29	
336	**H) Operation**	**Thu 10/04/01**	**Fri 16/04/22**	**329,312**
337	Pre Testing Activities (Set-up time)	Thu 10/04/01	Thu 10/04/15	
338	Re-Engineering/Re-configuration	Thu 10/04/01	Thu 10/04/15	
339	**Testing Activities (Per TDRM Test Spec)**	**Fri 10/04/16**	**Wed 16/04/20**	**338**
340	IHX A (Metallic): Unit Cell Fatigue Life Test	Fri 10/04/16	Sun 12/04/01	
341	Re-Engineering/Re-configuration (Set-up Time)	Mon 12/04/02	Tue 12/04/17	340
342	IHX B: Fatigue Testing of unit cell of Compact Heat Exchanger	Wed 12/04/18	Fri 15/04/03	341
343	Re-Engineering/Re-configuration (Set-up Time)	Mon 15/04/06	Tue 15/04/21	342
344	IHX A (Ceramic): Fatigue testing of unit cell of compact Compact Heat Exchanger	Wed 15/04/22	Wed 16/04/20	343
345	Software Development/Code V&V	Fri 10/04/16	Fri 16/04/22	
346	**SSDT/Separate Effects Test 3 (IHX Unit Cell/Circulator Development)**	**Sat 09/02/28**	**Thu 15/12/24**	
347	**A) Pre-Title I Activities**	**Sat 09/02/28**	**Fri 09/05/29**	
348	Conceptual Design and Relevant Activities	Sat 09/02/28	Sat 09/02/28	
349	Concept Refinement	Wed 09/04/01	Fri 09/05/29	
350	**Research and Development**	**Wed 09/04/01**	**Fri 09/05/29**	
351	Completion of UUT Detailed Test Specification	Wed 09/04/01	Fri 09/05/29	
352	Software Development/Code V&V	Wed 09/04/01	Fri 09/05/29	
353	**Approval to Commence Preliminary Design (SSDT 3 Critical Decision 1)**	Sat 09/02/28	Sat 09/02/28	
354	**B) Preliminary Design**	**Mon 09/06/01**	**Sat 09/10/31**	**347**
355	Preliminary Design Activities	Mon 09/06/01	Sat 09/10/31	
356	Supporting Activities	Mon 09/06/01	Sat 09/10/31	
357	Software Development/Code V&V	Mon 09/06/01	Sat 09/10/31	
358	**Approval to Commence Final / Detailed Design (SSDT 3 Critical Decision 2)**	Thu 09/10/01	Thu 09/10/01	
359	**C) Detail Design**	**Sun 09/11/01**	**Wed 10/03/24**	**354**
360	Detail Design and Relevant Activities	Sun 09/11/01	Wed 10/03/24	
361	Supporting Activities	Sun 09/11/01	Wed 10/03/24	
362	Software Development/Code V&V	Sun 09/11/01	Wed 10/03/24	
363	**D) Construction Supervision & QC**	**Tue 09/07/07**	**Mon 10/11/29**	**354SS**
364	Final budget proposal	Tue 09/07/07	Mon 10/11/29	
365	Approval	Tue 09/07/07	Mon 10/11/29	
366	Other Documentation	Tue 09/07/07	Mon 10/11/29	
367	Supporting Activities	Tue 09/07/07	Mon 10/11/29	
368	**E) Hardware Procurement**	**Mon 09/06/01**	**Wed 10/05/26**	
369	Final budget proposal	Thu 10/03/25	Wed 10/05/26	360
370	Approval	Thu 10/03/25	Wed 10/05/26	369SS
371	Other Documentation	Thu 10/03/25	Wed 10/05/26	370SS
372	Equipment procurement	Thu 10/03/25	Wed 10/05/26	371SS
373	Long Lead Items	Mon 09/06/01	Wed 10/05/26	355SS,372FF
374	Supporting Activities	Thu 10/03/25	Wed 10/05/26	372SS
375	**Approval to Commence Construction or Enter Full-Scale Development (SSDT 3 Critical Decision 3)**	Mon 10/05/03	Wed 10/05/26	
376	**F) Construction**	**Thu 10/05/27**	**Fri 10/08/20**	**368**
377	Project Management	Thu 10/05/27	Fri 10/08/20	
378	Construction contracts	Thu 10/05/27	Fri 10/08/20	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

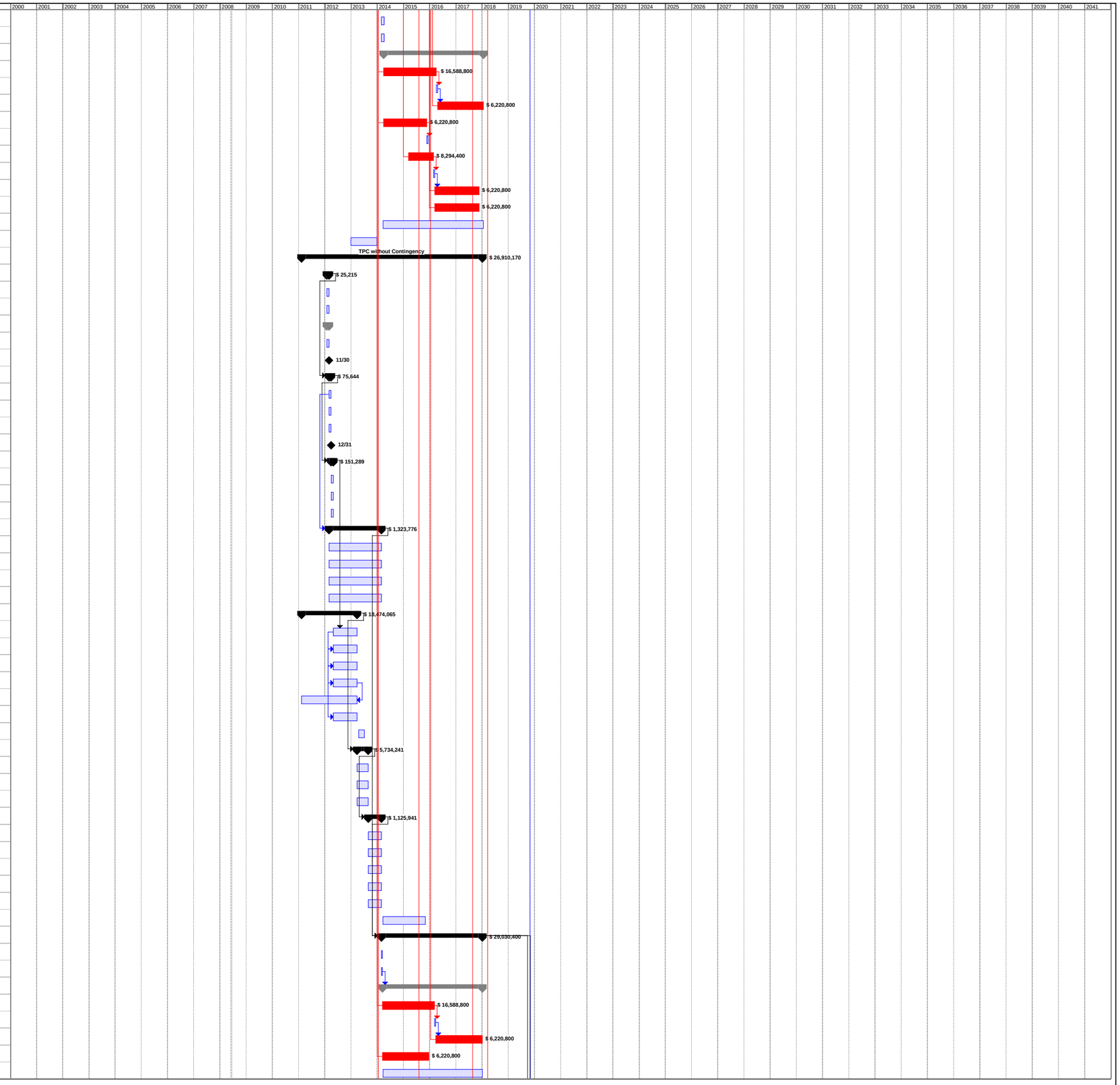
ID	Task Name	Start	Finish	Predecessors
379	Supporting Activities	Thu 10/05/27	Fri 10/08/20	
380	**G) Commissioning & Start-up**	**Mon 10/08/23**	**Tue 10/12/21**	**376**
381	General Activities	Mon 10/08/23	Tue 10/12/21	
382	Discipline Related Activities	Mon 10/08/23	Tue 10/12/21	
383	Supporting Activities	Mon 10/08/23	Tue 10/12/21	
384	Start-up Coordination, Material and Supplies	Mon 10/08/23	Tue 10/12/21	
385	Correction of Design/Construction Deficiencies	Mon 10/08/23	Tue 10/12/21	
386	**Approval to Commence Operation Testing (SSDT 3 Critical Decision 4)**	Wed 10/12/01	Wed 10/12/01	
387	**Operation**	**Wed 10/12/22**	**Thu 15/12/24**	**380,363**
388	Pre Testing Activities (Set-up time)	Wed 10/12/22	Wed 11/01/05	
389	Re-Engineering/Re-configuration	Wed 10/12/22	Wed 11/01/05	
390	**Testing Activities**	**Thu 11/01/06**	**Fri 15/12/18**	**389**
391	IHX A (Metallic): Heat Transfer Capability	Thu 11/01/06	Fri 11/12/30	
392	Re-Engineering/Re-configuration (Set-up Time)	Sat 11/12/31	Fri 12/01/13	391
393	IHX A (Ceramic): Heat Transfer Capability	Mon 12/01/16	Thu 13/01/03	392
394	Re-Engineering/Re-configuration (Set-up Time)	Fri 13/01/04	Mon 13/01/21	393
395	IHX B (Metallic): Heat Transfer Capability	Tue 13/01/22	Thu 14/01/16	394
396	Re-Engineering/Re-configuration (Set-up Time)	Fri 14/01/17	Mon 14/02/03	395
397	Blower Development: Expected Lifetime evaluation	Tue 14/02/04	Mon 15/02/02	396
398	Re-Engineering/Re-configuration (Set-up Time)	Tue 15/02/03	Wed 15/02/18	397
399	Transient Tests: Possible Temperature Transient Tests	Thu 15/02/19	Fri 15/12/18	398
400	Software Development/Code V&V	Wed 11/01/12	Thu 15/12/24	
401	**TDL/Technology Development Loop 1**	**Wed 11/06/01**	**Tue 18/10/23**	
402	**A) Pre-Title I Activities**	**Wed 11/06/01**	**Mon 11/10/31**	
403	Conceptual Design and Relevant Activities	Fri 11/07/29	Fri 11/07/29	
404	Concept Refinement	Wed 11/06/01	Mon 11/10/31	
405	**Research and Development**	**Wed 11/06/01**	**Mon 11/10/31**	
406	Completion of UUT Detailed Test Specification	Wed 11/06/01	Mon 11/10/31	
407	**Approval to Commence Preliminary Design (TDL 1 Critical Decision 1)**	Fri 11/07/29	Sun 12/07/15	
408	**B) Title I Preliminary Design**	**Tue 11/11/01**	**Sun 12/04/01**	**402**
409	Preliminary Design Activities	Tue 11/11/01	Sun 12/04/01	
410	Supporting Activities	Tue 11/11/01	Sun 12/04/01	
411	Software Development/Code V&V	Tue 11/11/01	Sun 12/04/01	
412	**Approval to Commence Final / Detailed Design (TDL 1 Critical Decision 2)**	Sun 12/01/01	Sun 12/01/01	
413	**C) Title II Detail Design**	**Mon 12/04/02**	**Tue 13/01/22**	**408**
414	Detail Design and Relevant Activities	Mon 12/04/02	Tue 13/01/22	
415	Supporting Activities	Mon 12/04/02	Tue 13/01/22	
416	Software Development/Code V&V	Mon 12/04/02	Tue 13/01/22	
417	**D) Construction Supervision & QC**	**Tue 11/11/01**	**Tue 14/08/05**	**408SS**
418	Final budget proposal	Tue 11/11/01	Tue 14/08/05	
419	Approval	Tue 11/11/01	Tue 14/08/05	
420	Other Documentation	Tue 11/11/01	Tue 14/08/05	
421	Supporting Activities	Tue 11/11/01	Tue 14/08/05	
422	**E) Hardware Procurement**	**Thu 12/07/05**	**Thu 13/12/19**	
423	Final budget proposal	Wed 13/01/23	Thu 13/12/19	413
424	Approval	Wed 13/01/23	Thu 13/12/19	423SS
425	Other Documentation	Wed 13/01/23	Thu 13/12/19	424SS
426	Equipment procurement	Wed 13/01/23	Thu 13/12/19	425SS
427	Long lead items	Thu 12/07/05	Thu 13/12/19	426FF
428	Supporting Activities	Wed 13/01/23	Thu 13/12/19	426SS
429	**Approval to Commence Construction or Enter Full-Scale Development (TDL 1 Critical Decision 3)**	Mon 14/01/06	Tue 14/11/25	
430	**F) Construction**	**Fri 13/12/20**	**Mon 14/05/26**	**422**
431	Project Management	Fri 13/12/20	Mon 14/05/26	
432	Construction contracts	Fri 13/12/20	Mon 14/05/26	
433	Supporting Activities	Fri 13/12/20	Mon 14/05/26	
434	**G) Commissioning & Start-up**	**Tue 14/05/27**	**Fri 14/11/28**	**430**
435	General Activities	Tue 14/05/27	Fri 14/11/28	
436	Discipline Related Activities	Tue 14/05/27	Fri 14/11/28	
437	Supporting Activities	Tue 14/05/27	Tue 14/11/25	
438	Start-up Coordination, Material and Supplies	Tue 14/05/27	Fri 14/11/28	
439	Correction of Design/Construction Deficiencies	Tue 14/05/27	Fri 14/11/28	
440	**Approval to Commence Operation Testing (TDL 1 Critical Decision 4)**	Sun 14/11/30	Wed 17/03/29	
441	**H) Operation**	**Sun 14/11/30**	**Tue 18/10/23**	**417,434**



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

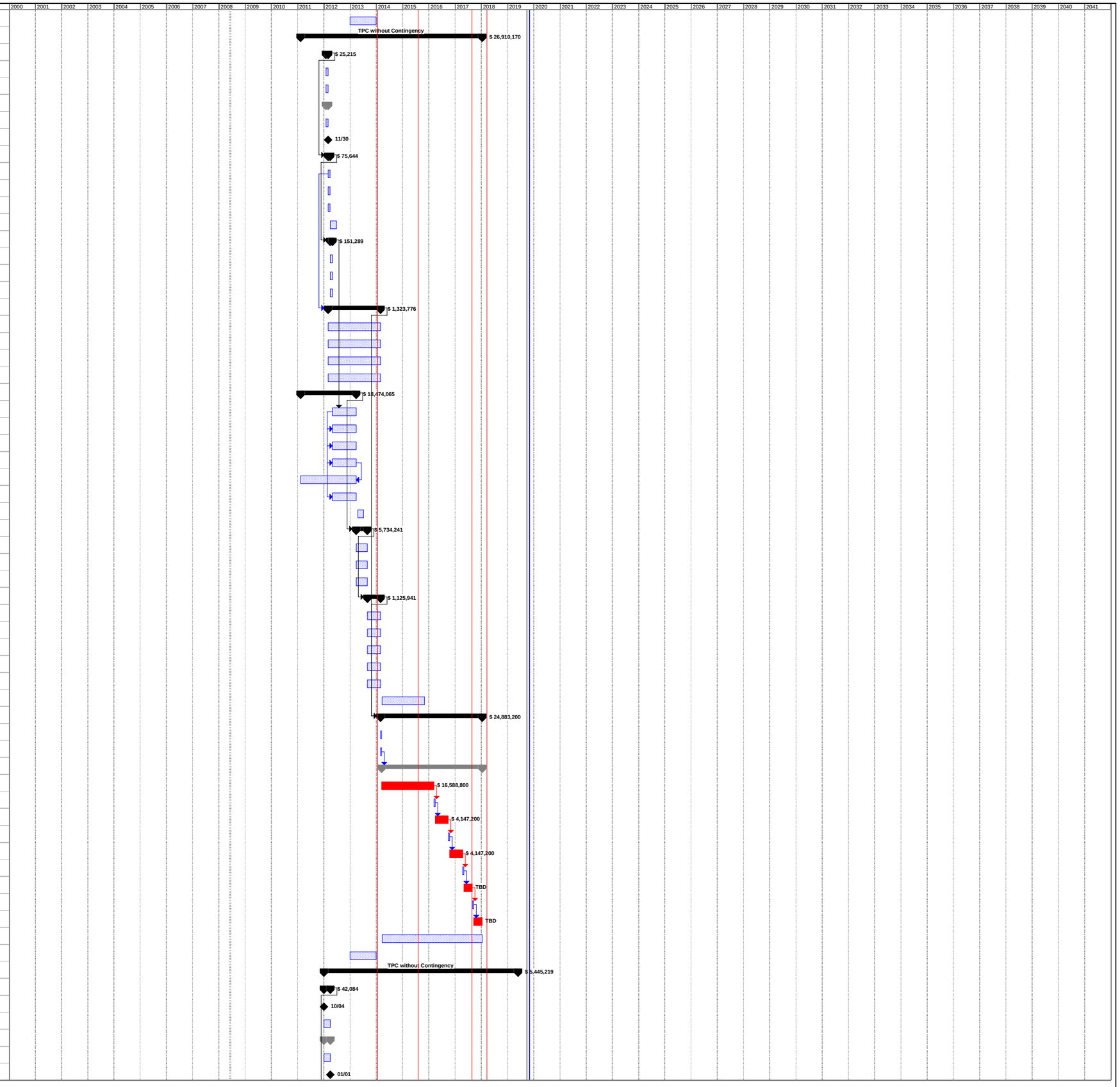
ID	Task Name	Start	Finish	Predecessors
442	Pre Testing Activities	Sun 14/11/30	Thu 15/01/08	
443	Re-Engineering	Sun 14/11/30	Thu 15/01/08	
444	**Testing Activities (Per TDRM Test Spec)**	**Thu 15/01/01**	**Tue 18/10/23**	
445	IHX A (Metallic): Specification of testing of compact heat exchanger module (1.2MW)	Thu 15/01/01	Wed 17/01/04	
446	Re-Engineering/Re-configuration (Set-up Time)	Thu 17/01/05	Mon 17/01/23	445
447	IHX A (Metallic): Shell Side Flow Distribution and Bypass Leakage Testing	Tue 17/01/24	Tue 18/10/23	446
448	IHX A (Metallic): Multi-module Heat Transfer Testing	Thu 15/01/01	Thu 16/08/25	
449	Re-Engineering/Re-configuration (Set-up Time)	Fri 16/08/26	Mon 16/09/12	448
450	IHX A (Ceramic): Specification of testing of compact heat exchanger module (1.2Mw)	Tue 15/12/15	Fri 16/11/25	
451	Re-Engineering/Re-configuration (Set-up Time)	Mon 16/11/28	Tue 16/12/13	450
452	IHX A (Ceramic): Shell-side Flow Distribution and Bypass Leakage Testing	Wed 16/12/14	Fri 18/08/24	451
453	IHX A (Ceramic): Multi-mode Heat Transfer Testing	Wed 16/12/14	Fri 18/08/24	
454	Software Development/Code V&V	Wed 14/12/24	Tue 18/10/23	
455	**CQL Critical Decision**	Tue 13/10/01	Tue 14/09/30	
456	**TDL/Technology Development Loop 2**	**Mon 11/11/14**	**Mon 18/10/08**	
457	**A) Pre-Title I Activities**	**Thu 12/11/01**	**Fri 12/11/30**	
458	Conceptual Design and Relevant Activities	Thu 12/11/01	Fri 12/11/30	
459	Concept Refinement	Thu 12/11/01	Fri 12/11/30	
460	**Research and Development**	**Thu 12/11/01**	**Fri 12/11/30**	
461	Completion of UUT Detailed Test Specification	Thu 12/11/01	Fri 12/11/30	
462	**Approval to Commence Preliminary Design (TDL 2 Critical Decision 1)**	Fri 12/11/30	Fri 12/11/30	
463	**B) Title I Preliminary Design**	**Sat 12/12/01**	**Fri 12/12/28**	**457**
464	Preliminary Design Activities	Sat 12/12/01	Fri 12/12/28	
465	Supporting Activities	Sat 12/12/01	Fri 12/12/28	
466	Software Development/Code V&V	Sat 12/12/01	Fri 12/12/28	
467	**Approval to Commence Final / Detailed Design (TDL 2 Critical Decision 2)**	Mon 12/12/31	Wed 13/03/27	
468	**C) Title II Detail Design**	**Mon 12/12/31**	**Tue 13/01/29**	**463**
469	Detail Design and Relevant Activities	Mon 12/12/31	Tue 13/01/29	
470	Supporting Activities	Mon 12/12/31	Tue 13/01/29	
471	Software Development/Code V&V	Mon 12/12/31	Tue 13/01/29	
472	**D) Construction Supervision & QC**	**Sat 12/12/01**	**Sun 14/11/30**	**464SS**
473	Final budget proposal	Sat 12/12/01	Sun 14/11/30	
474	Approval	Sat 12/12/01	Sun 14/11/30	
475	Other Documentation	Sat 12/12/01	Sun 14/11/30	
476	Supporting Activities	Sat 12/12/01	Sun 14/11/30	
477	**E) Hardware Procurement**	**Mon 11/11/14**	**Thu 13/12/26**	
478	Final budget proposal	Wed 13/01/30	Thu 13/12/26	468
479	Approval	Wed 13/01/30	Thu 13/12/26	478SS
480	Other Documentation	Wed 13/01/30	Thu 13/12/26	479SS
481	Equipment procurement	Wed 13/01/30	Thu 13/12/26	480SS
482	Long lead items	Mon 11/11/14	Thu 13/12/26	481FF
483	Supporting Activities	Wed 13/01/30	Thu 13/12/26	481SS
484	**Approval to Commence Construction or Enter Full-Scale Development (TDL 2 Critical Decision 3)**	Mon 14/01/20	Mon 14/04/07	
485	**F) Construction**	**Fri 13/12/27**	**Fri 14/05/30**	**477**
486	Project Management	Fri 13/12/27	Fri 14/05/30	
487	Construction contracts	Fri 13/12/27	Fri 14/05/30	
488	Supporting Activities	Fri 13/12/27	Fri 14/05/30	
489	**G) Commissioning & Start-up**	**Mon 14/06/02**	**Sun 14/11/30**	**485**
490	General Activities	Mon 14/06/02	Sun 14/11/30	
491	Discipline Related Activities	Mon 14/06/02	Sun 14/11/30	
492	Supporting Activities	Mon 14/06/02	Sun 14/11/30	
493	Start-up Coordination, Material and Supplies	Mon 14/06/02	Sun 14/11/30	
494	Correction of Design/Construction Deficiencies	Mon 14/06/02	Sun 14/11/30	
495	**Approval to Commence Operation Testing (TDL 2 Critical Decision 4)**	Tue 14/12/23	Thu 16/08/04	
496	**H) Operation**	**Mon 14/12/01**	**Mon 18/10/08**	**472,489**
497	Pre Testing Activities	Mon 14/12/01	Mon 14/12/15	
498	Re-Engineering	Mon 14/12/01	Mon 14/12/15	
499	**Testing Activities (Per TDRM Test Spec)**	**Tue 14/12/16**	**Mon 18/10/08**	**498**
500	IHX B: Testing of integrated compact Heat Exchanger	Tue 14/12/16	Fri 16/12/09	
501	Re-Engineering/Re-configuration (Set-up Time)	Mon 16/12/12	Tue 16/12/27	500
502	IHX B: Shell-side Flow Distribution and Bypass Leakage Testing	Wed 16/12/28	Mon 18/10/08	501
503	IHX B: Multi-mode Heat Transfer Testing	Tue 14/12/16	Thu 16/09/22	
504	Software Development/Code V&V	Wed 14/12/24	Mon 18/10/08	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

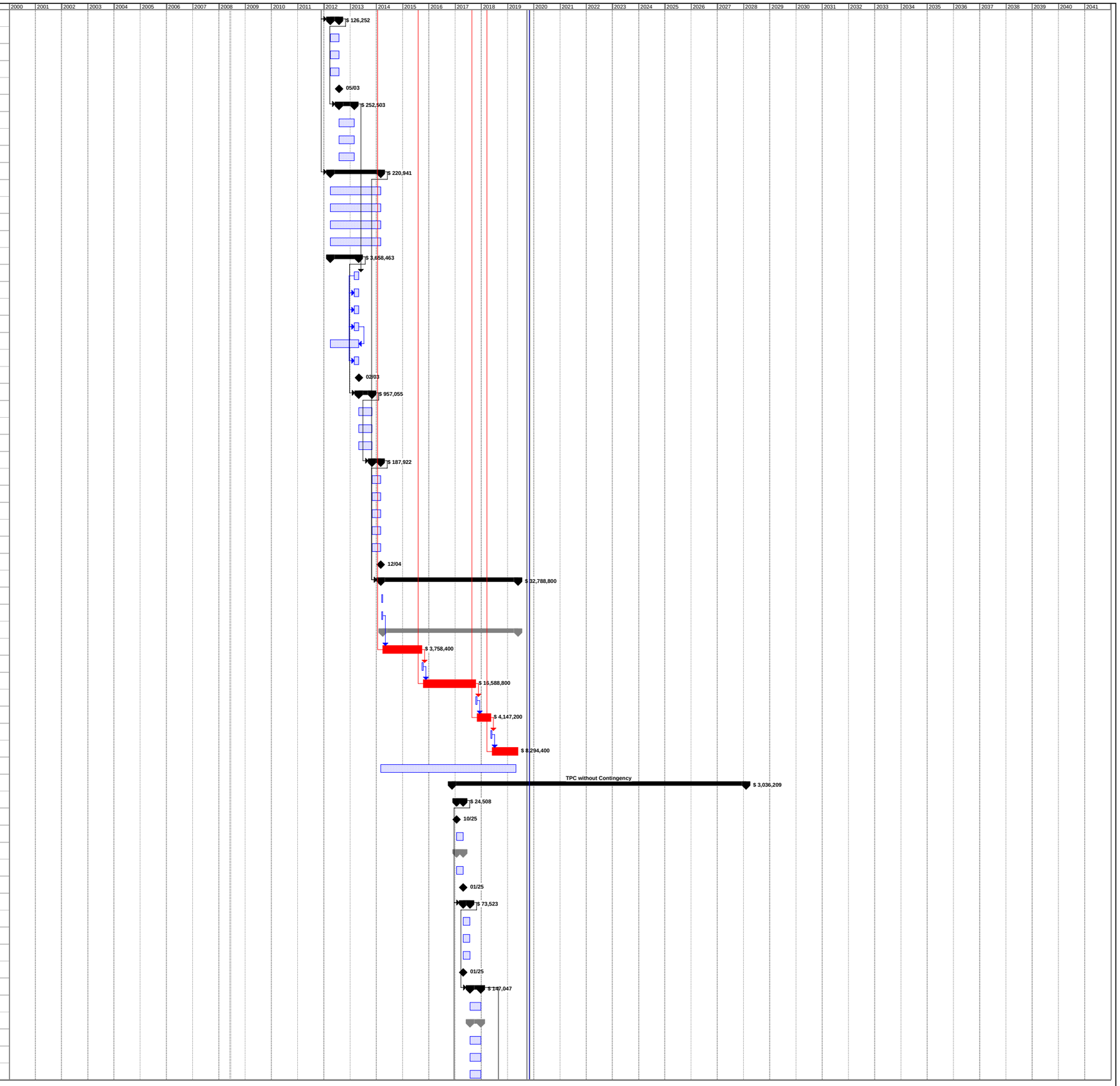
ID	Task Name	Start	Finish	Predecessors
505	**CQL Critical Decision**	Tue 13/10/01	Tue 14/09/30	
506	**TDL/Technology Development Loop 3**	**Mon 11/11/14**	**Tue 18/10/16**	
507	**A) Pre-Title I Activities**	**Thu 12/11/01**	**Fri 12/11/30**	
508	Conceptual Design and Relevant Activities	Thu 12/11/01	Fri 12/11/30	
509	Concept Refinement	Thu 12/11/01	Fri 12/11/30	
510	**Research and Development**	**Thu 12/11/01**	**Fri 12/11/30**	
511	Completion of UUT Detailed Test Specification	Thu 12/11/01	Fri 12/11/30	
512	**Approval to Commence Preliminary Design (TDL 3 Critical Decision 1)**	Fri 12/11/30	Fri 12/11/30	
513	**B) Title I Preliminary Design**	**Sat 12/12/01**	**Fri 12/12/28**	**507**
514	Preliminary Design Activities	Sat 12/12/01	Fri 12/12/28	
515	Supporting Activities	Sat 12/12/01	Fri 12/12/28	
516	Software Development/Code V&V	Sat 12/12/01	Fri 12/12/28	
517	**Approval to Commence Final / Detailed Design (TDL 3 Critical Decision 2)**	Mon 12/12/31	Wed 13/03/27	
518	**C) Title II Detail Design**	**Mon 12/12/31**	**Tue 13/01/29**	**513**
519	Detail Design and Relevant Activities	Mon 12/12/31	Tue 13/01/29	
520	Supporting Activities	Mon 12/12/31	Tue 13/01/29	
521	Software Development/Code V&V	Mon 12/12/31	Tue 13/01/29	
522	**D) Construction Supervision & QC**	**Sat 12/12/01**	**Sun 14/11/30**	**514SS**
523	Final budget proposal	Sat 12/12/01	Sun 14/11/30	
524	Approval	Sat 12/12/01	Sun 14/11/30	
525	Other Documentation	Sat 12/12/01	Sun 14/11/30	
526	Supporting Activities	Sat 12/12/01	Sun 14/11/30	
527	**E) Hardware Procurement**	**Mon 11/11/14**	**Thu 13/12/26**	
528	Final budget proposal	Wed 13/01/30	Thu 13/12/26	518
529	Approval	Wed 13/01/30	Thu 13/12/26	528SS
530	Other Documentation	Wed 13/01/30	Thu 13/12/26	529SS
531	Equipment procurement	Wed 13/01/30	Thu 13/12/26	530SS
532	Long lead items	Mon 11/11/14	Thu 13/12/26	531FF
533	Supporting Activities	Wed 13/01/30	Thu 13/12/26	531SS
534	**Approval to Commence Construction or Enter Full-Scale Development (TDL 3 Critical Decision 3)**	Mon 14/01/20	Mon 14/04/07	
535	**F) Construction**	**Fri 13/12/27**	**Fri 14/05/30**	**527**
536	Project Management	Fri 13/12/27	Fri 14/05/30	
537	Construction contracts	Fri 13/12/27	Fri 14/05/30	
538	Supporting Activities	Fri 13/12/27	Fri 14/05/30	
539	**G) Commissioning & Start-up**	**Mon 14/06/02**	**Sun 14/11/30**	**535**
540	General Activities	Mon 14/06/02	Sun 14/11/30	
541	Discipline Related Activities	Mon 14/06/02	Sun 14/11/30	
542	Supporting Activities	Mon 14/06/02	Sun 14/11/30	
543	Start-up Coordination, Material and Supplies	Mon 14/06/02	Sun 14/11/30	
544	Correction of Design/Construction Deficiencies	Mon 14/06/02	Sun 14/11/30	
545	**Approval to Commence Operation Testing (TDL 3 Critical Decision 4)**	Tue 14/12/23	Thu 16/08/04	
546	**H) Operation**	**Mon 14/12/01**	**Tue 18/10/16**	**522,539**
547	Pre Testing Activities	Mon 14/12/01	Mon 14/12/15	
548	Re-Engineering	Mon 14/12/01	Mon 14/12/15	
549	**Testing Activities (Per TDRM Test Spec)**	**Tue 14/12/16**	**Tue 18/10/16**	**548**
550	Piping: Performance&environmental testing: prototypical high-& low-temp piping/insulation system	Tue 14/12/16	Wed 16/12/14	
551	Re-Engineering/Re-configuration (Set-up Time)	Thu 16/12/15	Fri 16/12/30	550
552	Mixing Chamber: Enhanced Mixing Devices Test Specification	Mon 17/01/02	Fri 17/06/30	551
553	Re-Engineering/Re-configuration (Set-up Time)	Mon 17/07/03	Tue 17/07/18	552
554	Mixing Chamber: Vibration Damping Devices Test Specification	Wed 17/07/19	Wed 18/01/17	553
555	Re-Engineering/Re-configuration (Set-up Time)	Thu 18/01/18	Fri 18/02/02	554
556	Material: Elevated temperature testing in helium with no self-welding	Mon 18/02/05	Fri 18/06/01	555
557	Re-Engineering/Re-configuration (Set-up Time)	Mon 18/06/04	Tue 18/06/19	556
558	Lubricants: Testing of lubricants for high temperature helium environment	Wed 18/06/20	Tue 18/10/16	557
559	Software Development/Code V&V	Wed 14/12/24	Tue 18/10/16	
560	**CQL Critical Decision**	Tue 13/10/01	Tue 14/09/30	
561	**CTL/Circulator Test Loop**	**Thu 12/10/04**	**Thu 20/02/27**	
562	**A) Pre-Title I Activities**	**Thu 12/10/04**	**Tue 13/01/01**	
563	Conceptual Design and Relevant Activities	Thu 12/10/04	Thu 12/10/04	
564	Concept Refinement	Thu 12/10/04	Tue 13/01/01	
565	**Research and Development**	**Thu 12/10/04**	**Mon 12/12/31**	
566	Completion of UUT Detailed Test Specification	Thu 12/10/04	Mon 12/12/31	
567	**Approval to Commence Preliminary Design (CTL Critical Decision 1)**	Tue 13/01/01	Tue 13/01/01	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

ID	Task Name	Start	Finish	Predecessors
568	**B) Title I Preliminary Design**	**Tue 13/01/01**	**Wed 13/05/01**	**562**
569	Preliminary Design Activities	Tue 13/01/01	Wed 13/05/01	
570	Supporting Activities	Tue 13/01/01	Wed 13/05/01	
571	Software Development/Code V&V	Tue 13/01/01	Wed 13/05/01	
572	**Approval to Commence Final / Detailed Design (CTL Critical Decision 2)**	Fri 13/05/03	Fri 13/05/03	
573	**C) Detail Design**	**Thu 13/05/02**	**Sat 13/11/30**	**568**
574	Detail Design and Relevant Activities	Thu 13/05/02	Sat 13/11/30	
575	Supporting Activities	Thu 13/05/02	Sat 13/11/30	
576	Software Development/Code V&V	Thu 13/05/02	Sat 13/11/30	
577	**D) Construction Supervision & QC**	**Tue 13/01/01**	**Wed 14/12/03**	**568SS**
578	Final budget proposal	Tue 13/01/01	Wed 14/12/03	
579	Approval	Tue 13/01/01	Wed 14/12/03	
580	Other Documentation	Tue 13/01/01	Wed 14/12/03	
581	Supporting Activities	Tue 13/01/01	Wed 14/12/03	
582	**E) Hardware Procurement**	**Tue 13/01/01**	**Thu 14/01/30**	
583	Final budget proposal	Sun 13/12/01	Thu 14/01/30	573
584	Approval	Sun 13/12/01	Thu 14/01/30	583SS
585	Other Documentation	Sun 13/12/01	Thu 14/01/30	584SS
586	Equipment procurement	Sun 13/12/01	Thu 14/01/30	585SS
587	Lang Lead Items	Tue 13/01/01	Thu 14/01/30	586FF
588	Supporting Activities	Sun 13/12/01	Thu 14/01/30	586SS
589	**Approval to Commence Construction or Enter Full-Scale Development (CTL Critical Decision 3)**	Mon 14/02/03	Wed 15/04/15	
590	**F) Construction**	**Fri 14/01/31**	**Mon 14/08/04**	**582**
591	Project Management	Fri 14/01/31	Mon 14/08/04	
592	Construction contracts	Fri 14/01/31	Mon 14/08/04	
593	Supporting Activities	Fri 14/01/31	Mon 14/08/04	
594	**G) Commissioning & Start-up**	**Tue 14/08/05**	**Tue 14/12/02**	**590**
595	General Activities	Tue 14/08/05	Tue 14/12/02	
596	Discipline Related Activities	Tue 14/08/05	Tue 14/12/02	
597	Supporting Activities	Tue 14/08/05	Tue 14/12/02	
598	Start-up Coordination, Material and Supplies	Tue 14/08/05	Tue 14/12/02	
599	Correction of Design/Construction Deficiencies	Tue 14/08/05	Tue 14/12/02	
600	**Approval to Commence Operation Testing (CTL Critical Decision 4)**	Thu 14/12/04	Thu 17/08/17	
601	**H) Operation**	**Thu 14/12/04**	**Thu 20/02/27**	**577,594**
602	Pre Testing Activities	Wed 14/12/17	Wed 14/12/31	
603	Re-Engineering	Wed 14/12/17	Wed 14/12/31	
604	**Testing Activities (Per TDRM Test Spec)**	**Thu 15/01/01**	**Thu 20/02/27**	
605	Circulator: Partial or Full scale circulator Model Test Specification	Thu 15/01/01	Wed 16/06/29	603
606	Re-Engineering/Re-configuration (Set-up Time)	Thu 16/06/30	Mon 16/07/18	605
607	Piping: Performance and environmental testing	Tue 16/07/19	Wed 18/07/18	606
608	Re-Engineering/Re-configuration (Set-up Time)	Thu 18/07/19	Mon 18/08/06	607
609	Mixing Chamber: Vibration Damping Devices Test Specification	Tue 18/08/07	Tue 19/02/12	608
610	Re-Engineering/Re-configuration (Set-up Time)	Wed 19/02/13	Fri 19/03/01	609
611	Mixing Chamber: Partial or Full Scale Flow Mixing Chamber Model Test Specification	Mon 19/03/04	Thu 20/02/27	610
612	Software Development/Code V&V	Thu 14/12/04	Thu 20/01/30	
613	**CQL/Component Qualification Loop 1**	**Wed 17/08/23**	**Mon 28/11/06**	
614	**A) Pre-Title I Activities**	**Wed 17/10/25**	**Thu 18/01/25**	
615	Conceptual Design and Relevant Activities	Wed 17/10/25	Wed 17/10/25	
616	Concept Refinement	Wed 17/10/25	Thu 18/01/25	
617	**Research and Development**	**Wed 17/10/25**	**Thu 18/01/25**	
618	Completion of UUT Detailed Test Specification	Wed 17/10/25	Thu 18/01/25	
619	**Approval to Commence Preliminary Design (CQL 1 Critical Decision 1)**	Thu 18/01/25	Wed 25/03/05	
620	**B) Title I Preliminary Design**	**Thu 18/01/25**	**Mon 18/04/30**	**614**
621	Preliminary Design Activities	Thu 18/01/25	Fri 18/04/27	
622	Supporting Activities	Thu 18/01/25	Thu 18/04/26	
623	Software Development/Code V&V	Thu 18/01/25	Mon 18/04/30	
624	**Approval to Commence Final / Detailed Design (CQL 1 Critical Decision 2)**	Thu 18/01/25	Fri 18/04/27	
625	**C) Detail Design**	**Mon 18/04/30**	**Fri 18/09/28**	**620**
626	Detail Design and Relevant Activities	Mon 18/04/30	Fri 18/09/28	
627	**Supporting Activities**	**Mon 18/04/30**	**Fri 18/09/28**	
628	Project Management / Construction Management	Mon 18/04/30	Fri 18/09/28	
629	Documentation & Data Control	Mon 18/04/30	Fri 18/09/28	
630	Quality Control	Mon 18/04/30	Fri 18/09/28	



Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

ID	Task Name	Start	Finish	Predecessors
631	Software Development/Code V&V	Mon 18/04/30	Fri 18/09/28	
632	**D) Construction Supervision & QC**	**Thu 18/01/25**	**Thu 20/10/01**	**620SS**
633	Final budget proposal	Thu 18/01/25	Thu 20/10/01	
634	Approval	Thu 18/01/25	Thu 20/10/01	
635	Other Documentation	Thu 18/01/25	Thu 20/10/01	
636	Supporting Activities	Thu 18/01/25	Thu 20/10/01	
637	**E) Hardware Procurement**	**Wed 17/08/23**	**Fri 19/11/01**	
638	Final budget proposal	Fri 19/05/31	Fri 19/11/01	625
639	Approval	Fri 19/05/31	Fri 19/11/01	638SS
640	Other Documentation	Fri 19/05/31	Fri 19/11/01	639SS
641	Equipment procurement	Fri 19/05/31	Fri 19/11/01	640SS
642	Long lead items	Wed 17/08/23	Fri 19/11/01	641FF
643	Supporting Activities	Mon 19/06/03	Fri 19/11/01	641SS
644	**Approval to Commence Construction or Enter Full-Scale Development (CQL 1 Critical Decision 3)**	Fri 19/11/01	Mon 28/11/06	
645	**F) Construction**	**Mon 19/11/04**	**Tue 20/03/03**	**637**
646	Project Management	Mon 19/11/04	Tue 20/03/03	
647	Construction contracts	Mon 19/11/04	Tue 20/03/03	
648	**Supporting Activities**	**Mon 19/11/04**	**Tue 20/03/03**	
649	Project Management / Construction Management	Mon 19/11/04	Tue 20/03/03	
650	Construction management	Mon 19/11/04	Tue 20/03/03	
651	Documentation & Data Control	Mon 19/11/04	Tue 20/03/03	
652	Safety	Mon 19/11/04	Tue 20/03/03	
653	Environmental	Mon 19/11/04	Tue 20/03/03	
654	Quality Control	Mon 19/11/04	Tue 20/03/03	
655	**G) Commissioning & Start-up**	**Wed 20/03/04**	**Thu 20/07/02**	**645**
656	General Activities	Wed 20/03/04	Wed 20/07/01	
657	Discipline Related Activities	Wed 20/03/04	Wed 20/07/01	
658	**Supporting Activities**	**Wed 20/03/04**	**Wed 20/07/01**	
659	Project Management / Construction Management	Wed 20/03/04	Wed 20/07/01	
660	Construction management	Wed 20/03/04	Wed 20/07/01	
661	Documentation & Data Control	Wed 20/03/04	Wed 20/07/01	
662	Safety	Wed 20/03/04	Wed 20/07/01	
663	Environmental	Wed 20/03/04	Wed 20/07/01	
664	Quality Control	Wed 20/03/04	Wed 20/07/01	
665	Reviews	Wed 20/03/04	Wed 20/07/01	
666	Start-up Coordination, Material and Supplies	Wed 20/03/04	Wed 20/07/01	
667	Correction of Design/Construction Deficiencies	Wed 20/03/04	Thu 20/07/02	
668	**Approval to Commence Operation Testing (CQL 1 Critical Decision 4)**	Wed 20/07/01	Wed 20/07/01	
669	**H) Operation**	**Fri 20/10/02**	**Mon 28/10/23**	**632,655,496**
670	Pre Testing Activities	Fri 20/10/02	Mon 20/10/12	
671	Re-Engineering	Fri 20/10/02	Mon 20/10/12	
672	**Testing Activities (Per TDRM Test Spec)**	**Tue 20/10/13**	**Mon 28/10/23**	
673	Steam Generator: Performance testing of prototypical steam generator	Tue 20/10/13	Tue 24/10/08	671
674	Re-Engineering/Re-configuration (Set-up Time)	Wed 24/10/09	Thu 24/10/24	673
675	H2SO4 Decomposition Reactor Testing: Performance testing of H2SO4 proto-typical Decomposition reactor	Fri 24/10/25	Mon 28/10/23	674
676	Software Development/Code V&V	Fri 20/10/02	Thu 28/10/12	
677	**CQL/Component Qualification Loop 2**	**Mon 14/02/03**	**Wed 24/02/07**	
678	Pre-Concept Study	Mon 14/02/03	Mon 15/02/02	
679	Concept Design Baseline	Tue 15/02/03	Tue 15/02/03	
680	R&D Concept Refinement	Tue 15/02/03	Mon 15/08/03	678
681	Basic Design Baseline	Tue 15/08/04	Tue 15/08/04	
682	Preliminary Design	Tue 15/08/04	Sun 16/07/31	680
683	Detail Design Baseline	Mon 16/08/01	Mon 16/08/01	
684	Detail Design	Mon 16/08/01	Mon 17/07/31	682
685	Manufacturing Baseline	Tue 17/08/01	Thu 20/02/06	
686	Procurement, Plant Construction, Supervision and QC	Tue 17/08/01	Mon 19/06/10	684
687	Commissioning and Startup	Tue 19/06/11	Tue 20/06/30	686
688	Operational Baseline	Wed 20/07/01	Wed 20/07/01	
689	Plant Operation	Wed 20/07/01	Wed 24/02/07	496
690	**NGNP Original Start-up date**	Fri 21/10/01	Fri 21/10/01	
691	**Proposed NGNP Start-up Date**	Thu 39/11/03	Thu 39/11/03	

Project: Integrated Schedule_950_ove
Date: Fri 09/02/27

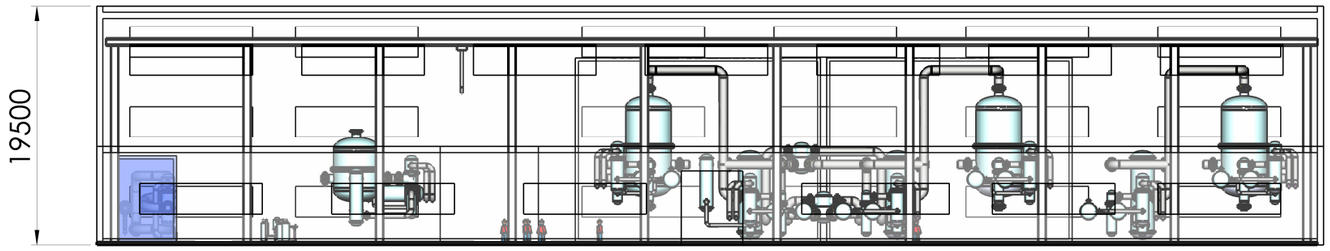
Task | Split | Progress | Milestone | Summary | Sub Heading | External Tasks | External Milestone | Deadline

Appendix B

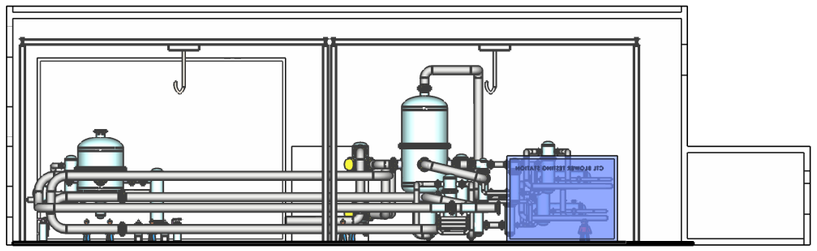
3D System Layout for the 950 °C NGNP ROT-based Tests (Very Aggressive Option)

Information contained in this drawing is the sole property of M-Tech Industrial (Pty) Ltd and reproduction in part or whole without the written permission from M-Tech Industrial (Pty) Ltd is prohibited.

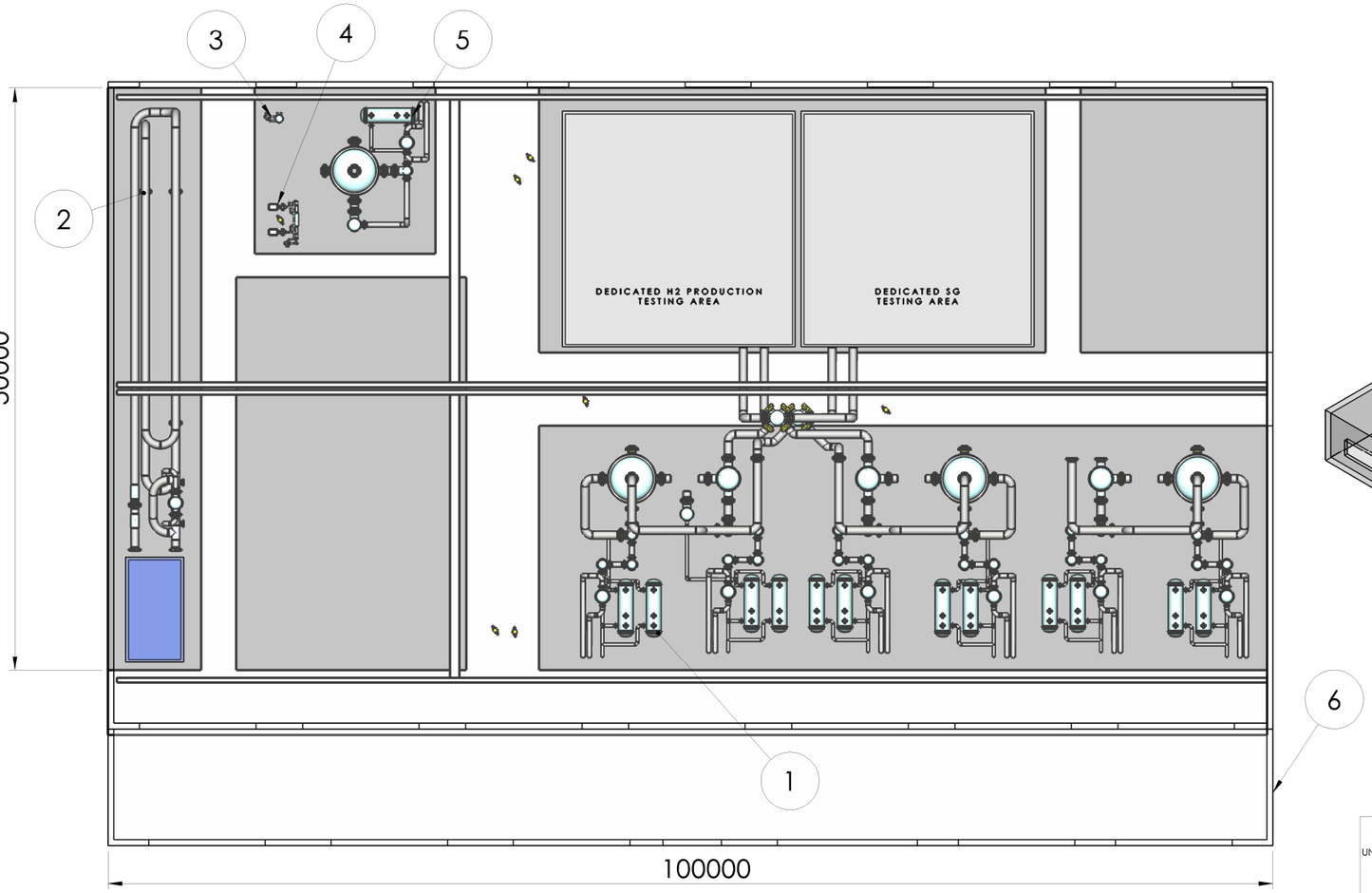
ITEM NO.	DESCRIPTION	QTY.
1	3 TDL's and the CQL	1
2	The CTL Layout	1
3	SSDT 1	1
4	SSDT 2	1
5	SSDT 3	1
6	Building	1



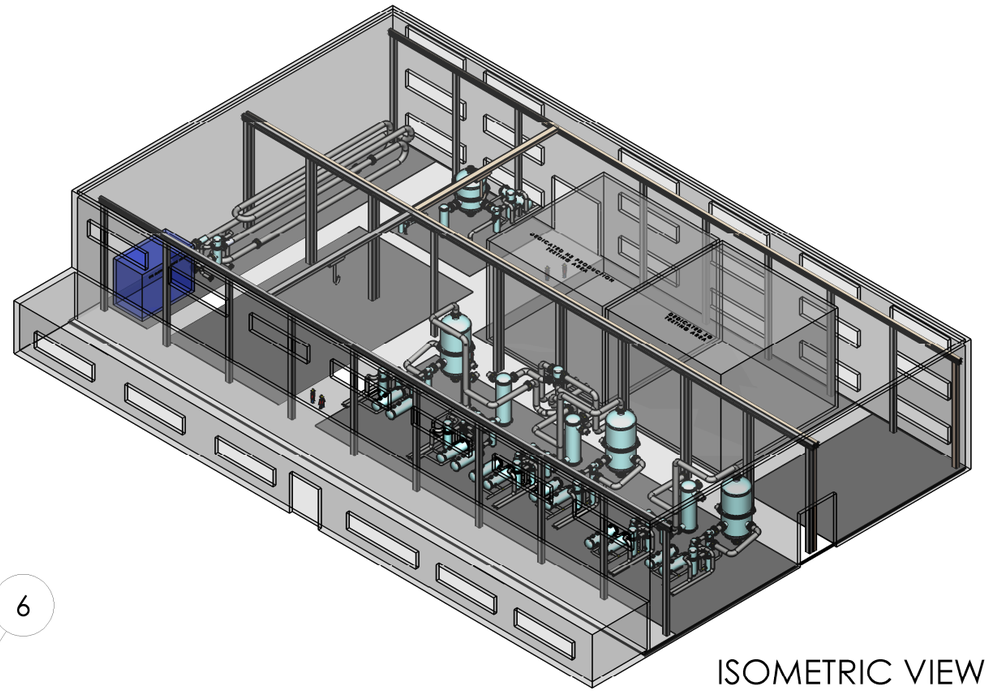
FRONT VIEW



SIDE VIEW



TOP VIEW



ISOMETRIC VIEW

MACHINING TOLERANCE: ±0.1 mm UNLESS INDICATED OTHERWISE

REMOVE SHARP EDGES AND BURRS: 0.3 - 0.5 mm

UNLESS OTHERWISE INDICATED, DIMENSIONS ARE IN MILLIMETERS. CAD GENERATED. DO NOT MANUALLY UPDATE. DO NOT SCALE. DRAWINGS TO SABS 0111.

	5)	
	4)	
	3)	
	2)	
First Release	1)	
Design History:		Source Document(s):

M-TECH INDUSTRIAL (PTY)LTD

5 LUKE STREET
POTCHEFSTROOM
SOUTH AFRICA

PO BOX 19855
NOORDBRUG, 2522
SOUTH AFRICA

Paper size: A3
Date: 2/25/2009
Drawn: MLP
Checked: RdB
Resp. Eng: JAH
Manuf. Eng:
Original Signed Copy at DDCC

Material: N / A

Scale:	Sheet:	Rev:	Qty Reqd:
NTS	1 of 1	1	N/A

CAD file: TLDR-SS-01-0001_Rev1.slddrw

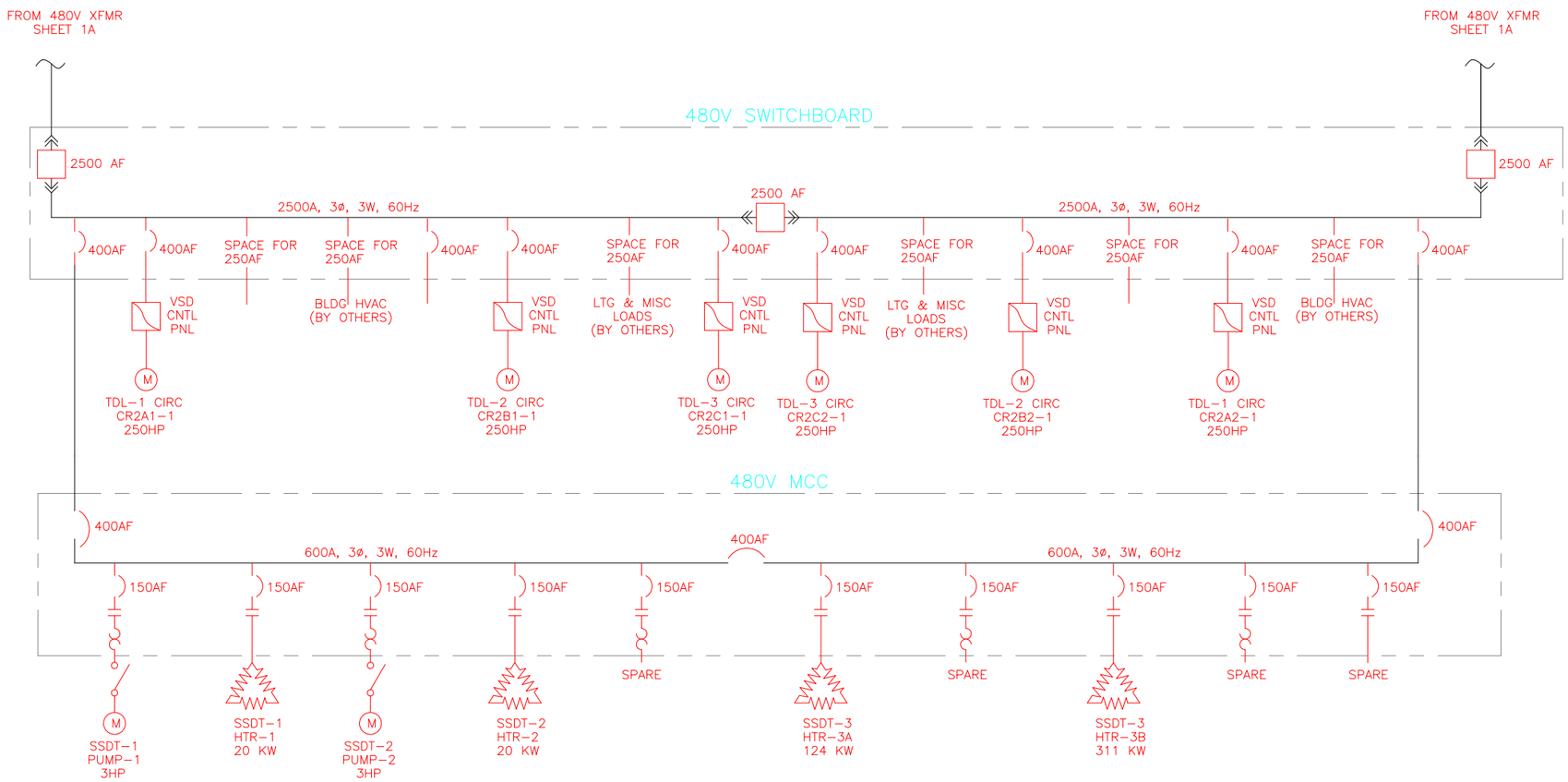
Description:

Integrated system layout 950 C

Drawing Number: TLDR-SS-01-0001

Appendix C

Electrical one-line drawings
(Very Aggressive Option)



NOTES:

1. FOR NOTES AND LEGEND SEE DWG NGNP-CTF-E-WIR-001-1A

NO	DATE	ISSUE DESCRIPTION	BY	CHKD	DISCP	APPR
X						

CLIENT

BATELLE ENERGY ALLIANCE
NGNP WITH HYDROGEN PRODUCTION
IDAHO NATIONAL LABORATORY

TITLE

COMPONENT TEST FACILITY (CTF)
ONE -LINE DIAGRAM - 950 ALTERNATE

Shaw Environmental, Inc.

DESIGNED BY | DRAWN BY | CHECKED BY
RESP. ENGR. | CERT. FOR CONST.

SCALE	CLIENT JOB NUMBER	DATE
		02/24/2009

J.O. NUMBER	DRAWING NUMBER	REV NO
133725	NGNP-CTF-E-WIR-001-2A	A

DRAWING NUMBER NGNP-CTF-E-WIR-001-2 REV NUMBER A

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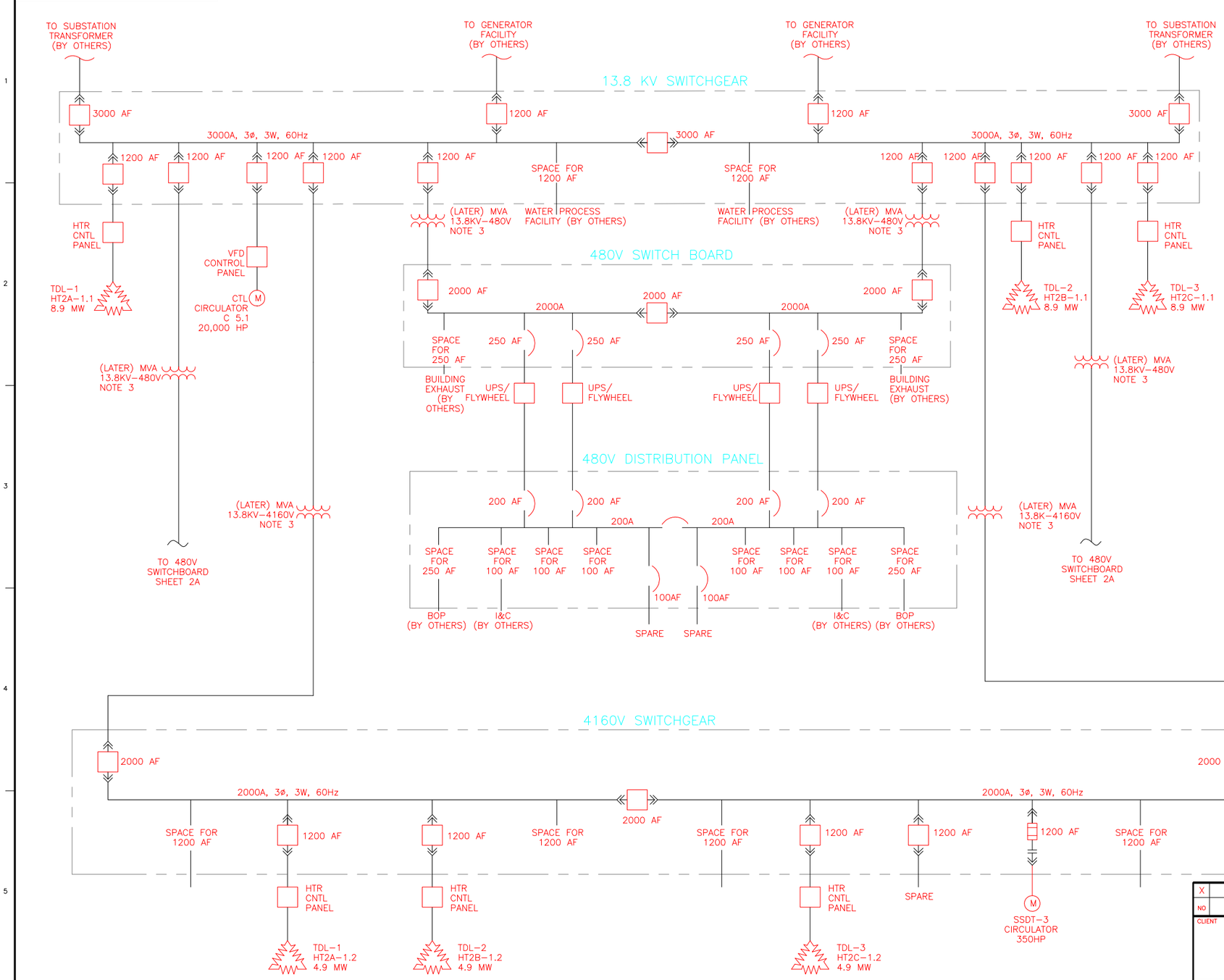

SYMBOLS & ABBREVIATIONS

- 200 AF — POWER CIRCUIT BREAKER–DRAWOUT TYPE 1200 AMPERE FRAME
- 100 AF — MOLDED CASE CIRCUIT BREAKER 100 AMPERE FRAME
- HEATER
- TWO WINDING TRANSFORMER
- M — MOTOR
- DISCONNECT SWITCH
- COMBINATION MOTOR STARTER
- VARIABLE SPEED DRIVE CONTROL PANEL

BLDG	– BUILDING
BOP	– BALANCE OF PLANT
CIR	– CIRCULATOR
CNTL	– CONTROL
CTL	– COMPONENT TEST LOOP
HTR	– HEATER
HVAC	– HEATING, VENTILATION & AIR CONDITIONING
I&C	– INSTRUMENTATION & CONTROL
KW	– KILOWATT
MCC	– MOTOR CONTROL CENTER
MW	– MEGAWATT
RECEPT	– RECEPTICLE
SSDT	– SMALL SCALE DEVELOPMENT TEST MODULE
TDL	– TECHNOLOGY DEVELOPMENT LOOP
VSD	– VARIABLE SPEED DRIVE

NOTES:

1. THE NUMBER OF TDL'S IS STILL UNDER CONSIDERATION & MAY CHANGE. FINAL NUMBER WILL BE REFLECTED IN THE INTEGRATED TEST SCHEDULE.
2. THE NUMBER OF SSDT HEATERS & SSDT PUMPS ARE STILL UNDER CONSIDERATION & MAY CHANGE. FINAL NUMBER WILL BE REFLECTED IN THE INTEGRATED TEST SCHEDULE.
3. TRANSFORMER SIZE TO BE DETERMINED LATER.

NO	DATE	ISSUE DESCRIPTION	BY	CHKD	DISCP	APPR
X						

CLIENT

BATELLE ENERGY ALLIANCE
NGNP WITH HYDROGEN PRODUCTION
IDAHO NATIONAL LABORATORY

TITLE

COMPONENT TEST FACILITY (CTF) ONE -LINE DIAGRAM

Shaw Environmental, Inc.

DESIGNED BY | DRAWN BY | CHECKED BY
RESP. ENGR. | CERT. FOR CONST.

SCALE	CLIENT JOB NUMBER	DATE
		02/24/2009

J.O. NUMBER	DRAWING NUMBER	REV NO
133725	NGNP-CTF-E-WIR-001-1	A

DRAWING NUMBER NGNP-CTF-E-WIR-001-1 REV NUMBER A

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Appendix D

Typical content of a Test Procedure Template

Typical content of a Test Procedure Template

Plant Safety (Pre Start-up)

- Confirm completion of maintenance, experimental set-up or both.
- Confirm evacuation of all personnel.
- Plant Inspection; confirm plant to be safe for operation.
- Complete the plant checks (all instrumentation are calibrated and records filed; maintenance performed on all equipment (e.g. oil, water and lubrication on running motors, cooling water adequately treated with anti-foam or other relevant chemicals to prevent corrosion). Register that plant is safely handed over from maintenance personnel to operators.
- Ensure availability of utilities and resources (water, electricity, gas, emergency cooling water, human resources).
- The Senior Engineer or the Project manager is to confirm that the plant is safe for operation.
- Follow procedures that indicate to personnel that the plant will soon be in operation or that the plant is in operation.

Start-up

- Conduct a pre-test check where all valves are switched to their proper positions, water levels checked and excess air is removed from the system. Check that the system is pressurized or depressurized. Check that instrumentation is zeroed or reset if applicable.
- Confirm which system(s) will be needed, depending on the test and ensure their readiness or availability.
- Switch on the auxiliary systems.
- Ensure that there is access control to the plant. (Safely restrict access to the electricity distribution board, boxes and cables, gas inventory, cooling water and running motors).
- Confirm that the plant is in “Standby mode”, i.e. that the plant is purged and that the valves are in correct positions.
- Confirm that the plant I&C is in “Standby mode”.
- Confirm the availability of auxiliary systems (HVAC, HICS and Cooling Water) and that they are in “Standby mode”.
- Confirm that the Client’s instrumentation is installed correctly and in “Standby mode”.
- Follow the plant specific start-up procedure i.e. pressurization, circulation start-up and heating start-up.

Testing and Data Capture

- Confirm that the plant has reached the stipulated test requirement conditions i.e. temperature, pressure, mass flow and others as per Client request.
- Confirm that the Client’s instrumentation is “active” and that it is logging measured data.

- Start testing. Control the plant (via operators) to give the desired conditions as per test requirement(s).
- Confirm the Client's data quality.
- End testing.
- Confirm that the Client's data is saved and stored.
- Fill in the checklist confirming the test and safely store all data.

Shut Down

- Follow the plant-specific shut-down procedure i.e. stop the heater, stop circulation and depressurization.
- Shut down auxiliary systems. Select standby mode or complete shut-down depending on circumstances.
- Confirm that the plant has been depressurized and cooled down to ambient temperatures.
- Shut down the plant I&C. Select standby mode or complete shut-down depending on circumstances.
- Follow procedures that indicate to personnel that the plant is not in operation and that maintenance or experimental set-up procedures may be initiated.
- Safely store the plant for short-term or hand the plant over to the maintenance personnel. The Senior Engineer or the Project Manager is to confirm the storage or hand-over of the plant.

Appendix E

Description of the cost breakdown

Description of the cost breakdown

Table 10-17: General form of Test Loop Cost Breakdown with cost factors

		Pre-Title I	Title I	Title II	Title III					30%		
		R&D, Concept refinement	Preliminary Design	Detail Design	Procurement	Plant Construction	Supervision and Quality Control	Commissioning and Startup	Subtotal	Contingency	Total	
		0.28 ED&I			Title III = 0.49 ED&I							
Mtech factors	Indirect Cost	0.1 A&E	0.3 A&E	0.6 A&E	0.2 Title III	0.5 Title III	0.3 Title III	0.23 ED&I				
for large loops	Direct Cost				DEC	Const = 0.2TDC						
					Direct Equipment Cost							
					ED&I = 0.43 Total Direct Cost							Indirect and Direct Cost Ratios
Mtech recommended factors for large loops	Indirect Cost	0.034	0.101	0.202	0.118	0.294	0.176	0.150	1.074	0.322	1.396	0.278 IDC/Total
	Direct Cost				**2.32**	0.470			2.790	0.837	3.627	0.722 DC/Total
									3.864	**TOTAL:**	**5.023**	
Mtech recommended factors for small test loops (SSDTs)	Indirect Cost	0.202	0.464	0.705	0.118	0.588	0.300	0.255	2.631	0.789	3.420	0.485 IDC/Total
	Direct Cost				**2.32**	0.470			2.790	0.837	3.627	0.515 DC/Total
									5.421	**TOTAL:**	**7.047**	

Direct Equipment Cost:	
Purchased equipment	**1.00**
Electrical	0.11
Transport	0.05
I&C	0.18
Buildings, Yard, Utilities	0.98
Total:	**2.32**

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The total Engineering, Design and Inspection costs (ED&I) is taken as equal to the total Indirect Cost for this project, while the Direct Cost is taken as that amount paid out to contractors during construction and for acquiring and installing all plant equipment.

From the IChemE "Blue Book" method, the Direct Equipment Cost is given in relative values as:

Purchased equipment	1.00
(Pressure vessels, coolers, compressors)	
Transport	0.05
Electrical equipment	0.11
Instrumentation and Control	0.18
Buildings, Yard, Utilities	0.98
	TOTAL 2.32

The above values are relative to the Purchased Equipment Cost.

For Instrumentation and Control, a quotation was obtained for the cost of the SCADA, PLC and all I/O modules. For the average cost of an instrument and its wiring and cable racks up to the I/O module, a value of R 27 638 was multiplied by the number of tags. Therefore, the factor for Instrumentation and Control was not used. Furthermore, the philosophy for the CTF is to have redundant, self-diagnosing instruments, which require many more instruments than is usually encountered on the process plants for which the IChemE factors were derived.

The value of R 27 638 was taken from the CTF Feasibility study and escalated according to the most recent CEPCI index for Process Instruments. Details of the calculation are in the System Integration Costing Spreadsheet.

The electrical cost was calculated with the abovementioned factor of 0.11.

For transport, a factor between 0.02 and 0.05 of Purchased Equipment cost was recommended by Uppal (1997) [10-12]. For overseas transport, this figure is typically between 0.05 and 0.1. A value of 0.05 is used as it is assumed that the plant components are manufactured in the country where the plant is located.

The IChemE gave the Direct Construction cost as 0.47 of the Purchased Equipment cost which results in a Direct Equipment Cost of 2.79 in relative terms.

In previous projects, ED&I cost was found to be 0.43 of the Direct Cost, i.e. 1.20 in relative terms to Direct Equipment Cost.

The total cost of the design phases has been found to be 0.28 of the ED&I cost, i.e. 0.33 in relative terms to Direct Equipment Cost. From previous experience, the ratios between Concept, Preliminary and Detail design are known as 1, 3 and 6, i.e. the following factors are calculated for these phases, relative to the Purchased Equipment Cost:

Concept:	0.1 x 0.33 = 0.033
Preliminary:	0.3 x 0.33 = 0.099
Detail:	0.6 x 0.33 = 0.198

Indirect costs for Title III (i.e. Procurement man-hours, Quality Assurance, Supervision and assistance with Plant Construction) are taken as 0.49 of ED&I costs (which is 0.588 in relative terms to Direct Equipment Cost. This is divided as follows:

Title III: Procurement	0.20 x 0.588 = 0.118
Title III: Plant Construction	0.50 x 0.588 = 0.294
Title III: Supervision and Quality Control	0.30 x 0.588 = 0.176

The distribution of these costs does not affect the total amount or scheduling. Therefore the above distribution of 20/50/30 was assumed.

For startup and commissioning, the DOE guideline DOE G 430.1-1 recommends a value between 0.5 and 10 percent of purchased equipment cost. This value is assumed to be for plants built with proven existing technology. From experience with other experimental facilities, this value is known to be higher, as most of the unforeseen technical difficulties arise during startup and commissioning. Therefore, a value of 15 percent is assumed.

10.1.1 Contingency

The Department of Energy Cost Estimating Guide (DOE G 430.1-1, 1997 edition, Chapter 11, Table 11-1) recommends a contingency of up to 40 percent for Experimental or Special Conditions at Budget Phase. Because of an amount of previous experience with

experimental type plants with high temperature and high pressure, a contingency of 30 percent of total cost is used for the CTF.

10.1.2 Conversion between currencies

Based on the three-month exchange rate history for the South African Rand and the United States Dollar, as shown in Figure 10-24, the use of an average value of R10/US$ is considered reasonable. Note that the value of R10/US$ will be modified according to the Purchasing Power Parity values described in the following paragraph.

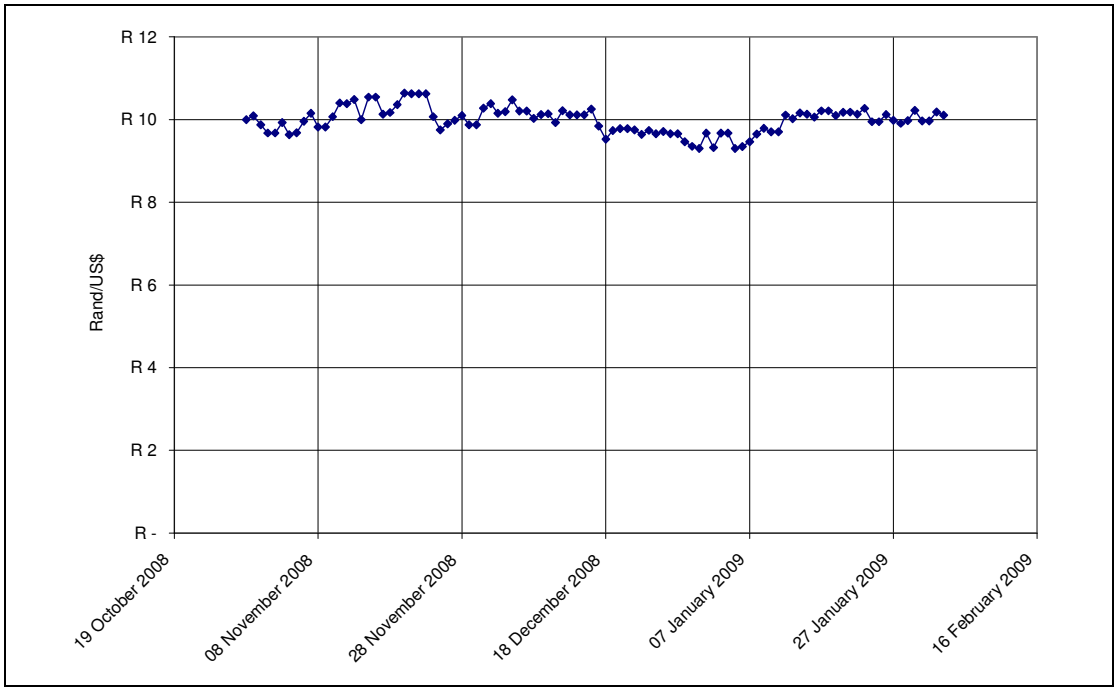

Figure 10-24: Three-month ZAR/USD exchange rate history at the time of writing.

The data shown in Figure 10-24 was obtained from the following source:
http://www.exchange-rates.org/history/ZAR/USD/T

10.1.3 Conversion of cost from South Africa to the USA

For converting South African quotations to expected cost in the USA, Purchasing Power Parity values are used. Purchase Power Parity is defined as the actual number of dollars (converted to local currency) required to buy the same as in the US. Therefore, Purchasing Power Parity values are dependent on the type of product or the sector of the economy.

At the time of writing, the best data that was readily available was from a 2005 survey by the World Bank, available on their website (http://ddp-ext.worldbank.org).

Table 10-18: Purchase Power Parity values for 2005, with the ratios that will be used in this report.

Product/Sector description	Exchange rate at time of survey [ZAR/USD]	Purchase Power Parity [ZAR/USD]	Ratio: Actual exchange/PPP
Housing, water, electricity, gas and other fuels	6.36	2.89	2.201
Transport	6.36	6.69	0.951
Construction	6.36	4.08	1.559
Machinery and equipment	6.36	6.09	1.044

It is assumed that the ratio between Purchase Power Parity and the exchange rate is still valid, due to the lack of better information. As the EFE method is based on the equipment cost quotations obtained in South Africa, only the equipment cost quotation values have to be converted to US values. As most of the quotations fall in the Product or Sector of "Machinery and equipment", all South African costs have to be multiplied with 1.044, which is rounded up to 1.05.

In the calculations, it will be implemented by dividing the exchange rate of R10/US$ by 1.05. Thus, the South Africa/USA cost conversion will be done by using an "effective exchange rate".

10.1.4 Escalation

The Chemical Engineering Plant Costing Index (CEPCI) [www.che.com] was used wherever escalation was required. The CEPCI is issued once a month and their database is available online. The CEPCI overall plant escalation factor is broken down into several categories of equipment and services required on a chemical plant, such as Process Machinery, Electrical Equipment, Construction Labor, etc. The index from 1998 up to September 2008 is given in Table 10-19.

Cost indexes have limitations, of which some are as follows:

- Accuracy is very limited. Two indexes may yield much different answers.
- Cost indexes are based on averages. Specific cases may be much different from the average.
- At best, 10 percent accuracy can be expected for periods up to 5 years.
- For periods over 10 years, indexes are suitable only for order of magnitude estimates.

Table 10-19: Chemical Engineering Plant Cost Index data from 1998 to September 2008.

	CE INDEX	Equipment	Heat Exchanges and Tanks	Process Machinery	Pipe, valves and fittings	Process Instruments	Pumps and Compressions	Electrical equipment	Structural supports	Construction Labor	Buildings	Engineering Supervision
1998	389.5	436	382.8	430.8	534.8	365.3	648.5	333.6	394.3	287.4	374.2	341.2
1999	390.6	435.5	371.2	433.6	531.6	363.5	658.4	335.8	413.1	292.5	380.2	339.9
2000	394.1	438	370.6	439.4	545.9	368.5	665.3	339.4	408.7	299.2	385.6	340.6
2001	394.3	437.3	363.9	439.5	548.1	362.9	683.2	341.2	413.9	302.3	385.6	341.5
2002	395.6	437.5	356.9	444.2	555.8	363.5	699.2	341.4	415.4	305.8	390.4	345.3
2003	402	445.1	363.6	450.3	570.7	363.4	705.4	341.6	428.6	309.3	400.6	347.3
2004	444.2	508.1	464.8	491.0	600.6	374.3	719.4	351.0	537.5	307.8	428.6	345.2
2005	468.2	543.7	513.9	519.7	623.7	381.8	752.5	372.1	584.8	305.6	445.1	346.8
2006	499.6	588	548	549.7	708	420.1	785.7	403.1	625.3	309.3	468.6	350.9
2007	525.4	624.4	592.1	598.3	733.6	425.2	831.2	430.5	662.6	315.1	476.8	357
Dec-07	525	623.3	593.6	597.9	727.2	414.4	840	436.3	660.8	317	477	356.2
Jan-08	530.7	632.7	602	609.3	743.8	413.3	854.3	442.2	669.1	314.3	478.9	355.1
Feb-08	539.8	645.8	618.4	610.3	768.2	420.2	850.5	445.3	684.6	316.2	483	354.5
Mar-08	549.2	659.5	631.5	616.4	795.7	431	857.6	452.2	694.7	317.1	486.8	354.9
Apr-08	560.9	676.7	660	628	804.7	437.7	860.2	451.6	720.4	317.8	492.4	354.3
May-08	583.9	710.3	712.4	644.3	835.6	445.6	862.1	453.8	770.6	319.7	504.8	353.7
Jun-08	597.1	729.7	738.2	658.7	858.8	452.8	865.9	459	793.1	319.4	515.3	353.9
Jul-08	608.8	746.4	760.1	669.5	875.5	459	869.9	468.2	815.8	322.1	521.5	352.9
Aug-08	619.3	761	784.2	680.7	881.5	457.8	872.9	468.1	843.9	325.3	529.8	352.3
Sep-08	608.9	744.4	758.4	674.3	865.6	446.8	886.3	468.5	817.8	328.2	529.9	351.7

Table 10-20: Cost Breakdown Summary per Test Loop

Test Loop		Pre-Title I	Title I	Title II	Title III					30%			
		R&D, Concept refinement	Preliminary Design	Detail Design	Procurement	Plant Construction	Supervision and Quality Control	Commissioning and Start-up	Subtotal	Contingency	Totals: Indirect, Direct Cost		Operating cost per hour
SSDT1:	IDC	$ 41,700	$ 95,909	$ 145,948	$ 24,325	$ 121,624	$ 62,028	$ 52,758	$ 544,291	$ 163,287	$ 707,579	IDC	$ 290
Creep&static	DC		All equipment,utilities,land:		$ 758,116	$ 97,240			$ 855,357	$ 256,607	$ 1,111,964	DC	
			Purchased equipment cost		$ 206,895	74%	Confidence level in purchased equipment cost			Total SSDT1:	$ 1,819,543		
SSDT2:	IDC	$ 44,419	$ 102,163	$ 155,466	$ 25,911	$ 129,555	$ 66,073	$ 56,199	$ 579,786	$ 173,936	$ 753,721	IDC	$ -
IHX Fatigue	DC		All equipment,utilities,land:		$ 767,918	$ 103,582			$ 871,501	$ 261,450	$ 1,132,951	DC	
			Purchased equipment cost		$ 220,387	65%	Confidence level in purchased equipment cost			Total SSDT2:	$ 1,886,672		
SSDT3	IDC	$ 212,195	$ 488,048	$ 742,681	$ 123,780	$ 618,901	$ 315,640	$ 268,468	$ 2,769,713	$ 830,914	$ 3,600,626	IDC	$ -
IHX Heat transfer	DC		All equipment,utilities,land:		$ 2,933,691	$ 494,824			$ 3,428,515	$ 1,028,555	$ 4,457,070	DC	
			Purchased equipment cost		$ 1,052,816	72%	Confidence level in purchased equipment cost			Total SSDT3:	$ 8,057,696		
TDL	IDC	$ 252,148	$ 756,443	$ 1,512,886	$ 882,517	$ 2,206,293	$ 1,323,776	$ 1,125,941	$ 8,060,004	$ 2,418,001	$ 10,478,005	IDC	$ 800
	DC		All equipment,utilities,land:		$ 17,591,548	$ 3,527,949			$ 21,119,497	$ 6,335,849	$ 27,455,346	DC	
			Purchased equipment cost		$ 7,506,273	84%	Confidence level in purchased equipment cost			Total TDL:	$ 37,933,351		
CQL 1	IDC	$ 24,508	$ 73,523	$ 147,047	$ 85,777	$ 214,443	$ 128,666	$ 109,437	$ 783,400	$ 235,020	$ 1,018,421	IDC	$ 1,330
	DC		All equipment,utilities,land:		$ 1,909,906	$ 342,903			$ 2,252,810	$ 675,843	$ 2,928,652	DC	
			Purchased equipment cost		$ 729,580	78%	Confidence level in purchased equipment cost			Total CQL1:	$ 3,947,073		
CQL 2	IDC	$ 3,018,750	$ 7,434,000	$ 11,481,750	$ 2,919,000	$ 441,000	$ 9,298,800	$ 8,491,953	$ 43,085,253	$ 12,925,576	$ 56,010,828	IDC	$ -
	DC		All equipment,utilities,land:		$ 146,061,585	$ 26,612,250			$ 172,673,835	$ 51,802,151	$ 224,475,986	DC	
			Purchased equipment cost		$ 39,696,300	0%	Confidence level in purchased equipment cost			Total CQL2:	$ 280,486,814		
CTL	IDC	$ 42,084	$ 126,252	$ 252,503	$ 147,294	$ 368,234	$ 220,940	$ 187,922	$ 1,345,229	$ 403,569	$ 1,748,797	IDC	$ 1,110
	DC		All equipment,utilities,land:		$ 3,511,170	$ 588,821			$ 4,099,991	$ 1,229,997	$ 5,329,988	DC	
			Purchased equipment cost		$ 1,252,810	90%	Confidence level in purchased equipment cost			Total CTL:	$ 7,078,786		

Appendix F

Graphs of System Integration Schedules illustrated for 750 °C NGNP ROT-based tests, assuming all tests except IHX A tests and Mixing Chamber tests as per the 950 °C NGNP ROT Schedule.

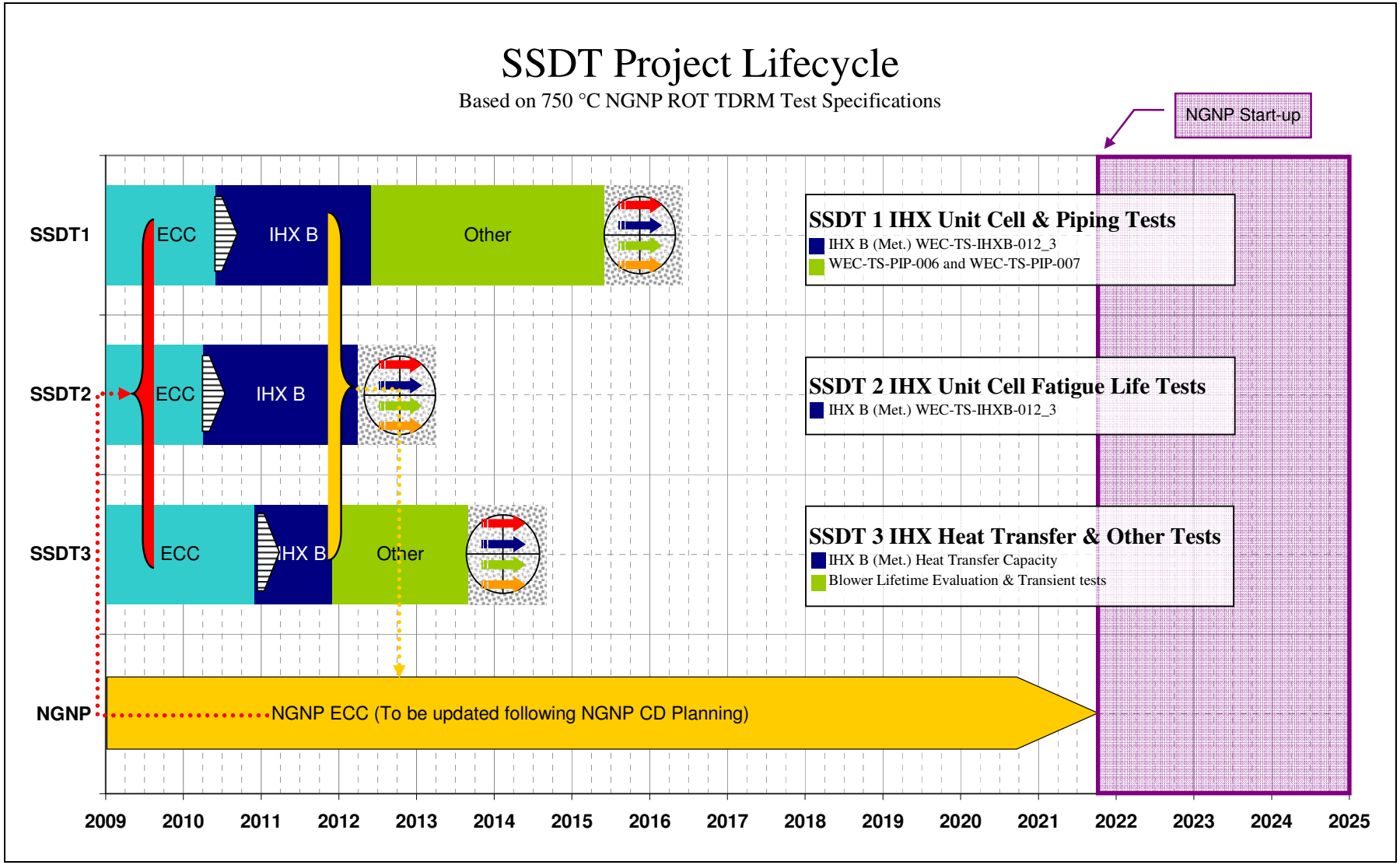

Figure 10-25: ECC and Test durations of the three different SSDTs for the 750 °C NGNP ROT Development Path.

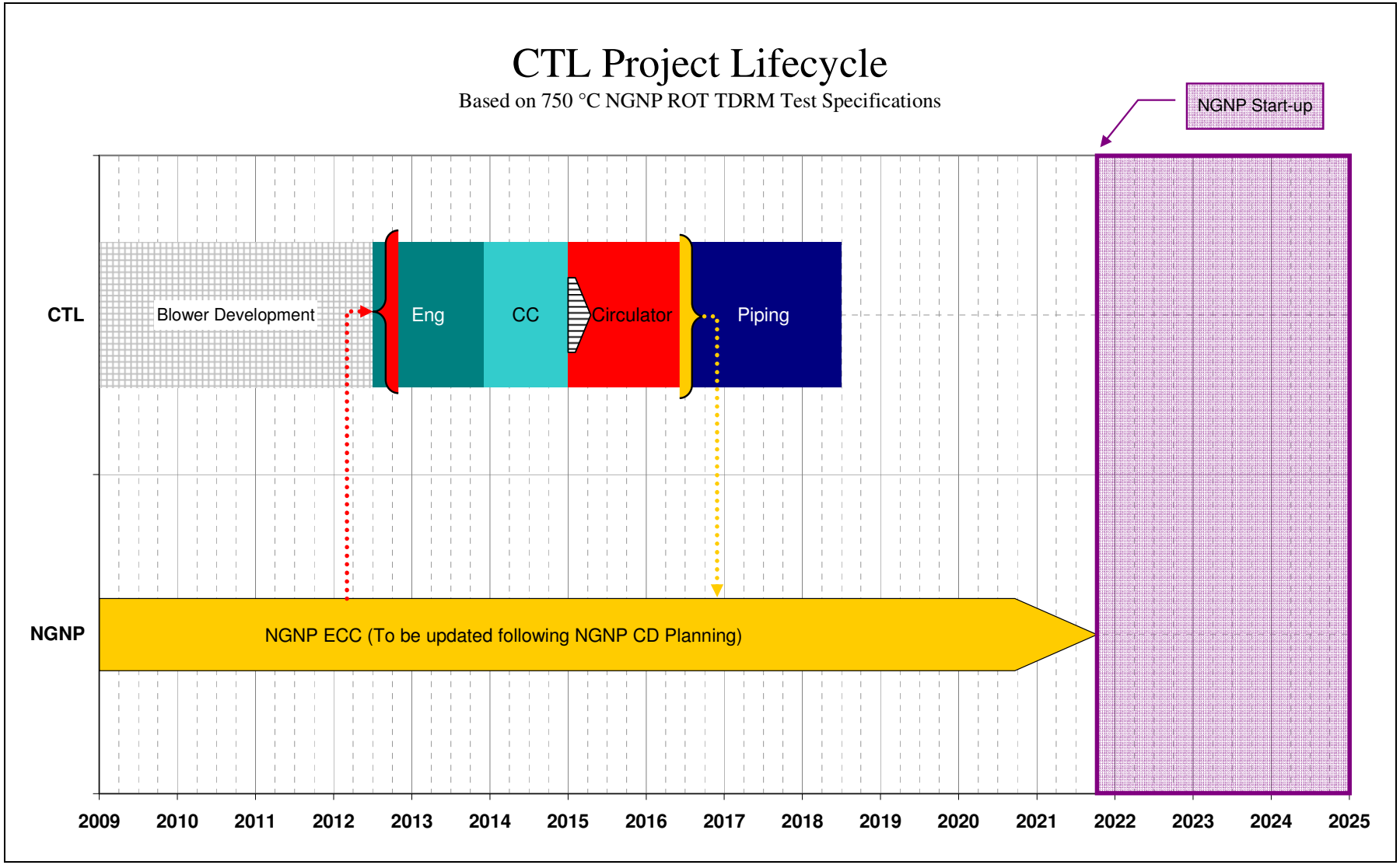

Figure 10-26: ECC and Test duration of one CTL for the 750 °C NGNP ROT Development Path.

[A-2]Moderate Approach for the Integrated CTF utilizing one TDL for a 750 °C NGNP ROT Development Path.

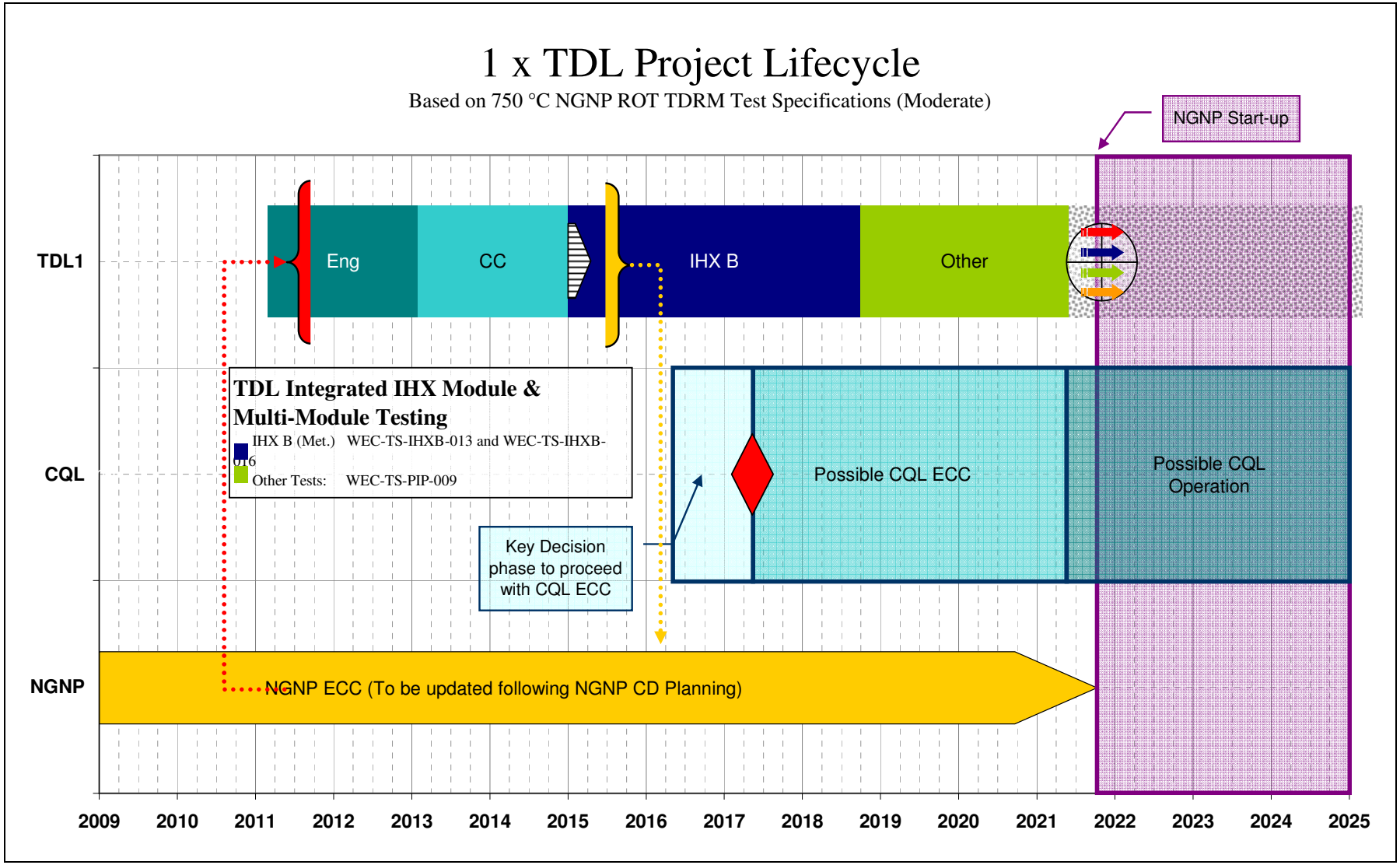

Figure 10-27: ECC and Test duration of one TDL for the 750 °C NGNP ROT Development Path.

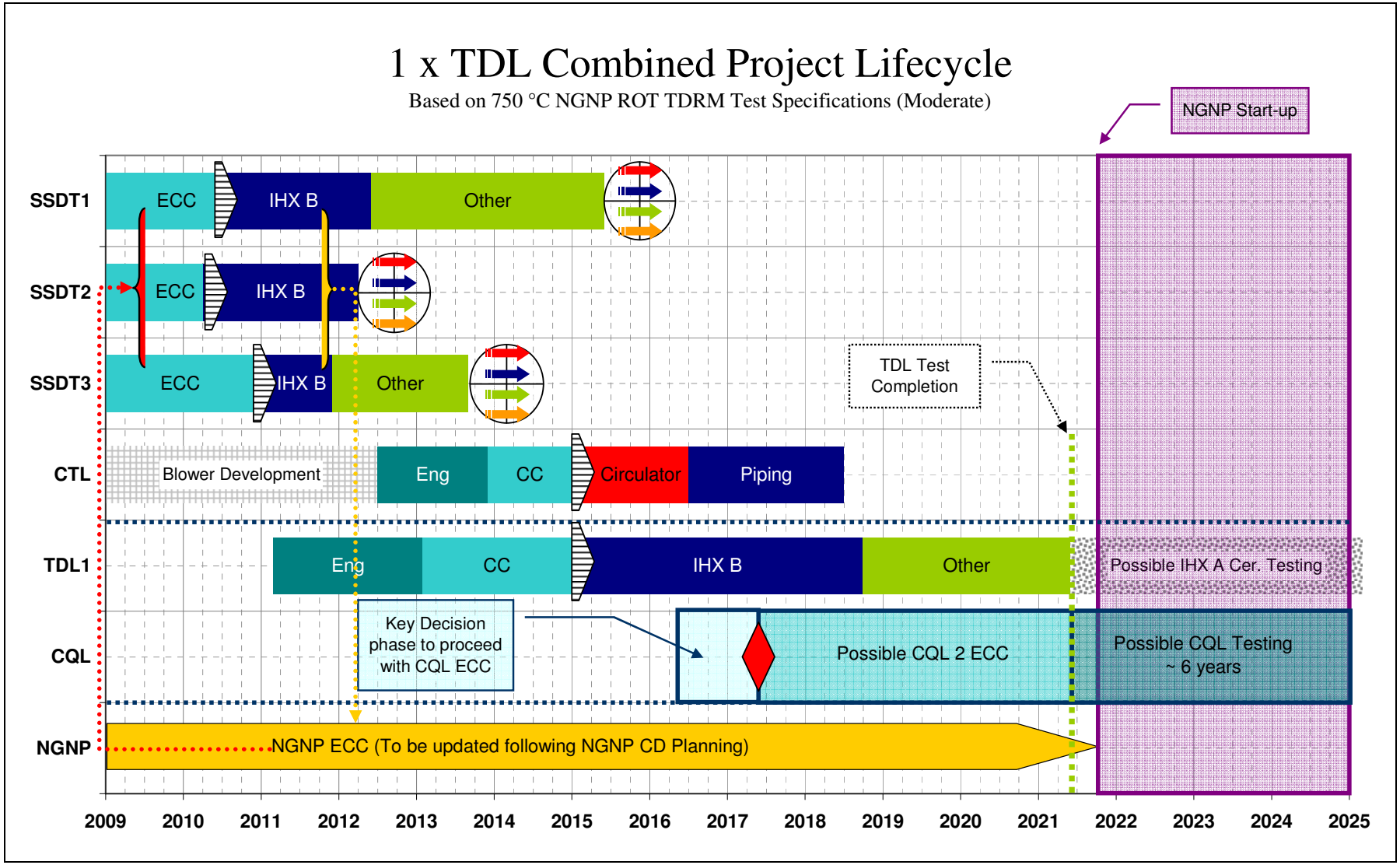

Figure 10-28: ECC and Test durations of one TDL and other fixed systems for the 750 °C NGNP ROT Development Path.

[B-2] Aggressive Approach for the Integrated CTF utilizing two TDLs for a 750 °C NGNP ROT Development Path.

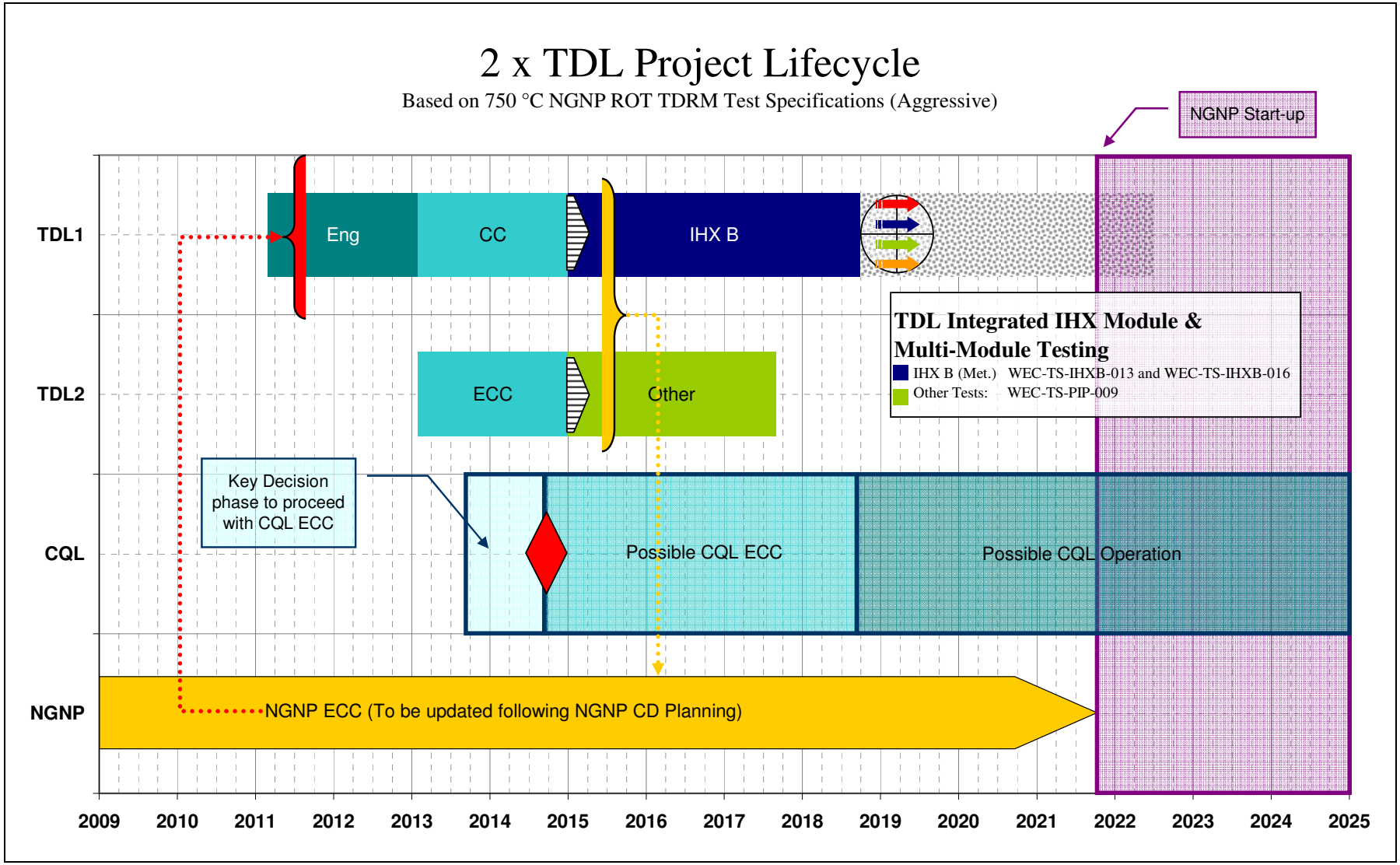

Figure 10-29: ECC and Test durations of two TDLs for the 750 °C NGNP ROT Development Path.

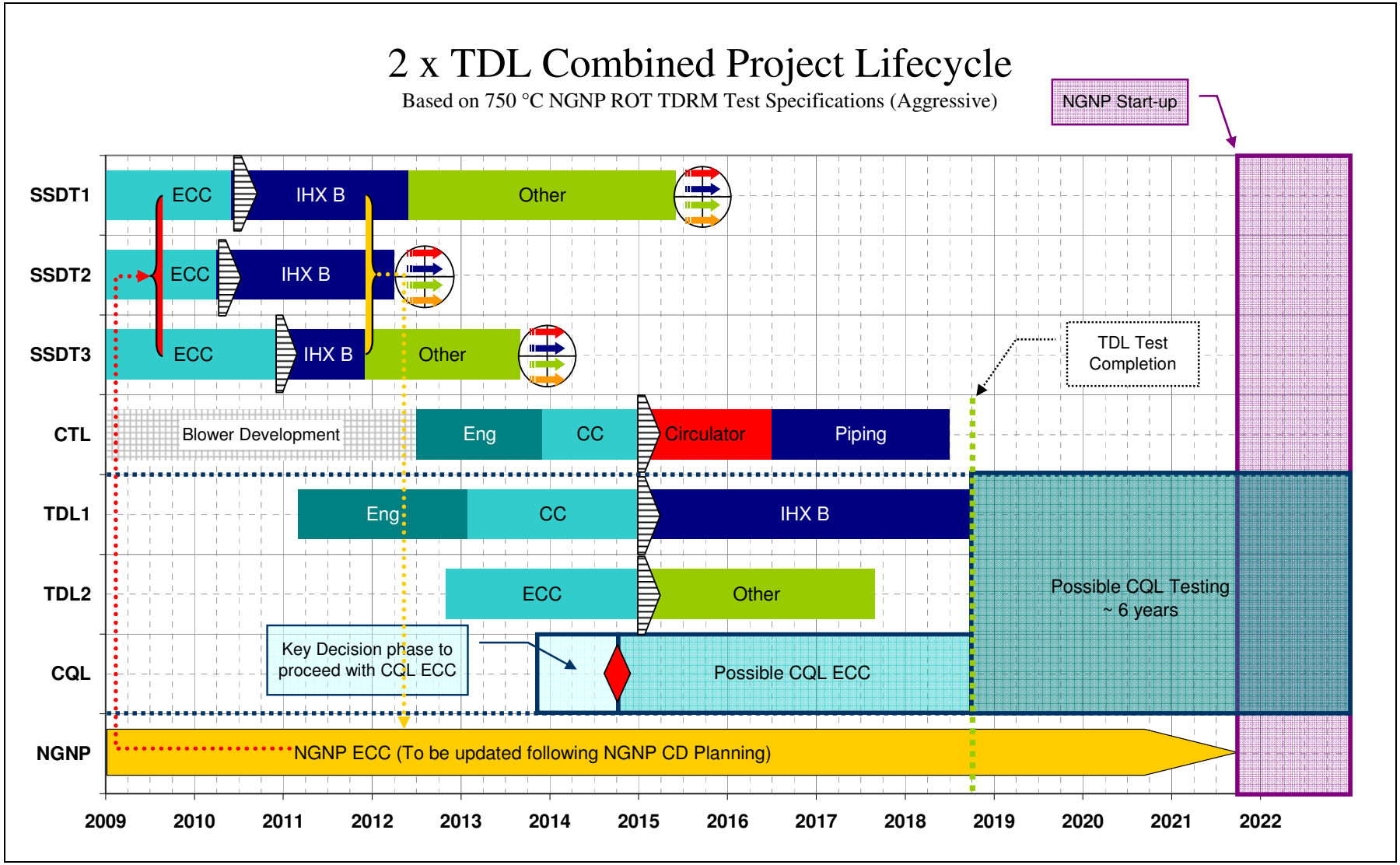

Figure 10-30: ECC and Test durations of two TDLs and other fixed systems for the 750 °C NGNP ROT Development Path.

[C-2] Very Aggressive Approach for the Integrated CTF utilizing three TDLs for a 750 °C NGNP ROT Development Path.

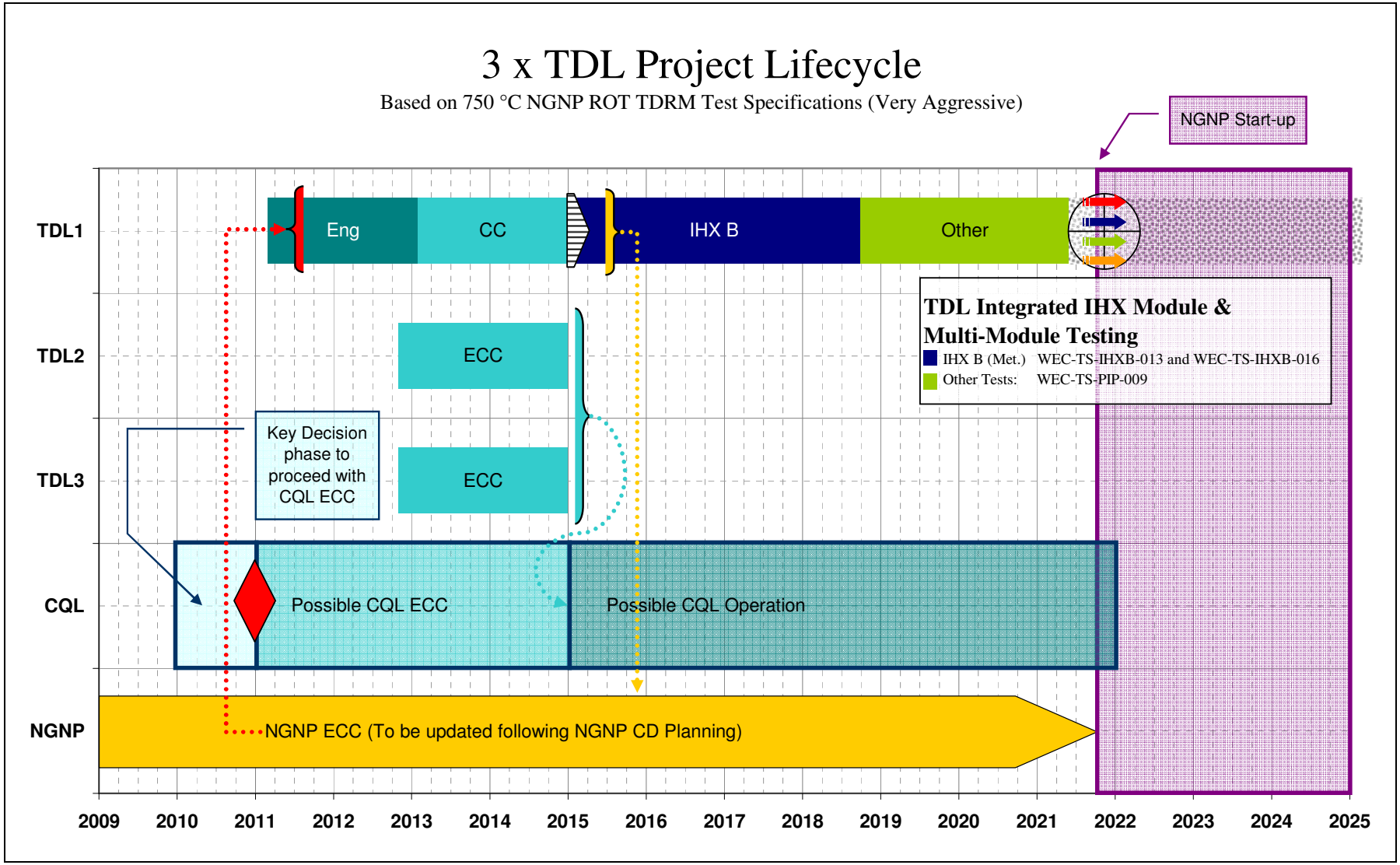

Figure 10-31: ECC and Test durations of three TDLs for the 750 °C NGNP ROT Development Path.

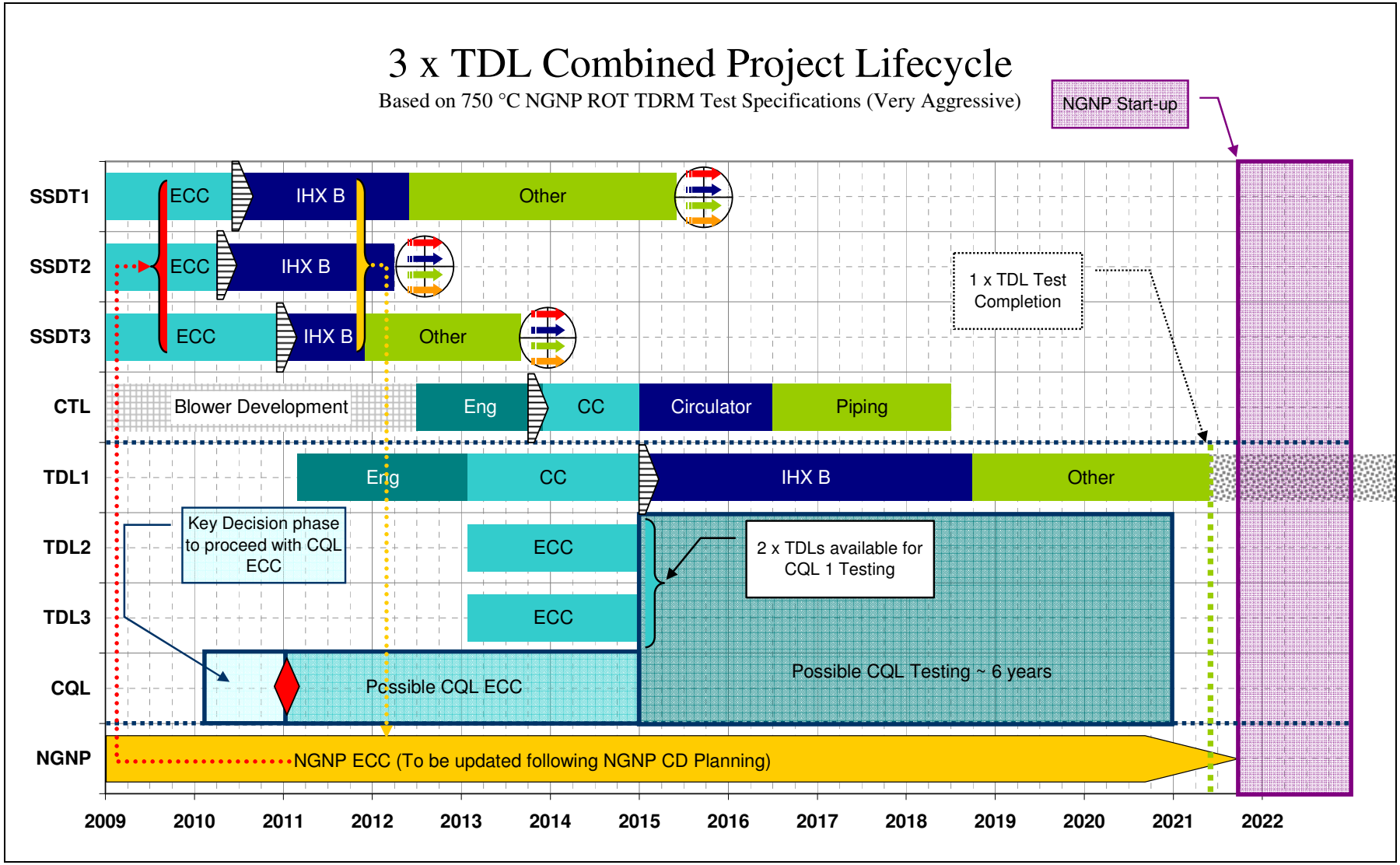

Figure 10-32: ECC and Test durations of three TDLs and other fixed systems for the 750 °C NGNP ROT Development Path.