INL/EXT-07-13146

NGNP Engineering White Paper: High Temperature Fluid Flow Test Facility

September 2007

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

Idaho National Laboratory

INL/EXT-07-13146

NGNP Engineering White Paper:
High Temperature Fluid Flow Test Facility

September 2007

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

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Next Generation Nuclear Plant Project

NGNP Engineering White Paper: High Temperature Fluid Flow Test Facility

INL/EXT-07-13146

September 2007

Approved by:

Larry Demick NGNP Engineering Director	9/19/07 Date
Rafael Soto NGNP Deputy Director	9/19/07 Date

ABSTRACT

This brief white paper discusses the needs for, functional and operational requirements and potential configuration of a High Temperature Fluid Flow Test Facility to support NGNP and commercial applications of High Temperature Gas Reactor technology.

CONTENTS

FIGURES

TABLES

ACRONYMS

AFCI	Advanced Fuel Cycle Initiative
ATR	Advanced Test Reactor
BEA	Battelle Energy Alliance
DOE	Department of Energy
EPAct	Environmental Policy Act of 2005
EPC	Engineering, Procurement, and Construction
F&OR	Functional and operational requirement
GT-MHR	Gas Turbine-Modular Helium Reactor
HTE	High Temperature Electrolysis
HTFFTF	High Temperature Fluid Flow Test Facility
HTGR	High Temperature Gas Reactor
HX	heat exchange
IHX	Intermediate Heat Exchanger
INL	Idaho National Laboratory
KVK	Komponenten Versuchs Kreislauf (German test loop)
MWt	mega-watt (thermal)
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
OKBM	OKB Mechanical Engineering (Russia)
PBMR	Pebble Bed Modular Reactor
PED	Project Engineering and Design
R&D	Research and Development
RFP	Request for Proposal
ROM	Rough Order of Magnitude
RSA	Republic of South Africa
THX	Tertiary Heat Exchanger
TRL	Technology Readiness Level
V&V	verification and validation

High Temperature Fluid Flow Test Facility

The following is a brief white paper discussing the needs for, functional and operational requirements and potential configuration of a High Temperature Fluid Flow Test Facility (HTFFTF) to support Next Generation Nuclear Plant (NGNP) and commercial applications of High Temperature Gas Reactor (HTGR) technology.

1. Mission Statement

A test facility (referred to as the HTFFTF) shall be sited at the Idaho National Laboratory (INL) for the purposes of supporting development of high-temperature gas-thermal hydraulic technologies, (e.g., helium, helium-nitrogen, CO_2) as applied in heat transport and heat transfer applications in HTGR. Such applications include but are not limited to primary coolant; secondary coolant; direct cycle power conversion; intermediate, secondary, and tertiary heat transfer; and demonstration of processes requiring high temperatures, (e.g., hydrogen production). The initial use of this facility will be in support of the completion of the NGNP. This test facility shall be open for use by the full range of suppliers, end-users, facilitators, government laboratories, and others in the domestic and international community supporting the development and application of HTGR technology.

The facility shall provide for full scale:

- Testing and qualification of high-temperature Fluid Flow systems, components, and equipment (e.g., circulators, Intermediate and Tertiary Heat Exchangers [IHX and THX], piping, isolation valves)
- Control and Instrumentation development and qualification, (e.g., reliability, calibration, response, stability, and transient response)
- Verification and validation (V&V) of methods/codes to support licensing and future commercial applications (thermal, hydraulic, transients, etc...)
- Heat transfer component development and fluid testing (e.g., shell & tube and compact heat exchangers, sulfuric acid decomposers)
- Materials performance, (e.g., metallics and ceramics)
- Mock-up for high-temperature heat applications testing and research (e.g., prior to installation into the NGNP).
- Fluid inventory and quality control systems
- Control room human factors
- Operations procedure development and qualification training (e.g., for NGNP and for future commercial plants).
- Operational problem/trouble shooting (e.g. for the NGNP prior to hot system repair/modifications and to support future commercial applications).
- High-temperature applications mockup engineering scale testing and qualifications (e.g., hydrogen production, coal to liquids, steam generators for Alberta Oil Sands application, etc...)
- Maintenance and repair program and process development
- Component replacement program and process development.

The following discusses justification for the facility; describes complementary activities in the Nuclear Hydrogen Initiative (NHI) program; summarizes the characteristics of existing test loop facilities; provides a preliminary summary of the functional and operational requirements (F&ORs) for the facility; discusses program management, cost, and schedule for design, construction, and commissioning of the facility; and provides examples of technical risk mitigation supported by the facility.

2. Justification

The 2005 Environmental Policy Act (EPAct) charges the Department of Energy (DOE) and INL with demonstration of the HTGR technology for the production of electricity and hydrogen by the year 2021 in an NGNP demonstration. Meeting this commitment requires INL to coordinate the efforts of several commercial and governmental entities over a wide range of technical areas. A significant fraction of the technology development required to meet this commitment lies in the transfer of heat from the reactor to the processes used to produce electricity and hydrogen in the NGNP, and ultimately in wider range commercial application of this technology following the NGNP. This heat transfer occurs in the primary helium and secondary (and possibly tertiary) fluid flow loops. In the NGNP, and in the early commercial applications of HTGR technology, the fluids in these loops will be gaseous, for example, pure helium, a mixture of helium and nitrogen, or other gases such as CO_2. Current efforts for development of the technologies supporting design, construction, operation, and maintenance of these loops are concentrated in test loops at laboratory and pilot scales. There are few facilities available or planned that have the capacity to develop and test equipment at a scalable engineering level or at full scale. Development of a full scale facility at INL provides this capability with the following advantages:

- Facilitates the INL role in coordinating, consolidating, and leading the development of the heat transfer and transport technologies needed to advance the application of HTGR technology
- Ensures the availability of the facility for NGNP and beyond development; the limited capacity and availability of other facilities (most of which are international and supporting other projects; see discussion below) could adversely affect NGNP schedule.
- Improves the efficiency of technology development for NGNP and follow-on technology upgrades
- Establishes INL as a world-class leader in development of HTGR technologies
- Provides a means for off-line trouble shooting of component and system problems and for development of programs and processes to ultimately support a growing commercial HTGR fleet
- Provides a long-term U.S.-based facility for continued development of advanced technologies to increase the capabilities and broaden the applications of the HTGR.

Department of Energy support of this initiative would demonstrate full commitment to development of HTGR technology well before the NGNP is scheduled for operation. Demonstration of this commitment will also support achieving industry participation in the Alliance and Public-Private Partnership, which is central to success of the NGNP project.

The development of this facility is a key part of the NGNP development project with an early start date required to ensure its timely availability. As discussed below, the current NGNP schedule shows initiation of a facility Feasibility Study in FY-08. This requires sufficient funding of the NGNP project to support this as well as the other tasks required to support NGNP starting the beginning of FY-08. Realization of the project will require additional funding in FY-09 to complete the design, construction, commissioning, and operation of the facility within FY-11.

3. Current NHI Component and Process Development Programs

3.1 Existing HX Testing Capabilities for the DOE Nuclear Hydrogen Initiative

The United States has only limited ability to test high-temperature (>700ºC) lab-scale heat exchangers. Ohio State University is constructing a bench-top helium closed-loop test apparatus that will allow testing of small (~1 kW) heat exchangers beginning early 2008. Plans also exist for a laboratory-scale single-effects heat exchanger testing laboratory at an Idaho State University facility adjacent to the INL that will allow for the performance of room temperature pressure-drop testing, static helium high-pressure leak testing at temperature, high-temperature air-to-air heat transfer flow experiments, thermal cycling experiments, and other such tests. If funded, the single-effects laboratory would be ready for use by the end of FY-08. Also, the University of Nevada Las Vegas, under their High Temperature Heat Exchanger Project, has developed capabilities to test simple heat exchanger configurations under scaled fluid conditions. The scaled tests are not performed at high temperatures, but the data can be easily scaled to high-temperature high-pressure conditions for the purposes of constructing and testing better heat exchanger models and optimizing heat exchanger designs.

Currently, there is no capability to test high-temperature heat exchangers that are larger than the laboratory-scale. Additional investment is needed to secure test data from foreign countries and to construct larger test loops in the United States.

3.2 Relevance of Large Helium Loop Test Facility to the DOE NHI

The construction and qualification of a large (~10's of MW) high-temperature helium loop facility in the 2011-2013 timeframe is crucial to the design effort for the heat transport loop that will connect the high-temperature nuclear reactor to the hydrogen production plant. The current DOE NHI long-term schedule shows pilot-scale operations (1-5 MW) of proposed nuclear hydrogen production processes beginning in 2011, and one goal of this testing phase is to power one or more of those processes using helium heat exchangers instead of direct heating. Without a large-scale helium loop test facility, the data needed to qualify and optimize heat exchanger designs and to test heat exchanger durability would be unavailable prior to larger-scale deployment. If built, the helium loop facility would be used to test pilot-scale and engineering-scale IHXs and hydrogen process heat exchanger designs (i.e., sulfuric acid decomposer modules, steam generators, helium-to-CO_2 heat exchangers, etc.).

To be of greatest relevance to the DOE NHI mission, a large-scale helium loop would need to be designed with the flexibility to perform multiple experiments side-by-side and at differing scales and with differing fluids, in addition to its ability to power a single full-sized helium heat exchanger. Figure 1 provides an example of a loop facility with this flexibility. In the figure, the primary loop is full-sized and can deliver the full power rating of the furnace to the full-sized heat exchanger. The secondary loops are spurs that also contain helium and can be used to test smaller helium-to-helium heat exchangers. The tertiary loops are used to test heat exchangers for non-helium fluids, such as supercritical CO_2, sulfuric acid, molten salts, and other such fluids. Non-helium fluids would be tested using the tertiary loop installations in order to protect the primary loop from chemical contamination. Other loop configurations are possible.

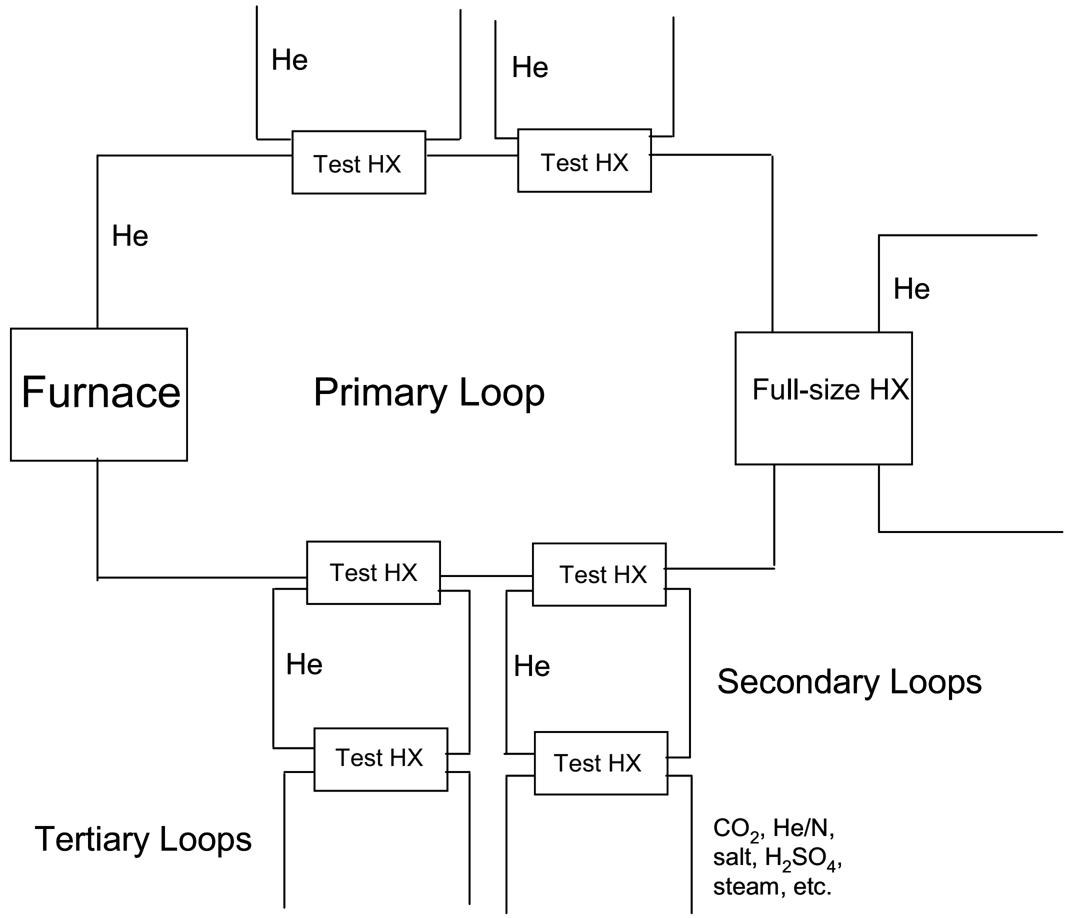

Figure 1. One possible configuration of a flexible helium loop facility.

In addition to heat exchanger testing, establishing and operating the loop facility would provide excellent information on managing and controlling heat loads, helium circulator technologies, high-temperature instrumentation, high-temperature valves and flow control devices, and materials performance. Such information is highly valued by the DOE NHI, and having this information prior to full-scale deployment would greatly enhance the reliability of the heat transport systems at the engineering scale.

3.3 Relevance of the High Temperature Helium Test Facility to High Temperature Electrolysis Testing

The High Temperature Electrolysis (HTE) process for splitting steam in hydrogen and oxygen needs heat at 800 to 850°C to heat the initial reagent water at 25°C to the inlet conditions for the HTE cell, 830°C. Depending on the amount of heat recuperation from the hydrogen and oxygen streams, steam generation and superheating consumes about 15-20% of the total energy needed in the hydrogen production process. The remainder of the energy is supplied as electricity. The operating pressures of the electrolytic cells will be 0.1 to 2.0 MPa, where the H_2 production efficiency favors low pressures and the sizing of manifolds is easier at the upper end of the range.

In its simplest configuration, high-temperature helium from the NGNP would heat the reagent water from the liquid state to 830°C using a counter-flow arrangement where the helium at reactor outlet conditions first flows through the superheater and then through the steam generator. In more thermally-optimized configurations, the heat of the hydrogen and oxygen products, exiting the cells at 800 to 830°C, is used in the superheaters and then in the steam generator. In this configuration, reactor heat at 850 to 900°C is needed only for the final superheating of the steam from about 750 to 830°C. If either the hydrogen or oxygen is to be used in various gasification or fuel-synthesis processes at the 830°C cell exit temperature, then correspondingly more reactor heat would be needed.

Thus, the primary needs for experiments in the HTFFTF on the part of the HTE process would focus of the design of the superheaters and steam generators needed for the reagent steam flow to the cells. In a 600 MWt NGNP-HTE hydrogen plant, the steam flow to the cells would be about 22.5 kg/s. The steam would be deionized and would contain no additives, so the conditions would be very similar to those in a 1525°F, low-pressure steam turbine plant.

In our experiments to date, we have been using Inconel tubing, coiled in the furnace interior, to heat the incoming steam to cell conditions. If there is little need for pure oxygen and/or if materials available for the balance of the hydrogen plant cannot tolerate a pure O_2 environment, the oxygen may be diluted with air or steam and swept from the cells. The “sweep gas,” (air or steam) would have to be heated to the cell temperature first by the exiting sweep gas – oxygen mixture and finally for reactor helium at the reactor outlet conditions. Therefore, there may also be a need to test He/air heat exchangers in this facility.

4. Preliminary Functional & Operational Requirements:

The HTFFTF shall be a high-power, high-temperature facility with the following operational and configuration characteristics *[Note: all values are preliminary – final values will be established during the conceptual design phase for the test facility.]*:

Temperature Ranges	{300 – 1000°C}
Primary Gas Flow Rate	{10 kg/sec to 20 kg/sec}
Secondary Gas Flow Rate	{Variable}
Power	{25 to 50 MWt}
Pressure	{9 MPA Maximum}
Gases	{Helium, Helium / Nitrogen, CO_2, etc.}
Other Fluids (long term)	{Molten Salt, Liquid Metals}
Components	{Ducting and insulation Circulators Heat Exchangers (e.g., shell & tube, compact) Valves (e.g., isolation, check, control) Hydrogen Production Components}
Materials	{SA508/533 Inconel 617 Incoloy 800H 2-1/4 Cr-1Mo-V 9Cr – 1Mo Ceramics}.

Uses of the facility shall include, but not be limited to:

- Development and testing:
  - Active components (e.g., circulators, valves, ducting)
  - Heat transfer components (e.g., heat exchanger designs such as shell & tube and compact at the engineering level, alternative materials such as ceramics, primary and secondary interface designs)
  - Instrumentation
  - Control systems, including confirmation of stability and transient response
  - Operator human factors
- Training:
  - Operation
  - Maintenance
  - Repair
  - Component replacement
- Trouble shooting
- Materials
  - Creep
  - Creep-fatigue
  - Erosion / Corrosion.

5. Current and Planned Test Facilities:

Table 1 summarizes the capacities and status of existing, in-development, and decommissioned high-temperature gas loops. A review of this table shows that the only test loops with close to full-scale test capacity include those in the Republic of South Africa (RSA) and that in Russia for OKB Mechanical Engineering (OKBM). The other large scale loop, the German Komponenten Versuchs Kreislauf (KVK) test loop, is no longer in operation. The remainder have much smaller capacities (i.e., laboratory and pilot scale) designed for special purpose testing.

As shown in Table 1, none of the test facilities listed is in the United States. Although this table may not include all of the test loops in the world, it is understood that those with significant capacity that could meet the objectives of the HTFFTF have been identified. Not only are these test loops located outside the United States, they are each related to a specific project, (e.g., the RSA He Test Facility on Pebble Bed Modular Reactor [PBMR] development, the OKBM test facility on development of the Gas Turbine-Modular Helium Reactor [GT-MHR]). Accordingly, if NGNP or other related HTGR projects wanted to use the facility, that use would have to be coordinated with the schedule for the principal project in that country (e.g., coordinate with the PBMR testing in South Africa). The NGNP Project would not, therefore, have control of its testing schedule, a situation that could have an adverse impact on the Project's schedule for completion. Additionally, many of the expected uses for the HTFFTF do not have a fixed schedule, (e.g., trouble shooting of operational problems in NGNP or commercial plants). As noted in the mission statement, a key objective of this facility is to support the development and maintenance of HTGR technology not only for NGNP but for the long term in commercial applications of the technology. The scheduling and capabilities of the facility must be flexible to adapt to evolutions in the technologies and emerging needs of those applying the technologies. It is not practical or desirable to rely on an off-shore test facility over which the project has no control to meet these objectives. Accordingly, it is concluded that there is no current or planned fluid flow test facility that could be used to satisfy the mission needs of the HTFFTF proposed herein. Such a facility should be built at the INL in a time frame that supports the NGNP. The required schedule is discussed below.

Some of the data in the table was extracted from INL report INL/EXT-06-11648, completed in August 2006, that describes a feasibility study for a High Temperature Gas Loop Test Facility to support NGNP[1]. This loop has a heating capacity of about 2 MWt. Table 2 and Figure 2 were extracted from that report and summarize the basic operational data and configuration for the design. These data are shown as an illustration of one concept of the test facility. It is judged that this facility will not be of sufficient capacity to fulfill the objectives of the HTFFTF.

In the current planning for NGNP, the required size for a test loop that satisfies the requirements outlined above (see Section 1.0) will be determined as an initial activity of the feasibility study for that facility, see schedule discussion below. It is judged based on current information that the facility will be significantly larger than that covered in the August 2006 feasibility study, or other available or planned test facilities listed in the table.

---

1 Note that although the title of this report states that a conceptual design was performed, the design development, cost estimate, and schedule addressed primarily the component and subsystem level to establish feasibility. Significant additional work is required to complete a conceptual design of the facility.

Table 1. Summary of Existing and Planned Fluid Flow Test Facilities

Facility	Country	Heating Power, MW	Flow Rate, kg/sec	Pressure,MPA	Tmax, DegC	Tmin, DegC	Comment
KVK Loop	Germany	10.0	4.0	4.0	950.0	350 to 400	Operated for 13,000 hours, 7,750 at 900 DegC 1981 to 1986
HENDEL (Helium Engineering Demonstration Loop)	Japanese	0.4	0.1	4.0	880.0	Unknown	Developed to evaluate components for the Sulfur-Iodine hydrogen production process & novel heat exchanger designs. Hydrogen production was achieved through decomposition of liquid sulfuric acid with two heat exchangers arranged in series.
OKBM Integrated Turbo-Compressor Facility	Russia	5.0	Unknown	Unknown	Unknown	Unknown	This facility is currently being designed and is scheduled for operation in 2014
ST1565 OKBM	Russia	0.50	Unknown	5.00	Up to 950 C	Unknown	Universal, Including helium purification system testing
ST1312-OKBM	Russia	12 to 15	Unknown	5.00	950 C	Unknown	Test of IHX and Steam Generators
ST1383-OKBM	Russia	6.00	Unknown	5.00	350 C	Unknown	Test of Helium Circulators
CLAIRE Loop for IHX Thermomechanical Testing	France	Transferred Power = .10	Primary = 0.4 to 0.2 Secondary = 0.4 to 0.2	Primary = 0.6 Secondary = 0.6	Primary = 510 & 950 C (In 2008), Secondary = 105 C (Inlet)	Unknown	Air, Cool-down: ~ 300°C in 5s Heat-up: ~ 300°C in 120s, CEA Grenoble
PAT Loop	France	Unknown	Air = 1.3 Steam = 5.5	Air = 1.5 Steam = 2.3	Unknown	Unknown	Air, Cold Conditions, Homogneity of Flow Distribution, EdF Chatou
HELITE Loop	France	Transferred Power = 1.0	Primary = 0.4 Secondary = 1.1	Primary = 4.0 to 8.0 Secondary = 4.5	Primary = 500 & 950 C, Secondary = 900 C	Unknown	Design Finalized, Construction 2007, Operations 2009 He Primary Circuit, 2010 He+N2 Secondary Circuit, Transient : Cool-down: 850 to 480°C in 100 s 5.5 to 2.5 Mpa in 15 s Cycling,
CORINTH CORALLINE CORSAIRE FLAMENCO ESTEREL Le Creusot	France	Unknown	Unknown	Unknown	Unknown	Unknown	Corrosion Loop, Purity Testing, Creep, Low Cycle Fatigue
AREVA He Heat Transfer Loop	France	1.0	0.4	Unknown	900 C	Unknown	Design is complete; project is on hold awaiting funding
HE-FUS3 Loop	France	0.21	0.05 to 0.35	10.50	510 C	Unknown	Primary Side: He, Secondary Side: He or HE-N2, approx 500 C, Compressor Power = .136 MW, ENEA Brasimone
Heat TransferTest Facility	South Africa	HTTU - 0.35 HPTU - 0.05	2.00	9.00	50ºC to 580ºC (1100ºC local)	Unknown	The HTF is situated at the Pelindaba site close to Centurion. It consists of blowers, valves, heaters, coolers, recuperator and other components to be tested at pressures up to 9 MPa and 1100 degrees °C. The facility consists of a totally enclosed 40m high (8 levels) test tower with a 10m x 13m footprint and a 20 ton overhead crane with a passenger lift (ground - level 6). The facility is designed up to 9 MPa with 5 independent process streams able to operate at 50ºC - 580ºC (1100ºC local) up to 2kg/s.
Experimental Plate-out Test Facility	South Africa	Unknown	Unknown	Unknown	Unknown	Unknown	Plate-Out Test Facility (POTF) at Pelindaba, which include the Isopiestic Plate Out Test Facility (IPOF) and the Experimental Plate Out Test Loop (EPOL), used to validate the RADAX code and to obtain plate-out parameters for specific materials. The purpose of tests done in the Experimental Plate-out Test Facility (POTF) is to obtain representative PBMR material plate-out parameters and, if possible (to be determined by second feasibility study), to obtain graphite dust and fission product interaction data.
AREVA Recommendations for full scale test facility		Transferred Power = 10.0 to 20.0 MW	Primary = 5.0 to 10.0 Secondary = 30.0	Primary = 7.0 Secondary = 7.0	Primary = 950 C, Secondary = 900 C	Unknown	He Primary Circuit, He+N2 Secondary Circuit, Transient : Cool-down: 850 to 480°C in 100 s 5.5 to 2.5 Mpa in 15 s Cycling

Note: Some of this information was extracted from Appendix B of INL/EXT-06-11648, "Conceptual Design for a High-Temperature Gas Loop Test Facility", August 2006. Other data was obtained in a survey of the NGNP Pre-conceptual design subcontractors to support this white paper.

STATUS			
(grey)	**Decommissioned**	(cyan)	**Planned or in Construction**
(green)	**Operational**	(yellow)	**Recommended**
(white)	**Unknown**		

Table 2. High Temperature Gas Loop Test Facility Specifications

Primary Loop	
Composition	Pure He
Mass Flow	0.80 kg/s
Supply Temperature to IHX	950°C
Return Temperature from IHX	550°C
Secondary Loop	
Composition	80% N_2, 20% He
Mass Flow	2.12 kg/s
Supply Temperature to IHX	500°C
Return Temperature from IHX	900°C

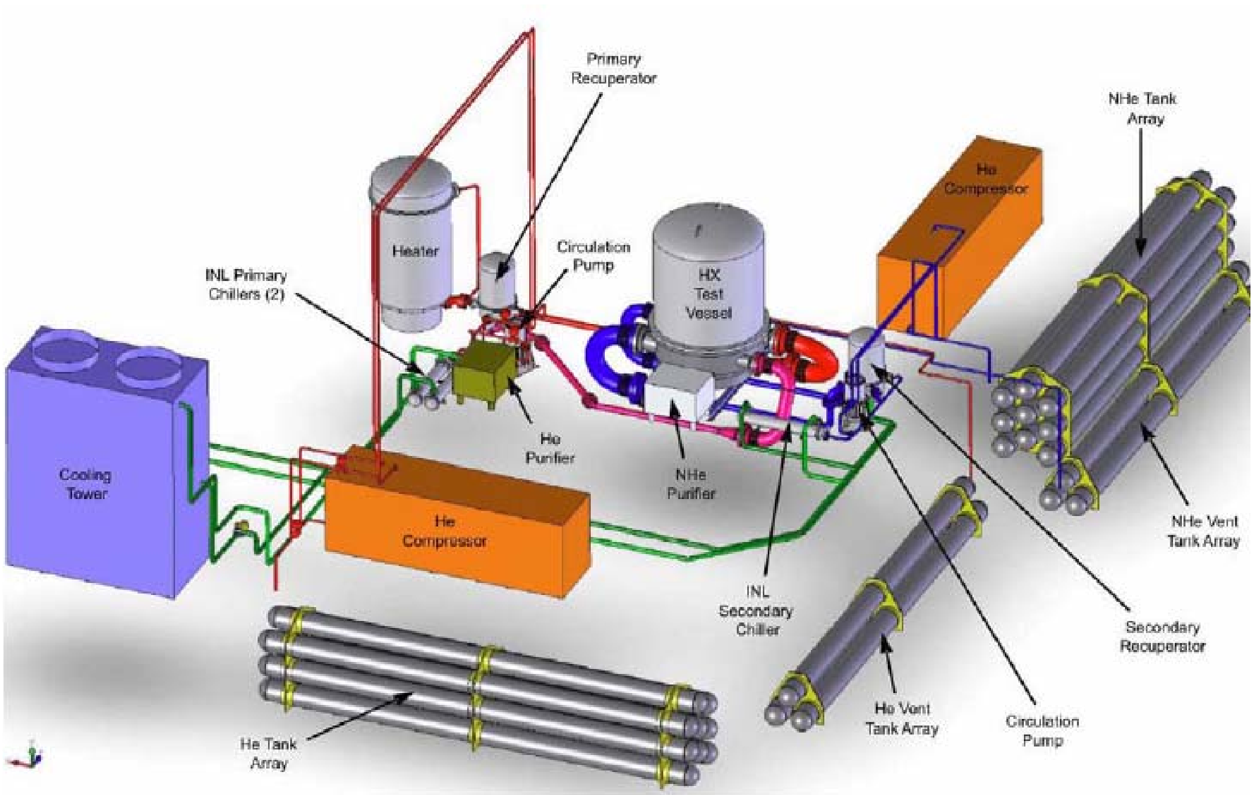

Figure 2. Conceptual layout drawing of the High Temperature Gas Loop Test Facility

For reference, the NGNP power may be as high as 500 to 600 MWt with primary flow rates of ~160 to ~280 kg/sec; a maximum outlet temperature of 950°C, and a minimum inlet temperature of 350°C. The current judgment is that the HTFFTF should be in the range of 25 to 50 MWt with gas flow rates of 10 to 20 kg/sec, and temperatures that bound those for NGNP. This would permit full-scale testing of the major components (e.g., IHX modules or scale models) and hydrogen process modules (e.g., sulfur-iodine or hybrid sulfur sulfuric acid decomposer modules) before installation in the NGNP.

The last line in Table 1 summarizes the characteristics of a helium test loop proposed by AREVA as part of the NGNP Pre-Conceptual Design work (see Figure 3). It is anticipated that the test facility proposed herein could be somewhat larger (25 to 50 MWt) but will have similar characteristics. The facility shown in Figure 3 is the German KVK 10 MWt test facility. It is no longer operating but is recommended by AREVA as a model for the INL facility. A larger depiction of this facility is shown in Figure 4. Such a facility at 25 to 50 MWt will represent a significant extension in worldwide high-temperature fluid flow testing capacities. The characteristics of this facility have been used to develop the basis of estimate for the costs and development schedule provided below.

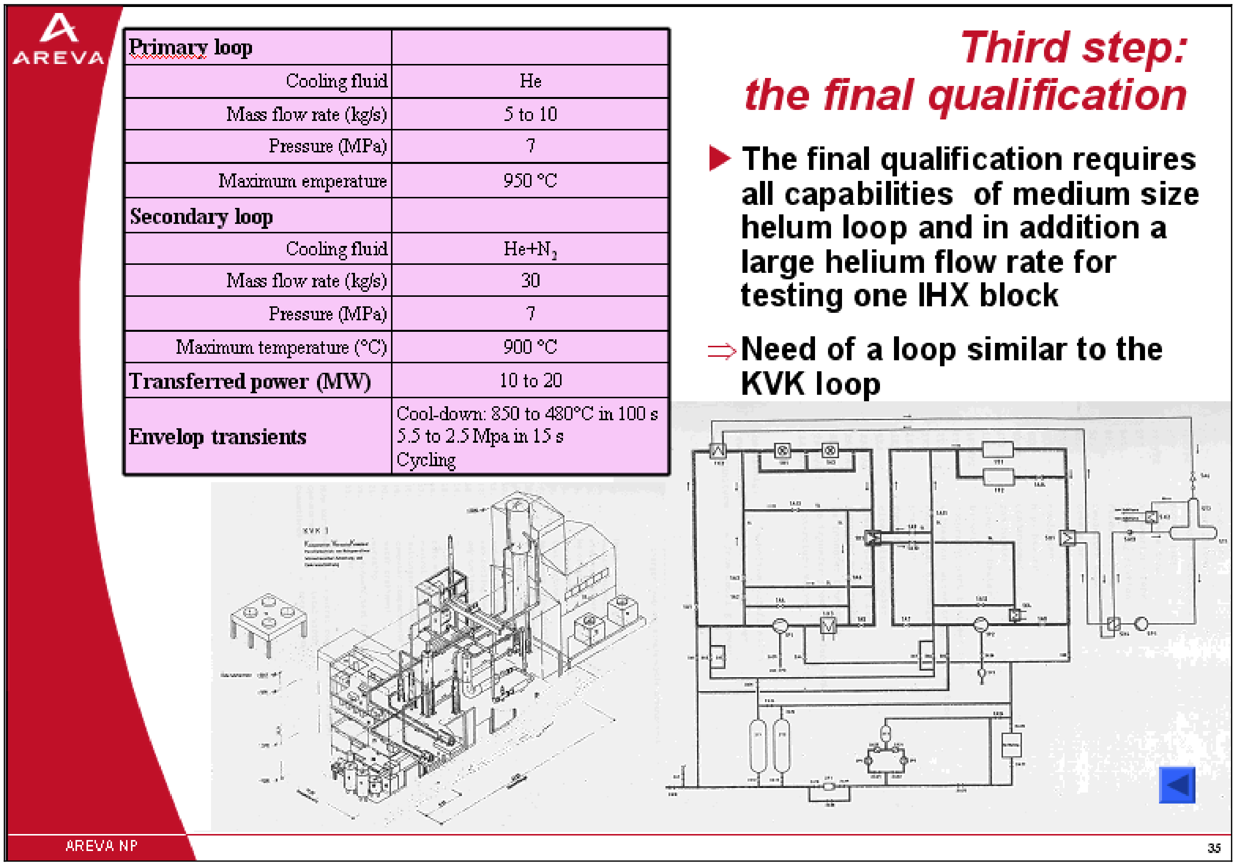

Figure 3. Helium Test Loop proposed by AREVA

It is noted that prior work has also been done to scope the costs and schedule for installing a gas loop in the INL Advanced Test Reactor (ATR) for the purposes of supporting development and irradiation testing of advanced fuel designs under the Generation IV, Advanced Reactor Design and Advanced Fuel Cycle Initiative (AFCI) programs [Ref: Memorandum, R.J. Turk to W.R. Ridgeway, "CD-1 Life Cycle Cost Summary for the ATR Gas Loop Project," July 18, 2005]. The F&ORs, configuration, and uses of this loop are different than that proposed herein; however, this is a program that is complementary to the HTFFTF and should be pursued to support the NGNP fuel development and acquisition program.

Figure 4 shows the German KVK 10 MWt Helium Test Facility, which is no longer operating but is similar to the 1MWt Test Facility that AREVA has designed and is waiting for funding to build. It is also similar to the 10 to 20 MWt facility that they recommended for NGNP support as part of the pre-conceptual design work. This facility is significantly more complex than that developed in the August 2006 feasibility study shown in Figure 2. An adaptation of this facility design in the to 50 MWt range is judged to be necessary and sufficient to meet HTFFTF objectives.

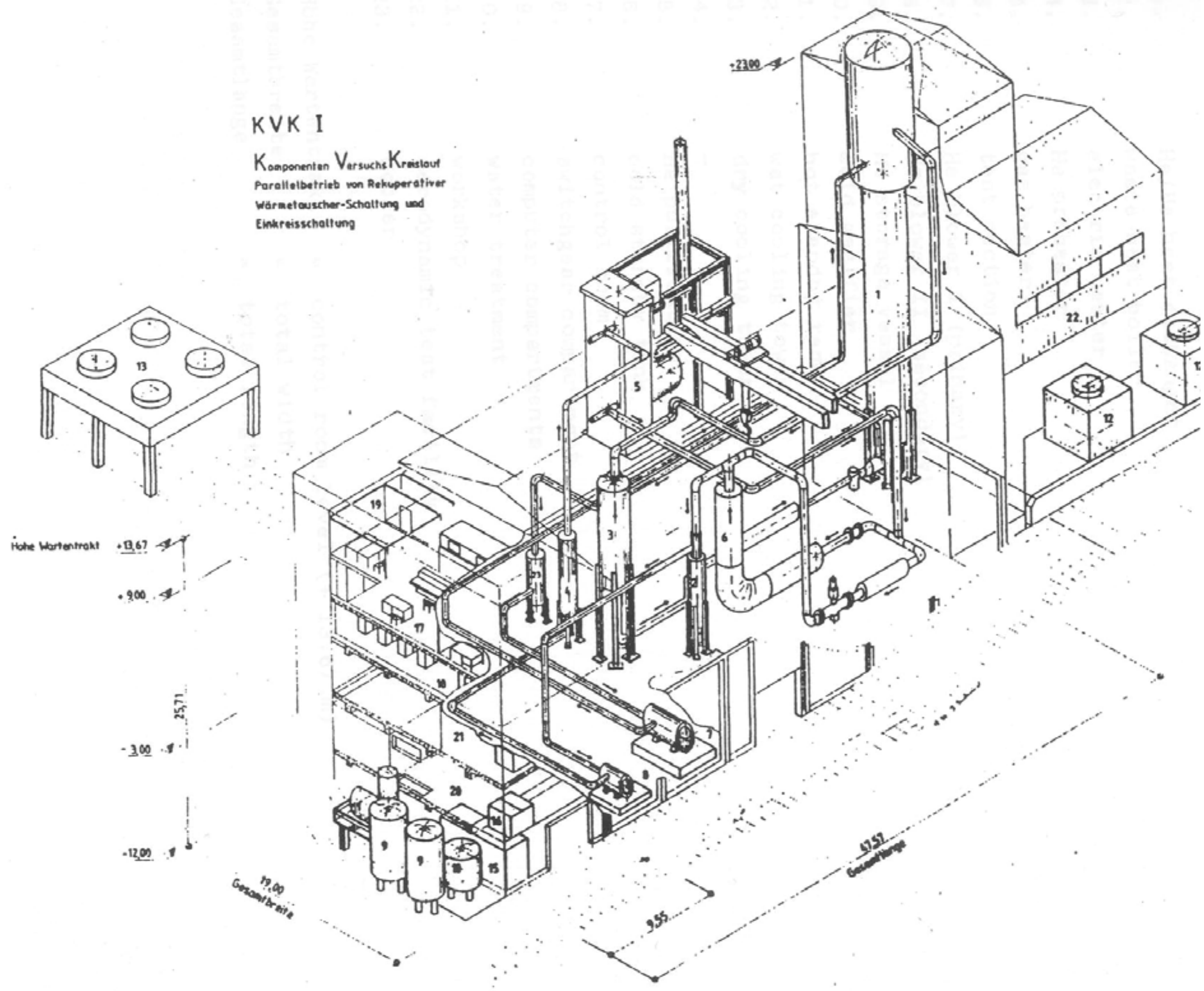

Figure 4. German KVK 10 MWt Helium Test Facility

6. Program Management, Schedule and Cost Estimate

6.1 Program Management

The HTFFTF will be designed, constructed, and turned over to operations under DOE O-413.3. It will be funded by DOE and managed by Battelle Energy Alliance (BEA) as a subproject to the NGNP Project. Due to the critical nature and constrained schedule, full funding is required to complete this facility in a timely manner. This will require a Project Execution Plan that takes all of the elements of DOE O 413.3 on an accelerated effort.

6.2 Schedule

The attached schedule (see Figure 5) shows that the NGNP Project currently plans to complete a feasibility study for the HTFFTF beginning in early FY-08. At that time, the BEA NGNP Project will also be leading the conceptual design effort for NGNP and conducting several design development studies addressing key high-risk technical and configuration issues that need to be resolved to define the final F&ORs and basic configuration of the NGNP. This latter work is to be performed through directed tasks defined by the NGNP Project, to be completed by the sub-contractor teams that performed pre-conceptual design work in FY-07 and potentially other qualified suppliers of Engineering Services. With sufficient funding, the NGNP project will include the development of the HTFFTF design work at that time using the resources of the subcontractor teams.

Part of the feasibility study activities for the HTFFTF will be to establish the schedule for initiating operation to support the NGNP project. Based on the current NGNP schedule, which supports initial operation in 2018, it is judged that the HTFFTF will need to be on-line in the 2011 time frame. This also coordinates well with the NHI programs for hydrogen production and heat transfer/transport development, which plan to be ready to transition from the pilot/engineering-scale testing to full-scale testing in that same time frame. During FY-08, NGNP engineering and BEA procurement personnel will prepare and issue an Engineering, Procurement, and Construction (EPC) Request for Proposal (RFP) for the facility, obtain proposals from qualified suppliers, evaluate the proposals, select the supplier, and negotiate the contract so that Conceptual Design can begin October 1, 2008.

To ensure the work on the HTFFTF is initiated to support this schedule, Project Engineering & Design (PED) Funding requests will be required by August 2007 to support initiating the facility design development in FY-09.

In summary, to meet the NGNP Project needs, the feasibility study should be initiated October 1st 2007, with Conceptual Design starting in October 2008 and completion of Final Design in March 2010. Construction should be started in May 2009 with Testing and Turnover occurring in October 2011. These dates will become more definitive during Conceptual Design.

6.3 Cost Estimate

With the limited information established at the date of this paper regarding the operational characteristics and configuration of the test facility, an accurate estimate of cost is not possible. A more detailed estimate will be prepared as part of the feasibility study and conceptual design for the facility. As part of pre-conceptual design work, AREVA provided a rough order of magnitude (ROM) estimate of $110M for design, construction, and commissioning of a 10 MWt helium test loop that they specified as required for prototype tests of components. As noted above, this recommendation and cost was based on experience with the German KVK facility. On this basis, it is estimated that the design, construction, commissioning equipment, testing, and qualification costs for the larger test facility discussed herein could be in the $150M range.

Assuming that sufficient funding is provided in FY-08, the feasibility study for the HTFFTF will be funded under the NGNP Project Engineering work scope. However, additional funding will be required specifically for completing the design, construction, commissioning, and operation of this facility beginning in FY-09. The required funding schedule will be established during the conceptual design activities. A rough estimate of the required funding schedule based on a total project cost of $150M is shown in Figure 5.

7. Examples of Technical Risk Mitigation Supported by the Test Facility

A full-scale helium test facility is needed to provide prototype testing and qualification of heat transfer system components (e.g., IHX, valves, hot gas duct), to mitigate the associated technical risks, and to increase the Technology Readiness Levels (TRLs) for these components. Since such a facility does not exist at the capacity needed for NGNP, it must be built. Failure to complete the facility in time to do prototype testing could delay NGNP startup or could result in incomplete risk mitigation with potential adverse impact on plant performance if the NGNP was started up without prototype component testing and qualification. The following are brief examples of high-level testing requirements for three of the key high-temperature loop components: the IHX, Primary Loop Isolation Valves, and the Hot Gas Duct (Note: these were identified during the pre-conceptual design work for NGNP).

7.1 IHX

- Primary concerns are temperature level, corrosion, manufacturing, and thermal mechanical resistance. The IHX research and development (R&D) needs, which are considered "High Priority," include:

    1. Development of visco-plastic model (material data-base to be completed)
    2. Corrosion tests on base and coated materials in a representative environment
    3. Development of manufacturing techniques
    4. Tests on representative IHX mock-ups from both thermo-hydraulic and manufacturing point of views.

- A three-step approach is recommended for component qualification. These are:

    1. Tests in air with sub-scale mock-ups
    2. Tests in helium with sub-scale mock-ups (about 1 MWt test loop). These tests will provide a basis for recommendations on which type of concept should be used for the NGNP.
    3. Final qualification on a full-scale mock-up in a full-scale test facility.

7.2 Isolation Valves

- Qualification of the isolation valve has a "High Priority." Qualification steps are:

    1. Elementary tests to characterize the operating conditions, assembly techniques, spacers, etc.
    2. Full-scale mock-up tests in a relevant helium-nitrogen environment.

- These tests should cover:

    1. Manufacturing parameters
    2. Depressurization tests
    3. Pressure loss, heat loss, support tube temperature tests in a relevant helium-nitrogen environment
    4. Leak tightness tests of the valve
    5. Closing and opening

6. Fatigue and creep-fatigue of specific areas.

7.3 Hot gas duct

- The hot gas duct designs appear to be compatible with the reactor expected outlet temperature, subject to demonstrating that no significant hot streaks occur. The hot gas duct testing and qualification should be performed in three steps:
    1. Elementary tests to characterize the material conditions, assembly techniques, spacers, etc.
    2. Sub-scale mock-up tests, about 1 MWt in helium, to validate material specifications
    3. Full-scale mock-up tests.
- These tests should at least cover:
    1. Depressurization tests
    2. Pressure loss, heat loss, temperature of the support tube (in helium)
    3. Leak tightness tests of connections
    4. Fatigue and creep-fatigue tests (e.g., bellows, spacers, etc).

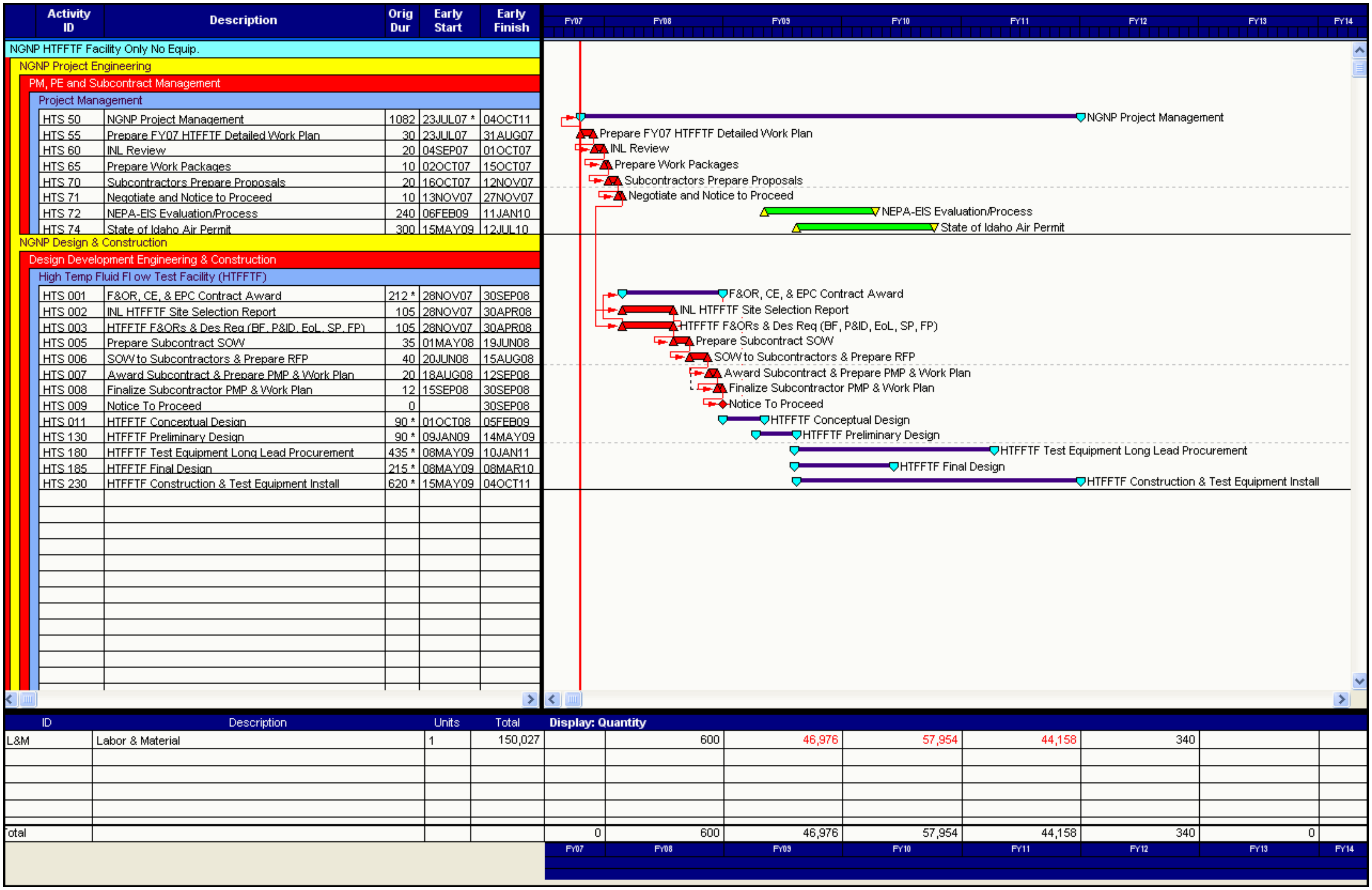

Figure 5. NGNP Project schedule showing planned completion of a feasibility study for the HTFFTF beginning in early FY-08