NGNP-TRL & DRL REPORT **April 2009**
Revision 2

NEXT GENERATION NUCLEAR PLANT

Report on Technology Readiness Levels and Design Readiness Levels for NGNP Steam Production at 750-800°C

APPROVALS

Function	Printed Name and Signature	Date
Author	Daniel Allen Technology Insights	April 23, 2009
Reviewer	Jan van Ravenswaay M-Tech Industrial (Pty) Ltd.	April 23, 2009
Reviewer	Gert Jansen van Rensburg Pebble Bed Modular Reactor (Pty) Ltd	April 23, 2009
Reviewer	Michael Correia Pebble Bed Modular Reactor (Pty) Ltd	April 23, 2009
Approval	Edward Brabazon Shaw Environmental & Infrastructure	April 23, 2009

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

LIST OF CONTRIBUTORS

Name and Organization	Date
Werner Koekemoer M-Tech Industrial (Pty) Ltd.	April 2009
Jan van Ravenswaay M-Tech Industrial (Pty) Ltd.	April 2009
Guido Baccaglini Technology Insights	April 2009
Dan Mears Technology Insights	April 2009
Scott Penfield Technology Insights	April 2009
Phil Rittenhouse Technology Insights	April 2009
Fred Silady Technology Insights	April 2009
Barend Botha Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Cobus Bruwer Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Rudolf Bester Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Tertius Baard Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Michael Correia Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Pieter Coetzer Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Ivan Drodskie Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Kevin Gettliffe Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Gert Jansen van Rensburg Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Erik van der Linde Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Jaco Lindeboom Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Hanno van der Merwe Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Mark Mitchell Pebble Bed Modular Reactor (Pty) Ltd.	April 2009

Name and Organization	Date
Yeshern Maharaj Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Ruttie Nel Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Steven Pieterse Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Leslie Thiart Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Carel Wilken Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Roger Young Pebble Bed Modular Reactor (Pty) Ltd.	April 2009
Karl Goff Shaw Environmental & Infrastructure	April 2009
Attie Ferreira Westinghouse Electric South Africa	April 2009
Marius Fox Westinghouse Electric South Africa	April 2009

BACKGROUND INTELLECTUAL PROPERTY

Section	Title	Description
NONE		NONE

REVISION HISTORY

RECORD OF CHANGES

Revision No.	Revision Made by	Description	Date
0	Daniel Allen Technology Insights	Initial Issue	September 27, 2007
1	Daniel Allen Technology Insights	Revision for 750-800°C ROT	March 31, 2009
2	Daniel Allen Technology Insights	Updated with client comments	April 23, 2009

DOCUMENT TRACEABILITY

Created to support the following Document(s)	Document Number	Revision

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

Abbreviation or Acronym	Definition
AGC	Advanced Graphite Capsule
AGR	Advanced Gas-Cooled Reactor
ATR	Advanced Test Reactor, Idaho
AVR	40MWt Developmental High-Temperature Reactor (Atomversuchsreaktor), Jülich, Germany
BOP	Balance of Plant
BUMS	Burn-Up Measuring System
DDN	Design Data Need
DPP	Demonstration Power Plant
DRL	Design Readiness Level
EMB	Electro-Magnetic Bearing
FHSS	Fuel Handling and Storage System
GT-MHR	Gas Turbine Modular Helium Reactor
HTF	Helium Test Facility, Pelindaba, South Africa
HTTF	High Temperature Test Facility, South Africa
HTTR	30MWt High Temperature Engineering Test Reactor, operating in Oarai, Japan
HTGR	High Temperature Gas-Cooled Reactor
HTR	High Temperature Reactor
HTR-10	10MW Developmental HTGR operating in China
HTR-Modul	200MW HTGR, designed in 1987 by Siemens/Interatom
IHX	Intermediate Heat Exchanger
INM	Institute of Nuclear Materials, Zarechny. Sverdlovsk region, Russia (sometimes Institute of Reactor Materials) -- research and development branch of the Dollezhal Research and Development Institute of Power Engineering (NIKIET - научно-исследовательский и конструкторский институт энерготехники имени Н.А. Доллежаля), Moscow
NA	not applicable
NGNP	Next Generation Nuclear Plant

Abbreviation or Acronym	Definition
NHSF	Nuclear Heat Supply Facility
NHSS	Nuclear Heat Supply System
OKBM	Afrikantov Experimental Machine Building Design Bureau (Опытное конструкторское бюро машиностроения имени И.И. Африкантова), Nizhniy Novgorod, Russia
PBMR	Pebble Bed Modular Reactor
P&ID	Piping & Instrumentation Diagram
PCF	Power Conversion Facility
PCS	Power Conversion System
PFD	Process Flow Diagram
PHTS	Primary Heat Transport System
PIE	Post-Irradiation Examination or Postulated Initiating Event
RCCS	Reactor Cavity Cooling System
ROT	Reactor Outlet Temperature
SAS	Small Absorber Sphere
SG	Steam Generator
SHTS	Secondary Heat Transport System
SSC	Structure, System and/or Component
TDRM	Technology Development Roadmap
THTR	750MWt Thorium High Temperature Reactor, demonstration plant, Hamm-Uentrop / Schmehausen, Germany
TRL	Technology Readiness Level

Nomenclature

Breadboard/Experimental Scale – An assembly to be tested that will provide the data or demonstration intended but is not necessarily like the design of the final SSC.

Pilot/Engineering Scale – A model or facsimile of the SSC used as a basis or standard for proof-of-principle testing and/or operation. The model or facsimile may progress through several evolutions, but is not necessarily in form or fit a final version.

Prototype – Subsequent to Pilot/Engineering Scale model or facsimile of the SSC, a version that is intended to be the final version or is an evolutionary step toward the final version. A prototype has the functions, the general design and the features of the final design, although likely at smaller scale. (This is interconnected with the design progressing to a point where the "final design" is at least anticipated.)

Lab Environment – Refers to a controlled environment where effects can be quantified with appropriate accuracy.

Demonstration – This in general will be by testing. However, it could be by analysis, if the analysis inputs are appropriate to the task.

Relevant Environment – Refers to an environment that does not necessarily have the same fluence, temperatures and pressures, but is close. Not necessarily the same fluids, but chemically similar insofar as thermo-fluid and corrosion/reaction. A relevant environment is one close enough in all aspects that results can be extrapolated to the operational environment.

Operational Environment – For SSCs normally operating when the plant is running, the operational environment consists of the normal operating fluids, and anticipated temperatures (*i.e.,* both static and transient) and pressures (static and transient). For SSCs not normally operating, the operational environments are the design basis operating fluids, temperatures and pressures.

Report on Technology Readiness Levels & Design Readiness Levels

1.0 Summary and Conclusions

This revised report presents the Technology Readiness Level (TRL) assessment and the Design Readiness Level (DRL) assessment of the currently progressed WEC Team design for the PBMR based NGNP. The listing of critical Systems, Structures and Components (SSCs) is revised. TRL ratings are updated accounting for 1) the design progress, 2) evolved definitions of the TRL ranking and 3) the NGNP change to primary coolant operating conditions. The last specifically concerns the change of Reactor Outlet Temperature (ROT) to 750 - 800°C and a plant configuration with only steam generation, *i.e.* - without a hydrogen process facility.

DRLs noted herein for the SCCs are the DRLs as given in the previous issue of the report and have not been reassessed in this issue. However, DRLs that are no longer applicable for higher ROTs, *e.g.* - hydrogen processes, have been deleted.

In total, there are 24 critical SSCs for which there are 22 completed Rating Sheets with a selected DRL and TRL rating, and the basis for the ratings. Not counting SSCs which take their rating from their subcomponents, there are 17 SSCs requiring technology development based on the PCDR and Technology Development Roadmaps (TDRMs).

The DRL ratings for the 24 SSCs ranged from a low of 1 to a high of 5, with the distribution in Table 1.

Table 1: DRLs

DRL Rating	Number of SSCs With this rating
1	4
2	7
3	5
4	2
5	6

The TRL ratings for the 17 SSCs, not counting SSCs which take their rating from their subcomponents, ranged from a low of 3 to a high of 7, with the distribution in Table 2.

Table 2: TRLs

TRL Rating	Number of SSCs With this rating
3	2
4	3
5	1
6	9
7	2

Changes to the TRL ratings from the initial issue are summarized in Table 3 and further discussed in Section 6.2.

Table 3: Changed TRLs from Initial Issue to Rev. 1

Doc # Note 1	Critical Structure, System or Component	Initial Issue	Rev. 1	Comment
	Nuclear Heat Supply Facility			
	Nuclear Heat Supply System			
001	Reactor Unit System			
002	Fuel Elements (Spheres)	6	7	Note 5
003	Core Barrel Assembly	6	8	Note 3, removed from critical SSCs
008	Reactor Pressure Vessel	6	8	Note 4, removed from critical SSCs
011	Fuel Handling and Storage System	6	5	Note 4
012	Helium Services System	6	8	Note 3, removed from critical SSCs
013	Primary Heat Transport System (PHTS)	2	3	Note 2
016	Intermediate Heat Exchanger (IHX) - Compact, Metallic	2	3	Note 2
017	IHX Metallic Compact Core	4	3	Note 3
018	IHX Internal Ducts, Headers, Supports and Insulation	2	3	Note 4
019	IHX Vessel, Supports & Insulation	6	7	Note 3
020	Intermediate Heat Exchanger (IHX) - Ceramic	2	- -	no longer in plant design
024	PHTS Piping	6	4	Note 2

025	Pressure Boundary Piping, incl. External Supports and Insulation	5	8	Note 5, removed from critical SSCs
026	Piping Internal Ducts, Supports and Insulation	6	4	Note 3
027	Secondary Heat Transport System (SHTS)	2	4	Note 2
029	SHTS Piping	6	4	Note 2
030	Pressure Boundary Piping, incl. External Supports and Insulation	6	8	Note 5, removed from critical SSCs
031	Piping Internal Ducts, Supports and Insulation	6	4	Note 3
032	SHTS Flow Coupling and Mixer	2	- -	no longer in plant design
	Hydrogen Production Facility (HPF)			no longer in plant design
	Power Conversion Facility (PCF)			none

Notes:
1. The "Doc #" in the leftmost column are the same used in the initial issue
2. TRL changed because lower level SSC changed
3. Changed in the TDRM assessment
4. Changed in review and consultation with system engineers since the TDRM report
5. Changed because of 750-800°C ROT

In most cases, the TRL rating is higher than before, due to the less demanding ROT related challenges. However, there are cases where the TRL is lower due to feedback from the earlier Technology Development Roadmaps (TDRMs) development process.

The work that is summarized in this report provides a starting point for the next phase, the revision of the TDRMs.

2.0 Introduction

2.1 Introduction to the Initial Issue (Rev. 0)

In response to the Battelle Energy Alliance (BEA) request, an evaluation of the Westinghouse (WEC) Team's preconceptual design of the PBMR NGNP (Ref. 1) has been performed relative to Technology Readiness Levels (TRLs) and Design Readiness Levels (DRLs) for critical Structures Systems and Components (SSCs) as developed for other industries and recommended by GAO for this DOE supported project. The WEC Team reviewed the various references, in particular the NASA, GAO and GNEP reports (Refs. 2 thru 5) as background on the use of the DRL and TRL evaluation process. Based on the methodology used in these references, the WEC Team subject matter experts applied the same process to the SSCs for the PBMR NGNP.

In summary, the purpose for developing the DRLs and TRLs is to:

- Provide a semi-quantitative measure of the readiness of the technology of critical SSCs for commercialization;
- Provide a semi-quantitative measure of the readiness of the design of critical SSCs for full-scale deployment;
- Provide the ability to compare the design and technology readiness of any SSC relative to another SSC to assist in programmatic decisions;
- Provide input to the path forward for the Technology Development Roadmap;
- Provide design "hold points" that reflect and coordinate technology development with the design process that trigger a dramatic increase in project risk if not adhered to or mitigated, and
- Establish a rational process and criteria to communicate the current state and advancement of the technology development and the design among the NGNP project team and stakeholders.

The term "semi-quantitative" is used because the TRL and DRL ratings are partially subjective. The fact that the levels are numbered is only a method to categorize the levels, and they could have been assigned letters instead of numbers.

Based on the above, the DRLs and TRLs have been developed, with the associated basis, to allow a comparison of the overall design and technology readiness of the critical SSCs. This allows a comparison of the relative status of various SSCs regarding the DRL and TRL, as well as comparing the selected DRL and TRL for a given critical SSC

This report provides a process for assessing DRLs and TRLs using recommended generic definitions for the DRLs and TRLs and a ten point rating system. In addition, this report documents the process used to perform the overall analysis. This process is based upon work developed by the WEC Team as part of the pre-conceptual design effort, process planning by INL and work developed by other organizations, as described in Section 3.

Section 4 of this report defines the generic definitions used in assessing the ratings. Rating numbers are then assigned to the PBMR NGNP critical SSCs. The definition of a critical SSC is taken from the SOW as follows: "Critical SSCs shall at a minimum be defined as those components that are not commercially available or do not have proven industry experience." This is interpreted to mean that an SSC is not critical if it is either commercially available or there is proven industry experience or both. By definition, therefore, all SSCs that are not critical SSCs are TRL-8 or higher and critical SSCs have levels of TRL-7 or lower.

Definitions, as well as assigned ratings, for the SSCs are documented using a form specifically designed for this task. A generic version of this form is included in Section 5 of the report. To ensure that future DRL and TRL assessments are consistent with the intended process, instructions for completing the generic form are also included in Section 5.

Section 6 includes a summary table of the DRL ratings and the TRL ratings for the selected SSCs. This table summarizes the completed Rating Sheets, which are included in Appendix A.

2.2 Introduction to Revision 1

In the period of time since the initial issue of this report, design studies have been concluded that clarify the direction of the conceptual design of the NGNP. TRL ratings are updated accounting for the design progress and the NGNP changes to primary coolant operating conditions and secondary coolant circuit configuration (Ref. 9). The change to the primary coolant operating conditions is the reduction of the reactor core mean outlet temperature (ROT) from 950°C to 750-800°C. The changes to the secondary coolant configuration are to utilize one Intermediate Heat Exchanger (IHX) in place of two IHXs in series and to eliminate the hydrogen production facility in the heat transport circuit.

There have been design decisions made in the NGNP, such as the use of a compact heat exchanger for the IHX (Ref. 10). This changes the definition of critical SSC slightly. For example, the IHX would not be a critical SSC if its design were indeterminate, because IHXs have operating experience in the form of tubular heat exchangers. However, the currently specified compact heat exchanger concept is neither commercially available nor proven in industry for the application.

Since the initial issue of this report (Ref. 6), refined definitions of TRLs were published by BEA/INL (Ref. 7). These definitions were used in the TDRM report (Ref. 8). The only significant

difference from the definitions in the initial report is that TRL-6 correlated to systems proven elsewhere. Under the present definitions SSCs in that former category would be either TRL-6 or TRL-7 depending on how prototypic it was of the NGNP design and whether it was tested in a relevant or the operational environment. Regardless, TRL ratings have been reviewed with the new definitions.

For this update, the WEC Team's PBMR based NGNP design adopts a ROT of 750- 800°C to a single compact IHX. In addition, the hydrogen process facility is removed from the secondary heat transport loop and only the steam generation aspects remain. The TRL ratings are reviewed for these changes in design and the Rating Sheets in Appendix A revised accordingly. The arrangement and parameters for the plant design used for the purposes of this study are shown in Appendix B.

3.0 Key References

The DRL and TRL definitions and the overall process used in the preparation of this report are based in part on the following documents:

1. Initial identification of critical structures, systems and components in Westinghouse team "NGNP and Hydrogen Production Preconceptual Design Report (PCDR)", May 2007, Section 3.

2. General Accounting Office Report – GAO-07-336, Appendix V: "Definitions of Technology Readiness Levels"

3. John C. Mankins, "Technology Readiness Levels- A White Paper", Advanced Concepts Office, Office of Space Access and Technology - NASA, April 6, 1995

4. Carol Reid and Ron Klinger, "Accelerated Implementation and Decision-Making Using Focused Technology Road Mapping", Idaho National Laboratory

5. H. Heydt, K. Perry, B. Dixon, "Prototype Application of Gen IV Technical Maturity Assessment Methodology", June 2006

6. "NGNP and Hydrogen Production, Report on Design Readiness Levels and Design Technology Readiness Levels", NGNP-TRL & DRL REPORT, Rev. 0, Westinghouse Electric Company LLC, September 21, 2007.

7. "Technical Readiness Level Plan, Next Generation Nuclear Plant", INL/EXT-08-14251, draft, Idaho National Laboratory, May 12, 2008.

8. "NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, NGNP-CTF MTECH-TDRM, Rev. 0, Westinghouse Electric Company LLC, December 2008.

9. "Next Generation Nuclear Plant System Requirements Manual", INL/EXT-07-12999, Rev. 2, Idaho National Laboratory, March 2009.

10. "NGNP Conceptual Design Study: IHX and Heat Transport System", NGNP-HTS-RPT-TI001, Rev. 0, Westinghouse Electric Company LLC, April 1, 2008.

11. "NGNP Hydrogen Plant Alternatives Study", NGNP-HPS SHAW-HPA, Rev. 1, Westinghouse Electric Company LLC, March 2009.

4.0 DRL and TRL Definitions

4.1 General

The generic definition for DRL has been selected based on various reference sources, and the experience of the subject matter experts from the WEC Team. DRL definitions are elaborated upon in the following section. The principal reference used is the General Accounting Office Report – GAO-07-336, Appendix V: Definitions of Technology Readiness Levels (Ref. 2).

The TRL definitions are refined from those provided by BEA/INL in Reference 7, and are elaborated upon in Section 4.3.

4.2 Design Readiness Levels for Critical Structures, Systems and Components of a Generic Nuclear Facility

The DRLs are applicable to facilities, structures, systems, and components, either individually or by grouping the SSCs. In general, they follow the normal design evolution, through the three phases of design: conceptual design; preliminary design, and final design. Appropriate staging of the design process through these phases will occur and culminate with the design being implemented through construction and operation. Table 4 presents the DRL generic definitions.

As shown in Table 4, the first 8 ratings are the steps required to reach the completion of final design, which typically is considered to be the completion of the design effort with issue of documents required for fabrication and/or construction. However, for this analysis, the step of implementing the design in construction, as well as the successful startup, testing and operation of the constructed design, are considered important elements in the validation that the design is acceptable. This is especially true for a first-of-a-kind design.

It is recognized that many design functions are iterative, and that they continue through the three phases with more fidelity and detail as the stages progress.

The basis for a rating at a specific definition level can be based on the specific project being considered, or a similar project (*e.g.*, a test facility, demonstration project or another commercial project).

It is also recognized that parts of the definitions are more applicable to systems, and ultimately facilities, rather than to individual components. Design steps, such as safety analysis, cost estimates and so forth, are normally applied to the system level rather than the component level. This consideration was taken into account in the ratings by assessing the maturity of the component. In this way mature

components did not receive a reduced rating simply because the overall system and/or facility may not have progressed to the same stage as the component.

Table 4: Design Readiness Level Generic Definitions

Rating Level	Design Readiness Generic Definition
1	**Design need or concept identified** in white papers or feasibility study reports. Goal and scope defined. Typically part of Pre-Conceptual Design. In most instances, design need identification is indicative that a design concept is not presently known.
2	**Initiate Conceptual Design**. Establish functional & operational requirements and define design criteria. Identify alternative configurations and materials. Prepare scoping cost and schedule estimates. Establish top level requirements. Allocate requirements to SSCs
3	**Complete Conceptual Design**. Complete trade studies, selection of alternatives, and select initial configuration and materials. Initial Overall Plant Design Specification (System Requirements Manual) and initial portions of Facility Design Descriptions (FDDs), and System Design Descriptions (SDDs) issued for facilities, major systems, structures and components. (FDDs, SDDs, scoping calculations, drawings, and outline specifications. Block Flow Diagrams, Mass Balances, Process Flow Diagrams (PFDs) and Piping & Instrumentation Diagrams (P&IDs), one lines, Instrument & Control (I&C) diagrams, plant layout, Floor plans, General Arrangements, Systems Configurations, etc. are initiated) Perform Value Engineering and evaluate changes that can reduce cost. Preliminary Cost & Schedule Baseline Range. This rating is associated with a 15% completion of the overall design.
4	**Initiate Preliminary Design**. Perform preliminary safety and other analyses, complete additional trade studies, engineering analysis, preliminary calculations, preliminary performance specifications and PFD and P&IDs. This rating is associated with a 25% completion of the overall design.
5	**Complete Preliminary Design**. Issue preliminary key design output documents. The major key documents are SDDs, calculations, drawings, and specifications. PFDs and P&IDs, one lines, I&C diagrams, plant layout, floor plans, typical sections, general arrangements, systems configurations, *etc.* When finalized and all key documents are placed under cost & schedule change control. Complete initial startup and operation planning. Final Cost & Schedule Performance Baseline established. All facilities, associated systems, structures and components have been identified, sized and integrated. This rating is associated with a 40% completion of overall design.

Rating Level	Design Readiness Generic Definition
6	**Initiate Final Design**. Validate design selections, and safety and other engineering analyses. This rating is associated with a 50% completion of the overall design.
7	**Continue Final Design**. Prepare final FDDs, SDDs, calculations, drawings, and procurement and construction specifications. Develop operating manuals and operator training programs. Long Lead procurement initiated. This rating is associated with a 75% completion of the design.
8	**Complete Final Design**. Issue construction and procurement specifications and drawings for use. Complete final startup and operation documentation. This rating is associated with a 100% of the final design, but not including changes during construction and start-up.
9	**Facilities, SSCs manufactured and/or constructed**, inspected, tested and ready for turnover to operations.
10	**Facilities, SSCs successfully operated** for one full cycle. As built drawings reviewed and approved.

4.3 Technology Readiness Levels for Critical Structures, Systems and Components for the NGNP

TRLs are applicable to SSCs. In general, they follow the progression of identifying technology risk issues evaluating these risk issues and subsequently resolving them. This is accomplished through a process involving:

- Analysis;
- Laboratory tests;
- Tests and inspections in other test configurations, (*e.g.*, irradiation test assemblies, Post-Irradiation Examination (PIE) facilities, high temperature fluid flow tests);
- Tests at plants similar to the end use (*e.g.,* the PBMR Demonstration Power Plant (DPP), OKBM GT-MHR), and;
- Tests at the actual plant.

The definitions can apply to the three physical items, or SSCs, which make up the separate facilities that comprise the entire plant. The definitions recognize the logical progression from

developing and proving attributes at less than prototypical conditions, to more integrated tests of the SSCs at prototypical conditions. Table 5 presents the TRL generic definitions from Ref. 7.

Table 5: Technology Readiness Level Definitions

Rating Level	Technology Readiness Level Definition
1	**Basic principles observed** and reported in white papers, industry literature, lab reports, etc. Scientific research without well defined application.
2	**Technology concept and application formulated.** Issues related to performance identified. Issues related to technology concept have been identified. Paper studies indicate potentially viable system operation.
3	**Proof-of-concept:** Analytical and experimental critical function and/or characteristic proven in laboratory. Technology or component tested at laboratory scale to identify/screen potential viability in anticipated service.
4	**Technology or Component is tested at bench scale to** demonstrate technical feasibility and functionality. For analytical modeling, use generally recognized benchmarked computational methods and traceable material properties.
5	**Component demonstrated at experimental scale in relevant environment**. Components have been defined, acceptable technologies identified and technology issues quantified for the relevant environment. Demonstration methods include analyses, verification, tests, and inspection.
6	**Components have been integrated into a subsystem** and demonstrated at a pilot scale in a relevant environment.
7	**Subsystem integrated into a system** for integrated engineering scale demonstration in a relevant environment.
8	**Integrated prototype of the system is demonstrated** in its operational environment with the appropriate number and duration of tests and at the required levels of test rigor and quality assurance. Analyses, if used support extension of demonstration to all design conditions. Analysis methods verified and validated. Technology issues resolved pending qualification (for nuclear application, if required). Demonstrated readiness for hot startup
9	**The project is in final configuration** tested and demonstrated in operational environment.
10	**Commercial-scale demonstration** is achieved. Technological risks minimized by multiple units built and running through several years of service cycles.

The above definitions are generic in application to SSCs. For the level of detail in this report, all SSCs are systems or collections of systems. Definitions referring to subsystems or components or definitions keyed to scale of the demonstration can not be applied where demonstration of the technology requires integrated system function. For such systems the following are alternates to the Table 5 definitions for TRL-6 and TRL-7.

Table 6: Technology Readiness Level Alternate Definitions

	As in Table 5	Changed
6	**Components have been integrated into a subsystem** and demonstrated at a pilot scale in a relevant environment.	Model, test article (not prototype) or similar SSC tested in relevant environment
7	**Subsystem integrated into a system** for integrated engineering scale demonstration in a relevant environment.	• Prototype or prototypic section tested in relevant environment - or - • Model, test article or similar SSC tested in operational environment

5.0 Rating Sheet and Instructions for Use

5.1 Rating Sheet

A Rating Sheet has been prepared to develop the TRL and DRL rating level and the basis for each. This sheet is presented below in Figure 1. Examples of completed forms may be found in Appendix A. Instructions for completing the form are included in Section 5.2 below.

Figure 1: Rating Sheet

TRL/DRL Rating Sheet				
P B M R   Document Number:				Revision:
☐ Facility ☐ System ☐ Structure ☐ Subsystem ☐ Component				
Title:				
Description:				
Facility: ☐ NHSF ☐ PCF ☐ BOP				
ISSCTBS:			WBS:	
Design Readiness Level				
	Next Lower Rating Level	Rating	Next Higher Rating Level	
Generic Definitions *(abbreviated)*				
DRL				
Basis for Rating (Attach additional sheets as needed)				
Technology Readiness Level				
	Next Lower Rating Level	Rating	Next Higher Rating Level	

Generic Definitions *(abbreviated)*			
TRL			

Basis for Rating (Attach additional sheets as needed)

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

Actions (list all)	Schedule	Cost (k$)

DDN(s) supported:

References (incl. technology Case File):

Subject Matter Expert Making Determination:

Date:	Originating Organization:

Rev. JAN09, DTA

5.2 Instructions for Use of the Rating Sheet

This section provides guidance for completing the various fields of the generic DRL and TRL readiness assessment Rating Sheet. In addition, the instructions illustrate the overall process that was developed and implemented in completing the DRL and TRL assessments for the various SSCs under consideration for NGNP and documented in this report.

Document Number & Revision – Each form was considered to be a separate document for this phase of the DRL and TRL assignments, but the collection of forms could also be maintained as pages of one document. In later stages of the design development is assumed that document numbers will be given by a document control authority. It is not intended that the numbers have to be significant or sequential. For the drafts in Appendix A, arbitrary numbering has been assigned.

Revision number (Rev.) will be tracked once the document control authority is in place. For the drafts in Appendix A, "002" is used, because "000" was used in the initial TRL & DRL report and "001" would be the Rating Sheets in the intervening TDRM report.

Structure, Major System, Subsystem or Component – This is a set of check boxes to indicate whether the form is being filled-in for a SSC. Systems are differentiated between major systems and other systems. Major systems for the NGNP are identified in Preconceptual Design Report (Ref. 1).

Title – The Preconceptual Design Report (Ref. 1) provides a tabular listing of the critical SSCs identified for the NGNP. An updated version of this listing is included as Table 7 in Section 6 of this document. Critical SSCs are defined as those components that are not commercially available or do not have proven industry experience.

Description – This is a brief description of the critical SSC for the purpose of refreshing the reader's reference.

Facility – The Preconceptual Design Report (Ref. 1) defines the organizational structure of the plant. This is a set of check boxes to indicate into which of the major divisions of the plant this particular critical SSC belongs. The 750-800°C NGNP is comprised of two facilities and the Balance of Plant (BOP). The two facilities are the Nuclear Heat Supply Facility and the Power Conversion Facility. Each facility and the BOP are made up of two parts: systems and buildings & structures. One overall system is associated with each facility, and within each overall system are several major systems. The overall systems are the Nuclear Heat Supply System (NHSS), the Power Conversion System (PCS) and the BOP Systems. The subsystems within these three overall systems are itemized in an appendix in the Preconceptual Design Report (Ref. 1).

WBS No. – The WBS number will orient the reader to the location of the particular SSC more specifically in the plant organization than just naming its facility. The WBS is left blank for the present for the drafts in Appendix A, because the numbering system at the SSC level is not yet released and will be finalized as part of the Conceptual Design.

Design Readiness Level, Generic Definition – DRLs follow in progression where level 1 corresponds to preconceptual design. Levels 2 and 3 correspond to conceptual design, and 4 and 5 are preliminary design. Levels 6 through 8 are steps in final design. In moving from DRL-1 to DRL-8 the final design progress is from 0% to 100%. DRL-9 is attained when the design has had the benefit of feedback from manufacturing and construction, such as in the form of approved vendor changes, field modifications and as-built details. The final level, DRL-10, integrates operational experience and any further changes from successful operation.

(DRL) Selected Rating – The abbreviated generic definition, a specific definition (if applicable) and the DRL number are highlighted.

(DRL) Next Lower Rating Level – The lower rating level is shown on the form to clarify the position of the selected rating compared to the lower rating. This is to serve as a check that the selection is valid. The abbreviated generic definition, a specific definition (if applicable) and the DRL number for the level below are shown.

(DRL) Next Higher Rating Level – The higher rating level is shown on the form to clarify the position of the selected rating compared to the next rating. This is to serve as an indication of the next needed development tasks. The abbreviated generic definition, a specific definition (if applicable) and the DRL number for the level above are shown.

Specific Definition – For some critical SSCs the generic definitions are too broad and by its nature the particular critical SSC needs a more detailed and specific definition. For example, this is the case with the nuclear fuel, which has specific definitions for design and technology readiness that utilize terms from nuclear engineering and uses terms related to nuclear licensing.

Basis for Rating – In this box the justification for the selection is to be summarized in three to five lines. The determination is to be made based upon the state of design and the definitions of DRLs. The basis can state why the next higher level has not been attained. This is in contrast to the "Path Forward on the Technology Roadmap" box, below, where the emphasis is to be on the programmatic approach to the next and higher levels. The generic definition is usually sufficient, but for some critical SSCs a specific definition applies.

Technology Readiness Level, Generic Definition – TRLs follow a sequence similar to DRLs from no technology identified through levels 1 through 3 in which the technical concept is developed and proven. Levels 4 through 7 are separately defined steps of validation, demonstration, learning and

proof-of-engineering principle. Levels 8 and 9 are steps in demonstration and qualification in the form of the final design and in the operational environment of the object application.

Much of the presently non-commercial technology for the NGNP is already in development or has been demonstrated in other high-temperature gas-cooled nuclear reactor experimental and demonstration plants. This is not a unique situation, and it has a parallel in the NASA TRL definitions where a system or component has flown on another mission but is yet to be qualified for the mission that is the object of the ranking. The generic definition of TRL-6 is used to identify a technology that has been used in a relevant environment but in another configuration or in another application.

(TRL) Selected Rating – The abbreviated generic definition, a specific definition (if applicable) and the TRL number are highlighted.

(TRL) Next Lower Rating Level – The lower rating level is shown on the form to clarify the position of the selected rating compared to the lower rating. This is to serve as a check that the selection is valid. The abbreviated generic definition, a specific definition (if applicable) and the TRL number for the level below are shown.

(TRL) Next Higher Rating Level – The higher rating level is shown on the form to clarify the position of the selected rating compared to the next rating. This is to serve as an indication of the next needed development tasks. The abbreviated generic definition, a specific definition (if applicable) and the TRL number for the level above are shown.

Basis for Rating – The DRLs and TRLs as defined are applied distinctly differently. The DRLs are applied to the NGNP design re-defined by Reference 9. The levels track the designs that are in hand among the WEC team. The TRLs are selected based on known technology from documented sources. For TRLs the rankings account for results from pebble bed reactor development in Germany and China and from the overall HTGR experience elsewhere.

The Approach to Reach the Next Level (TRL) – A Technology Development (R&D) Plan for the PBMR NGNP was prepared as Section 16 of the Preconceptual Design Report and has been expanded in the TDRMs (Ref. 8). Included in these are the highest-priority enabling technology development activities required for the design, licensing, construction and operation of the NGNP. In developing these plans, the approach was to challenge the lead engineers of the major facilities, the NHSF and PCF, to identify DDNs for the "enabling" technologies, as noted in previous sections. These same lead engineers then prepared high level R&D plans that respond to the DDNs with appropriate scope, schedule and estimated costs.

Actions – As shown in the Rating Sheets, the documented TRLs represent the next step in the process of refining the Technology Development Plan. This box in the TRL/DRL form is completed with a brief summary of the path forward for the individual critical SSC. The Path Forward summary on

the form can be prepared when the Technology Development Plan is next revised, and this process would be repeated as the technology matures in increasing TRL values.

DDN Supported – Design Data Needs (DDNs) have been defined by the engineers responsible for each facility and overall system. These DDNs are documented in the respective design sections of the Preconceptual Design Report. The DRL/TRL form has a box for the listing of reference DDNs for each critical SSC. The correspondence between DDNs and DRL/TRLs is not direct. Some TRLs apply to components and specific design needs and others more broadly to needs for design of a system. Some SSCs may not have any DDNs because no data need has yet been defined for the technology development program. Finally, some DDNs are not addressed by advances in technology, for example design methods development or needed codes and standards.

References (incl. technology Case File) – Reference document in support of the TRL level and subsequent maturation activities are listed here to serve as input to the TRL review board that will verify the listed TRL level.

Subject Matter Expert Making Determination, Date and Originating Organization – The format of this section of the form will be revised to suit the ultimate document control system.

6.0 DRL & TRL Ratings

6.1 SSCs List and Summary of Ratings

Using the generic form presented in Section 5, forms were developed for each of the SSCs identified by the WEC Team in Section 3 of their Preconceptual Design Report (Ref. 1) and modified in the TDRM Report (Ref, 8). These completed forms may be found in Appendix A. Table 7 presents a summary of both DRL and TRL ratings, as documented in the Rating Sheets. The organization of the SSCs generally follows the work breakdown structure presented in the Preconceptual Design Report, and is organized by facility, system and system component.

Table 7: Summary of Ratings

Doc #	Critical Structure, System or Component	DRL	TRL
	Nuclear Heat Supply Facility		
	Nuclear Heat Supply System		
001	Reactor Unit System	3	4
002	Fuel Elements (Spheres)	5	7
004	Core Structure Ceramics - graphite	5	6
005	Core Structure Ceramics - ceramic, composite, *etc.*	4	4
006	Reactivity Control Systems	5	6
007	Reserve Shutdown System	5	6
009	Core Conditioning System	5	6
010	Reactor Cavity Cooling System	4	6
011	Fuel Handling and Storage System	5	5
013	Primary Heat Transport System (PHTS)	1	3
014	PHTS Circulator	2	6
015	PHTS Valve	2	6
016	Intermediate Heat Exchanger (IHX) - Compact, Metallic	1	3
017	IHX Metallic Compact Core	2	3
018	IHX Internal Ducts, Headers, Supports and Insulation	1	3
019	IHX Vessel, Supports and Insulation	2	7
024	PHTS Piping	3	4
026	Piping Internal Ducts, Supports and Insulation	3	4
027	Secondary Heat transport System	1	4
028	SHTS Circulator	2	6
029	SHTS Piping	3	4
031	Piping Internal Ducts, Supports and Insulation	3	4

Doc #	Critical Structure, System or Component	DRL	TRL
	Nuclear Heat Supply System Buildings and Structures		
	none identified	NA	NA
	Power Conversion Facility		
	Power Conversion System		
048	Main Steam System	2	6
049	Steam generator	2	6
	Power Conversion System Buildings and Structures		
	None Identified	NA	NA
	Balance of Plant		
	Balance of Plant Systems		
	None Identified	NA	NA
	Balance of Plant Buildings and Structures		
	None Identified	NA	NA

Note that SSCs at a higher level of indenture can have a lower DRL than the SSCs of which they are comprised. However, the TRL of an SSC is, by definition, the TRL of its lowest element.

6.2 Changes from Earlier Critical SSC Lists

Following are brief descriptions of the changes to TRL rating from the initial issue of this report. The "Doc #" numbers in the leftmost column of Table 7 are the same as in the corresponding table of the initial issue, and so because of changes made they are discontinuous. In the following sections these numbers are used to identify the SSCs with changed ratings.

6.2.1 Changes from TDRMs

SSCs 017, 019, 026 and 031 were revised in the past TDRM exercise (Ref. 8). SSCs 013, 016, 024, 027 and 029 changed because one or more of the SSCs at a lower indenture level changed due to the TDRM work.

Two SSCs were deleted in the past TDRM exercise. These were the Core Barrel Assembly (003) and the Helium Services System (012). They were considered to be TRL-8 and not critical SSCs.

6.2.2 Review since TDRM Report

In the period of time since the preparation of the TDRM Report (Ref. 8) which expanded the SSC list and revised TRL levels, the conceptual design phase has progressed to the point of including additional system engineers with expertise in their respective technical areas. Upon their review of this report changes are made to some TRLs. SSC 011 has been given lower TRL assessments and SSC 018 given one higher than in the initial report.

6.2.3 Plant Configuration Change

The change in the design to include one IHX and no Hydrogen Production Facility and Hydrogen Production System (HPS) results in two SSCs being deleted from the NHSS design and removed from the critical SSC list. These are the Ceramic IHX and the SHTS Flow Coupling and Mixer. These were SSCs numbered 020 through 023 and number 032.

Removal of the HPS eliminates SSCs numbered 033 through 047. However, the hydrogen production DRLs and TRLs were reevaluated since the initial issue of this report, and the results can be found in Ref. 11.

6.2.4 Reactor Outlet Temperature

The change of ROT to 750 - 800°C has affected four SSCs. SSC number 002, the Reactor Fuel Element changes from TRL-6 to TRL-7. The Fuel Element is up-rated because operation of the similar fuel elements in other pebble bed reactors is a non-prototypic test in the operational environment for this temperature range.

Three SSCs were re-rated TRL-8 and deleted from the list of critical SSCs as a consequence of the ROT change. These are the Reactor Pressure Vessel and the PHTS and SHTS Pressure Boundary Piping. These were SSCs numbered 008, 025 and 030.

Appendix A - Completed DRL & TRL Rating Sheets for Critical SSCs: NGNP Steam Production at 750-800°C

TRL/DRL Rating Sheet

Document Number: **001** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Reactor Unit System**

Description:

The Reactor Unit System consists of everything within the reactor vessel, comprising the fueled core including the fuel elements – the core reflector, core support structure, flow channels, the reactivity control systems and the reactor pressure vessel.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Conceptual Design.	Complete Conceptual Design.	Initiate Preliminary Design.
DRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

The Reactor Unit design is to be essentially the same as that for the PBMR DPP. Preliminary design for DPP is underway, but design of the NGNP is at a more conceptual stage, particularly in the configuration of the Reactor Pressure Vessel.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Proof-of-concept in laboratory or analytical model.	Component or system breadboard in laboratory environment or analytical model.	Component or system breadboard validates the concept in relevant environment.
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

There is operating experience with PBMR reactors, but the technology for the Reactor Unit as a whole is not fully validated. Particularly, technology for the ceramic and composite core structural materials is beyond proof-of-concept, and so above TRL-3, but lacks experimental validation, and so is not TRL-5. See DRL/TRL Document Number 005, Core Structure Ceramics - ceramic, composite, *etc.*.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen / rev. C. Bester & G. Jansen van Rensburg		
Date: 12SEP07 rev. 20APR09	Originating Organization: Technology Insights / rev. Pebble Bed Modular Reactor (Pty) Ltd.	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **002** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Fuel Elements (Spheres)**

Description:

The "pebbles", comprising the nuclear reactor core; part of the Reactor Unit System; made up of Triple Coated Isotropic (TRISO) particles containing Low Enriched Uranium (LEU) kernels, embedded in a pressed graphite matrix.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

Fuel element design for NGNP will be identical to fuel element for the DPP. Preliminary design for DPP fuel element is complete and final design is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment	Integrated prototype of the system is demonstrated in its operational environment
Specific Definitions *(as developed in TRL & DRL Report, Rev. 0)*	Fuel fabrication processes for kernels, coatings and sphere formation have been transferred from the	Pebble bed reactors have been built and operated in similar environment to NGNP. Commitments made for fuel irradiation tests in Dutch Petten HFR	The planned fuel qualification test program for DPP (NGNP) is completed. Accident simulation tests completed

	earlier German manufacturer, NUKEM, to the PBMR facility in SA. An irradiation test program has been planned for confirming that the fuel quality from the PBMR fuel plant is equal to the quality of the earlier German fuel.	and Russian IVV-2M reactors. Commitments made for source materials for sphere matrix, which duplicate materials proven in German program.	on irradiated production fuel.
TRL	6	**7**	8

Basis for Rating (Attach additional sheets as needed)

Pebble bed reactors have been built and operated with comparable performance capability (*e.g.* AVR/THTR/HTR-10). The Ref, 1, 2 and 3 reports and special studies have been evaluated.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

Fuel testing and qualification has been identified in DDNs. Condition: NGNP to operate fuel system within fuel qualification envelope.

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Production fuel sphere irradiation in Russia (INM). • Production fuel sphere heat-up tests at 1600°C and 1800°C. • Fuel Graphite irradiation tests.	• Starting FY2012 • Following irradiation tests • Starting FY2012	Costs not provided due to business confidentiality

DDN(s) supported:

NHS-01-01, NHS-01-02 and NHS-01-03

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Preconceptual Design Report, Section 5: Reactor Fuel, NGNP-05-RPT-001, APR07.

Ref. 2 - NGNP Conceptual Design Study: Reactor Parametric Study, NGNP-NHS-PBMR001, AUG08.

Ref. 3 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 11: Fuel Elements, NGNP-CTF MTECH-TDRM-011, Rev. 1, DEC08.

Subject Matter Expert Making Determination: D. Allen / rev. H. van der Merwe

Date: 12SEP07
rev. 20APR09

Originating Organization:
Technology Insights / rev. Pebble Bed Modular Reactor (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **004** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Core Structure – Graphite**

Description:

The graphite components within the Reactor Vessel, principally the bottom, side, top and central reflector blocks; part of the Reactor Unit System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

Graphite core internals for NGNP will be identical to core internals for the DPP. Preliminary design for DPP core internals is complete, and final design is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment
Specific Definitions -- systems	same	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

There is operating experience with graphite core internals from the several graphite moderated and gas-cooled nuclear reactors, but none is prototypical of the PBMR. Particularly the design basis is the German designs for the Thorium High Temperature Reactor (THTR) and later reactors, but these are not considered prototypical. If they were to be considered prototypical, then this is TRL-7. It also can be elevated to TRL-7 when PBMR DPP graphite qualification is complete. The additional graphite technology qualification specifically for NGNP is intended to bring the rating from TRL-7 to TRL-8.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

see Ref. 1

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
see Ref. 1		

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 12: Core Structure Ceramics, NGNP-CTF MTECH-TDRM-012, Rev. 1, DEC08.

Subject Matter Expert Making Determination: D. Allen / rev. Mark Mitchell

Date: 16AUG07
Rev. 20APR09

Originating Organization: Technology Insights / rev. PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw® Document Number: **005** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Core Structure Ceramics - ceramic, composite, *etc.***

Description:

The ceramic and composite components within the Reactor Vessel, including the Lateral Restraint Straps, Tie Rod assemblies and insulation; part of the Reactor Unit System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Complete Conceptual Design.	Initiate Preliminary Design.	Complete Preliminary Design.
DRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

Composite and ceramic core internals for NGNP will be similar to core internals for the DPP. Preliminary design for DPP is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Proof-of-concept in laboratory or analytical model.	Component or system breadboard in laboratory environment or analytical model.	Component or system breadboard validates the concept in relevant environment.
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

Operating experience with other HTRs does not apply to advanced materials, such as

composites. Technology is beyond proof-of-concept, and so above TRL-3, but lacks experimental validation, and so is not TRL-5.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) see Ref 1 Plan is to be updated in the forthcoming TDRM task.		
Actions (list all)	Schedule	Cost (k$)
see Ref. 1		
DDN(s) supported:		
References (incl. technology Case File): Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 12: Core Structure Ceramics, NGNP-CTF MTECH-TDRM-012, Rev. 1, DEC08.		
Subject Matter Expert Making Determination: D. Allen / rev. Mark Mitchell		
Date: 10AUG07 Rev. 20APR09	Originating Organization: Technology Insights / rev. PBMR (Pty) Ltd.	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **006** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Reactivity Control System**

Description:

Reactivity Control System consists of the Control Rods and the Shutdown Rods; part of the Reactor Unit System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

Reactivity control system for NGNP will be identical to reactivity control system for the DPP. Preliminary design for DPP reactivity control system is complete, and final design is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment
Specific Definitions -- systems	same	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

There is operating experience with similar reactivity control systems in other gas-cooled, graphite-moderated reactors, particularly Fort Saint Vrain, the Japanese HTTR and the German THTR, but those are not prototypical of the PBMR. The RCS can have a TRL-7 when the present HTF test program provides demonstration. The TRL can be elevated to a TRL-8 when PBMR DPP operates.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

The present HTF testing program will suffice to validate the technology at TRL-7. For the NGNP, analyses need to be performed to determine the operating conditions to support testing and move to TRL-8.

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Functional/Performance testing in the HTF • Materials characterization (DDN COMP-01-02, "Characterize Race Track Strap and Tie Rod Materials", Ref. 1)	FY2009 - FY2012	See Ref. 2

DDN(s) supported:

COMP-01-02

References (incl. technology Case File):

Ref. 1 - NGNP Conceptual Design Study: Composites R&D Technical Issues, NGNP-NHS TI-COMP, 31OCT08, Appendix 1.

Ref. 2 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 14: Reactivity Control System, NGNP-CTF MTECH-TDRM-014, DEC08.

Subject Matter Expert Making Determination: D. Allen / P. Coetzer

Date: 12SEP07 rev. SEP08 rev. 20APR09	Originating Organization: Technology Insights / rev. PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **007** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Reserve Shutdown System**

Description:

Reserve Shutdown System consists of the Small Absorber Spheres and their associated storage, delivery and recovery equipment; part of the Reactor Unit System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

Reserve Shutdown System (RSS) for NGNP will be identical to the RSS for the DPP. Preliminary design for DPP RSS is complete, and final design is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment
Specific Definitions -- systems	same	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

Operating experience exists for similar shutdown systems in other gas-cooled, graphite-moderated reactor applications, in particular Fort Saint Vrain and the Japanese HTTR, as well as results from the German HTR-Modul qualification program.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

The DPP RSS can be at TRL-7 when the present HTF test program provides demonstration and a TRL-8 when DPP commissioning is complete.

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Functional/Performance testing of the RSS in the HTF o SAS Valve actuation o Insertion and transportation at 90 bar, 700°C o Hot drop test (Pre-heated SAS at 900°C) o SAS thermal induced lock-up test in discharge pipe	FY2009 - FY2012	See Ref. 1

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 13: Reserve Shutdown System, NGNP-CTF MTECH-TDRM-013, Rev. 1, DEC08, Section C.1.4.

Subject Matter Expert Making Determination: D. Allen / rev. S. Pieterse

Date: 12SEP07 rev. SEP08	Originating Organization: Technology Insights / rev. Pebble Bed Modular Reactor (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw® Document Number: **009** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Core Conditioning System**

Description:

The Core Conditioning System removes decay heat from the reactor when the PHTS blower is not functional or during maintenance conditions.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

The Core Conditioning System for NGNP will be identical to the Core Conditioning System for the DPP. Preliminary design for the DPP Core Conditioning System is complete, and final design is underway. Design issues remain in the area of helium valve actuators and certification of instrumentation.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Subsystem integrated into a system and demonstrated in a relevant environment	Components have been integrated in a subsystem and demonstrated
Specific Definitions - for systems	same	Similar SSC tested in operational environment, or prototype tested in relevant environment	Similar SSC tested in relevant environment

TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

There is operating experience with a similar system for HTF. CCS can be TRL-7 when appropriate tests are complete at HTF.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 1

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
see Ref. 1		

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 15: Core Conditioning System, NGNP-CTF MTECH-TDRM-015, Rev. 1, DEC08.

Subject Matter Expert Making Determination: D. Allen

Date: 09AUG07 | Originating Organization: Technology Insights.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **010** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Reactor Cavity Cooling System**

Description:

The Reactor Cavity Cooling System removes heat from the reactor cavity and limits temperatures of the Reactor Unit System and NHS structure.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Complete Conceptual Design.	Initiate Preliminary Design.	Complete Preliminary Design.
DRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

The Reactor Cavity Cooling System for NGNP will be identical to the Reactor Cavity Cooling System for the DPP. Preliminary design for the DPP Reactor Cavity Cooling System is underway.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Subsystem integrated into a system and demonstrated in a relevant environment	Components have been integrated in a subsystem and demonstrated
	same	Similar SSC tested in operational environment, or prototype tested in relevant environment	Similar SSC tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

The integrated system has been demonstrated through analysis using two independent internationally recognized software codes (RELAP5™ and SPECTRA™) to evaluate the passive operation of the RCCS. To date, both software codes have indicated that the RCCS will adequately satisfy its requirements. However, due to the complexities of modeling natural convection driven two-phase flow in this application, the verification and validation offered by the code developers require careful consideration. Failure to validate the codes for this specific application could require some verification testing and may result in a re-assessment of the TRL level.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 1

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
See Ref. 1	FY 2009 - FY 2012	

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 16: Reactor Cavity Cooling System, NGNP-CTF MTECH-TDRM-016, Rev. 1, DEC08.

Subject Matter Expert Making Determination: D. Allen / rev. I. Drodskie, W. Grant & T. Baard

Date: 22AUG07 rev. SEP08 rev. 30MAR09	Originating Organization: Technology Insights / revs. PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw® Document Number: **011** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Fuel Handling and Storage System (FHSS)**

Description:

The Fuel Handling and Storage System stores and replenishes the system with fresh fuel elements, circulates used fuel elements through the reactor core, loads and unloads the core and stores spent fuel elements.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Preliminary Design.	Complete Preliminary Design.	Initiate Final Design.
DRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

The Fuel Handling and Storage System for NGNP will be identical to the Fuel Handling and Storage System for the DPP. Preliminary design for the Fuel Handling System is complete, and final design is underway, with the exception of the Fuel Storage System. The Fuel Storage System is entering a second iteration of preliminary design to embody an alternative storage methodology.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Technology or component testing demonstrates feasibility and functionality	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated
Specific Definitions - for systems	same	same	Similar SSC tested in relevant environment

TRL	4	**5**	6

Basis for Rating (Attach additional sheets as needed)

A pebble bed reactor fuel handling system has been successfully operated in THTR. THTR is the basis for the design of the FHSS with the exception of the Burnup Measuring System (BUMS).

The BUMS requires development before moving beyond the experimental phase, and so until then the FHSS can not advance beyond TRL-5.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

Plan is to be included in the forthcoming TDRM update task.

Actions (list all)	Schedule	Cost (k$)
To be developed. Planning is to be included in the forthcoming TDRM update task		

DDN(s) supported:

none

References (incl. technology Case File):

Subject Matter Expert Making Determination: D. Allen / C. Bruwer

Date: 20APR09	Originating Organization: Technology Insights / PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **013** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Primary Heat Transport System (PHTS)**

Description:
The heat transport circuit between the Reactor Unit and the secondary heat transport circuit.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*		Design concept identified.	Initiate Conceptual Design.
DRL		**1**	2

Basis for Rating (Attach additional sheets as needed)

Requirements and configuration for NGNP were done in pre-conceptual design phase. Design readiness is limited by the IHX design development.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Technology concept and application formulated.	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality
TRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

There is operating experience with gas circuits from other reactors built and tested. However, the technology readiness of the IHX limits the system TRL. See DRL/TRL document number 016, IHX, for basis of rating.

Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 20MAR09	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

PBMR Shaw Document Number: **014** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **PHTS Circulator**

Description:

The helium circulator (blower), which provides the pressure difference to drive the primary helium heat transport system, the circulator motor and auxiliaries form part of the Primary Heat Transport System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

The helium circulators have not been designed. Nominal performance requirements are established. Requirements and configuration for NGNP were done in pre-conceptual design phase.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment
Specific Definitions - for systems	same	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

There is relevant operating experience with gas circulators in several gas-cooled reactors that have been built and tested. There is experience with similar helium circulators in THTR and HTTR, and both have operated at the operating conditions that are relevant for NGNP.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

Following the selection of a reference circulator design, the circulator components that require technology development will be validated with supporting single effect tests. After that, the circulator subsystem will be validated with a partial scale or full-scale integrated test.

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Validation of EMBs, if they are selected over oil bearings. • Validation of primary boundary external rotating seals, if the electric motor is located outside • Integrated test of a partial or full-scale model of the circulator subsystem	• August 2010 • August 2010 • August 2013	See Ref. 1

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 3: PHTS Circulator, NGNP-CTF MTECH-TDRM-003, Rev. 1, DEC08, Section C3.

Subject Matter Expert Making Determination: G. Baccaglini	
Date: 03SEP08	Originating Organization: Technology Insights

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw Document Number: **015** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **PHTS Valve**

Description:

The PHTS Valve prevents backflow through the primary heat transport system; part of the Primary Heat Transport System.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

A conceptual level design decision has been made (Ref. 1) that the valve will be integrated into the PHTS Circulator, and the PHTS Circulator has not been designed. Nominal performance requirements are established. Requirements and configuration for NGNP were done in pre-conceptual design phase.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment
Specific Definitions -- systems	same	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment

TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

There is experience with similar helium valves in Fort Saint Vrain and HTTR, and both have operated at the operating conditions that are relevant for NGNP.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See 014, PHTS Circulator

Actions (list all)	Schedule	Cost (k$)
See 014, PHTS Circulator		

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 3: PHTS Circulator, NGNP-CTF MTECH-TDRM-003, Rev. 1, DEC08, Section C3.

Subject Matter Expert Making Determination: D. Allen

Date: 15AUG07
rev. 20MAR09

Originating Organization: Technology Insights

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw Document Number: **016** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **Intermediate Heat Exchanger (IHX) – Compact, Metallic**

Description:

The IHX is the site of heat transfer between the primary and secondary heat transport circuits; part of the Primary Heat Transport System (PHTS).

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*		Design concept identified.	Initiate Conceptual Design.
DRL		**1**	2

Basis for Rating (Attach additional sheets as needed)

In the Preconceptual Design phase the IHX has not been designed beyond conceptual arrangement and performance parameters.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Technology concept and application formulated.	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality
TRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

The technology for compact metallic heat exchangers is formulated but the concept of an integrated unit is limited to concepts. The technology readiness of the IHX Core and IHX Internals limit the IHX system TRL. See DRL/TRL Document Numbers 017, IHX Core, and 018, IHX Internal Ducts,

Headers, *etc.*, for basis of rating.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 20MAR09	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw Document Number: **017** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **IHX Compact, Metallic Core**

Description:

The heat exchanger section of the IHX, for which a compact, micro channel printed-circuit or plate fin design has been tentatively selected (Ref. 3); part of Intermediate Heat Exchanger (IHX) - Compact, Metallic.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

The IHX has not been designed, beyond selection of a compact metallic configuration (Ref. 3). Nominal performance requirements are established. Requirements and configuration for NGNP were done in pre-conceptual design phase

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Technology concept and application formulated.	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality
TRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

There is experience with similar compact heat exchange cores with applicable technology, but these are not identical to the NGNP IHX core in design or materials, nor have they been used in a relevant environment.

Designs and materials for an IHX operating at 760°C were proposed and evaluated in recent studies reported in Refs. 1, 2 and 3.

There is insufficient materials data related the corrosion of thin sections to support a statement of full-life functionality for the compact core design.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 4

IHX is presently subject of the "HTS/IHX Development and Trade Studies" task, which may alter development plans, and the IHX development plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Alloy 800H and Hastelloy X Material Specifications and Procurement • Database for Brazed and Diffusion Bonded Alloy 800H and Hastelloy X • Alloy 800H and Hastelloy X High Temperature Materials Properties • Effects of Thermal Aging and Environment on Alloy 800H and Hastelloy X Properties • Effects of Environmental Exposure on Alloy 800H and Hastelloy X Braze and Diffusion Bonded Joints • Effects of Grain Size and Section Thickness on Alloy 800H and Hastelloy X Properties • Corrosion Allowances for Alloy 800H and Hastelloy X • ASME Section III Materials Code Cases for Alloy 800H and Hastelloy X • Thermal/Fluid Modeling Methods • Methods for Stress/Strain Modeling • Criteria for Structural Integrity • Performance Modeling Methods	2009 through 2015	See Ref. 4

DDN(s) supported:

HTS-01-13, HTS-01-14, HTS-01-15, HTS-01-16, HTS-01-17, HTS-01-16, HTS-01-19, HTS-01-22, HTS-01-23, HTS-01-24, HTS-01-25, HTS-01-26, HTS-01-27, HTS-01-28, HTS-01-29, HTS-01-30

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Preconceptual Design Report, Special Study 20.3: High Temperature Process Heat Transfer and Transport, NGNP-20-RPT-003, JAN07.

Ref. 2 - NGNP and Hydrogen Production, Preconceptual Design Report, Section 6: Heat Transport System, NGNP-06-RPT-001, APR07.

Ref. 3 - NGNP Conceptual Design Study: IHX and Heat Transport System, NGNP-HTS-RPT-TI001, APR08.

Ref. 4 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 5: Intermediate Heat Exchanger B, NGNP-CTF MTECH-TDRM-005, Rev. 1, DEC08.

Subject Matter Expert Making Determination: P. Rittenhouse / rev. Y. Maharaj

Date: 16SEP08 rev. 25MAR09	Originating Organization: Technology Insights / rev. PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw Document Number: **018** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **IHX Internal Ducts, Headers, Supports and Insulation**

Description:

The internals of the IHX vessel: 1) the ducts and headers that connect the heat exchanger Core section(s) to the IHX vessel inlet(s) and outlet(s), 2) structure internal to the IHX vessel and 3) insulation internal to the IHX vessel. Part of Intermediate Heat Exchanger (IHX) – Compact, Metallic.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*		Design concept identified.	Initiate Conceptual Design.
DRL		**1**	2

Basis for Rating (Attach additional sheets as needed)

The IHX has not been designed. The conceptual IHX design incorporates active cooling with DPP-like insulation on the primary side and passive insulation on the secondary side Internal configuration and interconnection have not been addressed in any further detail and trade studies are planned.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Technology concept and application formulated.	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality
TRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

Although there have been internal ductwork, supports and insulation in other gas-cooled reactors, these are not similar to what is anticipated for the NGNP IHX. There are design concepts only for the IHX internal headers but not for supports nor for the internal insulation.

Regarding insulation, Microporous insulation (*e.g.*, Microtherm®) is available commercially and believed to be adequate, but has not been adequately tested in a relevant environment.

The TRL-3 level is assigned pending further conceptual design progress to select the technology employed and define the service environment. This is necessary before feasibility can be asserted.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 1

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
See Ref. 1	See Ref. 1	See Ref. 1

DDN(s) supported:

HTS-01-13, HTS-01-14, HTS-01-15, HTS-01-16, HTS-01-17, HTS-01-18, HTS-01-19

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 5: Intermediate Heat Exchanger B, NGNP-CTF MTECH-TDRM-005, Rev. 1, DEC08.

Subject Matter Expert Making Determination: D. Allen / S. Penfield / rev. Y. Maharaj

Date: 10AUG07
rev. 20APR09

Originating Organization: Technology Insights / rev. PBMR (Pty) Ltd.

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **019** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **IHX Vessel, Supports and Insulation**

Description:

The IHX pressure vessel, support structure and insulation external to the vessel; part of Intermediate Heat Exchanger (IHX) – Compact, Metallic.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

The IHX vessel, supports and insulation have not been designed. Nominal performance requirements are established. Requirements and configuration for NGNP were done in pre-conceptual design phase.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Components have been integrated in a subsystem and demonstrated	Subsystem integrated into a system and demonstrated in a relevant environment	Integrated prototype of the system is demonstrated in its operational environment
Specific Definitions -- systems	Similar SSC tested in relevant environment	Similar SSC tested in operational environment, or prototype tested in relevant environment	same

TRL	6	**7**	8

Basis for Rating (Attach additional sheets as needed)

There is experience with similar vessels and supports for gas-cooled reactors with metallic pressure vessels, such as HTTR and HTR-10, in the same thermal environment as the NGNP with 750-800°C ROT.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 1

Actions (list all)	Schedule	Cost (k$)
See Ref. 1	See Ref. 1	See Ref. 1

DDN(s) supported:

none

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 5: Intermediate Heat Exchanger B, NGNP-CTF MTECH-TDRM-005, Rev. 1, DEC08, Section 17.

Subject Matter Expert Making Determination: D. Allen

Date: 09AUG07 rev. 20MAR09	Originating Organization: Technology Insights

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **024** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **PHTS Piping**

Description:

The ductwork and insulation inside piping of the primary heat transport circuit; part of the PHTS Piping (Reactor to IHX - both hot and cold legs).

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS: | WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Conceptual Design.	Complete Conceptual Design.	Initiate Preliminary Design.
DRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

Requirements and configuration for NGNP were done in pre-conceptual design phase. Design readiness is limited by the absence of design development beyond pre-conceptual.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality	Component demonstrated at experimental scale in relevant environment
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

There is experience with similar piping and ducts for gas-cooled reactors with metallic pressure vessels, such as HTTR and HTR-10. However, the technology readiness of the PHTS Piping Internal Ducts, Supports and Insulation limit the system TRL. See DRL/TRL Document Number 026, Piping

Internal Ducts, Supports and Insulation, for basis of rating.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 20MAR09	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **026** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **PHTS Piping - Internal Ducts, Supports and Insulation**

Description:

The ductwork and insulation inside piping of the primary heat transport circuit; part of the PHTS Piping.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Conceptual Design.	Complete Conceptual Design.	Initiate Preliminary Design.
DRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

Ductwork and insulation inside piping for NGNP will be similar to the ductwork and insulation inside piping for the DPP. Preliminary design has not been started for the NGNP. Requirements and configuration for NGNP were done in pre-conceptual design phase.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality	Component demonstrated at experimental scale in relevant environment
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

Microporous insulation (*e.g.*, Microtherm®) is available commercially and believed to be adequate, but has not been adequately tested in a relevant environment. The TRL-4 level is assigned

pending further conceptual design progress to select the technology employed and define the service environment.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Refs. 1, 2 & 3

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• High-Temperature [750-800°C] PHTS piping cooling, liner, and insulation options • Low-Temperature [<300°C] PHTS piping liner and insulation options trade study • Medium-temperature [700-750°C] SHTS piping liner and insulation options trade study • Low-temperature [<250°C] SHTS piping liner and insulation options trade study	2009 through 2010	See Ref. 4

DDN(s) supported:

HTS-04-01

References (incl. technology Case File):

Ref. 1 - NGNP and Hydrogen Production, Preconceptual Design Report, Special Study 20.3: High Temperature Process Heat Transfer and Transport, NGNP-20-RPT-003, JAN07.

Ref. 2 - NGNP and Hydrogen Production, Preconceptual Design Report, Section 6: Heat Transport System, NGNP-06-RPT-001, APR07.

Ref. 3 - NGNP Conceptual Design Study: IHX and Heat Transport System, NGNP-HTS-RPT-TI001, APR08.

Ref. 4 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 6: HTS Piping, NGNP-CTF MTECH-TDRM-006, Rev. 1, DEC08, Section C4.

Subject Matter Expert Making Determination: P. Rittenhouse / S. Penfield / rev. D. Allen

Date: 12SEP08
rev. 20MAR09

Originating Organization: Technology Insights

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **027** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Secondary Heat Transport System (SHTS)**

Description:
The heat transport circuit between the primary heat transport circuit and the PCS.

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*		Design concept identified.	Initiate Conceptual Design.
DRL		**1**	2

Basis for Rating (Attach additional sheets as needed)

Requirements and configuration for NGNP were done in pre-conceptual design phase. Design readiness is limited by the IHX design development.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality	Component demonstrated at experimental scale in relevant environment
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

There is operating experience with gas circuits from other reactors built and tested. However, the technology readiness of the SHTS Piping limits the PHTS system TRL. See DRL/TRL Document Number 029, SHTS Piping, for basis of rating.

Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 20MAR09	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet					
P B M R		Shaw	Document Number: **028**	Revision: **02**	
☐ Facility	☐ Overall System	☐ Major System	☑ System	☐ Subsystem	☐ Component
Title: **SHTS Circulator**					
Description: The helium circulator (blower), which provides the pressure difference to drive the secondary helium heat transport system, the circulator motor and auxiliaries form part of the Secondary Heat Transport System.					
Facility: ☑ NHSF	☐ PCF	☐ BOP			
Refer to the Rating Sheet for the PHTS Circulator (014)					
Subject Matter Expert Making Determination: D. Allen					
Date: 20MAR09	Originating Organization: Technology Insights				

Rev. JAN09, DTA

TRL/DRL Rating Sheet

P B M R Shaw Document Number: **029** Revision: **02**

☐ Facility ☐ Overall System ☐ Major System ☑ System ☐ Subsystem ☐ Component

Title: **SHTS Piping**

Description:

The pipes, ducts and internal insulation of the secondary heat transport circuit from the IHX to the Steam Generator and from the Steam Generator to the IHX; part of the Secondary Heat Transport System (SHTS).

Facility: ☑ NHSF ☐ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Initiate Conceptual Design.	Complete Conceptual Design.	Initiate Preliminary Design.
DRL	2	**3**	4

Basis for Rating (Attach additional sheets as needed)

Requirements and configuration for NGNP were done in pre-conceptual design phase. Design readiness is limited by the absence of design development beyond pre-conceptual.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Concept's critical function and/or characteristic proven	Technology or component testing demonstrates feasibility and functionality	Component demonstrated at experimental scale in relevant environment
TRL	3	**4**	5

Basis for Rating (Attach additional sheets as needed)

There is experience with similar piping and ducts for gas-cooled reactors with metallic pressure vessels, such as HTTR and HTR-10. However, the technology readiness of SHTS Piping Internal Ducts,

Supports and Insulation limit the system TRL. See DRL/TRL Document Number 031, Piping Internal Ducts, Supports and Insulation, for basis of rating.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 20MAR09	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet					
P B M R		Shaw	Document Number: **031**	Revision: **02**	
☐ Facility	☐ Overall System	☐ Major System	☑ System	☐ Subsystem	☐ Component
Title: **SHTS Piping - Internal Ducts, Supports and Insulation**					
Description: The ductwork and insulation inside piping of the secondary heat transport circuit; part of the SHTS Piping.					
Facility: ☑ NHSF	☐ PCF	☐ BOP			
Refer to the Rating Sheet for the PHTS Piping Internal Ducts, Supports and Insulation (026)					
Subject Matter Expert Making Determination: D. Allen					
Date: 20MAR09	Originating Organization: Technology Insights				

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **048** Revision: **02**

☐ Facility ☐ Overall System ☑ Major System ☐ System ☐ Subsystem ☐ Component

Title: **Main Steam System**

Description:

The Main Steam System conveys thermal power from the NHS and generates electric power from it. The system includes the steam generator, main and extraction steam piping and valves, and the steam turbine-generator.

Facility: ☐ NHSF ☑ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

Design thus far is limited to converged heat balances and power output analysis.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Subsystem integrated into a system and demonstrated in a relevant environment	Components have been integrated in a subsystem and demonstrated
Specific Definitions -- systems	same	Similar SSC tested in operational environment, or prototype tested in relevant environment	Similar SSC tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed) Only the Steam Generators are other than completely developed and ready technology. See DRL/TRL Document Number 049, Steam Generator, for basis of rating.		
Outline of a plan to get from current level to next level (Attach additional sheets as needed) NA (see Rating Sheets for constituent systems)		
Actions (list all)	Schedule	Cost (k$)
NA (see Rating Sheets for constituent systems)		
DDN(s) supported: NA (see Rating Sheets for constituent systems)		
References (incl. technology Case File): NA (see Rating Sheets for constituent systems)		
Subject Matter Expert Making Determination: D. Allen		
Date: 14AUG07	Originating Organization: Technology Insights	

Rev. JAN09, DTA

TRL/DRL Rating Sheet

Document Number: **049** Revision: **02**

☐ Facility ☐ System ☐ Structure ☑ Subsystem ☐ Component

Title: **Steam Generator**

Description:

The Steam Generator is the site of energy transfer from helium to the Rankine cycle power generation circuit; part of the Main Steam System within the Power Conversion System.

Facility: ☐ NHSF ☑ PCF ☐ BOP

ISSCTBS:	WBS:

Design Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Design concept identified.	Initiate Conceptual Design.	Complete Conceptual Design.
DRL	1	**2**	3

Basis for Rating (Attach additional sheets as needed)

The Steam Generator design concept was identified in the Preconceptual Design phase and functional & operational requirements are set.

Technology Readiness Level

	Next Lower Rating Level	Rating	Next Higher Rating Level
Generic Definitions *(abbreviated)*	Component demonstrated at experimental scale in relevant environment	Subsystem integrated into a system and demonstrated in a relevant environment	Components have been integrated in a subsystem and demonstrated
Specific Definitions -- systems	same	Similar SSC tested in operational environment, or prototype tested in relevant environment	Similar SSC tested in relevant environment
TRL	5	**6**	7

Basis for Rating (Attach additional sheets as needed)

Steam Generators have been demonstrated in numerous gas-cooled reactors and in other high temperature gas reactors, specifically Peach Bottom, AVR, Fort Saint Vrain, the AGRs, THTR, HTTR and HTR-10, in a thermal environment relevant to the NGNP with 750-800°C ROT. Application of the existing technology and scale-up to the proposed NGNP thermal rating requires testing to reduce risks with the next level.

Outline of a plan to get from current level to next level (Attach additional sheets as needed)

See Ref. 1

Plan is to be updated in the forthcoming TDRM task.

Actions (list all)	Schedule	Cost (k$)
• Development tests • Scale prototype testing in CTF • NGNP Prototype SG	2009 through 2013	TBD

DDN(s) supported:

PCS-01-01 to PCS-01-18

References (incl. technology Case File):

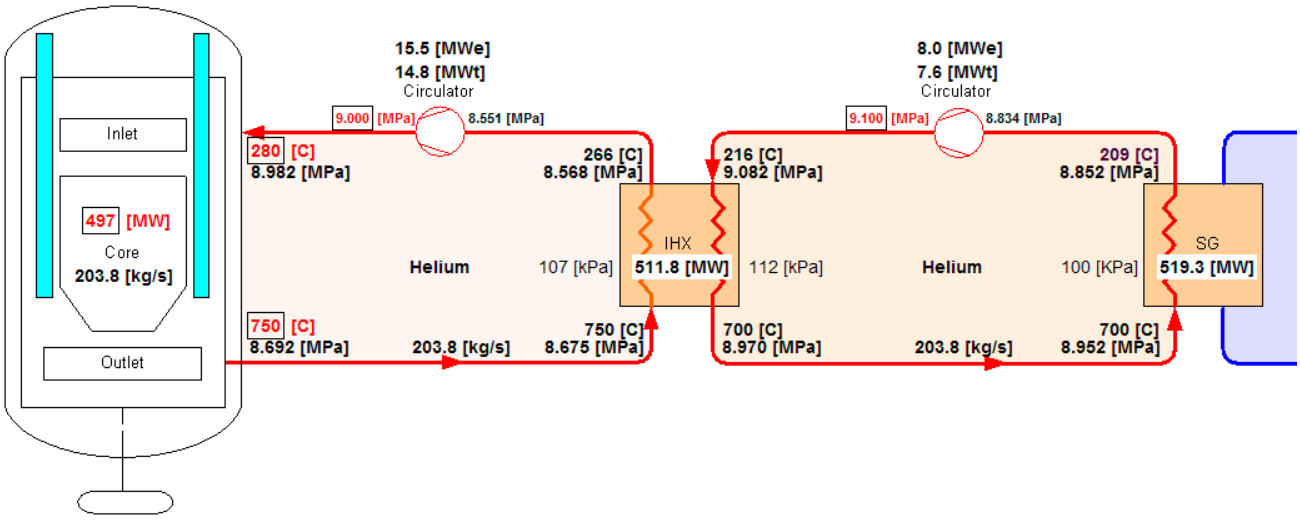
Ref. 1 - NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 9: Power Conversion System, Steam Generator, NGNP-CTF MTECH-TDRM-009, Rev. 1, DEC08.

Subject Matter Expert Making Determination: A. Spring

Date: 18OCT08 rev. 30MAR09	Originating Organization: Westinghouse

Rev. JAN09, DTA

Appendix B - NGNP Reference Design for 750-800°C ROT



From "NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 0: Executive Summary Report", NGNP-CTF MTECH-TDRM-000, Figure 0-3.