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Infrastructure Readiness Assessment for the NGNP

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000	All	Initial issue
001	All	Update of most report sections. Key changes include incorporation of INL comments, verification of preliminary information, incorporation of key reference data, and addition of Section 6, Infrastructure Readiness Summary Table.
002	Table of Acronyms	Added Table of acronyms
002	Section 1.2	Deleted Section
002	Appendix A	Moved previous Section 4.3.1 into Appendix A
002	Various	Addressed minor comments from INL.

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Table of Acronyms

AGC	Advanced Graphite Capsule
AGR	Advanced Gas-cooled Reactor
BLM	Bureau of Land Management
BNFL	British Nuclear Fuels LTD.
DOE	Department of Energy
FOAK	first-of-a-kind
HTGR	High Temperature Gas-cooled Reactor
HTTR	High Temperature engineering Test Reactor
IHX	Intermediate Heat Exchanger
INET	Institute of Nuclear and new Energy Technology
ITER	International Thermo-nuclear Experimental Reactor
JSW	Japan Steel Works
LWR	Light Water Reactor
MHTGR	Modular High Temperature Gas-cooled Reactor
MT	metric ton
NEAC	Nuclear Energy Advisory Committee
NGNP	Next Generation Nuclear Plant
NOAK	Nth-of-a-kind
NRC	Nuclear Regulatory Commission
ODS	oxide dispersion strengthened (metals)
QA	quality assurance
RCCS	Reactor Cavity Cooling System
TBD	To be Determined
THTR	Thorium Hochtemperatur Reaktor
TRISO	Tristructural-isotropic

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Next Generation Nuclear Plant (NGNP) project supports the development, demonstration, and deployment of high temperature gas-cooled reactor (HTGR) technology. The HTGR has the potential for high efficiency electricity production and the supply of high temperature process heat. The NGNP project includes a variety of activities such as fuel development and qualification, materials R&D, design, licensing, and potentially demonstration.

NGNP project Phase 1 activities are currently being performed. At the conclusion of NGNP Phase 1, a review of the project will be performed by the Nuclear Energy Advisory Committee before proceeding with NGNP project Phase 2 (design, licensing, and demonstration). This report is intended to provide one input to that review.

1.1 Infrastructure Readiness Assessment

This report presents an assessment of the infrastructure readiness for NGNP deployment. The assessment is independent of the reactor technology deployed, that is, it does not assume a particular reactor design (prismatic or pebble) as a basis.

In general, the infrastructure readiness assessment examines the current state and plans to address the various infrastructure elements necessary to support deployment of the NGNP. The focus is on industrial capabilities as opposed to laboratory infrastructure or capabilities. It concentrates on the actual infrastructure for construction and start of operations for an NGNP, with an understanding that the same infrastructure could be brought to bear on follow-on HTGR deployment.

Hence, one primary focus is on the adequacy of the infrastructure necessary for near-term deployment of the initial NGNP demonstration plant. However, consideration is also given to the broader infrastructure needed for commercial deployment of a fleet of HTGRs including future more advanced concepts.

Design readiness is not covered in this infrastructure assessment. Design readiness is a serious question and a factor that touches every other aspect of this and other assessments. For example, it is difficult to assess the adequacy of the industrial infrastructure to supply NGNP components when the details of those components are undefined. Nonetheless, the assessments must be made using available information in order to manage risk successfully while allowing the project to move forward in a timely fashion.

This is an infrastructure readiness assessment, not a technology maturity assessment. This assessment assumes that the basic underlying technology is adequately developed. The assessment of technical maturity has been the direct focus of past studies and may be evaluated again outside this assessment. Nonetheless, additional implementation development may be necessary in some cases to industrialize specific technologies.

Fuel supply for the NGNP is not addressed in this assessment. The DOE Advanced Gas-cooled Reactor (AGR) program is facilitating the development and qualification of tristructural-isotropic (TRISO) particle fuel. Industrialization of fuel supply for the NGNP will be required. Industrialization of the fuel supply is a key issue for NGNP and further HTGR deployment, but it is not addressed in this assessment. It will be evaluated elsewhere.

Licensing readiness is also not addressed in this assessment. Licensing is evaluated elsewhere.

2.0 NGNP CONCEPT

The near-term NGNP concept considered in this assessment is a steam cycle HTGR with a reactor outlet temperature in the range of 750-800°C. The steam generator is located directly in the primary circuit, maximizing thermal performance and eliminating the need for an intermediate heat exchanger and secondary gas loop. This concept will likely be the first-of-a-kind (FOAK) design built as the initial NGNP demonstration plant. Key characteristics of the FOAK concept are shown in the second column of Table 2-1.

This assessment also considers the readiness of the industrial infrastructure for follow-on deployment of a fleet of HTGRs. Such a fleet would be assumed to include Nth-of-a-kind (NOAK) copies of the initial FOAK plant as well as more advanced NOAK plants. The follow-on HTGRs might differ from the initial FOAK plant is several ways. First, the reactors might simply be larger both in output and physical size. More importantly, they would probably serve a variety of applications beyond simple high temperature steam. These could include direct process heat (with an intermediate heat exchanger and a secondary heat transfer loop using gas or molten salt). They could also include electricity production with a direct Brayton cycle or a combined cycle gas turbine.

The burden of this subsequent fleet of plants on the industrial infrastructure would be greater than the first plant due to the following factors:

- Large number of plants
- Larger components
- Higher temperature materials
- Different components (e.g., IHX, gas turbine, etc.)

Some sample characteristics of the potential NOAK plants are shown in the third column of Table 2-1.

Table 2-1: Plant characteristics for infrastructure assessment

	FOAK	NOAK
Power Level	200–350 MWt	200–600 MWt
Reactor Outlet Temp.	750–800°C	750–950°C
Reactor Inlet Temp.	280–325°C	280–500°C
Primary Fluid	He	He
Primary Pressure	7–9 MPa	7–9 MPa
Configuration	Single loop w/steam generator with cross duct	Single or multiple loops with steam generator or IHX
Steam Generator Pressure	17 MPa	17 MPa
Pressure Vessel Material	SA 508/533	SA 508/533 SA 508/533 with active cooling Mod 9Cr-1Mo (Grade 91)

	FOAK	NOAK
RPV Attributes	Inside dia. 6.55 m	Inside dia.: 6.55–7.22 m
	Wall thickness: top: 133 mm bottom: 191 mm	Wall Thickness: 133–216 mm
	Height 22.5 m	Height: 22–30 m
	Weight 810 tonnes	Weight: 728–1,328 tonnes
Cross Vessel Dimensions	Outside dia. 1.9 m	TBD
	Wall thickness 50.7 mm	
Steam Generator Vessel Dimensions	Inside dia.: 4.36 m	TBD
	Wall thickness: Top: 140 mm Bottom: 95.3 mm	
	Height: 28 m	
	Weight (w/o tube bundle): 322 tonnes	
Steam Generator Materials	2-¼ Cr – 1 Mo	2-¼ Cr–1 Mo
	Alloy 800H	Alloy 800H
		Inconel 617
IHX Design	NA	Compact or shell and tube
IHX Materials	NA	Inconel 617
		Hastelloy X
		Hastelloy XR
No. of Loops	1	1–3 Loops
Main Circulator	3.6 MWe	4–12 MWe (depending on # of loops)
Core Barrel Material	800H	800H
	316H	316H
	2 ¼ Cr-1Mo	Grade 91
Graphite Material	NGB-18	NGB-18
	PCEA	PCEA
	NGB-17	NGB-17
	IG-110	IG-110
	2110	2110
		Advanced graphites
High Temp Valves	N/A	TBD

	FOAK	NOAK
Pressure Vessel Fabrication Options	Rolled plate w/welds Ring forgings Nozzle forgings	Same as FOAK
PCS	Rankine cycle steam plant	Rankine cycle steam plant Brayton cycle (direct) Combined cycle
Reactor Vessel Internals	800H Hastelloy X/XR Composites	800H Hastelloy X/XR Composites
Instrumentation and Control	Primary loop instrumentation	Primary loop instrumentation
Reactor Building	High-temperature concrete Full or partial embedment	High-temperature concrete Full or partial embedment

3.0 CONSIDERATIONS FOR INFRASTRUCTURE ASSESSMENT

The industrial infrastructure must be prepared for NGNP deployment on three distinct levels:

- Technical readiness — Does the required industrial technology exist? This is related to technology maturity, but it goes beyond the fundamental science. The primary question is whether or not the required processes have been adequately industrialized. For example, the welding process for a certain alloy may have been developed and optimized in the laboratory. But it is not industrialized until standard welding procedures and equipment have been developed and qualified on the shop floor.
- Industrial readiness — Do the required facilities and supplies exist for industrial scale production? It is not enough to have the process defined. The required foundries, forges, shops, processing facilities, etc., must be available. The skilled labor must be available and trained as well. Similarly, qualified input materials and feedstocks to the production processes must also be available.
- Commercial readiness — Is it commercially attractive enough for industry to support NGNP deployment? Even if the process and facilities exist, it might still be difficult to support NGNP deployment if those facilities are committed to other existing or more profitable business.

Specific topics to be addressed include:

A. Ability to provide components

B. Ability to meet quality assurance (QA) requirements

C. Capability to transport components

D. Workforce readiness

E. Construction capabilities

These topics must be addressed for both the FOAK NGNP demonstration plant and for potential follow-on NOAK plants. Readiness for the FOAK plant will be dominated by technical readiness and basic industrial readiness. Industry's ability to support follow-on plants in the future will be dominated more by broader industrial readiness and commercial readiness. In most cases, finding the resources to support a single one of a kind plant can be worked out. However, supporting a potential fleet of follow-on plants requires a more significant commitment often involving expansion or major realignment of facilities and staff.

Where appropriate, consideration will also be given to changes or relaxation of NGNP design requirements that might alleviate potential infrastructure readiness challenges.

4.0 INFRASTRUCTURE READINESS FOR FOAK NGNP

The infrastructure readiness for deployment of the anticipated FOAK NGNP concept is assessed for each major component or system.

4.1 Primary Coolant Vessels

The primary system boundary for the FOAK NGNP is expected to be fabricated using conventional SA508/533 material. The vessels will be similar to conventional LWR vessels except that the NGNP vessel is expected to be larger in size and it is not expected to require internal cladding.

4.1.1 Ability to Provide Vessel Components

The industrial capability to produce the envisioned SA508/533 NGNP vessels currently exists. Though the envisioned vessel sizes are generally larger than LWR vessels, the wall thicknesses are less than or equal, ensuring that weld thicknesses are bound by previous experience.

The reactor vessel is most challenging due to its large size. References 2 and 3 provide a comprehensive review of the ability to fabricate key reactor vessel components, along with an examination of existing capabilities of both national and international suppliers. Reference 4 represents a vessel acquisition strategy developed by INL based on these review documents. Since the date of publication of these references, additional capacity has been added at the Saarschmiede GmbH Freiformschmiede plant. This plant was upgraded to supply all components of the Westinghouse AP1000 plant, including an upgraded forging press capacity of 12,000 tons and an estimated maximum ingot size of 330 tons. At this point it is not clear whether this plant will have the capacity to produce the largest NGNP forgings (the reactor vessel flange ring). Even without this capacity, however, the excess forging capacity at this facility should help alleviate schedule constraints at other forges. AREVA has also added to its manufacturing capacity in the US, through the development of the AREVA/Northrup Grumman facility in Newport News Virginia. This facility is designed to produce the heavy components for the EPR reactor. It has the capacity to produce components in excess of 500 tons and a throughput of the equivalent of 1 set of EPR components per year.

There are two fundamental parts of the vessel production process. First, forgings of the required material (and plates if needed) must be produced. Then a vessel fabricator assembles these pieces into a finished vessel.

There are multiple suppliers of SA508/533 forgings and plates. The most significant challenge is the ring forgings for the reactor vessel, especially the main vessel flanges due to ingot size and forging diameter. These large forgings would probably have to be produced by Japan Steel Works (JSW). JSW has the required processes and facilities to provide these forgings. However, the production capability is limited, and there is usually a significant backlog with production slots generally being reserved years ahead of time. At the present time, the backlog is substantial, although this is subject to change as the nature of the “nuclear renaissance” continues to evolve.

An important consideration is the number of ultra-heavy forgings required. If the reactor vessel is to be fabricated entirely from forgings, then several ultra-heavy forgings would be required. However, if the vessel is fabricated using plates, then perhaps only two or three ultra-heavy forgings would be required. In that case, smaller forgings required for nozzles, etc., could be provided by other forges.

If the vessel is to be fabricated with forgings, it is questionable whether the required forgings could be procured in time to meet the current NGNP schedule. On the other hand, arrangements could possibly be made to obtain the limited number of ultra-heavy forgings required to support a plate vessel by negotiating adjustments in the existing production schedule at JSW. Major vendors such as AREVA do have some ability to shift or reallocate production slots to meet specific project needs. Obviously, this is easier, if the number of forgings involved is small.

There are multiple fabricators capable of producing the finished NGNP vessels once the required forgings have been procured. This fabrication also affects the project schedule, but the bottleneck is not as severe as for the forgings. Current fabricators predominantly build nuclear vessels using forgings, but the capability to build the vessels using plate is also available and has been accepted by regulators. Some nuclear reactor vessels are still built from plate. Forgings are preferred because they significantly reduce the required labor and inspection, but either process can provide an acceptable vessel.

In summary, the industrial technology and required facilities to produce the NGNP primary vessels are established. However, these facilities have limited capacity and are seeing significant demand. Therefore, commercial readiness is a challenge. Steps must be taken to minimize the risk to the project schedule. The longer this is delayed the more significant the risk, and the fewer options that will be available.

4.1.2 Ability to Meet QA and ASME Code Requirements for Vessels

The current infrastructure does not pose any significant challenges to meeting the quality assurance or ASME code requirements for the primary coolant vessels. The current infrastructure addresses these same requirements for current LWRs. It is expected that critical reactor vessel parameters, such as vessel material and weld thicknesses, will remain within the experience base defined by the currently supplied LWR vessels.

4.1.3 Capability to Transport Vessel Components

Depending on the location of the NGNP, delivery of the vessel components to the plant site may pose a challenge due to the size of the reactor vessel. Delivery to coastal sites or sites near navigable waterways is feasible using the current infrastructure. However, delivery to inland sites requiring long distance transport by rail or roadway is probably not feasible for the reactor vessel.

For inland sites, completion of reactor vessel fabrication at the NGNP site provides an alternative to delivery of the intact vessel. Such action is certainly feasible. Similar activities are currently employed in support of the replacement steam generator market. However, it would require the duplication of significant vessel fabrication facilities at the reactor site. This would result in additional cost and potential delay for the project.

For most future commercial sites, heavy component delivery is not believed to be an insurmountable problem, since navigable waterways are in reasonable proximity to most industrial regions. For example, location of the NGNP demonstration plant on the gulf coast of Texas would minimize this concern.

Delivery of major components is an important consideration in the site selection process for any reactor, including the NGNP. Ultimately a detailed transportation study will be required. Transportability is determined by various factors including dimensions, weight, shape, environment, packaging, etc. It is always site dependent.

4.1.4 Workforce Readiness for Vessel Production

Skilled workers are required to staff the industrial facilities in which heavy components such as nuclear reactor vessels are manufactured. The existing pool of workers is adequate for the current production facilities. Moreover, additional workers will be trained for the new facilities now being developed or planned for the future. This is the same challenge being dealt with in current LWR projects.

There are no reasonable modifications to current NGNP requirements that would further mitigate the schedule challenges associated with vessel fabrication. These challenges are similar to those faced by LWR projects planned for the near future.

4.2 Core Support Structures

The core support structures considered here are the metallic structural components which surround and support the graphite core structures and reflectors as well as the graphite reactor outlet plenum. These include the metallic core support structures beneath the core, the core barrel which provides lateral support, the upper core restraint structures which maintain alignment of the upper core graphite structures in the prismatic reactor design, and the lateral restraint straps and tie rod assemblies in the pebble bed reactor design.

4.2.1 Reactor Internals Metallics

Historically alloy 800H has been used in HTGRs for these structures both in past operating HTGRs as well as HTGR design programs such as the MHTGR and the HTR-Module. A variety of other alloys are also currently being considered by NGNP designers including 316H, 2¼ Cr – 1Mo, Grade 91, Hastelloy X, and Hastelloy XR. In addition, ceramic composites are being considered for some components, particularly the upper core restraint structures.

All of these alloys (except Hastelloy XR as noted below) are widely available in industry. There is substantial industrial experience in producing components from these alloys. For example, they are used extensively in the petrochemical industry. However, their use in the nuclear industry has been limited. So the overall infrastructure for these components should be adequate, but some adjustment to produce nuclear components may be required. Either current fabricators working with these materials will have to institute procedures and quality programs to meet nuclear industry requirements (as applicable to the specific component being fabricated), or current nuclear component fabricators will have to expand their use of these materials. Both of these approaches are feasible and able to meet the requirements of the NGNP project given reasonable planning and preparation.

The one exception to the above is Hastelloy XR. This alloy has seen limited use in the nuclear industry in Japan. Most vendors do not have familiarity with this material and the current experience base is proprietary. Nonetheless, the current infrastructure for this alloy is believed to be adequate, assuming that an existing Hastelloy XR vendor is selected as the component supplier. Otherwise, significant collaboration with an existing vendor would have to be arranged in order to develop new vendor capabilities.

4.2.2 Reactor Internals Ceramic Composites

Ceramic composites as discussed herein (and sometime referred to as simply "composites") include both carbon/carbon (C/C) composites (i.e. carbon fibers in a carbonaceous matrix) and SiC/SiC composites (i.e., SiC fibers in a SiC matrix). Ceramic composites are being considered as alternatives to the above alloys for some reactor internals components such as the upper core restraint structures, lateral restraints and tie rods. These

structures would offer significantly increased tolerance of off-design temperature excursions. References 5, 6, and 7 document previous NGNP composite material studies. These studies detail the advantages and disadvantages of the use of composites, along with reviews of existing vendor capabilities in these areas.

A substantial industrial infrastructure exists for composite materials and components including C-C composites, particularly in the aerospace industry. However, there is little experience with these composites in the nuclear industry.

Composite materials have fundamentally different characteristics than metallics. As a result, the design, fabrication, and qualification of composite components are different than metallic nuclear components.

The existing infrastructure for composite fabrication should be adequate to produce the required composite components.

However, the qualification of these components for use in the NGNP poses a fundamental challenge which has yet to be resolved. Once a qualification strategy is developed, decisions will have to be made how and where in the industrial infrastructure the strategy is to be implemented. The timeliest approach would probably be to adjust the quality programs at an existing composite fabricator, but developing the composite fabrication infrastructure at the reactor vendor could also be considered.

Clearly the infrastructure for composite components is not as mature as for metallic components. Even though composites offer the potential for enhanced performance and potentially increased design margins, design alternatives which minimize their use will maximize project readiness. For example, metallic upper core restraint elements may be preferred, even if their replacement is required following an accident. In some cases, a compromise approach may be best in which a component includes composites only where most beneficial and composite geometries are simplified in order to minimize any fabrication or qualification challenges.

To the extent that composites are still desirable, careful planning and preparation will be required to ensure the readiness of the supporting infrastructure.

4.3 Graphite Components

There are three basic types of graphite components in any HTGR - fuel elements, reflectors, and core support structures. While the details of each of these components will depend on the specific NGNP design selected, all will require graphite of high purity with stable properties.

Due to its favorable properties, graphite has been produced for nuclear reactors since the beginning of the nuclear age. The technology and infrastructure for production of nuclear grade graphite has improved significantly over the past 60 years. Today, there are only a few graphite suppliers actively considered as suppliers by potential NGNP reactor vendors: GrafTech, SGL Group, Toyo Tanso, and Carbone Lorraine (Mersen).

Graphite properties and graphite component performance are determined by both the feedstocks used in the graphite and the graphite production process. Graphites used in previous HTGRs in the US cannot be produced today, because the feedstock is no longer available. However, using current processes, the current graphite vendors have available newer graphite grades with comparable properties. The DOE Advanced Graphite Capsule (AGC) program, the aim of which is to identify and qualify reliably available graphite materials in support of HTGR development activities, is currently working with the graphite vendors to support characterization and qualification of these graphite grades. References 8 and 9 provide some detail as to the graphite selection strategies of this program as well as some initial irradiation test plans.

The required quantity of graphite for the FOAK NGNP is small compared to the total production volume of any of the graphite vendors. However, the nuclear graphite specifications require production steps that have much more limited capacities. The existing infrastructure is believed to be adequate to produce the quantity of the selected grade of nuclear graphite on the planned NGNP production schedule. However, this assumes that the required quantity of graphite is ordered in a timely manner.

Graphite machining capability must also be considered in assessing the industrial infrastructure. All of the graphite parts to go into the NGNP must be machined. The specific machining requirements cannot be determined until the detailed core design geometry is established. It is clear that some specialized machining may be required. Again, this is not expected to be a problem for the FOAK NGNP schedule, provided that adequate lead time is included in the NGNP procurement process.

These graphite vendors are experienced at producing graphite for nuclear applications. They understand and are able to meet the quality requirements for nuclear components.

Vendors are able to control the properties of the finished product by controlling the feedstocks used and maintaining appropriate process controls. They are experienced at keeping properties within the expected specifications and impurities below their limits.

All graphite has some variability in properties. The key requirement is to understand the variability and to set appropriate requirements to bound the variability. Then the reactor vendors can design components for the specified variability, while vendors ensure that the actual variability is within the specification. While the variability of a material such as graphite may be larger than some more common materials, this fundamental nature of the design process is not that different.

4.3.1 Graphite Vendor Questions

Given the central nature of graphite as both a structural material and reflector material for HTGR plants, and the unique nature of its required fabrication and qualification processes, direct contact was made with two vendors currently involved in production of graphite for various global HTGR uses. These vendors were asked a series of questions designed to help assess both the short-term and long-term issues surrounding assurance of a stable qualified supply. These two vendors were Toyo Tanso, through their Toyo Tanso USA office in Troutdale OR, and SGL Group, through their SGL Carbon GmbH group in Meitingen Germany. The questions asked and the answers received, are presented in Appendix A of this report.

4.3.2 Graphite Vendor Summary

Based on the interactions with these two graphite suppliers, coupled with the qualification activities being carried out by INL through the AGC program, it is concluded that supply of graphite for the initial NGNP plant should be within the capabilities of the existing graphite supply infrastructure. Key fabrication durations and required ordering lead times discussed in Appendix A also seem to be well within the required schedule constraints for deployment of the NGNP.

For the NOAK fleet, the potential exists to meet the demand, but it will require specific business arrangements to divert existing capacity or to add required capacity. Should expansion be required, it is not seen to be problematic given the right business environment.

4.4 Control Rods

Two basic technologies are currently considered for the NGNP control rods. One approach uses segmented metallic rods similar to those used successfully in previous HTGRs (e.g., Fort St. Vrain). The other approach uses rods fabricated partially or entirely with ceramic materials.

The current infrastructure is adequate for the metallic rods. There is no question that reactor vendors could fabricate the metallic rods for use in the NGNP. They have significant experience fabricating components of similar complexity to nuclear QA requirements on a frequent basis.

The infrastructure for the ceramic rods is less well established. These rods would use C-C or SiC-SiC composites for some or all of the major structural elements of the rods. The infrastructure issues identified for the composite reactor internals components apply to these as well. Significant composite fabrication experience relevant to the control rods exists outside the nuclear industry. However, the infrastructure issues associated with SiC-SiC are believed to be more significant than those of the C-C composite material, since the overall industrial experience with C-C is substantially greater. The control rod components have somewhat of an advantage in that they are generally smaller than the major reactor internals components. However, the control rods will see a significantly higher neutron fluence which must be taken into account as part of the qualification process.

The selection of advanced composite components within the control rods will require a clear path to confirm the required technology development and qualification process. While outside the scope of the industrial infrastructure assessment, there is nonetheless a clear relationship between the technology development and the implementing industrial infrastructure. As was the case for the composite reactor internals, to the extent that composites are still desirable, careful planning and preparation will be required to ensure the readiness of the supporting infrastructure.

It should be noted that control rods are replaceable components. Therefore, the path with least risk for near-term deployment may involve initial use of metallic rods at the beginning of plant life with future substitution of composite or hybrid metallic-composite rods for improved performance margins.

4.5 Hot Duct

The hot duct is a fabricated structure that includes a structural tube, internal insulation, and cover plates which keep the insulation in place. The structural tube also provides the pressure boundary between the hot reactor outlet gas and the cold reactor inlet gas. Hot duct designs also typically include one or more bellows to accommodate thermal expansion.

The main issue of consideration for the hot duct is the specification of the liner material. The liner is exposed to the hot reactor outlet gas. For the near-term FOAK NGNP concept, the reactor outlet temperature should be low enough to allow use of a metallic liner such as alloy 800H.

In general, the hot duct is well within the capabilities of the current industrial infrastructure. The materials of fabrication are routine. The component sizes do not place any unreasonable demands on the infrastructure. Addressing fabricability issues during the design process will ensure that no unusual demands arise.

4.6 Steam Generator

The technology for the FOAK NGNP steam generator is relatively mature. Similar technology was developed for earlier reactors, and actual steam generators have been built for Fort St. Vrain, Thorium Hochtemperatur Reaktor (THTR), and other past HTGRs.

However, the industrial processes to build a helical coil HTGR steam generator are complex. They involve bending and welding a large number of tubes in a relatively complex geometry which interacts with a radial support structure. While these components have been built in the past, the details of the processes are unique to the specific component design. This is the reason that past lists of development needs have identified fabrication R&D as a requirement to support steam generator fabrication. This development work includes such activities as building fabrication mockups and jigs, etc. Such work cannot be finalized until the detailed steam generator design is more mature.

Industry is familiar with the materials anticipated for the steam generator.

The current industrial infrastructure can provide the NGNP steam generator. However, it will be necessary to ensure that the project schedule is adequate to allow the required preproduction development activities.

Steam generator size is an important consideration for both manufacture and delivery of the steam generator. Current shop facilities are large enough to provide a steam generator in the 300-350 MWt range and probably larger.

The steam generator will be smaller than the reactor vessel, so delivery to most sites would not be a problem. However, sites without navigable water access will have to be assessed in detail. The completed steam generator is expected to be close to the limits of rail or roadway transportability. Whether or not the steam generator can be transported to a specific isolated site will depend on the specific design of the steam generator and the specific obstacles in the vicinity of the site. For most anticipated industrial sites, this will not be an issue.

4.7 Main Circulator

A main circulator of the size required for the near-term FOAK NGNP concept is within the capability of the current industrial infrastructure. Discussions have been held in the past with current and potential future circulator suppliers to review the feasibility of circulators in various size ranges. Circulators up to about 4 MWe (and potentially up to 6 MWe) are within current capacity and could be contracted for today.

The required subsystems and components have been reviewed by the potential vendors including impeller and diffuser, bearings, motor, and power supplies. Current experience in each of these areas brackets the FOAK NGNP requirements. The facilities and processes within the current infrastructure are adequate to produce the required component. Reference 10 presents the results of detailed interactions with one prominent circulator vendor, Howden, related to the current state of readiness to supply circulators for HTGR reactors. These results are consistent with discussions that AREVA has held with this vendor outside of the frame of the NGNP program.

Potential circulator vendors are familiar with nuclear industry quality requirements.

Delivery and installation of the main circulator would not be a problem.

4.8 Auxiliary Cooling System Heat Exchanger

The details of the auxiliary cooling system heat exchanger will depend on the specific design selected. However, some general characteristics are clear which allow an assessment of the infrastructure's readiness to supply this component.

The auxiliary heat exchanger will be considerably smaller than the steam generator. It will have a much smaller heat duty than the steam generator, and it need not have high thermal effectiveness. However, for some designs, the auxiliary heat exchanger will probably be designed to accept much higher inlet gas conditions during off-design conditions. This suggests that high temperature materials may be required. These considerations suggest that the auxiliary heat exchanger will be designed to minimize manufacturing challenges rather than to maximize thermal efficiency.

As a result, the current infrastructure should be able to provide this heat exchanger without significant challenge.

Transport and installation of the auxiliary heat exchanger will not be a major challenge.

4.9 Auxiliary Cooling System Circulator

In most aspects, the auxiliary cooling system circulator is expected to be much less challenging than the main circulator. The required capacity is much smaller.

In past assessments of the (MHTGR) Shutdown Cooling System circulator, one significant concern was the motor speed turndown ratio. Since the system is intended to operate over a wide range of conditions including fully pressurized and fully depressurized, a wide range of speed would be required to achieve the required mass flow rate under all conditions. This places significant requirements on the motor and the power supply. While this was a concern, the MHTGR system was believed to be adequate.

Given advances in recent years in synchronous motors and solid state power electronics, this is not expected to be a significant issue today.

Hence, the current industrial infrastructure should be able to supply the auxiliary cooling system circulator without difficulty.

The anticipated suppliers would likely be the same as the main circulator suppliers who are familiar with nuclear industry requirements.

4.10 Reactor Building

The specific requirements for the reactor building will depend on the details of the FOAK NGNP design. The specifics provided in Table 2-1 assume a fully or partially embedded structure, and they also assume the need for high-temperature concrete.

4.10.1 Infrastructure Readiness and High Temperature Concrete

The advisability of using high temperature concrete in the NGNP reactor building depends strongly on the design of the reactor module and the location within the building. High temperature concrete is considered here as concrete with specific material additions designed to raise its allowed temperature tolerance. In particular, the

design of the reactor vessel, the reactor cavity cooling system (RCCS), the vessel supports, the structure of the reactor cavity within the reactor building, and the relative position of each of these all combine to determine the required temperature specification for the concrete during normal operation and accident conditions. For example, appropriate design of the RCCS might limit concrete temperatures for all design basis conditions such that high temperature concrete is not required. Or if higher concrete temperatures are expected, they may only require high temperature in the vicinity of the vessel support structures. For example, adequate support of the vessels is clearly necessary, but superficial damage to concrete in the cavity wall surface at the reactor beltline (hottest location) may have no significant impact on safety.

If a decision is made to use high temperature concrete for the NGNP, the ability to procure that concrete will depend on its specific requirements. This depends primarily on time and temperature constraints as well as strength requirements. High temperature concrete can be specified for a variety of applications. Compared to other applications such as refractory installations, the temperature requirements anticipated for the NGNP reactor building would be relatively modest even if high temperature concrete is recommended.

In general the infrastructure exists to provide high temperature concrete. However, since concrete production and installation is ultimately a local process linked directly to the site, final preparation of the infrastructure cannot occur until a site is selected and the specific concrete requirements are established. At that time vendors would be selected and qualified including the production of sample batches meeting the project quality requirements. Of course, this situation is not that different from the process that would be required if conventional concrete is specified throughout the building.

Depending on the temperature for which the concrete will be exposed, the ingredients may not be what the local concrete producer would use. The cement may require different characteristics than normal Type II Portland Cement and the aggregates may need to be a shale, clay or slate material containing a lower percentage of quartz. For the FOAK scenario, the necessary materials could be shipped to the site. It may be more cost effective to explore the use of more local materials for the follow-on NOAK plants.

The concrete plants will need to be designed to store and handle multiple sources of materials to accommodate those required for the various mix designs, including high temperature concrete. The batching and mixing of high temperature concrete is the same as conventional concrete, therefore special or separate plants would not be required.

To ensure the mix design and material availability, high temperature concrete should be treated like a long lead procurement. The mix design could be developed and tested by a laboratory prior to selecting the concrete supplier.

While an infrastructure to provide high temperature concrete at the NGNP site does not exist today, there is no reason to believe that the required infrastructure could not be in place in time to support the project.

4.10.2 Infrastructure Readiness and Impact of Building Embedment

Some candidate NGNP concepts have selected fully embedded reactor buildings while others have preferred partially embedded structures. This decision is a function of many factors including construction, operation, plant maintenance, external hazards, cost, etc.

Techniques exist to build both embedded and partially embedded structures at hard rock and soft soil locations, including locations with high water tables. However, the cost of each type of structure will vary substantially for

the different types of ground conditions. The construction schedule will also be affected. Therefore, it may be appropriate to revisit the structure type once a specific location has been selected.

Ultimately, the current construction infrastructure can support either building approach.

4.11 Power Conversion System

The Rankine cycle steam plant anticipated for the NGNP is based on very mature technology. Systems with comparable steam conditions and similar capacities have been used in a variety of fossil power generating applications.

The current infrastructure is clearly ready to support the FOAK NGNP power generating system.

4.12 Helium Purification System

The helium purification system uses conventional process technology and components. Moreover, such systems have been built and operated for past and current HTGRs. So the general infrastructure should be able to provide the equipment which makes up the helium purification system without any unusual difficulty.

However, since several of the components are not expected to be off the shelf items, it is prudent to anticipate some procurement and fabrication delays. Thus, early planning, design, and procurement activity will be required to avoid impacting the project schedule.

4.13 Instrumentation

Specific NGNP instrumentation requirements depend on the detailed FOAK design, including the final control and protection system details. The requirements will also be influenced by the evolution of the NGNP licensing process. At this time only a general evaluation of the NGNP instrumentation needs and their relationship to the industrial infrastructure is possible.

Current concepts do not require significant exotic instrumentation. Temperature sensors are available to measure core outlet temperature. Flux sensors are available that can operate significantly higher than reactor inlet temperature (for operation in reflectors or cooled channels as necessary).

Therefore, the current infrastructure should be able to meet anticipated NGNP instrumentation needs.

4.14 Control and Protection Systems

The NGNP project is expected to use a modern digital control system and a digital protection system. Such systems are standard in conventional process and energy facilities. Moreover, nuclear facilities have begun converting various control systems to digital technology, and the first U.S. nuclear reactors are now being converted to digital protection systems. New LWRs now being licensed intend to use digital control and protection systems.

Since the NGNP project will just follow the first wave of new LWRs now being licensed, the industrial infrastructure will be adequate to support supply, installation, and commissioning of the NGNP control and protection systems.

4.15 Miscellaneous Auxiliary Systems

The NGNP will include several supporting auxiliary systems. Some of these will be unique to an HTGR facility while others will be truly generic.

The fuel handling system for either the prismatic or pebble bed concepts will be unique. The technologies which support this system are generally mature and in use in various industries. However, this system will require a supplier to merge several technologies including machine design, shielding, robotics, automation, and data management systems. While this system is within the capabilities of the current industrial infrastructure, detailed planning will be required to ensure that design, fabrication, testing, and delivery can be accomplished within the anticipated project schedule.

The RCCS is another system that is unique to the NGNP. Several RCCS concepts are currently under consideration by potential NGNP designers. However, all of them utilize very conventional components and structures. Therefore, the current infrastructure is ready to provide this system. Careful integration of this system with the reactor building design will be required. This integration must include evaluation of the building construction sequence in order to ensure that installation of the RCCS equipment does not adversely impact project schedule.

Most other plant systems are truly generic, being similar to comparable systems in other nuclear or fossil power plants. Such systems might include cooling water systems, electrical power buses, etc. While the detailed design of these systems is specific to the NGNP, the general architecture of the system will be similar to other facilities, and the major components would be off the shelf. This current infrastructure is adequate for these systems.

Overall these auxiliary systems do not pose unique challenges for the NGNP. In general, the current infrastructure is adequate to provide and install these systems.

4.16 Generic Nuclear Power Infrastructure

Many elements of the NGNP will rely on exactly the same infrastructure as other nuclear construction projects. These generic elements include placing concrete, erecting steel structures, routing cables and piping, component installation and connection, etc. Each of these activities requires the supply of basic materials as well as a variety of skilled labor.

These needs are common to the overall nuclear renaissance. As the renaissance begins, competition for some resources might be significant until the infrastructure is able to catch up. In this regard, the current schedule of the NGNP project is advantageous, since construction of the FOAK NGNP will come slightly after the first wave of new LWRs planned in the US. Thus, any infrastructure limitations should be diminishing as the NGNP moves forward. In any event, these constraints are not expected to have a serious impact on the NGNP project.

5.0 INFRASTRUCTURE READINESS FOR FOLLOW-ON HTGRS

Subsequent deployment of a fleet of follow-on HTGRs for a variety of applications will require a larger infrastructure than that needed to deploy the initial FOAK NGNP. Potential factors driving the greater infrastructure requirements include:

- Large number of reactor modules (mass production)
- Larger components (higher module power levels)
- Higher temperature systems (higher reactor inlet and outlet temperatures)
- New HTGR plant configurations (Brayton cycle, IHX, etc.)

5.1 Large Scale HTGR Deployment

Large scale HTGR deployment could eventually involve hundreds of reactor modules. This would require mass production of HTGR components. Construction of the FOAK NGNP would entail fabrication and erection of a single module over the course of 4-5 years, whereas large scale deployment would effectively entail building several reactors every year. The current industrial infrastructure could support deployment of a single FOAK NGNP, but significant expansion of the infrastructure would be required for large scale deployment.

The capacity challenges for wide scale deployment fall into four key areas: large scale components, graphite components, general equipment, and skilled construction labor.

For large scale components, this will require increased capability to produce heavy forgings. Such capacity addition is certainly feasible, but it will require clear demonstration of a sustainable market. This need is shared by the nuclear renaissance in general, so expansion of heavy component capacity need not be supported solely by the HTGR business.

For graphite components, increased production rates for graphite billets and graphite machining will be required. Again such capacity addition is feasible if there is a clear sustainable market. A consideration for graphite is the adequacy of production feedstocks. It is believed that feedstocks for desired graphite grades will be adequate, but this must be confirmed. This need is unique to the HTGR business.

For general equipment and skilled construction labor, this need is shared with the rest of the nuclear industry and even the non-nuclear energy and process industries. Again, capacity addition is feasible if driven by sustained market forces.

Fortunately, market penetration by HTGRs will inevitably be gradual, so demand for follow-on HTGRs will increase in more manageable steps over time. This will allow expansion to be driven by demand.

5.2 Helium Supply

It appears that supplies of helium will be adequate to support initial plant and fleet HTR operations. As current U.S. production declines, through depletion of natural gas fields that are the current source of helium and the sale of U.S. government reserves, it is expected that new sources, both domestic and foreign will off-set the decline in

production. More reliance on foreign helium, or helium from less economic domestic natural gas sources, may impact future price assumptions.

5.2.1 Background - World Helium Resources

More than 85 % of the world's current helium supply comes from the U.S. as a by-product of natural gas production and sell-off of U.S. helium reserves. U.S. natural gas containing more than 0.3 percent helium is generally considered economic for helium extraction.

A brief history of the actions taken by the U.S. Government is necessary to understand the development of the U.S. "captive" helium supply. U.S. Government concern over the strategic value of helium resulted in passage of the 1925 Helium Act. This Act nationalized U.S. helium production making it the responsibility of the U.S. Bureau of Mines. In 1960, because of increasing concern over availability of Helium, the government amended the Helium Act by committing to purchase all recoverable helium from certain helium bearing natural gas fields at a predetermined price for the next 22 years. This resulted in the construction of extraction facilities by many private companies specifically for the production of helium for sale to the U.S. Government. By 1973, the Government cancelled its purchase commitment after accumulating a helium inventory of 1 billion nm^3. This cancellation and attendant oversupply stimulated the development of commercial applications for helium in the U.S. In 1996 the U.S. Congress passed the Helium Privatization Act which directed the Government to discontinue the production and sale of refined helium by April 1998. The Act also required the Government to sell all of the helium operations it had acquired except for the facility near Amarillo and to offer its helium inventory for sale starting in 2005 with the intention to reduce it to 16 million nm^3 by 2015. Although the US production of helium is currently declining because the natural gas fields that are the source of helium have begun to deplete, the availability of government reserves has off set the decline in production.

USGS reports that in 2003 sales of Grade-A helium (99.995 % or greater purity) were about 80.8 million cubic meters in the U.S. and exports by private producers were 41.3 million cubic meters for total sales of 122 million cubic meters. From 1998 to 2003, the market growth rate was about 2.4 % per year. For the near term, sales of U.S produced helium are expected to remain level because the increased demand for helium exports will be tempered by a reduced domestic demand. Also, increases are expected in foreign production that may slow down the demand for US helium. The Asian market is also expected to remain stable for the next several years.

The above information is based on the data provided in Reference 14.

5.2.2 Availability of Helium to Support Future HTR Operations

Because helium availability is tied to natural gas production and processing, analysis of past and present natural gas reserves is a somewhat useful means of gauging the availability of future helium supplies. Although there is no absolute assurance that supplies of natural gas will be available in the future, its availability is reasonably assured because of its importance as a source of energy throughout the world. Continued supplies of natural gas are a result of the dynamic natural gas industry in the United States, which is readily replacing produced reserves through new field exploration and improved recovery technology.

Although helium may play a role in gas field development decisions, companies do not specifically target exploration for helium because its economic status is that of a minor by product. As a result, the geological characteristics and processes that form helium-rich gas deposits are not well known, making deliberate exploration for helium difficult. However, natural gas producers and operators of natural gas processing plants are becoming increasingly aware of the economic rewards of helium extraction. US Bureau of Land Management

(BLM) conservation and storage programs have played a large role in getting this industry going and in stimulating interest in extraction. As future uses of helium grow, the awareness of helium extraction is likely to grow, perhaps resulting in a larger percentage of helium being extracted from available natural gas streams or even in deliberate exploration for new sources of helium.

It is possible that the U.S. resource base for helium could increase in the future, perhaps from natural gas/helium sources that are not currently economical to produce. This could result from either an increase in the price of natural gas and/or helium. Similar observations could be made with regard to worldwide helium supplies. Liquefied natural gas is an important component in the world's energy supplies. Because methane liquefaction concentrates the remaining gas stream, there are potentially other sources of helium throughout the world, even in low-helium-concentration gases such as those found in Algeria. (Reference 15)

Conversely, we know of no new helium extraction facilities that are expected to come on line in the U.S. in the near future although new facilities in Algeria and Qatar were expected to begin production in 2005 and 2006, respectively. Startup of the facility in Algeria was delayed because of an explosion in a faulty boiler in the natural gas plant and we do not know its current status. It is possible that demand will begin to exceed supply in the near term if there are further delays in foreign production. Should foreign supply not meet expectations, a faster drawdown in the U.S. helium reserves could occur and may “squeeze” the supply, driving prices to higher levels in the future.

5.2.3 Helium Requirements for HTR Deployment

The helium inventory required by each reactor module depends on the specific configuration, but a reasonable assumption is 2000 kg of helium per reactor module. The required helium supply for each reactor module must include both the initial inventory and makeup supply for operating losses. A conservative assumption is to assume the loss of one inventory per year for each module. For example the MHTGR leakage requirement is only 10% of the primary inventory per year. Assuming 1 inventory per year means a single reactor module would require 2000 kg per year for sustained operation. This is a trivial quantity in the context of the overall annual helium market. The existing helium infrastructure can readily meet this need.

The ability of the helium infrastructure to support a whole fleet of plants is a more significant question. For a fleet of 500 reactor modules, the total annual helium requirement would be at the most about 1,000,000 kg per year. This compares to annual global production of over 30 million kg/year. Therefore, a fleet of HTGRs would be conservatively expected to require only about three percent of current annual global production. If helium is also used for high temperature heat transport loops, this would increase the total helium requirement somewhat, but the basic conclusion would not change. A fleet of HTGRs would not have a large effect on the global helium market.

5.2.4 Helium Supply Conclusions

It is likely that supplies of helium will be adequate to support both initial HTR operation and eventual operation of a fleet of HTRs. It is estimated that the yearly helium demand for a fleet of HTRs will not exceed a few percent of the total worldwide helium demand. This level of demand should be readily accommodated by existing and future helium supply infrastructure, particularly given the long lead times associated with new HTR reactor deployments.

Availability is reasonably assured in the near term because helium is tied to natural gas production which is an important source of energy throughout the world. Also, there are many other uses for helium that will support a

market for this gas. Ultimately, new helium reserves will be brought into production to off-set the decline in the U.S. inventory and depletion of the current U.S. gas fields.

5.3 Larger Vessels

As indicated in Table 2-1, future deployment of HTGRs may also lead to larger reactor modules. While some initial designs are in the 200-350 MWt range, modular HTGRs can retain their passive heat removal characteristics up to about twice that size (approximately 500 MWt for pebble bed designs and 600 MWt for prismatic designs). Such a change would require a larger reactor vessel. A single loop configuration would also require a larger steam generator and steam generator vessel, although a multiple loop configuration would possibly be preferred.

For SA508, the forgings required for the larger vessel are just within current infrastructure capacity. Therefore, this expansion would not require additional infrastructure development.

Transportation of the larger reactor vessel would be slightly more challenging. However, this is not expected to be a strong discriminator, since transportation of the intact vessel is already difficult for the smaller reactor vessel unless a navigable waterway is in reasonable proximity to the site.

5.4 Higher Temperature Vessels

Several potential follow-on HTGR applications would entail higher reactor operating temperatures, including a higher reactor inlet temperature. For some current configurations, this would result in exposing the inner surface of the reactor vessel to higher temperatures, likely above the limits for SA508/533. Several potential design solutions exist to address this problem:

1. Higher temperature reactor vessel material (e.g., modified 9Cr-1Mo)
2. Move the coolant flow path away from the vessel
3. Add thermal protection to the inside surface of the vessel
4. Use a vessel cooling system

The preferred option would be to change the vessel material to a higher temperature alloy such as modified 9Cr-1Mo. This approach would also provide even greater margins for accident conditions. The other solutions are feasible, but they each involve other tradeoffs which reduce their desirability. In general, they increase design complexity and make assembly more challenging. And they reduce maintainability and reduce performance. While use of the higher temperature alloy requires qualifying a new material, it results in a more optimal design. However, each of the approaches is believed to be feasible.

With respect to infrastructure readiness, only option 1 above would require a significant expansion of the existing infrastructure. While the other options increase the complexity of the system, they are within the capacity of the current infrastructure.

However, fabricating the vessel from modified 9Cr-1Mo imposes challenges slightly beyond the current infrastructure. Two main issues are obtaining heavy forgings of modified 9Cr-1Mo and welding thick sections of modified 9Cr-1Mo.

JSW currently cannot cast and forge modified 9Cr-1Mo ingots as large as the ring forgings for a modular HTGR reactor vessel. To be able to do the main flange forgings, larger remelt furnaces and special quenching facilities would be required. These are substantial investments that would only be undertaken in more compelling market conditions.

An alternative approach would be to fabricate the entire vessel from modified 9Cr-1Mo plate except for the nozzle forgings. The individual nozzle forgings are smaller than the vessel ring and main flange forgings. It is believed that the nozzle forgings for this approach could be procured, although that has not been confirmed.

Either fabrication approach would require welding of thick sections of modified 9Cr-1Mo. Significant difficulty obtaining quality welds of thick section modified 9Cr-1Mo has been encountered in the past. AREVA has developed a process to successfully weld thick sections of modified 9Cr-1Mo, but this process has not been fully industrialized.

So for future HTGRs with higher reactor inlet temperatures, the preferred solution would be to use a higher temperature material such as modified 9Cr-1Mo for the vessel. However, this will require significant expansion of the current vessel fabrication infrastructure. This expansion is believed to be achievable, but it will be expensive and therefore require strong market incentives. The alternative is to provide thermal protection for the inside surface of the vessel, resulting in other design compromises.

It is conceivable that when HTGRs move into higher temperature markets, the first generation of plants will use conventional vessel materials with engineered thermal protection features. Then the capability for higher temperature vessel materials could be realized once the market for these reactors was well established.

5.5 Higher Temperature Internals

5.5.1 Core Support Structures for Higher Temperature NOAK HTGRs

For reactor internals components which see the reactor inlet temperature, higher temperature designs are not expected to pose any major challenges. Assuming inlet temperatures increase up to 500°C, alloy 800H still has considerable margin, though use above 800°F would require evaluation of long-term creep effects and may also require extension of ASME Code stress-time relationships and allowable durations beyond current limits.

Of course the upper core restraint structures will see temperatures above the reactor inlet temperature during accident conditions, and these temperatures will likely be somewhat higher due to the increase in reactor inlet temperature. Therefore, the decision to make these structures from ceramic composites becomes more attractive for the higher temperature design. The infrastructure assessment of this approach is provided in Section 4.2.2. The time when these components would be needed for follow-on plants is far enough in the future, that the process of establishing the required capabilities within the nuclear industry framework is achievable.

It may also be appropriate to employ ceramic composites in the upper plenum shroud which surrounds the reactor inlet plenum for come concepts. This approach would rely on essentially the same infrastructure as the upper core restraint structures. However, expansion of the composite component infrastructure would be necessary, if a single monolithic composite structure was specified for the upper plenum shroud.

The core support structures which see reactor outlet temperature are entirely graphite. These structures are unaffected by the higher temperatures.

5.5.2 Hot Duct for Higher Temperature NOAK HTGRs

Follow-on HTGR plants with higher reactor outlet temperatures will likely use ceramic composite liners for the hot duct inner surface.

The industrial infrastructure should be able to supply these composite components without significant difficulty. As discussed in Section 4.2.2, current industrial experience with composite structures is significant although it is generally outside the nuclear industry. The time when these components would be needed for the hot duct of follow-on plants is far enough in the future, that the process of establishing the required capabilities within the nuclear industry framework is achievable.

5.6 Intermediate Heat Exchangers

Some potential future HTGR applications will require direct delivery of very high temperature heat. This is expected to be done via an intermediate heat transport loop connected to the reactor primary circuit through an intermediate heat exchanger (IHX). Various heat transport fluids have been suggested for the secondary heat transport loop, but the most likely candidate for first units would be gas (e.g., high pressure helium). Molten salt has been suggested as an alternative to reduce pumping power requirements, but this technology is not as mature.

Two basic approaches are considered for the IHX design. The traditional approach is the shell and tube heat exchanger. This is similar in concept to the helical coil steam generator, but the design details and materials of construction are different due to the higher temperatures and the use of different fluids. Tubular IHXs are large, and practical units are limited to about 200 MWt. Therefore, a reactor module would probably require two or three loops.

The alternate approach is the use of compact heat exchangers. A variety of concepts are being considered including plate-fin, printed circuit or plate machined heat exchangers, plate stamped heat exchangers, etc. These heat exchangers provide a large heat transfer area in a relatively small volume. However, the individual heat exchanger module size is limited to the MW size range, perhaps up to 5-10 MWt in some cases. Hence, a functional IHX for a reactor module would consist of several of these modules connected in parallel. Obviously the required network of headers is not an insignificant challenge, since each module requires four header connections and all relative thermal expansions must be accommodated.

Design and fabrication of a full size IHX is a major technical challenge due to both the high temperatures involved as well as the complexity of the mechanical interfaces.

In discussing the IHX, it is useful to consider two different temperature ranges:

- Moderate temperature (up to 800°C or possibly 850°C)
- Very high temperature (above 850°C)

Below 800°C, it may be feasible to use more familiar alloys such as 800H. Above this, it is necessary to use higher temperature alloys such as Inconel 617, Hastelloy X, etc., and even then, these alloys are severely challenged.

The temperature range is very important to the IHX manufacturing infrastructure, because it determines the materials used. For some compact heat exchanger concepts, it also affects the joining technology which might be

used (e.g., diffusion bonding, brazing, selection of bonding material, etc.). Thus, the manufacturing processes which must be qualified are different for an IHX operating at 750°C compared to one designed for 950°C.

It is important to note that as the hot gas temperature approaches 950°C, it becomes increasingly difficult to develop a successful IHX design using existing materials. At some point in this vicinity, it will become necessary to use exotic materials such as perhaps oxide dispersion strengthened metallics (ODS) or more probably ceramic heat exchangers. While these technologies are being explored in the laboratory, the required industrial infrastructure necessary to deploy them in follow-on HTGRs does not exist. Development of this infrastructure would require a large effort.

For a tubular IHX, the manufacturing infrastructure is similar to that required for the steam generator (Section 4.6); however the details and the materials of construction are different. This infrastructure existed in the past in Germany, but it would have to be reestablished to support IHX production for a follow-on HTGR for direct heat supply. There is no reason that this could not be done with adequate planning and preparation ahead of time.

Current nuclear component fabricators should be able to satisfy relevant nuclear industry quality requirements for a tubular IHX.

Transportation of the tubular IHX to the plant site would be roughly comparable to delivery of a steam generator. For sites where the reactor vessel could be delivered intact, delivery of a tubular IHX would not be a problem. For less accessible sites, a specific assessment would have to be made taking into account the details of the IHX design as well as local rail and roadway restrictions.

The infrastructure required to provide a compact heat exchanger IHX has two distinct parts. One deals with the production of the individual heat exchanger modules. The other deals with the work required to assemble multiple modules into an integrated IHX.

Significant work has been done in the development of compact IHX modules for HTGR applications. Moreover, industrial production of compact heat exchangers for other non-nuclear applications is done routinely, albeit for lower temperature service. Therefore, assuming successful completion of compact heat exchanger technology development activities, it is reasonable to assume that a supporting manufacturing infrastructure for compact IHX modules could be established. However, more time would be required than for the tubular IHX, since the fabrication processes are not currently as well defined.

Less work has been done on the design issues associated with integrating compact IHX modules into a complete HTGR IHX. This will require a variety of technologies including complex structural support, bellows and other techniques for accommodating thermal expansion, flow balancing, module inspection and replacement techniques, etc. These issues are not unreasonably challenging individually, but they must all be considered in the final design approaches which will then be reflected in the required fabrication, assembly, inspection, and integration processes. Again, it is reasonable to assume that this infrastructure could be established with adequate planning, once the details of the design are defined.

Industrial production of compact IHXs for HTGR applications may require reinterpretation of conventional nuclear industry quality requirements. Full inspection of compact heat exchanger flow passages and volumetric inspection of the assembled heat exchanger modules is generally not practical. Other strategies to assure quality of the finished product must be assessed.

There are two possible approaches to deliver the compact IHX to a plant site. Either final assembly of the integrated IHX is done in the factory and the whole IHX shipped intact, or individual compact IHX modules can

be shipped to the plant site and the final integration completed there. Integration is easier if done in the factory shop with the appropriate space, specialized tooling, and trained staff. However, the resulting integrated IHX is extremely large and heavy. Depending on the final design, the vessel housing the integrated IHX may be as large as the reactor vessel. Even if final assembly is done at the site, the IHX housing vessel and piping must still be shipped to the site. Hence, the compact IHX has shipping constraints comparable to the other large components. For sites where the reactor vessel can readily be shipped, compact IHX delivery should not be a problem. Other less accessible sites will require detailed evaluation. Depending on the final design of the IHX, some extreme sites might even require on-site fabrication of the IHX vessel.

Previous NGNP studies documented in References 10, 11, and 12 provide detailed discussions of many of these issues.

5.7 High Temperature Valves

Some direct process heat HTGR configurations may require very high temperature helium valves for isolation of the primary or secondary heat transport circuit. Such valves were developed and tested as part of the German HTGR process heat program in the 1980s.

The technology to fabricate these valves exists today, however there are currently no known manufacturers producing such valves. It is reasonable to assume that such valves could be procured in the future provided attractive business incentives were available for potential manufacturers. However, significant lead time would be required. It is likely that past design approaches would be updated with current materials. In any event, assembly processes would have to be developed and qualified. If the design was not identical to the past concept tested in Germany, a significant component qualification program might be required. As for many components for advanced very high temperature reactors, significant long-term planning would be required to ensure that the critical path would not be impacted. Nonetheless, with such adequate planning, procurement of very high temperature valves should not pose a major issue.

5.8 Brayton Cycle PCS

Since the 1970s it has been recognized that direct coupling of a closed Brayton cycle to a HTGR could offer advantages for efficient electricity production. It is reasonable to assume that future follow-on HTGRs might adopt this configuration.

The gas turbine to be used in an HTGR would most likely be a helium turbine on magnetic bearings, although oil bearing systems have also been considered. The machine would be smaller than large stationary gas turbines in common use today. It would be expected to have tighter tolerances. However, it is well within the overall range of gas turbines produced today.

The gas turbine industry produces a wide variety of machines, ranging from small to extremely large aircraft engines and aero-derivative stationary engines to large stationary engines designed for dedicated power production. They include units designed for marine propulsion and very small units used in spacecraft applications with various fluids.

It should be mentioned that some integrated gas turbine generators that have been considered for advanced HTGRs challenge the limits of current magnetic bearing technology, particularly for the thrust catcher bearing. While this is more of a technology development issue than an infrastructure readiness issue, the two issues are

undoubtedly connected. This could limit the size or configuration of gas turbine installations until necessary technology development is completed.

The current gas turbine infrastructure is adequate to produce a gas turbine for a closed Brayton cycle HTGR system.

The closed Brayton cycle also requires a recuperator for efficient operation. Current recuperator technology should be adequate for this application. The industrial infrastructure is adequate to provide a recuperator for a closed Brayton cycle HTGR system.

6.0 INFRASTRUCTURE READINESS SUMMARY TABLE

The following table provides a summary of many of the issues discussed in the earlier sections of this report using a three tier system as follows:

A – No significant issues, normal project planning practices should be sufficient

B – Minor issues. Project schedule should be supportable with advanced planning and focus

C – Significant problems/development required, may impact project schedule

Table 6-1 Infrastructure Assessment Review Summary

	Ability to Provide Components			Ability to Meet QA Requirements	Capability to Transport Components	Workforce Readiness	Construction Capability
	Technical Readiness	Industrial Readiness	Commercial Readiness				
FIRST-OF-A-KIND HTGRs							
Primary Coolant Vessels	A	A	B[1]	A	B[2]	A	A
Core Support Structures	--	--	--	--	--	--	--
Reactor Internals Metallics	B[3]	A	A	A	B[2]	A	A
Reactor Internals Ceramics	A	A	A	C[4]	A	A	A
Graphite Components	A	A	A	B[5]	A	A	A
Control Rods	--	--	--	--	--	--	--
Metallic Control Rods	A	A	A	A	A	A	A

	Ability to Provide Components			Ability to Meet QA Requirements	Capability to Transport Components	Workforce Readiness	Construction Capability
	Technical Readiness	Industrial Readiness	Commercial Readiness				
Ceramic Control Rods	A	A	A	C[4]	A	A	A
Hot Duct	A	A	A	A	A	A	A
Steam Generator	A	A	B[6]	A	B[2]	A	A
Main Circulator	A	A	A	A	A	A	A
Auxiliary Cooling System Heat Exchanger	A	A	A	A	A	A	A
Auxiliary Cooling System Circulator	A	A	A	A	A	A	A
Reactor Building	--	--	--	--	--	--	--
High Temperature Concrete	A	B[7]	A	B[7]	A	A	A
Impact of Building Embedment	A	A	A	A	A	A	A
Power Conversion System	A	A	A	A	A	A	A
Helium Purification System	A	A	B[8]	B[8]	A	A	A
Instrumentation	A	A	A	A	A	A	A
Control and Protection Systems	A	B[9]	B[9]	A	A	A	A

	Ability to Provide Components			Ability to Meet QA Requirements	Capability to Transport Components	Workforce Readiness	Construction Capability
	Technical Readiness	**Industrial Readiness**	**Commercial Readiness**				
Miscellaneous Auxiliary Systems	A	A	A	A	A	A	A
Generic Nuclear Power Infrastructure	A	A	A	A	A	A	A
FOLLOW-ON HTGRS							
Large Scale HTGR Deployment	A	B[10]	B[10]	A	B[11]	B[10]	A
Larger Vessels	A	B[12]	B[12]	A	B[12]	A	A
Higher Temperature Vessels	A	C[13]	C[13]	A	B[2]	A	A
Higher Temperature Internals	--	--	--	--	--	--	--
Core Support Structures for Higher Temperature NOAK HTGRs	A	A	A	B[14]	A	A	A
Hot Duct for Higher Temperature NOAK HTGRs	A	B[14]	A	B/C[14]	A	A	A
Intermediate Heat Exchangers	C[15]	C[15]	C[15]	B[16]	B[17]	A	A
High Temperature Valves	A	A	B[18]	A	A	A	A
Brayton Cycle PCS	A	A	B[19]	B[19]	A	A	A

Notes on individual Rankings:

1. Production of the Reactor Vessel will be limited by the forged vessel flange ring. It appears at this time that a single vendor (JSW) can produce this forging. Given the significant role that this vendor plays in the ongoing nuclear renaissance, early ordering of this component critical to minimize schedule risk.

2. Locations away from navigable waterways may need to consider shipment of the reactor vessel as partially completed components, with final assembly conducted in site. Shipping of reactor internals components and steam generators to these sites may also require special considerations.

3. Codification of candidate materials for the explicit service conditions anticipated may need to be completed.

4. Most vendors of ceramic composite components do not have NRC approved QA programs. Additionally, the NRC does not have a precedent for acceptance of composite materials.

5. Reproducibility of graphite material properties will need to be addressed with the NRC.

6. Development of modern fabrication techniques is needed for the helical coil design. The ongoing nuclear renaissance may limit the number of vendors willing to incur this expense and schedule impact for a one-of-a-kind plant.

7. Procurement of the required quantities of specialized concrete to NRC approved standards will be based on local suppliers, which may add some schedule risk or may require development or expansion of a local infrastructure.

8. Though helium purification systems were procured for past HTGRs, most of today's suppliers will not have NRC approved QA programs. The relatively small size of the potential near term market may limit the number of vendors willing to make this investment.

9. Current reactors are just beginning to implement digital controls. As this technology matures and receives more NRC attention, this area may become a less significant risk.

10. As more HTGRs are planned, competition for available resources with other reactor types may result. In addition, supplies of HTGR-specific materials (graphite precursor materials, helium, etc.) will need to be addressed.

11. Larger deployments of HTGRs may result in more reactors being located away from navigable waterways, increasing the need for on-site assembly of reactor vessels.

12. Production of vessels much larger than those for the largest currently envisioned plants (around 600 MWth) will require increased forging capability. These vessels will increase the likelihood of required on-site final assembly.

13. The current material envisioned for higher temperature operation (Modified 9Cr-1Mo) requires development and industrialization of production welding processes. In addition, it is not clear that JSW will be willing, or able, to produce the largest required vessel forgings in a timely manner.

14. Higher temperature operation may require extension of currently Codified limits for key materials. For ceramic composite materials that may be required for use in the Hot Duct, extensive code development may be necessary.

15. Significant IHX development is required prior to implementation. Development needs depend on IHX type, working fluid characteristics, plant operating temperatures and powers, amongst other considerations.

16. Many IHX designs currently under consideration will require development of specific testing and acceptance requirements that have not been considered in the nuclear industry.

17. Transportation of tubular IHXs will involve many of the same considerations as encountered in transportation of reactor vessels and steam generators.

18. Though high temperature valves have been produced and tested in the past, process and equipment development will be required of a new vendor to produce this type of valve. This will require a strong business incentive for the vendor.

19. Most vendors considered able to supply Brayton cycle components do not currently supply the nuclear industry. Process and program updates will likely be required.

7.0 CONCLUSIONS

7.1 Summary of Current Infrastructure Readiness

Key points regarding the readiness of the current industrial infrastructure to support the FOAK NGNP are summarized below:

- The industrial technology and required facilities to produce the NGNP primary vessels are established. However, these facilities have limited capacity and are seeing significant demand. Therefore, commercial readiness is a challenge. Steps must be taken to minimize the risk to the project schedule. In 2008 AREVA had recommended that vessel procurement be initiated as soon as possible. The longer this is delayed the more significant the risk, and the fewer options that will be available.

- The current infrastructure can meet the quality requirements for the primary coolant vessels.

- Depending on the location of the NGNP, delivery of the vessel components to the plant site may pose a challenge due to the size of the reactor vessel. Delivery to coastal sites or sites near navigable waterways is feasible using the current infrastructure. For inland sites, completion of reactor vessel fabrication at the NGNP site provides an alternative to delivery of the intact vessel. This would result in additional cost and potential delay for the project. For most future commercial sites, heavy component delivery is not believed to be an insurmountable problem, since navigable waterways are in reasonable proximity to most industrial regions.

- A variety of alloys are under consideration for reactor internals components. There is substantial industrial experience in producing components from these alloys. However, their use in the nuclear industry has been limited. Either current fabricators working with these materials will have to institute procedures and quality programs to meet nuclear industry requirements (as applicable to the specific component being fabricated), or current nuclear component fabricators will have to expand their use of these materials. Both of these approaches are feasible and able to meet the requirements of the NGNP project given reasonable planning and preparation.

- Clearly the infrastructure for ceramic composite reactor internals components is not as mature as for metallic components. A substantial industrial infrastructure exists for composite materials and components including C-C composites, particularly in the aerospace industry. However, there is little experience with these composites in the nuclear industry. The qualification of these components for use in the NGNP poses a challenge. Once a qualification strategy is identified, it will have to be implemented within the production infrastructure.

- The graphite infrastructure is believed to be adequate to produce the quantity of the selected grade of nuclear graphite on the planned NGNP production schedule. This assumes that the required quantity of graphite is ordered in a timely manner.

- The current infrastructure is adequate for metallic control rods.

- The infrastructure for the ceramic composite control rods is less well established. Careful planning and preparation will be required to ensure the readiness of the supporting infrastructure.

- It should be noted that control rods are replaceable components. Therefore, the path with least risk for near-term deployment may involve initial use of metallic rods at the beginning of plant life with future substitution of composite or hybrid metallic-composite rods for improved performance margins.
- The current infrastructure is adequate to provide the hot duct.
- The current infrastructure is adequate to provide the steam generator.
- The current infrastructure is adequate to provide the main circulator.
- The current infrastructure is adequate to provide the auxiliary cooling system heat exchanger.
- The current infrastructure is adequate to provide the auxiliary cooling system circulator.
- High temperature concrete is currently available. However, the local concrete supply infrastructure will have to be qualified to produce concrete based on the NGNP requirements (whether high temperature concrete is specified or not).
- The construction infrastructure can support both fully and partially embedded structures for a range of site conditions. However, for a given site, cost and schedule may vary significantly between the two approaches.
- The current infrastructure for the Rankine power conversion system is adequate to support the FOAK NGNP project.
- The current infrastructure can provide the helium purification system equipment assuming adequate lead time is provided for procurement of custom equipment.
- The current infrastructure should be able to meet anticipated NGNP instrumentation needs.
- The developing infrastructure will be able to provide digital control and protection systems required for the FOAK NGNP project.
- Overall the auxiliary systems do not pose unique challenges for the NGNP. The current infrastructure is adequate to provide and install these systems. Timely planning and preparation will ensure that supply of the systems using significant components which are not off the shelf (e.g., fuel handling) does not adversely impact project schedule.
- Infrastructure concerns due to general material and skilled labor constraints are common to the overall nuclear renaissance. Given that construction of the FOAK NGNP will come slightly after the first wave of new LWRs, infrastructure limitations should be diminishing as the NGNP moves forward. These constraints are not expected to have a serious impact on the NGNP project.

7.2 Summary of Infrastructure Readiness for Follow-On NOAK Plants

Key points regarding the capability of the industrial infrastructure to support deployment of a future fleet of HTGRs including follow-on plants with enhanced capabilities are summarized below:

- Large scale deployment of HTGRs will require expansion of the industry capacity for large components (e.g., heavy forgings) and for nuclear grade graphite. The required expansion should be achievable given that market penetration by HTGRs will inevitably be gradual. This will allow expansion to be driven by demand.

- Larger vessels to accommodate higher module capacity up to the limit of passive cooling are within current infrastructure capacity for SA508 vessels. Transportation of the larger reactor vessel would be slightly more challenging, although this is not expected to be a strong discriminator.

- For future HTGRs with higher reactor inlet temperatures, the preferred solution would be to use a higher temperature material such as modified 9Cr-1Mo for the vessel. However, this will require significant expansion of the current vessel fabrication infrastructure. This expansion is believed to be achievable, but it will require strong market incentives. The alternative is to provide thermal protection for the inside surface of the vessel, resulting in other design and performance compromises.

- Higher reactor inlet temperatures are not expected to pose any major challenges for reactor internals components. Alloy 800H still has considerable margin at the anticipated temperatures. Therefore, the existing infrastructure should be adequate.

- However, due to slightly higher accident temperatures for the higher temperature design, the decision to use ceramic composites for the upper core restraint structures becomes more attractive. If composites are selected, the infrastructure for ceramic composite reactor components would be necessary. In that case, it might also be appropriate to employ ceramic composites in the upper plenum shroud.

- Follow-on HTGR plants with higher reactor outlet temperatures will likely use ceramic composite liners for the hot duct inner surface.

- For a tubular IHX, the manufacturing infrastructure would have to be reestablished to support IHX production for a follow-on HTGR for direct heat supply. There is no reason that this could not be done with adequate planning and preparation ahead of time. It should be able to satisfy relevant nuclear industry quality requirements. Transportation of the tubular IHX to the plant site would be roughly comparable to delivery of a steam generator.

- For a compact IHX, the infrastructure required to produce the individual heat exchanger modules and to assemble multiple modules into an integrated IHX does not exist today. Assuming successful completion of compact heat exchanger technology development activities, it is reasonable to assume that a supporting manufacturing infrastructure for compact IHX modules could be established. It is also reasonable to assume that the infrastructure to assemble the integrated IHX could be established with adequate planning, once the details of the design are defined. However, more time would be required than for the tubular IHX, since the fabrication processes are not currently as well defined.

- Quality requirements may have to be reinterpreted for compact IHXs, since full inspection of compact heat exchanger modules is generally not practical.

- For sites where the reactor vessel can readily be shipped, compact IHX delivery should not be a problem. Other less accessible sites will require detailed evaluation.

- At some point in the vicinity of 950°C, the IHX will require exotic materials such as ODS or ceramic heat exchangers. Development of the industrial infrastructure necessary to deploy such IHXs would require a large effort.

- The current gas turbine infrastructure is adequate to produce a gas turbine for a closed Brayton cycle HTGR system. (Catcher bearing limitations could constrain some limiting configurations until necessary technology development is completed.)

- The current industrial infrastructure is adequate to provide a recuperator for a closed Brayton cycle HTGR system.

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Appendix A – Graphite Vendor Responses to Questions

Short Term Graphite Supply – FOAK Plant

Question 1: Do you currently produce any components from nuclear grade graphite? If so, what are they? What quantities do you produce? Is there a quality standard? If so, what is it?

Toyo Tanso Answer

Toyo Tanso produces a variety of components from nuclear grade graphite.

We have IG-110 graphite, IG-430U graphite and CX-2002U carbon fiber composite for nuclear applications. Both IG-110 and IG-430U are included in the INL AGC program.

IG-110 Graphite is currently used for High Temperature Gas-Cooled Reactors (HTGR). We have sales and production experience for the High Temperature engineering Test Reactor (HTTR) (Japan) and HTR-10 (China). We are currently producing material to supply for the HTR-PM demonstration reactor (China). IG-430U graphite and CX-2002U carbon fiber composite are used for Fusion Reactor applications, though IG-430U is being considered as a possible HTGR material due to its enhancement of strength through particle distribution control while maintaining other important HTGR properties. We have production experience at JT-60 (Japan), LHD (Japan), and KSTAR (South Korea). It is now also supplied to JT-60SA (Japan). In addition, CX-2002U is the only candidate material in ITER (EU).

Our current production capacity for nuclear applications is approximately 1000 ton per year.

We have a quality standard to satisfy requirements of ISO -9001, which also complies with HTTR inspection standard for graphite products. We were also recently audited by Idaho National Laboratories to be a qualified supplier for NGNP as well as a precursor to NQA-1.

SGL Answer

SGL is delivering fuel sleeves to Westinghouse UK (formerly BNFL) for the British Advanced Gas Reactors. The material is similar to our NBG17 and NBG18 (main difference is in the way the graphite is manufactured. The sleeves are extruded while NBG17 and NBG 18 is vibro-moulded.). We are constantly running small batches of NBG17 and NBG18 for research. Furthermore we are the chosen supplier for the Chinese HTR-PM project for the moderator balls based on our extruded material MLRF-1. We are delivering synthetic graphite powder for the fuel matrix to Babcock & Wilcox, Institute of Nuclear and new Energy Technology (INET), and others.

The quantities for Westinghouse UK are more than 500 MT (metric tons) annually, but further details cannot be disclosed. For NBG17 and NBG18 we produce between 5 and 10 MT annually. The dummy balls for the Chinese Project will be in the several hundred of thousands.

All involved production sites are certified according to ISO 9001. Production fulfils NQA-1 requirements. Testing is done according to ISO, ASTM and ASME standards as well as other country or customer specific requirements.

Question 2: How much time is required to produce the required quantity of raw graphite material required for the NGNP? How much lead time is required to order this quantity of materials?

Toyo Tanso Answer

Lead time will be determined by the quantity demanded for the NGNP design. Production schedules are determined by the quantity of material needed by the customer. Under the assumption that the NGNP HTGR uses up to 2000 tons, it would take approximately two and a half to 3 years with lead-time of approximately 6 month.

SGL Answer

The demand of the competing technologies prismatic vs. pebble, are not negligible. However for this questionnaire we will assume that the graphite needed is comparable. Assuming approx. 1,200 MT of graphite parts, it would take 3 years to produce the required material. Depending on ones needs, more resources could be allocated to reduce delivery times. A business case would need to be completed to determine how the additional resources would change delivery times and their effect on pricing.

It will take roughly 3 years to establish a new location to manufacture the graphite if the graphite manufacturing is to be located near the reactor construction site. This time would be dependent on using an existing SGL site and revamping it or if we need to build a new facility. If delivery is initiated from our current production facility it will only take 1 year. A machine shop would be set up locally no matter where the material is produced, but this would not add extra time because the production of the material is the long lead time item in the system. A machine shop can be set up within the timeframe to produce the graphite itself.

Question 3: Would the vendor do the required machining? What is the estimated time to complete fabrication of the components?

Toyo Tanso Answer

Toyo Tanso has the full capability of graphite production, purification, machining and inspection of the graphite. In order to estimate lead time it is important to understand the product shape and quantity of the requested material. We have a large capacity of machining available in Japan, US, China and European countries. Without product specifications and design it is difficult to show accurate machining numbers however estimating a 2000 ton consumption of graphite for the NGNP, machining time could be two to three years, with a 1 to 1.5 year required lead time from initial order to start of machining operations.

SGL Answer

Yes, we would machine the components out of the graphite.

The machining lead-time is included in the 3 years overall schedule. Parts would start to be machined from the first available material (approx. after 1 year) until the end of the delivery schedule. The defining part in determining the overall delivery time is the graphite manufacturing and not the machining. Machining can be easily adapted within reasonable costs to the predicted output of the graphite manufacturing.

Question 4: Is the vendor compliant with NQA-1, ISO, ASME, ASTM or other quality standards? If so, what are the quality standards?

Toyo Tanso Answer

Toyo Tanso is complying with ISO-9001 standards which meet with HTTR inspection standards for graphite products. Toyo Tanso also participates in ASME and ASTM standards meetings as they are being developed for nuclear graphite. Inspection can be performed to JIS, ASTM or other standards requested by the end user. Toyo Tanso is not currently NQA-1 certified, but have been placed on the INL QSL for supply of AGC graphite.

SGL Answer

Certified according to ISO 9001. Production fulfils NQA-1 requirements. Testing is done according to ISO, ASTM and ASME standards as well as other country or customer specific requirements.

Question 5: Which industry specifications and/or codes would be envisioned to govern the production of the graphite material? Are code improvements needed? If so, what are they?

Toyo Tanso Answer

We have been producing graphite products for many years according to a professional QC progress schedule which we have established within Toyo Tanso. Our material has been produced with a track record of high quality and property stability for many years. We can show over 35 years of consistency in our IG-110 nuclear graphite. We feel it is not necessary to change our QC progress schedule. We are currently working with ASTM to develop useful specifications and standards.

SGL Answer

ASTM and ASME. The ASME would encompass the NQA-1 and ASTM.

The ASME shall be finalized. The ASTM is continuously improved. The current set-up for development and improvement are sufficient and satisfactorily.

Not applicable.

Question 6: What is your process for demonstrating that the graphite produced meets key performance attributes, required specifications, and standards? In other words, how is reproducibility of the graphite product demonstrated such that qualification tests are shown to be applicable to the graphite actually used for reactor components?

Toyo Tanso Answer

The process parameters and product characteristics are strictly measured and controlled on each process of production to meet requirements.

We inspect physical properties, Bulk density, Hardness, Electrical resistivity, Flexural strength, Compressive strength, CTE and so forth. We have confidence in the consistency of each grade of our material based on the quality standards and material specification which have been put in place. We can

demonstrate long term production histories and stability for our materials. Reference 13 provides more details regarding long term material reproducibility.

SGL Answer

Sampling and testing (both destructive and nondestructive) of raw materials, intermediate and final products according to relevant industry specifications and/or standards and codes. Testing can be done in-house as well as by 3rd parties. All testing laboratories should have an accreditation to the relevant industry specifications and/or codes and standards.

Production is done according to a quality plan including procedures where all recipes and process parameter are fixed. This quality plan will be aligned at the beginning of the project with the customer, independent inspectors as well as the responsible nuclear regulator. It would be comprised with the applicable codes and standards, further customer or industry specifications, recipes, production processes and parameters, sampling and testing procedures, the involved testing facilities and laboratories and it would define the HOLD- and WITNESS-points.

Long Term Graphite Supply – NOAK Plants

Question 7: What is the long-term outlook for the availability of the identified preferred grade(s) of graphite from this vendor?

Toyo Tanso Answer

The IG-110 graphite grade has been in production for over 35 years from development to the present, and it is used not only for the nuclear graphite but also as global standard grade for various isotropic graphite applications.

Toyo Tanso has also succeeded the development of IG-430 graphite as a material for the next generation of nuclear applications based on the sufficient production experience and know-how obtained through IG-110 production.

We are confident with the ability to supply stable next generation graphite for long term projects.

SGL Answer

All recipes and production processes are frozen and in all detail defined in a quality plan. The raw material supply is secured by a long-term supply agreement. SGL is prepared to deliver nuclear graphite as of today, however long term outlooks, in particular for NOAK plants, can only be based on bilateral agreements as NOAK plants would definitely require considerable expenditures and the allocation of resources.

Question 8: What actions can be taken to establish alternate supplies of key feed materials? What, if any impact would the use of such alternates have on the properties and qualification status of the graphite grade?

Toyo Tanso Answer

The raw materials used for our graphite production have a stable supply source secured for a long term basis. We are confident with our stable supply chain in the future. As an alternative product grade to IG-110 we have IG-430 raw material supply of which has been also prepared.

SGL Answer

Alternative supplies for raw materials and also significant changes in the specification of the raw materials would normally require a new qualification of the grade. Understanding of the influences of exchanging the raw material for the "nuclear" properties, in particular behavior in irradiation is not fully understood by many parties. Thus, any "new" raw material might lead to a "new" graphite grade in terms of nuclear properties. However in Germany this problem was already "solved" and the information is available to SGL as we were the chosen supplier for the German HTR project at that time. In any case a "new" grade requires qualification via a program as currently initiated by the DOE.

This question can not be answered currently as the impact on the "nuclear" properties is not enough understood. Therefore it is essential to freeze the recipes and production processes and bind the suppliers with long-term agreements.

Question 9: What is the anticipated achievable production rate for this material? In other words, how many new plants can be supplied per year? How many fuel reloads? How many reflector replacements? What can be done to increase this production rate?

Toyo Tanso Answer

In order to accurately answer this question we will need to understand the production requirements in amounts per year to replace the reflector graphite and the fuel graphite. With a 2000 ton graphite consumption assumed for the NGNP, we are capable of supplying 2 plants per year equivalent graphite as needed. If necessary we can also build a new production factory to satisfy the quantity of customer demand.

IG-110 is used by many industries beyond the nuclear industry and forms a large portion of Toyo Tanso business. Plans are in place to provide for expansion of capacity to support various business scenarios. Since feed stocks are by-products of the petroleum industry, suppliers of these materials are expected to be able to easily respond to changes in supply needs.

SGL Answer

There are no technical limitations to the achievable production rate, but time-frame and commercial issues need to be studied. SGL has a strong presence in North America and is one of the globally leading manufacturers of carbon and graphite. Any availability of existing resources in the long term cannot be predicted, but any producer aims at loading its plants at full capacity. Therefore agreements need to be implemented to secure the supply of graphite for HTR's as the amount needed is considerable for specialty graphite. Based on such agreements a capacity for nuclear graphite in the range of 10-15,000 MT seems to be technically possible.

Assuming 1200 MT for the graphite for a HTR (regardless if it is a pebble or prismatic design) a capacity of 10,000 MT would yield 8 plants per annum.

Assuming 1000 MT for a reflectors and 200 MT for fuel blocks on a prismatic design 5 fuel reloads would equal 1 new reactor. However for a pebble bed design this constraint does not exist as the graphite manufacturer only delivers graphite powder for the fuel compacts.

Question 10: What situations can be envisioned that would impact the answers to the above questions? For example, are there other industries that may impact production schedules or impact feed supplies?

Toyo Tanso Answer

We are not worried about any other applications significantly affecting the nuclear material supply. Unexpected market changes could have a small impact in production however this would be expected to be short term and not affect any long term projects.

SGL Answer

Not only is the US pursuing the HTR opportunity, but several other countries as well. Thus all global buyers of nuclear grade graphite would compete for the same raw materials and resources. All customers in this industry among other industries would require graphite and they all would be competing for similar raw materials and the same manufacturing resources.

Other industries which are major consumers of graphite and can have an impact on graphite availability, include steel, aluminum, batteries, photovoltaic's, LED, etc.

Question 11: How would changes to the fabrication process be evaluated and shown to produce graphite that is equivalent to that used in qualification experiments?

Toyo Tanso Answer

Toyo Tanso has been producing stable graphite for many years and there have not been any significant variations such as changes in the coke brand in the same graphite grade.

If a production change is deemed necessary it is executed based on procedures that satisfy ISO-9001. The result of the process change is examined by three groups within Toyo Tanso (Production Division, Research & Development Division and Quality Assurance Dept.) and steps are then taken to verify if the new procedure meets the requirements for the process change.

If it is determined that the process change could cause any influence on the quality more than deemed acceptable by the above groups the approval of the quality management groups and the customer are necessary.

If a customer does not approve the process change we continuously perform qualification examinations until desired results are obtained.

SGL Answer

Whenever changes occur tests will need to be conducted to show the influence of the changes. Subsequently a severity rating is determined and if there is an impact on the properties of the final product the customer will be informed from the occurrence to determination accordingly.