ASCENTRUST LLC ™

The POWER of ENGINEERING

AN INTRODUCTION TO
NUCLEAR TECHNOLOGY PEBBLE BED MODULAR REACTOR
(NTPBMR)
FOR
STAKEHOLDERS AND CONSULTANTS

SECTION ONE: PREAMBLE

Nuclear Power Industry activities can be broadly divided into fuel cycle activities, reactor activities and support activities. Fuel cycle activities include uranium mining and milling to produce ore concentrates (yellowcake), conversion of uranium ore concentrates into uranium hexafluoride, uranium enrichment, fuel fabrication, spent fuel reprocessing and nuclear waste management, and the design and construction of fuel cycle facilities. Reactor activities include reactor design, licensing and construction, reactor operation, maintenance and decommissioning.

AscenTrust, LLC. (**The Company**) and its strategic partners, own or control the intellectual property, the processes and the manufacturing facilities and control the engineering, procurement, construction and fabrication capabilities to design, license and build an American based infrastructure for the manufacturing of all the systems and sub-systems required to build a safe, clean **Nuclear Technology Pebble Bed Modular Reactor (NTPBMR)** electric generating power plants. The Company will mandate that 85% of the supply chain for the components of the project be manufactured in the **United States.**

The Company and its strategic partners, own or control the intellectual property, the processes and the manufacturing facilities and control the engineering, procurement, construction and fabrication capabilities to design, license and build an American based infrastructure for the manufacturing of all the systems and sub-systems required to build a carbon-dioxide charged, methane and oxygen fired closed cycle turbine generating plant.

Using only private funding, the company is working with the County Judges and Commissioners of Matagorda, Jefferson, Orange, Montgomery and Harris Counties, and will harness the support of the Governor of the State of Texas to design, license and build the main manufacturing plants required to fully implement the **NTPBMR Technology.** The primary fabrication facilities will all be situated in the State of Texas.

The environmentally benign aspects of nuclear power, compared to alternative energy sources are important to developing economies as well as Industrialized Nations. Our Nuclear Power Project can contribute significantly to the responsible use of natural resources found on the American Continent and create an energy production supply chain which is sustainable and has a very small carbon dioxide footprint. However, the Company and its nuclear industry partners are also aware of the serious safety and proliferation hazards associated with nuclear facilities and we are committed to developing the **NTPBMR** in a manner consistent with **NRC** and **IAEA** safety and non-proliferation standards. The Senior Engineer has already outline the design process for **Defence in Depth** to be used for the **NTPBMR.**

Both reactor and fuel cycle services rely upon a number of support activities, including consulting, legal services, parts manufacturing, fuel transportation and fuel supply fabrication, research and development (R&D) institutions (government, enterprise or university-based) and industry bodies. The Company will work with Dr. Gary Sorensen and Mr. Howard Selman of **The Living Space Initiative** to flesh out the residential and commercial side of the support structures required for the successful implementation of this supply chain in the sixteen states belonging to the **Southern States Energy Board,** the epicenter of the project will be in Orange County, Texas.

One of the most attractive facets of the **NTPBMR** project is the number of high value jobs which we will be able to create across the Supply Chain of the Nuclear Fuel Cycle. We estimate that we will be able to create more than 100,000, direct, permanent, high value jobs in Engineering, Research and Development, Manufacturing, Construction, etc. The multiplication factor for these types of jobs is more than five so that we can expect to create over 500,000 permanent jobs all across the Southern States.

0.1. INTRODUCTION

The ramp-up in gasoline prices in the summer of 2008 gave national prominence, once again, to the issues of energy supply and demand. The crisis highlighted our dependence on fossil fuels for the production of this electrical energy. The energy ethos in the **U.S.** has been, for a large part of the history of its growth in the 20th Century : **Not in my back yard.**

Increased demand coupled with a strict regulatory environment has stopped the licensing and construction of new power plants. The "crisis" apparently came and went and was soon forgotten. What it did accomplish however was a more lively discussion, in the most liberal area of the **United States of America,** of the importance of supply, recognizing the ever increasing demand as we electrify. In this discussion of demand came the realization that approximately 20% of the nation’s electricity was being generated by nuclear energy. This 20% also represents approximately 69% of the zero carbon footprint electrical energy production in the U.S.

The net consequence of a number of factors, such as a faulty deregulation schemes, were rolling blackouts due to lack of generation at any price. We, in Texas, will feel this consequence for the short term future. The Obama administration has given us clear indication that they intend to close down all coal-fired power plants. The construction of new plants fired by the use of hydrocarbons is frowned upon and the regulatory climate somewhat hostile, companies are leery in making generation investments.

On a different but somewhat parallel track, in terms of energy use versus planetary environmental health is the issue of the slight increases in low levels of carbon dioxide (**CO_2**) in the atmosphere over the last few years. The level of **CO_2**, in the atmosphere, ranges from 250 parts per million to 350 parts per million. This carbon dioxide becomes part of what the environmentally involved scientist call “greenhouse” gases. These greenhouse gases absorb light in the infrared and prevent the re-emission of photons in the lower bands of frequencies which allows the earth to cool itself. This absorbed energy gets trapped in the atmosphere and is causing an increase in the mean global temperature of the earth. Increased carbon dioxide emissions in the atmosphere have increased the amount of rhetoric, often vitriolic, in reference to the existence and implications of increasing greenhouse gases in our environment due to the burning of these same fossil fuels. While the environmental ministers of nations from around the world seek to find ways to meet the 1992 Kyoto accords which call for reductions in CO_2 and other greenhouse gases to 10% below 1990 levels, the reality, 25 years later, is that CO_2 emissions have not decreased at all but increased by 10%.

As everyone involved with nuclear technologies know, one of the key advantages of nuclear energy is that it is essentially a greenhouse-gas-emission-free technology. Yet, at its most recent meeting in Copenhagen, Denmark, the **Conference of the Parties** COP 15, these same environmental ministers voted to specifically exclude nuclear energy from helping address the global warming problem.

Clearly, there is something wrong here since, in the United States, nuclear energy provided over 69% of the emission-free generation, far exceeding the 30% hydroelectric power. Solar and other renewable forms of energy provide the rest (~1%).

Concerns about global warming policies that might eventually lead to the inception of a CO_2 tax which will impair investments in coal-fired power plants, and coupled with attractive operating economics recently experienced in the production of electricity with the use of **Nuclear Power,** Public sentiment is slowly being led towards acceptance of **Nuclear Power** as a viable element of the energy production mix.

In the past 25 years, nuclear power plants have shown tremendous operational improvements and many have been up-rated to add generating capacity. Many of the existing nuclear facilities have applied and been approved for extensions to their operating licenses. Average capacity factors have increased from 66 percent in 1990 to about 90 percent in 2005, owing primarily to increased availability as refueling outages have been shortened from an average of 104 days to 38 days and to improved maintenance programs that have reduced forced outages.

Although existing nuclear plants have demonstrated high reliability and very low operating costs, the next generation of nuclear plants will almost certainly have higher capital costs than conventional fossil fuel units. However, interest in diversifying the fuel mix and the fact that nuclear power does not emit any **CO_2** have led to 10 proposals for new nuclear units, reflecting serious interest in reviving this technology as a base-load option.

Some of the project sponsors have already filed for **Early Site Permits**, and are expected to file for combined construction and operating licenses within the next few years, which could lead to construction beginning on some of the plants soon. The Energy Policy Act, EP Act 2005 also encourages new nuclear facilities with a combination of loan guarantees, production tax credits, and risk protections for initial project developers. The time horizon for new nuclear investments is such that these investments are not likely to contribute to upward rate pressures for the foreseeable future. However, utilities that are planning these units will incur some outlays, and future investments in the construction phase of their projects which are likely to be substantial in both size and risk.

For many years, nuclear energy, while arguably a non-**CO_2** emitting energy source, has been judged to be unacceptable for reasons of safety, unstable regulatory climate, a lack of a waste disposal solution and, more recently, economics. In recent years, however, the nuclear industry has made a remarkable turnaround. While a number of older plants have been shutdown for largely economic reasons, the 104 operating nuclear plants' performance has increased to the point, that as an overall fleet, its capacity factor was 91% in 2014. This means that these plants were operating full power for over 91% of the year. This improvement in the last 20 years is essentially the same as building 23 new 1,000 Mwe plants in that time period, based on historical performance averages. In addition, all safety statistics, as measured by the **Nuclear Regulatory Commission**, have shown dramatic improvements as well. **The Three Mile Island** accident occurred over 30 years ago. The image of nuclear energy as an unsafe technology still persists. Yet the record is quite the opposite.

The utilities have not put in an application for a nuclear power plant since the mid 1970's. The reason for the lack of new orders was the high capital cost. When operating in a difficult regulatory environment, utility executives simply avoided new nuclear construction and went to the cheapest and fastest way to make on-line generation available, which was natural gas. Combined cycle gas plants were the generation source of choice for many years for those companies that needed to build plants.

Today, utility executives still do not have new nuclear plant construction in their future plans even though the regulatory regime has stabilized. Although the regulatory environment has stabilized the utility companies and still uncertain how the passive systems mandated by the **Nuclear Regulatory Commission** can be successfully implemented, within the budgetary constraints of competition with gas-fired electrical generation plants.

Nuclear plants are performing extremely well. Safety issues have been addressed with no new issues emerging and slow progress is being made to finally dispose of spent fuel at **Yucca Mountain**. What has happened is a consolidation of the utility and nuclear industry with some larger utilities purchasing existing nuclear plants from companies that do not want to be in the business.

To address the inevitable problem of replacing existing nuclear generation, utilities have chosen to re-license existing plants from the current 40 years to 60 years. Several nuclear plants have applied and received Nuclear Regulatory Commission approval to do so. These extensions will allow utilities to continue to use these plants as long as they are economic and continue to be safely operated. Unfortunately, we still don't see a rush to build new nuclear plant. One of the main reasons lies in the financial risk involved in the licensing and construction of a new nuclear plant. Combined with the uncertain costs associated with new nuclear construction and the low risk and cost of building a Combined-cycle, natural gas fired power plant, we do not see a rise in investment in nuclear in the next ten years.

This need for a new approach, in the construction of **Nuclear Power Plants** is the basis for the formation of **Nuclear Technologies, Inc.** to look into the production of a Prototype **PEBBLE BED MODULAR REACTOR** (PBMR).

The major challenge faced by the Nuclear Industry for the reintroduction of nuclear energy into the world energy mix, is the development of a nuclear power system that:

1. Does not include water as a coolant or a moderator.
2. Is competitive with other energy alternatives, such as natural gas. oil or coal.
3. A Nuclear Reactor system which can successfully go through a **LOCA (**Loss of Coolant accident**)**
4. Can address the issue of containment
5. Can address the issue of Terrorism
6. Has to address the issue of proliferation
7. Can address the issues of nuclear Waste

As the power of the **Global Warming** Lobby increases the pressure on politicians, including the President of the **U.S.,** increases for the **U.S.** to sign the **Kyoto Treaty.** If the U.S. signs on to the Treaty, we will see the adoption of a CO_2 emission tax as an associated penalty in the use of power generation facilities which produce carbon dioxide as a by-product of combustion of fossil fuels. The environmental imperative of nuclear energy is obvious. No greenhouse gases emitted, small amounts of fuel required and small quantities of waste to be disposed of.

Unfortunately, historically the capital costs of new nuclear plants is quite large relative to the fossil alternatives. Despite the fact that nuclear energy's operating costs in terms of operations and maintenance and, most importantly, fuel are much lower than fossil alternatives, the barrier of high initial investment is a significant one for utilities around the world. The associated regulatory risk makes the construction of a water cooled nuclear power plant a very distant possibility.

In order to deal with this challenge, the Senior Engineer of **The Company,** started the redevelopment of a technology that was originally invented, tested and prototyped in Germany in the 1970's and 80's. A pebble bed research and demonstration reactor operated at the Juelich Research Institute, in Germany, for over 22 years, demonstrating the soundness of the technology.

This **Pebble Bed Modular Reactor** technology is the central theme of this document because it is the technology which we at **The Company** have been working on for so long. Unfortunately, Germany has abandoned its nuclear program for all practical purposes but there is now a world wide resurgence of interest in the development of this technology. The Chinese, the South Africans, the group at M.I.T. and the Engineering group of **The Company** has been researching and testing this technology for many years.

The nuclear energy plant which we are developing is a modular, 110 Megawatt-electric (Mwe), high temperature, pebble bed reactor, using helium gas as a coolant and conversion fluid and gas turbine technology. The fundamental concept of the reactor is that it takes advantage of the high temperature and high pressure properties of the **Brayton Cycle**, using helium as a coolant. Use of the Brayton cycle in the production of electricity permit theoretical thermal efficiencies close to 50%.

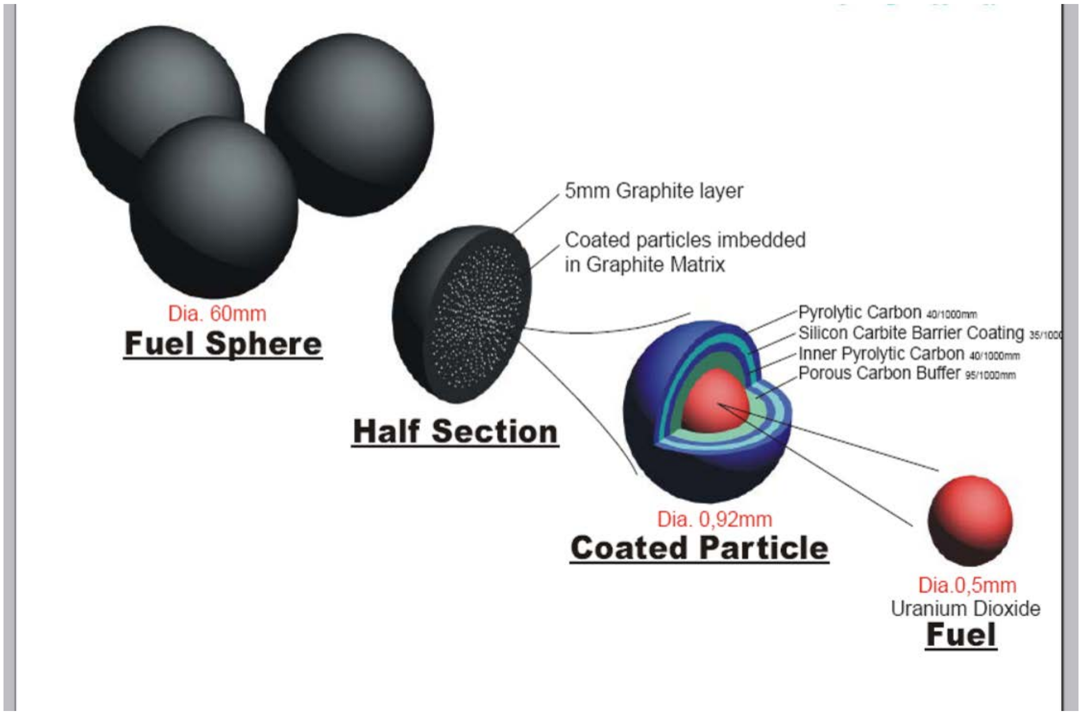
The PBMR utilizes an online refueling system that can yield capacity factors in the range of 95% because it does not have to be shut down to re-fuel. The pebble which form the fuel elements are constantly being re-circulated. Its modularity design concepts, in which all the systems and sub-systems of the plant can fit on specially designed railroad cars and flatbed truck and can be shipped from the factory, allows for a 3 to 5 year construction period, with expansion capabilities to meet merchant plant or large utility demand projections.

2. THE NTPBMR TECHNOLOGY

The **NTPBMR** technology consists of extensions of successfully designed, built and operated, helium cooled reactors built by the Germans in the 1970's and 1980's. The Principal characteristics of the **NTPBMR's** are;

2.1. THE FUEL ELEMENT

TRISO COATED FUEL ELEMENTS CREATED BY NUKEM FOR THE NTPBMR PROTOTYPE PROJECT



2.1.1. PROPERTIES OF TRISO COATED FUEL ELEMENTS

- The reactor core contains approximately 360,000 uranium fueled pebbles about the size of tennis balls. Each pebble contains about 9 grams of low enriched Uranium Oxide (**UO$_2$**) in 10,000 to 15,000 (depending on the design) tiny grains of sand-like micro-sphere coated particles each with its own a hard silicon carbide shell.
- The particle fuel consists of a spherical kernel of fissile or fertile fuel material encapsulated in multiple coating layers. The multiple coating layers form a miniature, highly corrosion resistant pressure vessel and an essentially impermeable barrier to release of gaseous and metallic fission products. This capability has been demonstrated at temperatures in excess of those predicted to be achieved under worst-case accident conditions in the **NTPBMR.**
- The micro-spheres are tri-coated with a porous layer of carbon, a layer of pyrolytic carbon and a layer of silicon carbide. The pyrolytic carbon layer absorbs the fission fragments and the Silicon Carbide coating retains these fission fragments and radioactive gasses within the micro-sphere. These micro-spheres are embedded in a graphite matrix material.
- The Uranium Oxide (**UO$_2$**) fuel micro-sphere has a melting temperature of approximately 2800^{o}C while the ceramic coating does not have a melting point and begins to degrade approximately at 2100^{o}C, and the degradation of the ceramic shell in the 50 or so hours required to empty the reactor would require temperatures in excess of 4000^{o}C. The temperature buildup in the core of the reactor in the event of a **Loss of Coolant Accident (LOCA)** is not expected to exceed 1600^{o}C

2.2 THE NUCLEAR ISLAND

2.2.2 PROPERTIES OF THE NUCLEAR ISLAND

A. **On-line refueling capability:** A unique feature of pebble bed reactors is the online refueling capability in which the pebbles are re-circulated with checks on integrity and consumption of uranium. This system allows new fuel to be inserted during operation and used or damaged fuel to be discharged and stored on site for the life of the plant. Overall burn-up is increased through this recycling. The online refueling capability allows for the extraction of all the nuclear fuel in the event of a **LOCA.** Extraction of all the fuel elements in the core in the case of a nuclear event will ensure that the fuel elements will remain intact through the nuclear event without the possibility the fuel pebbles will melt.

B. **Graphite Moderator:** The moderating environment of the **NTPBMR** is nuclear graphite. The **Reactor Pressure Vessel (RPV)** will house several hundred tons of Nuclear Graphite. The nuclear graphite has high thermal mass and will allow for passive cooling of the reactor core in the loss of coolant event.

C. **Carbon Dioxide Emergency Core Fire Suppression System (ECFSS):** The **ECFSS** is liquefied carbon dioxide. The carbon dioxide fire suppression system will mitigate the risk of a graphite fire of the type which occurred at Windscale, in England, in the early days of the English gas-cooled Magnox program. The carbon dioxide will also act as a passive emergency core cooling system to extract heat from the core.

D. **Low Power Density:** The **NTPBMR** has very low power density in the core. Our preliminary design is for 3MWth per cubic meter. When one compares this figure with the 30 MWth power density in water cooled reactors, we can immediately see the increase in the level of safety in the **LOCA** event.

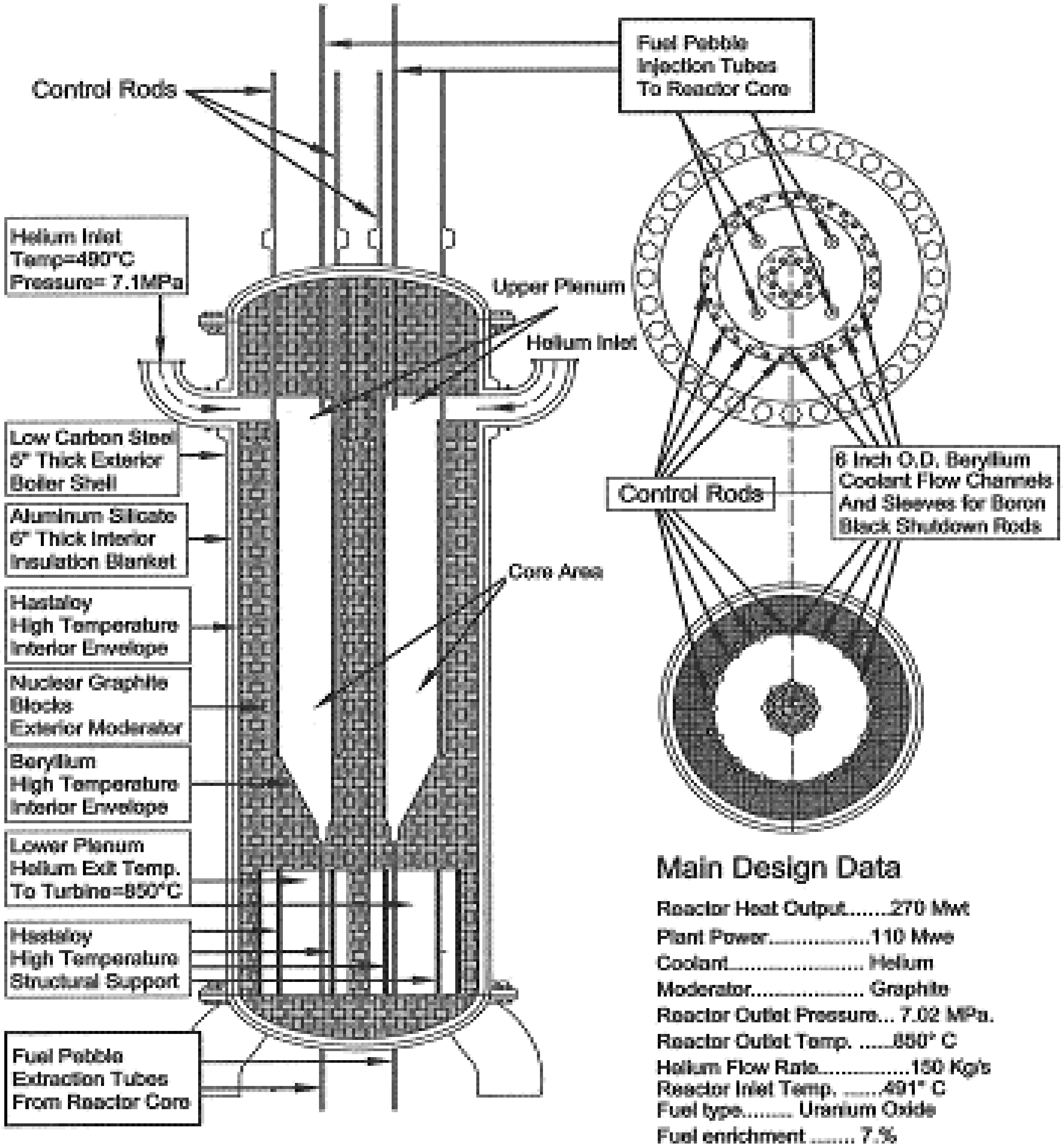
2.3 THE NUCLEAR HELIUM SUPPLY SYSTEM

Helium gas is used as the core coolant. Helium has a very small cross-section for neutron absorption, is inert and operating in a closed-loop, brayton cycle, single phase thermodynamic cycle which can power a turbine with high cycle efficiency.

- A Nuclear reactor using gas as the core coolant will eliminate completely the types of problem which occurred at Three Mile Island and Chernobyl, in their water-cooled nuclear reactor.
- Advances in gas turbine technologies will allow us to use helium as the coolant. Helium is an ideal cooling agent for a nuclear reactor since it is completely inert chemically, within the temperature ranges involved in a nuclear reactor vessel it remains in a single phase and it’s neutron absorption cross-sections are quite low. and operating in a closed-loop, brayton cycle, single phase thermodynamic cycle which can power a turbine with high cycle efficiency.
- The inert nature of Helium will allow the filtration system of the **Nuclear Helium Gas Supply System (NHGSS)** to extract nearly 100% or radioactive fission products from the coolant. The **NHGSS** with filtration will reduce the radioactivity level in the turbine room by three orders of magnitude over existing water-cooled reactors.

The low radioactivity level in the turbine will ensure that an insignificant amount of radiation will be added to the cooling water which will return to our thermal heat sink or cooling pond.

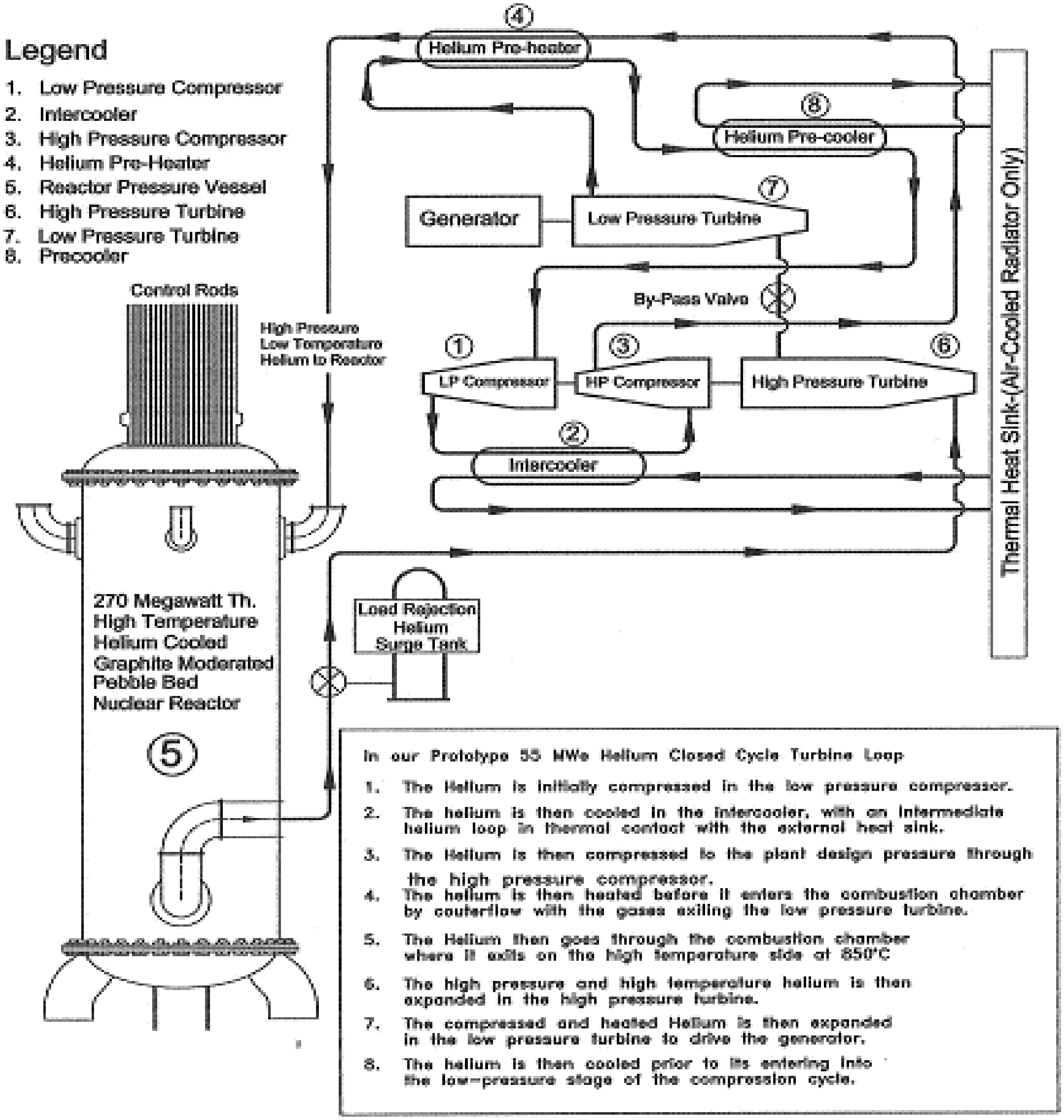
Nuclear Technology
Pebble Bed Modular Reactor
Preliminary Cross Section



Main Design Data

Reactor Heat Output	270 Mwt
Plant Power	110 Mwe
Coolant	Helium
Moderator	Graphite
Reactor Outlet Pressure	7.02 MPa.
Reactor Outlet Temp.	850° C
Helium Flow Rate	150 Kg/s
Reactor Inlet Temp.	491° C
Fuel type	Uranium Oxide
Fuel enrichment	7.%

Nuclear Technology
Pebble Bed Modular Reactor
Flow Schematic For 55 MWe
Helium Closed Cycle Turbine Loop (Air-cooled)



Legend

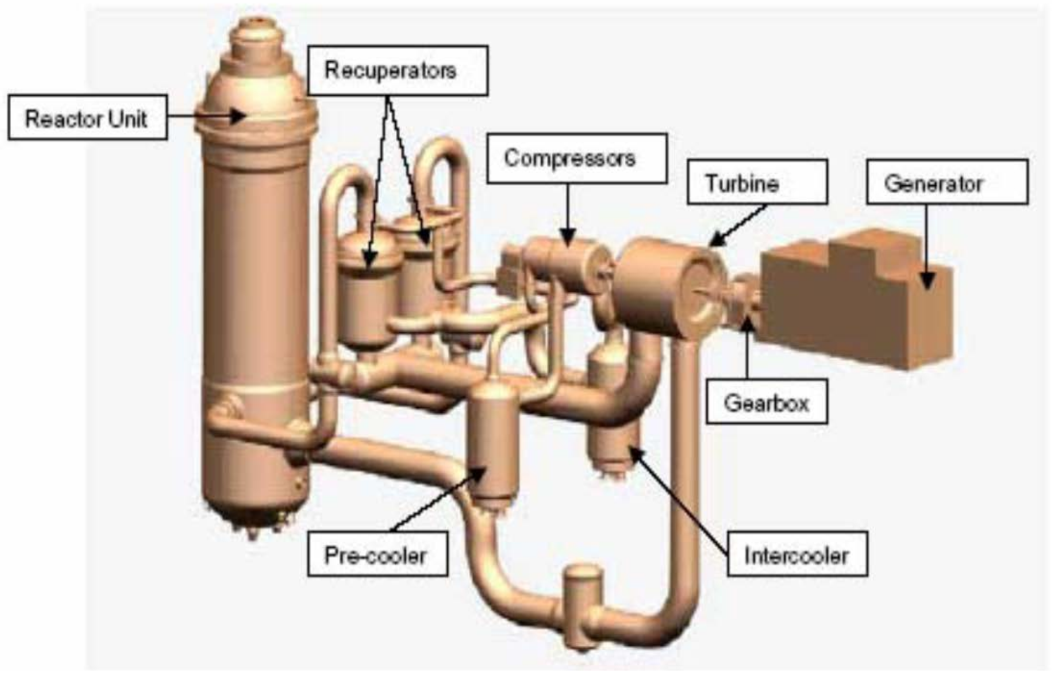
1. Low Pressure Compressor
2. Intercooler
3. High Pressure Compressor
4. Helium Pre-Heater
5. Reactor Pressure Vessel
6. High Pressure Turbine
7. Low Pressure Turbine
8. Precooler

In our Prototype 55 MWe Helium Closed Cycle Turbine Loop

1. The Helium is initially compressed in the low pressure compressor.
2. The helium is then cooled in the intercooler, with an intermediate helium loop in thermal contact with the external heat sink.
3. The Helium is then compressed to the plant design pressure through the high pressure compressor.
4. The helium is then heated before it enters the combustion chamber by couterflow with the gases exiting the low pressure turbine.
5. The Helium then goes through the combustion chamber where it exits on the high temperature side at 850°C
6. The high pressure and high temperature helium is then expanded in the high pressure turbine.
7. The compressed and heated Helium is then expanded in the low pressure turbine to drive the generator.
8. The helium is then cooled prior to its entering into the low-pressure stage of the compression cycle.

4. THE THERMODYNAMIC CYCLE OF THE NTPBMR

ISOMETRIC VIEW OF THE NUCLEAR TECHNOLOGY PEBBLE BED MODULAR REACTOR

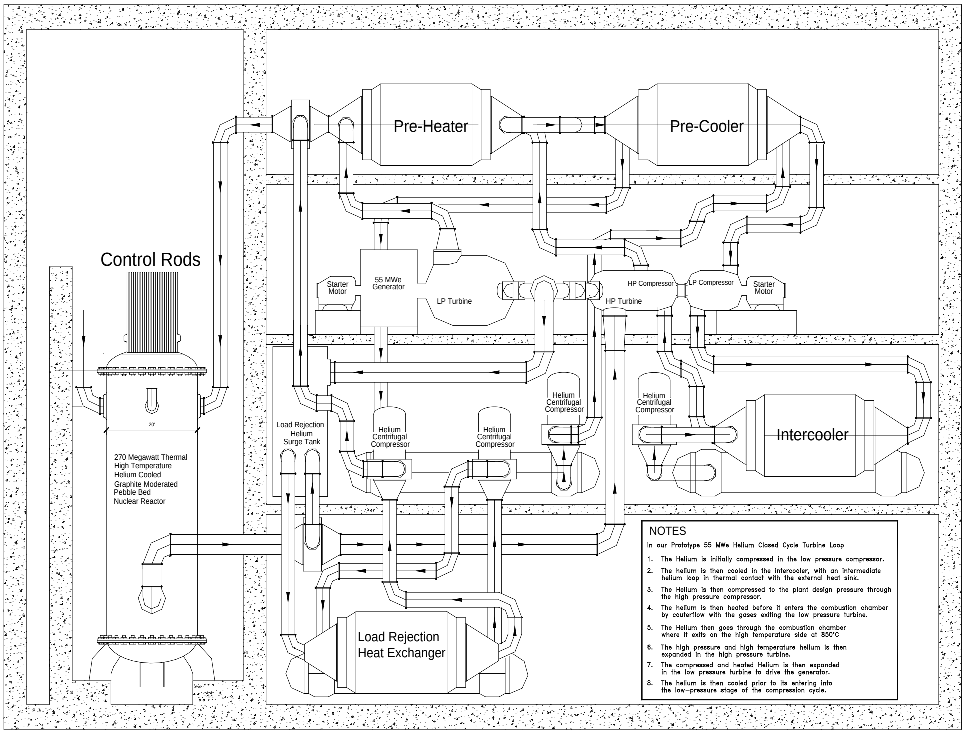


The Thermodynamic Cycle of the NTPBMR:

1. Fission in the Triso-coated micro-spheres creates kinetic energy through the recoil of the Uranium atoms which are split by the absorption of thermal neutrons.
2. The kinetic energy of recoil is transformed into thermal energy in the micro-spheres.
3. The thermal energy of the micro-sphere diffuses throughout the pebble and is transferred to the helium coolant by convective heat transfer.
4. The high pressure and high temperature helium is directed into the high pressure turbine. The high pressure turbine operates the compressors for the return of the helium to the reactor pressure vessel.
5. The helium is then directed to the low pressure turbine which operates the generator.
6. The helium is then cooled through a heat exchanger and the residual heat is exhausted to the atmosphere through an air powered radiator very much like an air conditioning unit on a house.
7. The cooled and compressed helium then re-enters the reactor pressure vessel

5. THE NTPBMR BALANCE OF PLANT

CROSS SECTION OF PLANT



NOTES

In our Prototype 55 MWe Helium Closed Cycle Turbine Loop

1. The Helium is initially compressed in the low pressure compressor.
2. The helium is then cooled in the intercooler, with an intermediate helium loop in thermal contact with the external heat sink.
3. The Helium is then compressed to the plant design pressure through the high pressure compressor.
4. The helium is then heated before it enters the combustion chamber by couterflow with the gases exiting the low pressure turbine.
5. The Helium then goes through the combustion chamber where it exits on the high temperature side at 850°C
6. The high pressure and high temperature helium is then expanded in the high pressure turbine.
7. The compressed and heated Helium is then expanded in the low pressure turbine to drive the generator.
8. The helium is then cooled prior to its entering into the low-pressure stage of the compression cycle.

COMPONENTS OF BALANCE OF PLANT

Each module produces 110MWe in two 55MWe turbine loops at shown in the cross-section above. The balance of plant consists of the following Systems and Sub-system which are important to the production of electricity and the safety of the technology in the event of a **LOCA.**

A. The turbo-machinery:
B. The on-line re-fueling system:
C. Balance of Plant Control and Load Rejection equipment
D. The heat exchangers
E. The Carbon-Dioxide Fire Suppression System:
F. Instrumentation and Control Systems
G. The centrifugal compressors for secondary heat removal

H. On site storage for fuel elements, helium and carbon dioxide

A. THE TURBO-MACHINERY:

All earlier **High Temperature Gas Reactors (HTGR)** installed steam cycles, because they were a mature technology at that time while helium gas turbine technology was not well understood. Use of the steam turbine cycles led to an indirect cycle with a steam generator coupled to the primary helium cycle which extracted heat from the core. The use of the steam turbines introduces extra capital costs and increases the possibility of water ingress from the steam cycle through the heat exchangers and the water-cooled bearing assemblies.

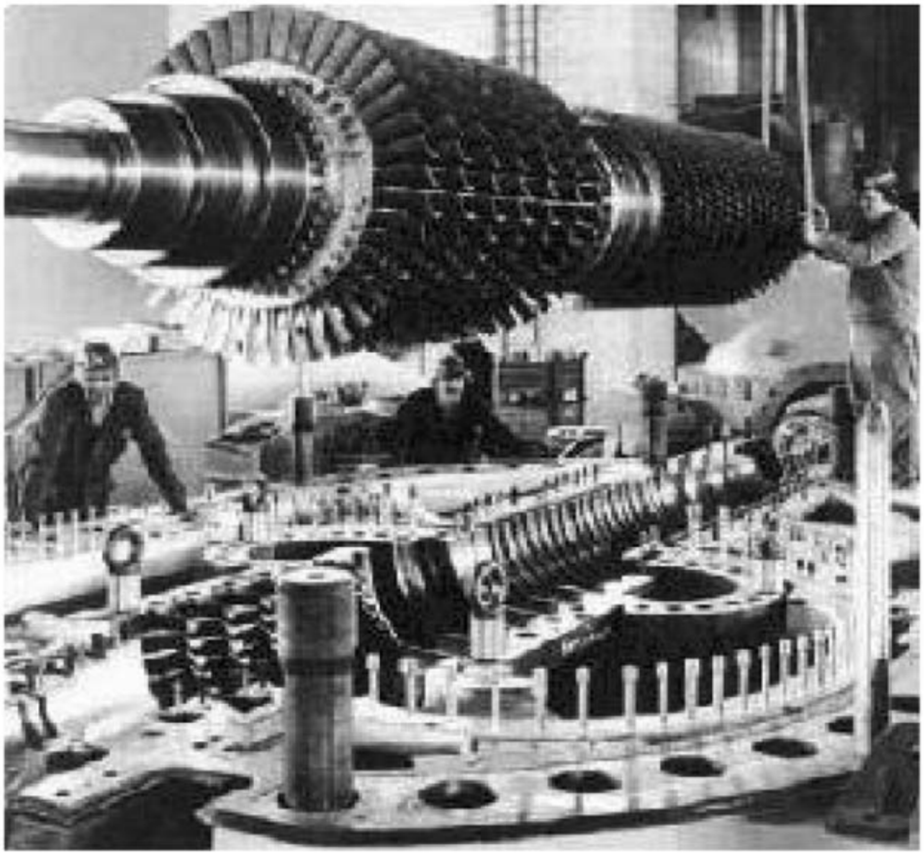
The **NTPBMR** technology proposes implementation of a helium gas turbine cycle rather than a steam turbine cycle. In our initial design we will even eliminate the water cooling on the exit side of the heat exchangers and will go directly to air cooling for the thermal heat sink.

This change leads to an increase in helium temperature, the direct cycle, and implementation of a modular concept with a compact, factory assembled helium cycle. The direct cycle enables elimination of the steam generator as well as the circulator. The size of the blades in a helium turbine is around 0.1 m whereas the blades are larger than 1 m in the steam turbine. As a result, the **NTPBMR** is economically competitive with large scaled water reactors even though the power level of the former is much lower than that of the latter. Therefore, the technology of the helium turbine cycle is essential in development of the **NTPBMR**.

The first and largest helium turbine to date was constructed in Germany in 1968. It was rated at 50 MWe at 750 C. Note that the largest helium turbine under design has an output of 400 MWe as GT-MHR. It was experimentally tested in a high-temperature, helium cooled nuclear reactor heat source generated by a fossil-fired heater with 53.5 MW for electricity generation (the HHT project) in 1968. The operating pressure for tests was up to around 1 MPa. The HHT project involved two experimental facilities. The first was an Oberhausen II helium turbine cogeneration plant operated from 1974 to 1988 by the German utility EVO (Energie Versorgung Oberhausen AG). The second facility was a high-temperature test plant (HHV) built in 1981. The main issues solved through these tests were material performance of the high temperature blades and disks and dynamic issues of rotor and magnetic bearings. The EVO was a milestone test facility that played an important role in the development of current **NTPBMR**.

For the turbo-machinery, a two-shaft arrangement with an interconnected gear was selected. The high-pressure (HP) turbine, which has a rotational speed of 5,500 rpm, drives the low-pressure (LP) compressor and high-pressure (HP) compressor on the first shaft. The low-pressure (LP) turbine is directly connected to the generator with a synchronous rotational speed of 3,000 rpm. The mass flow rate of helium is 84.8 kg/s. A photograph of the HP turbine rotor is shown in the figure directly below, in figure 1. The HP turbine and the LP turbine have 7 stages and 11 stages, respectively. The HP compressor and the LP compressor have 15 stages and 10 stages, respectively, both with 100% reaction. The EVO facility was operated for approximately 24,000 hours. However, the maximum electricity power output of EVO was 30.5 MWe, which is much less than the design power.

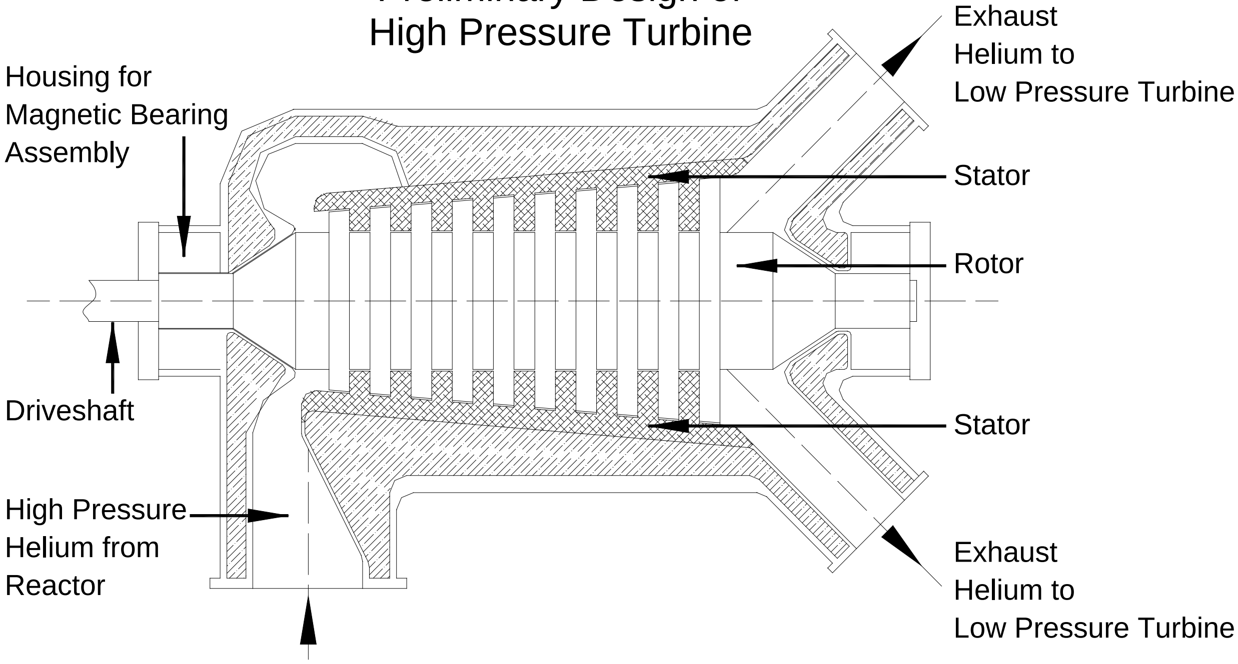
HIGH PRESSURE TURBINE ROTOR
FOR OBERHAUSSEN II- 50MWE, HELIUM



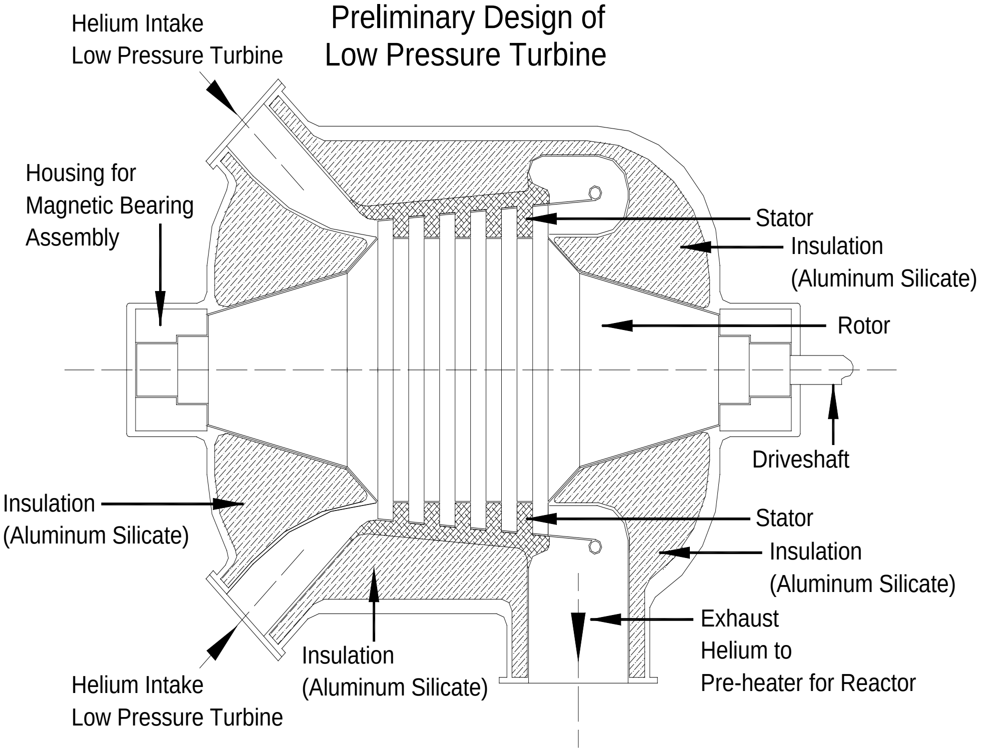
DESIGN CRITERIA FOR NTPBMR TURBOMACHINERY: For the turbo-machinery of the **NTPBMR Prototype,** a disconnected two-shaft arrangement has been selected.

- The high-pressure (HP) turbine which will have a design rotational speed of 7,200 rpm, drives the low-pressure (LP) compressor and high-pressure (HP) compressor on the first shaft.
- The low-pressure (LP) turbine is directly connected to the generator with a synchronous rotational speed of 3,600 rpm. The mass flow rate of helium is 184.8 kg/s. A preliminary design drawing of the HP turbine is shown in the figure directly below. The HP turbine and the LP turbine have 10 stages and 6 stages, respectively.
- The **NTPBMR** turbo-machinery is designed to operate up to 75MWe and will be optimized to operate with an output of 55MWe.

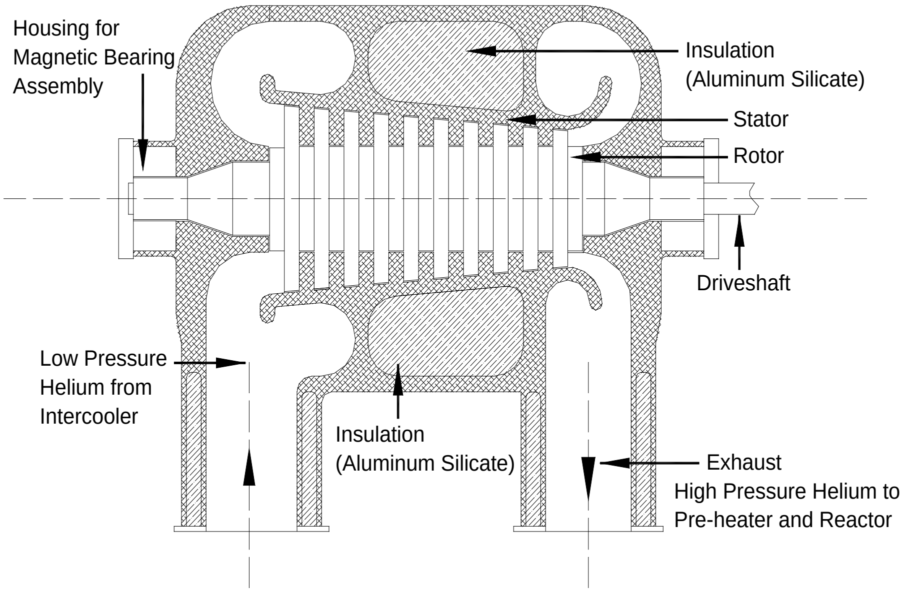
Senior Engineer's Preliminary Design of High Pressure Turbine



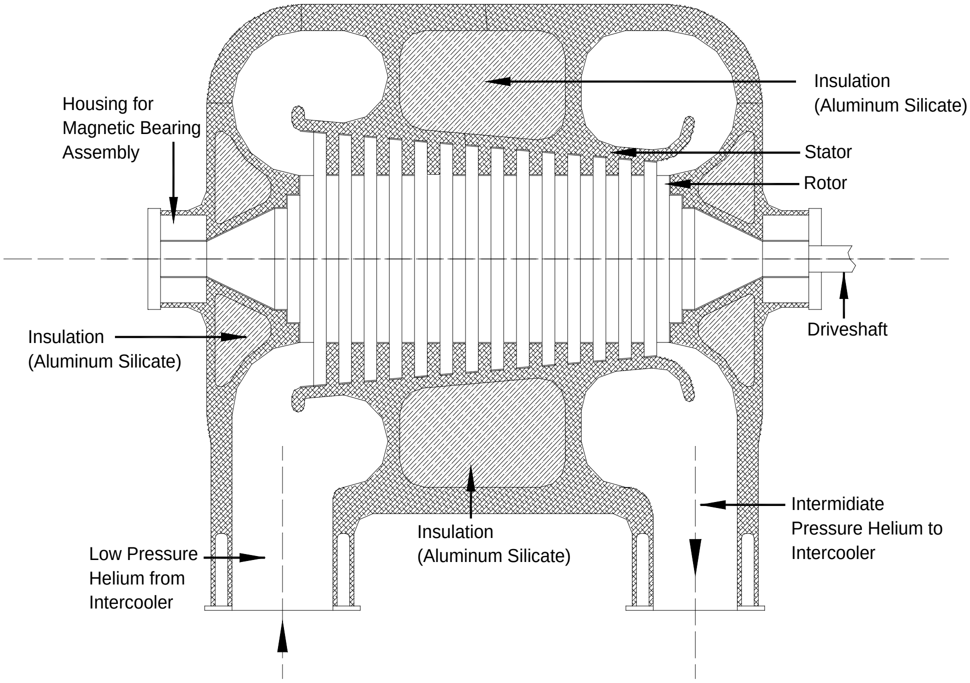
Senior Engineer's Preliminary Design of Low Pressure Turbine



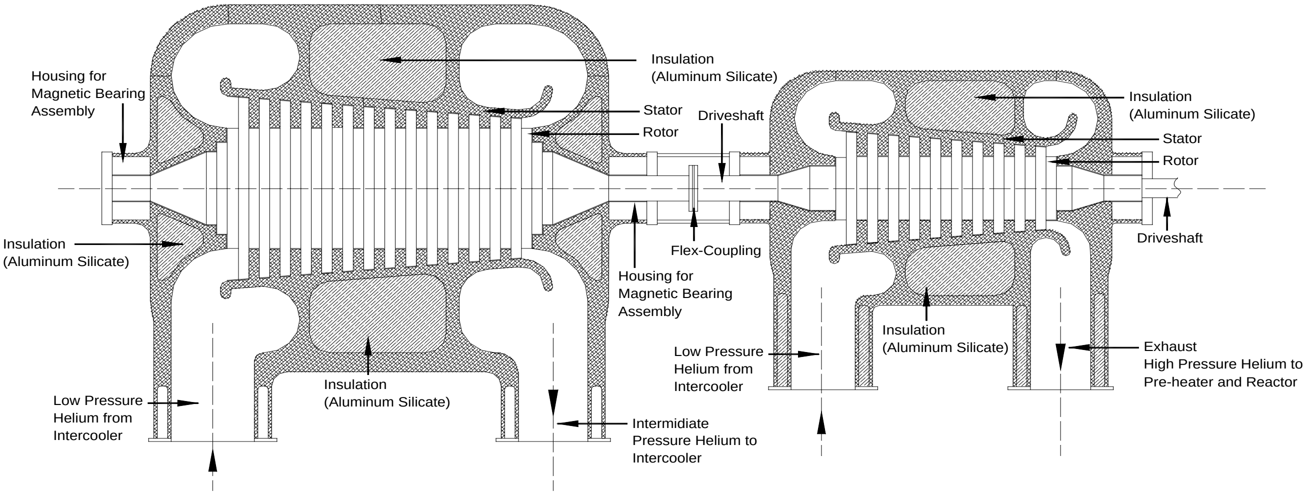
Senior Engineer's Preliminary Design of High Pressure Compressor



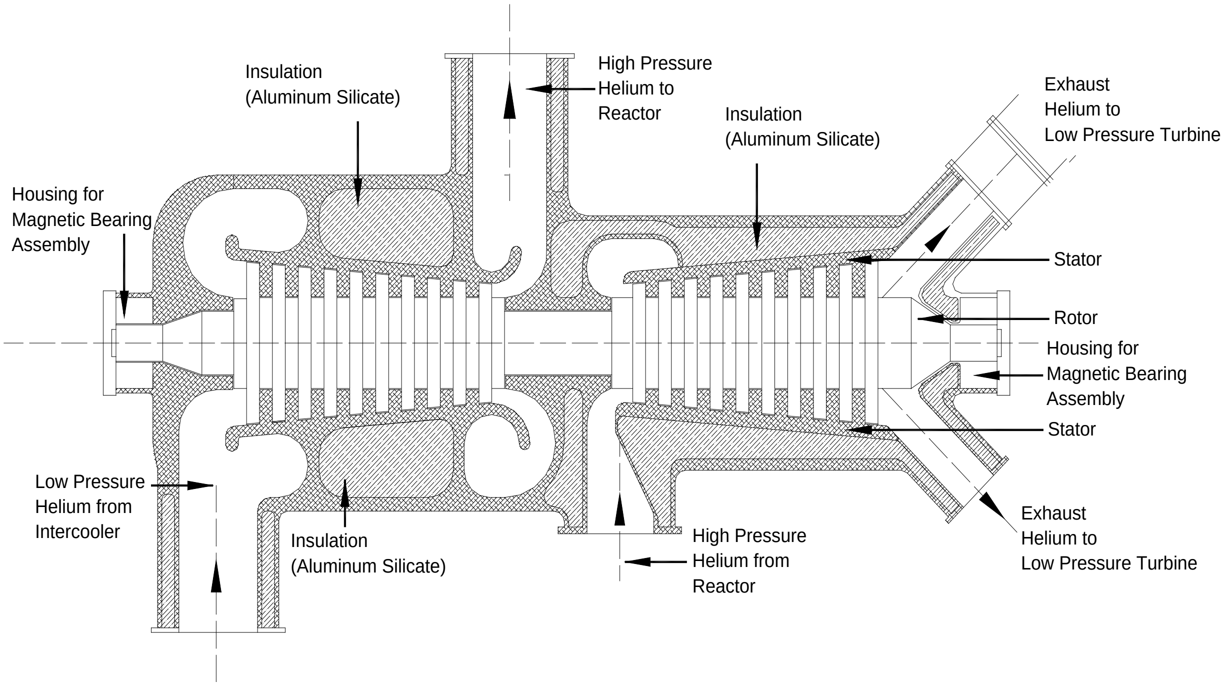
Senior Engineer's Preliminary Design of Low Pressure Compressor



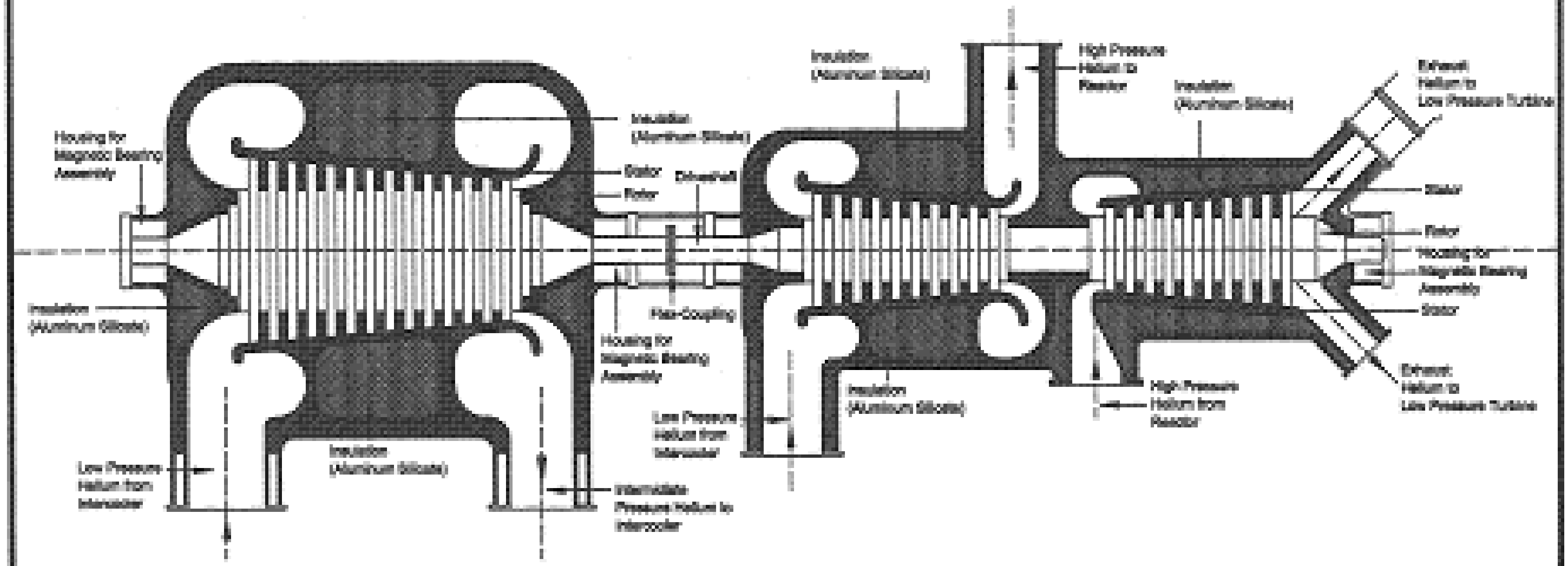
Senior Engineer's Preliminary Design of Coupling of High and Low Pressure Compressors



Senior Engineer's Preliminary Design of High Pressure Turbine/Compressor



Senior Engineer's Preliminary Design of Coupling of High/Low Pressure Compressors to High Pressure Turbine



REV.	DATE	DESCRIPTION	APP.

ASCENTRUST, LLC.
DESIGN CONTROL DOCUMENT

DRAWN BY JDF	NTPBMR DESIGN	DATE 4/11/07
CHECKED BY J.L.	HIGH PRESSURE TURBINE	INDEX NO. 406
	HIGH PRESSURE COMPRESSOR	
REVISED BY JDF	LOW PRESSURE COMPRESSOR	1

B. FUEL HANDLING AND STORAGE SYSTEM

The functions of the **FHSS** are:

- Initial loading of the core cavity with graphite spheres
- Loading the new fuel into the core
- Removing erroneously discharged fuel spheres from the graphite sphere system
- Preventing erroneously discharged graphite spheres initiating the loading of new fuel spheres, via radiation sensors fitted to the delivery line to the spent fuel storage tanks. A detected graphite sphere going the wrong way may not initiate the loading of a new fuel sphere.
- Removing fuel and graphite spheres from the discharge tube
- Separate out damaged spheres
- Separate fuel and graphite spheres
- Re-circulate partially used fuel spheres through the core.
- Measuring burn-up of partially used fuel spheres, and discharging spent fuel spheres into the spent fuel storage system
- De-fueling and refueling of the core, by transfer of the core inventory from the reactor into separate graphite and fuel storage tanks, during maintenance intervention requiring the venting of the main power system to the atmosphere
- Reloading the core from these tanks during refueling of the core.

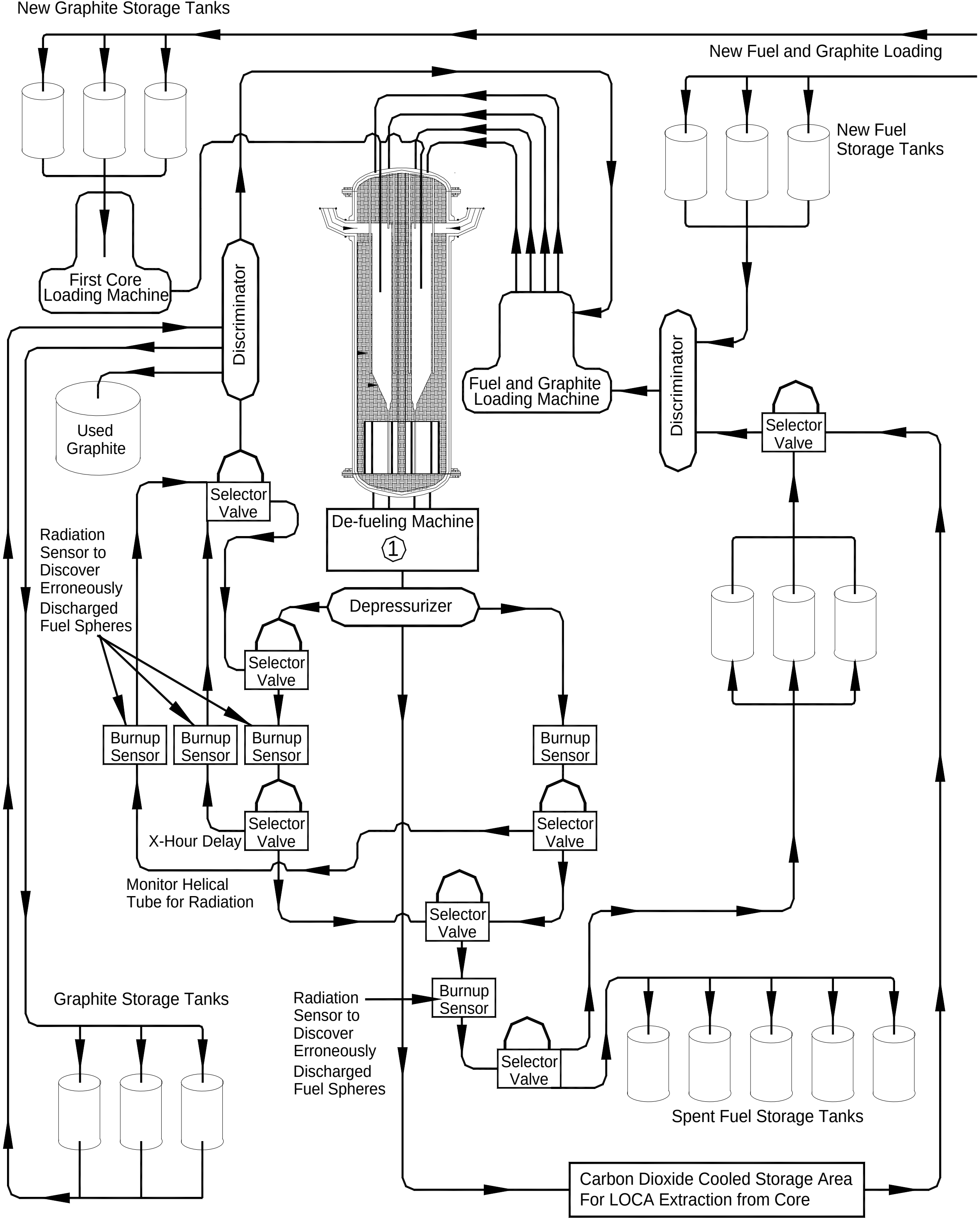
The **NTPBMR** core is to be operated according to the “multi-pass” fueling scheme: which means that fuel spheres are moved through the core more than once. In our particular case we anticipate that we will be able to circulate the fuel elements 10 times, before the fuel spheres reach the fuel burn-up levels which we are predicting to be achievable with this method.

One of the major benefits from the multi-pass fueling scheme is to provide for the uniform burn-up within the core, and thereby flattening the radial neutron flux profile and maximize the thermal power output of the modular unit.

The **FHSS** (see the figure on the next page), for the realization of the multi-pass fueling scheme, consists of the fresh fuel storage and feeding system, the fueling and de-fueling system, including the full discharge of the core in the event of a **LOCA (**Loss of Coolant Accident**).** The Storage Systems consists of the new fuel storage, graphite storage, spent fuel storage and the damaged fuel storage.

The main parts of the fuel handling system are located in the shielded, nuclear island portion of the reactor building. The spent fuel storage system will be designed to store the spent fuel of the power plant on site for the lifetime of the plant.

Nuclear Technology
Pebble Bed Modular Reactor
Fuel Handling System

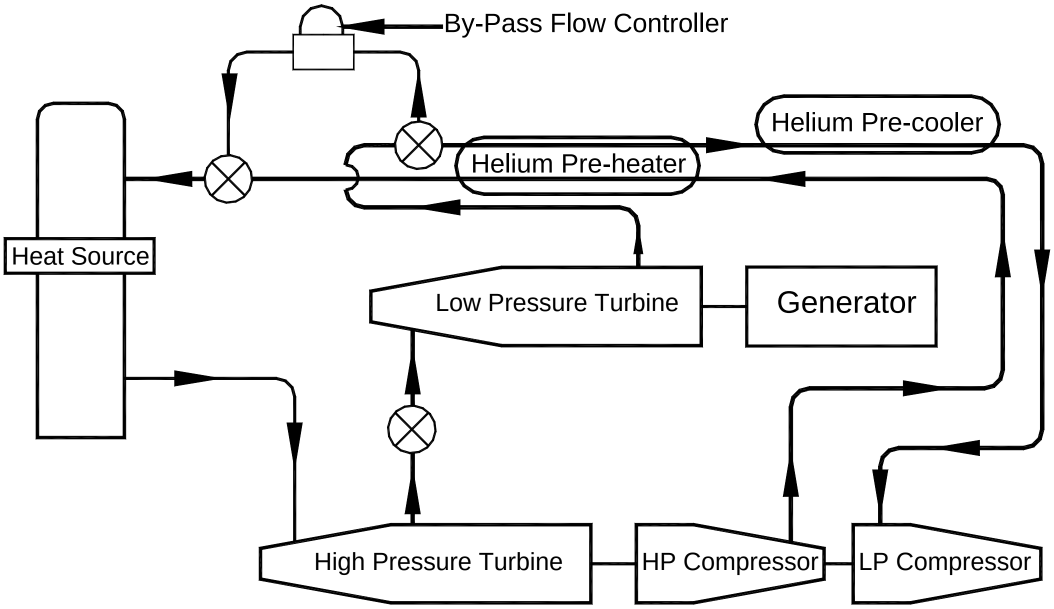


C. PLANT CONTROL AND LOAD REJECTION

a. **By-pass Flow Control:** As shown in the diagram below, a bypass valve bleeds high-pressure gas to short-circuit the heat source and the turbine. This throttling process is a source of irreversibility and thus reduces the cycle part load efficiency. One part of the high-pressure gas, bypassing the turbine, results in turbine output decrease. At the same time, the cycle pressure ratio is reduced, and thus the mass flow-rate through the compressor increases. If the rotational speed remains constant, the velocity triangles for the compressor and turbine are both not in the optimum condition, resulting in a decrease of the cycle efficiency.

The advantage of bypass valve control is that it can alter the turbine output rapidly to match the load variation. Thus, to achieve fast load change, bypass valve control will be included as one of the control functions in the closed gas turbine system, especially in a large system since the inventory control response is relatively slow. In the event of grid separation, the bypass valve control will also be used to prevent the shaft from over-speeding.

BY-PASS FLOW CONTROL OF A CLOSED BRAYTON CYCLE



b. **Temperature modulation:** Decreasing the turbine inlet temperature results in a decrease of the turbine output power and the turbine efficiency, and thus the cycle efficiency. The temperature modulation scheme utilizes this principle. For the **NTPBMR** gas turbine plant, adjusting the reactor power can alter the core outlet temperature, and thus the gas turbine inlet temperature.

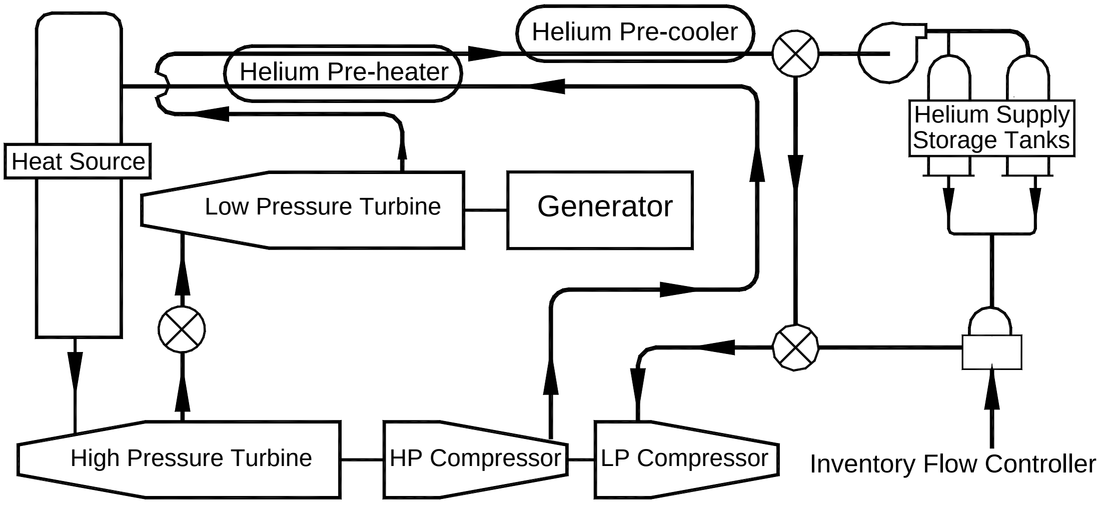
c. **Inventory Control:** As shown in the diagram below, the inventory of the working fluid in the closed power system is controlled by moving mass to or from a storage vessel. A compressor may be used to pump the working fluid from the system to the storage vessel as the load decreases although the ΔP across the compressor can also be used. The reduced mass inventory in the system results in a smaller mass flow rate, and thus a lower turbine power output.

When the load increases, the working fluid in the storage vessel is fed back to the system. To minimize the heat energy moving from the system to the storage vessel, the working fluid can be removed from a point with the lowest temperature of the cycle. With the reduced mass flow-rate, the temperatures and pressure ratio of the cycle remain constant, thus the thermodynamic cycle is unaltered.

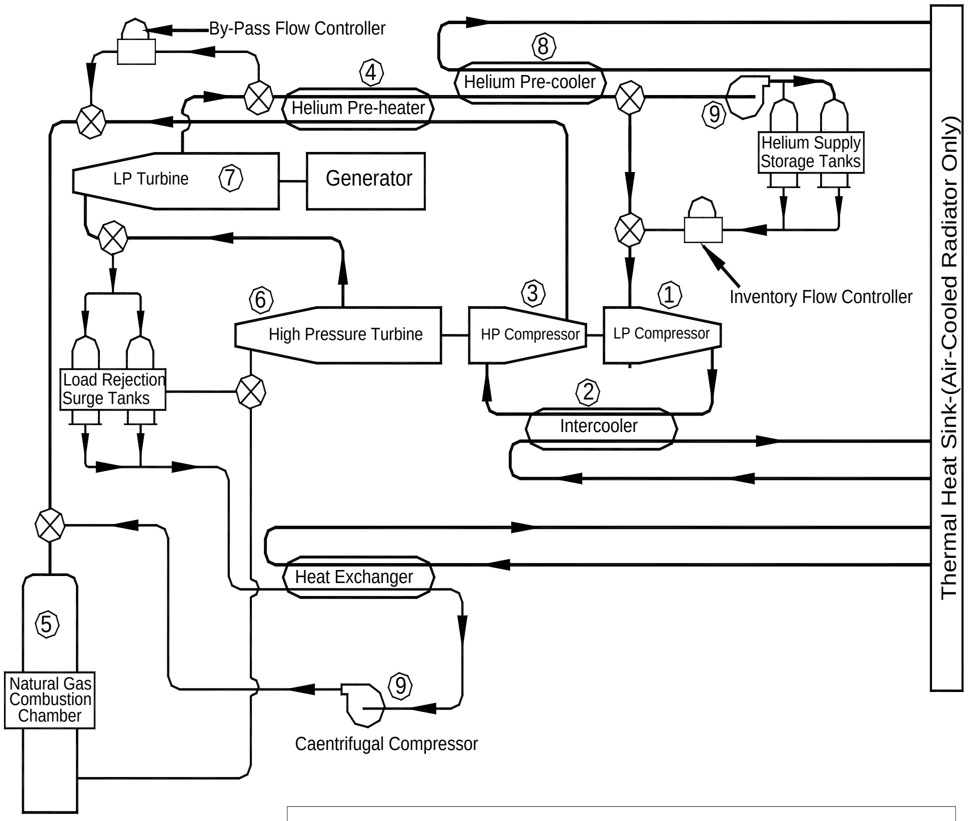
When the temperatures remain constant, the sonic speed of the working gas does not change as the mass flow-rate decreases. The blading and flow passage geometries fix the Mach number. This implies that the flow velocities along the cycle are constant and thus the mass flow-rate is proportional to the flow density. Also, the mass flow-rate is proportional to the pressure level.

As the pressure level decreases, the pressure losses will be slightly changed because the decrease in density also causes a decrease in the Reynolds number. The effect is that the cycle pressure ratio shifts from the design value and thus the cycle efficiency decreases slightly. Figure 2.8 Closed cycle with inventory control

INVENTORY FLOW CONTROL OF A CLOSED BRAYTON CYCLE



Nuclear Technology
Pebble Bed Modular Reactor
Turbo-machinery Control and Load Rejection



Legend

1. Low Pressure Compressor
2. Intercooler
3. High Pressure Compressor
4. Helium Pre-Heater
5. Heat Source
6. High Pressure Turbine
7. Low Pressure Turbine
8. Precooler
9. Centrifugal Compressor

Control of the methane-fired heater, helium closed loop turbine

There are two fundamentally different methods of controlling the closed loop brayton cycle

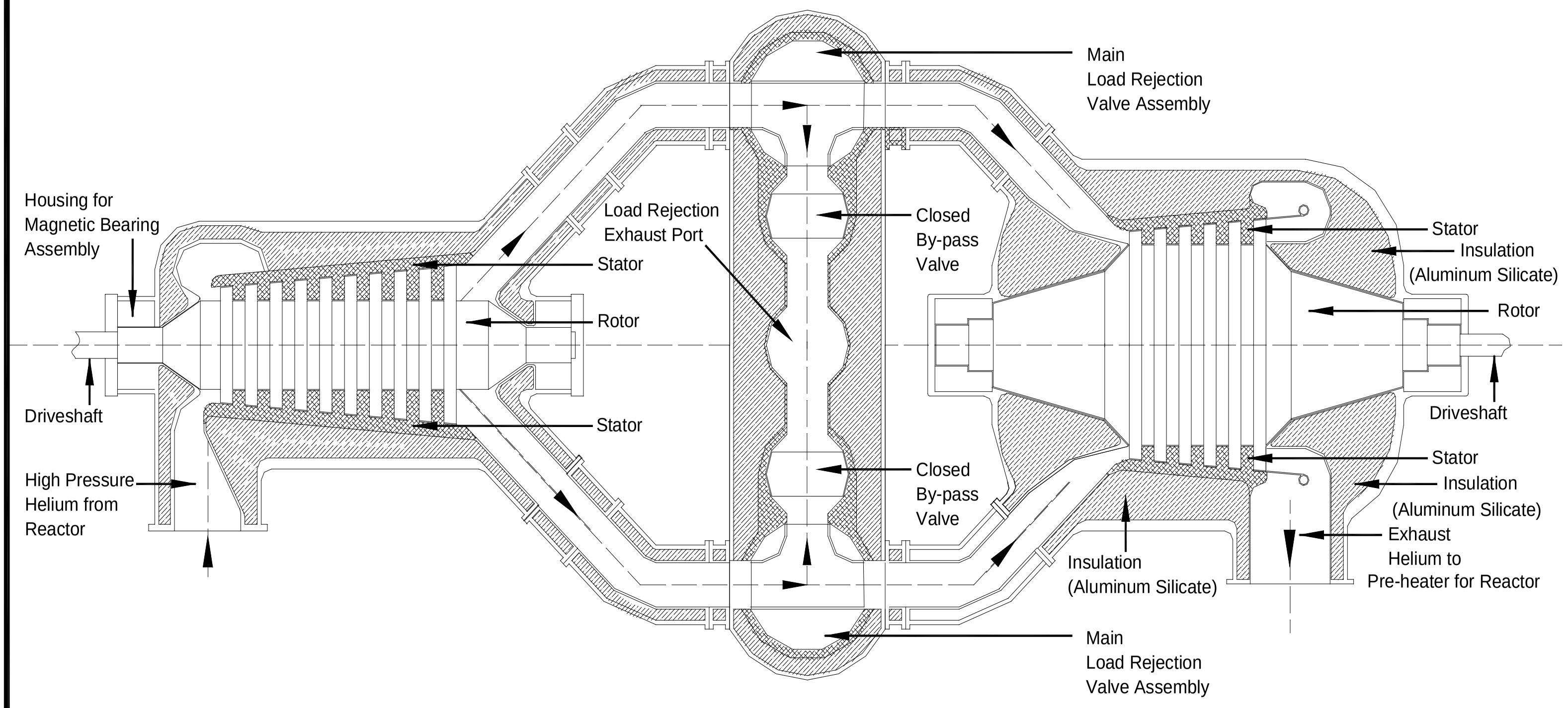
1. The first method is the bypass control at the heat source. A bypass valve bleeds high-pressure gas to short circuit the heat source and the turbine. The gas which bypasses the turbine causes a decrease in turbine output.

2. The second method which will be used to control the turbo-machinery is inventory control. As shown in the diagram above the inventory of the helium in the power system is controlled by moving mass to or from a storage vessel.

The load rejection portion of the control system is used in the event of a loss of connection to the grid, to prevent overspeed in the low pressure turbine.

d. Load Rejection between turbines: In the event in which the plant is tripped off-line, the low pressure turbine must immediately be by-passed in order to prevent over-speed due to the no-load situation created by the trip. The following diagram shows the preliminary design of the by-pass between the low and high speed turbines.

Senior Engineer's
Preliminary Design of
Load Rejection By-Pass System



REV.	DATE	DESCRIPTION	APP.

ASCENTRUST, LLC.
DESIGN CONTROL DOCUMENT

DRAWN BY JDF
CHECKED BY J.L.
DESIGNED BY JDF

NTPBMR DESIGN
HIGH PRESSURE TURBINE
LOW PRESSURE TURBINE
LOAD REJECTION ASSEMBLY

DATE 4/11/07
INDEX NO. 406
1

The POWER of ENGINEERING

6. OTHER CHARACTERISTICS OF THE NTPBMR TECHNOLOGY:

A. **Loss of Coolant Proof:** The low power density and high thermal mass of the technology and the online refueling capability will allow us to extract the pebble from the core in the event of a loss of coolant and allow the reactor to cycle through a loss of coolant event without raising the temperature in the core significantly.

B. **Proliferation Proof;** The fuel element is completely ceramic with the fuel inside of tiny micro-spheres. The extraction of sufficient quantities of plutonium from the fuel element to build a nuclear device will be impossible since it will require the acquisition of more than 200,000 fuel elements which have been in the core for more than three years. Since the on-line fuelling system is completely sealed, in a helium environment, the extraction of a single fuel element would have to break the pressurization of the core.

C. **Ease of Waste Management:** The **NTPBMR** fuel system leads itself easily to waste disposal: Either on-site or in an off-site permanent waste disposal facility. The fuel element completely contain the fission fragments and the whole fuel element is very robust. The spent fuel element can either be stored in dry storage above ground or can be sent to a burial facility.

D. **Modular Design:** The **NTPBMR** is modular in design and the comparatively small size and the lack of complexity in the design of the reactor adds to their economic feasibility. Each power module will produce approximately 110 megawatts (electric), with the use of two 55 MWe cooling loops.

The simplicity of design of our power plant is dramatic. These units will have only two dozen major plant subsystems which we believe can all be plant manufactured, licensed separately and moved to the proposed nuclear site. .

Each power module will produce approximately 110 megawatts electric, with the use of two 55 MWe cooling loops operating two closed loop brayton cycle gas turbines. The modules can easily be configured, in an energy park to produce up to 1.10 Gigawatts electrical power. The technology can also be scaled down to 55 megawatts by employing only one leg of the Helium cooling system.

E. **Safety Characteristics:** The **NTPBMR** has the highest level of safety available in a Nuclear Power Plant. Its safety is a result of the design, the materials used and the physical processes rather than engineered safety systems. The peak temperature that can be reached in the reactor core (1,600 degrees Centigrade under the most severe conditions) is far below any sustained temperature (2,000 degrees Centigrade) that will damage the fuel elements.

F. **Economic Benefits:** The **NTPBMR** modules will all be built in a factory. Only the reactor pressure vessel itself will have to be assembled in the Nuclear Island. This construction technique will allow the Company to capture the cost curve in the construction of Nuclear Power facilities, where the stakeholders have an equity position in the manufacturing of the components of the modules of the power plants. The Company's goal is to be able to design and build a Nuclear power Plant for less than $2000.00 per KW of electrical production. With the added incentive given to the owner in that the fuel cost of operating a nuclear power are not a significant percentage of the operating costs.

7. SUMMARY OF THE NTPBMR TECHNOLOGY

The **NTPBMR** turbine plant is being developed as a generation IV nuclear energy system which offers advantages in the areas of economic competitiveness, safety and reliability. The **NTPBMR** promises a number of significant advantages over conventional commercial water-cooled technology. First, by fully using the high gas temperature, the **NTPBMR** will provide a thermal efficiency approaching 45%. Higher efficiency leads to improved economics.

The **NTPBMR** will be a demonstrably safe nuclear plant system. This implies that the system will be designed such that any postulate accidents will not result in fuel melt, fuel damage or damage to the core. Thus, no fuel damage and release of radioactivity to the environment will occur. This inherent safety is due to the fact that the core will be designed with a negative temperature coefficient of reactivity and the decay heat can be removed to the ground by a passive heat transfer mechanism. The passive heat transfer mechanism includes conduction and natural convection.

Since the coolant is inert helium in the **NTPBMR**, corrosion of the components is not a concern so that the cost for replacement of the degraded components caused by corrosion such as in water-cooled reactors is avoided. This simplifies operation and maintenance and thus improves the economics.

Overall, the objective of the **NTPBMR** is that its economics can compete with natural gas. With regard to the balance of plant design, the requirements can be summarized as follows:

A. High efficiency over a broad operating range;
B. Load following;
C. Low capital cost;
D. Constructability;
E. Modularity;
F. Transportability;
G. Code compliance.

These goals will require that the design provides high efficiency during full power operation and also high efficiency during partial power operation. From a control point of view, the plant must be capable of meeting the utility requirement for load following as an advanced nuclear system. Considering the components in the power conversion system, the constructability, complying with current codes and with no significant R&D effort need to be considered in making design decisions.