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TRITON: A *TRI*modal capable, *T*hrust *O*ptimized, *N*uclear Propulsion and Power System for Advanced Space Missions

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The purpose of this paper is to address the design attributes of a Trimodal nuclear rocket system design based on the collaborative work of NASA Glenn Research Center, Pratt & Whitney, Aerojet, and RENMAR. This design is a derivative of an earlier Bimodal CERMET-based nuclear thermal rocket engine concept called ESCORT that was designed for to support USAF and NASA in-Space propulsion and power and planetary surface-based power requirements. The TRITON is a Trimodal engine design capable of operating across a wide range of propulsive thermal and vehicle electrical power requirements. The baseline TRITON is designed for primary propulsion mode that uses only LH2 fuel for moderate thrust levels near 66.7 KN (15klbf) and ISPs near than 911 seconds. The "augmented" thrust mode provides gasified oxygen into the nozzle down-stream of the throat to get an additional 200% more thrust when needed for heavy cargo earth departure missions. In the power-generation mode a dynamic power conversion unit provides electrical power to support spacecraft systems or electric thrusters for additional maneuvering. The baseline TRITON engine is powered by a fast-spectrum beryllium-reflected CERMET-fueled nuclear reactor. It uses a dual turbopump arrangement driven by an expander cycle using the LH2 and a gas generator add-on to drive the LANTR propulsive mode. When the TRITON is operating in electrical power mode, the reactor operating at less than 10% maximum thermal capability is used to heat a mixture of helium and xenon to drive a closed-loop power conversion cycle. The TRITON engine and power system unit concept has been analyzed relative to the design requirements for producing a range thrust from 44 KN to 334 KN and has a wide range of electrical power generation capability ranging up to nearly 200 kWe per engine. Baseline operating conditions are at 66% power per unit so that when used in "pods" of three and operating in "66% power mode", the total thrust to a spacecraft is near 130 KN and the power delivery capability is near 50 kWe. Data from a parametric design study of the pure hydrogen mode was used to define the performance for the LANTR mode. The POD TRITON engine concept thrust size of 66.7 KN and the power generation level of 25 kWe was selected based on trades performed for a "Return to the Moon" mission, a Manned Mars mission, and several other Deep Space exploration missions. This paper discusses the design analysis performed and provides information on the TRITON engine concept as it could be used for advanced manned and unmanned cargo missions within the Solar System.

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Nomenclature

CBC	=	*C*losed *B*rayton *C*ycle Engine, a Rotating, Dynamic Power Conversion Unit (PCU)
CERMET	=	*CER*amic-*MET*allic matrix approach to Uranium-fueled Reactor Core Elements, Based on 710 Reactor Program of the USAEC, Contract No. AT (40-1)-2847
ESCORT	=	Excore Scalable CERMET Orbital Repositioning Technology
FOC	=	First (fully) Operational Capability
LANTR	=	LOX Augmented Nuclear Thermal Rocket
NTP	=	Nuclear Thermal Propulsion
ROCETS	=	*ROC*ket *E*ngine Transient modeling System, Pratt & Whitney/NASA MSFC Premier Detailed, Modular Rocket Engine Modeling Code.
TRL	=	Technology Readiness Level

I. Introduction

The requirement for performing fast missions to Mars is tied directly to the propulsion and power that an interplanetary spacecraft depends on for the motive force, thermal management, and to sustain the life of the crew. NASA and industry studies since 1990 have indicated that nuclear thermal propulsion and power is the only technology mature enough to enable fast, piloted missions across the solar system within the next 20 years. Many detailed mission and system studies have been performed by industry (e.g. Boeing, Lockheed Martin, United Technologies, and AEROJET) and NASA engineers from Johnson Space Center (JSC), Glenn Research Center (GRC), and Marshall Space Flight Center (MSFC) and Jet Propulsion Laboratory (JPL). Many of the emeritus and current experts have indicated that the vision to develop and field advanced in-space nuclear thermal propulsion is a necessary technology for manned interplanetary flight. The physics that drove the results from those prior studies has not changed and even with advances in electronics, the net energy delivered by solar radiation to photo-voltaic arrays still is hampered by the inverse of the square of the distance traveled from the Sun. Nuclear thermal propulsion is the most near term, highest TRL advanced propulsion technology available to get the 2004 Moon-Mars vision off-planet and in-space. The recently released report from the *President's Commission on the Implementation of the United States Space Exploration Policy* in June of 2004 also identified nuclear thermal propulsion as an enabling technology under "Finding 4". Developing a nuclear thermal propulsion system to support fast, human missions should be paramount to this nation's and the world's efforts to expand humankind beyond LEO, to Lunar orbit, to Mars and the outer planets.

Resurrecting nuclear thermal propulsion via a modern state-of-the art design will mean that a reactor is needed that can be designed for operating at temperatures greater than 2,500-K to meet the propulsion performance requirements for fast missions. It also means that the reactor should also be able to produce power from the same design to minimize development cost and to have a higher TRL in-space and planetary power system at the end ot the NTP development. The total propulsion system will need to provide high thrust (e.g., 23 to 334 kN, mission optimized) to keep planetary departure/capture times to hours and not months and maximize spacecraft system life and durability. It will reduce the number of launches and in-orbit systems used for missions. Spacecraft systems (e.g., cooling propellants, supporting crew habitat environmental systems, communications and data handling, and possible electric propulsion thrusters) will need high power especially for long distance fast-transfer missions. The electric power capability from a bimodal nuclear thermal propulsion and power system can effeciently range from 10-kilowatts to several 100's of kilowatts depending on the scaling of the PCU. A bimodal or trimodal nuclear system that is safe, provides long-life and reusability, redundancy in power systems, and is highly responsive can provide the capability to perform fast missions to Mars and also be available to serve as a reusable Lunar human transport.

Reduction in transportation system mass and reduction in mission transit time leads to more affordable mission architectures. The same mission requirements identify nuclear technologies as key elements for NASA manned interplanetary mission architectures. NTP has been shown to allow reductions in these key areas. The primary driver in these reductions is the increased vacuum impulse (ISP) and the high thrust-to-weight afforded by these systems. An trimodal NTP system like TRITON can provide maximum vacuum impulses from 900 to 1,000 seconds and have thrust-to-weights from 3.6 (LH2 only) to 10 (LANTR mode). This is twice the ISP of typical chemical liquid oxygen and liquid hydrogen propulsion. In addition to providing high propulsion performance, the high power density nuclear reactor in a NTP system provides the foundation for a power conversion system for generating spacecraft electrical power on interplanetary missions. The TRITON nuclear reactor has been designed as a heat source for superheating hydrogen propellant for propulsion and as a heat source for a secondary working fluid for a closed cycle power conversion system.

Pratt & Whitney has previously defined several nuclear system designs capable of delivering both propulsion and power. The foundation for these designs was the XNR2000 pure nuclear thermal design and the ESCORT bimodal nuclear thermal design. The XNR2000 nuclear thermal propulsion system was scalablew from 111,200 Newtons (25,000-pounds) to 333,600 Newtons (75,000-pounds) thrust size and had a nominal ISP of 944 seconds. The original ESCORT system was designed for delivering 4448.22 N (1000-pounds) of vacuum thrust at a vacuum impulse of approximately 900 seconds. The power generation capability of the original ESCORT was limited to 10-20 kWe. The TRITON engine design currently under study is a derivative of the ESCORT bimodal design and has been evaluated at performance levels from 66,720 Newtons (5,000-pounds) to 333,600 Newtons (75,000-pounds) of thrust similar to the XNR2000. It has also been examined for sensitivity to variations in reactor exit temperature and pressure, and for variations in nozzle performance. The key to deriving the TRITON from the XNR2000 and ESCORT designs is that the CERMET reactor design has already had extensive neutronics and thermal-hydraulics analysis performed for all the reactor design points, as well as having had the heat transfer of the power-mode operation analyized.

The TRITON engine is also designed to accomodate the add-on of a LANTR (lox-augmentation) system as a design upgrade to increase the thrust capability to greater than 178 KN (~40,000-pounds) for a nominal 15,000-pound thrust design. Much design work has been accomplished on the 15,000-pound thrust size because that thrust size has been shown to be more easy to test from many perspectives. These perspectives include; possible enclosed facility testing with exhaust scrubbing at particular Idaho National Nuclear Engineering Laboratory CTF building, it presents a small enough system to possibly be tested in modified underground bunkers at the Nevada Nuclear Testing Site, and it can use current liquid rocket engine hardware designs to reduce the development and acquisition cost.

Current TRITON design study efforts have re-examined the neutronics for the specific 15,000-pound design, characterized the performance for the TRITON engine across a range of design operating levels, and have performed detailed mechanical design and mass properties analysis. Some of these will be discussed in Sections II, III, and IV.

II. TRITON Design Characteristics

The TRITON 15,000-pound thrust design is a bimodal nuclear thermal propulsion system capable of both delivering a wide range of thrust with the LANTR trimodal option, specific impulse performance above 900 seconds and a wide range of mission specific spacecraft electrical power requirements. The TRITON trimodal option includes the LANTR hardware that provides additional thrust by injecting oxidizer-rich exhaust gases into the supersonic section of the nozzle down-stream of the throat. The TRITON propulsion system flowpath is comprised of ducts and propellant feed lines from a primary hydrogen run-tank that interfaces with the pump of thehydrogen turbopump. The hydrogen flowpath then continues to the regeneratively-cooled nozzle and chamber sections. The hydrogen flow enters the nozzle and flows through the coolant passages of the nozzle and chamber and the exits to enter the hot section end of the BeO radial reflector. After cooling the reflector, the hot-hydrogen flow enters the turbine to serve as the drive fluid for the turbopump. The gaseous hydrogen then exits the turbopump and then enters the reactor inlet plenum above the axial BeO reflector section, where it enters the fast-spectrum CERMET-fueled reactor located within in a multi-walled pressure vessel. After cooling the reactor, the hydrogen has been superheated to nearly 2,700-K (nominal design exit temperature) and is then discharged to the throat-section of the regenatively-cooled nozzle and then exits the nozzle section into a carbon-carbon nozzle section to reach velocities near 9,000 meters per second. The TRITON power system loop is attached to the primary reactor via a multi-level plenum above the hydrogen injector plenum segment. The working fluid of the power system loop is transported into and out of the reactor via a dual flow path annular region within each fuel element. A schematic of the TRITON nuclear thermal propulsion and power system is shown in ***Figure 1***.

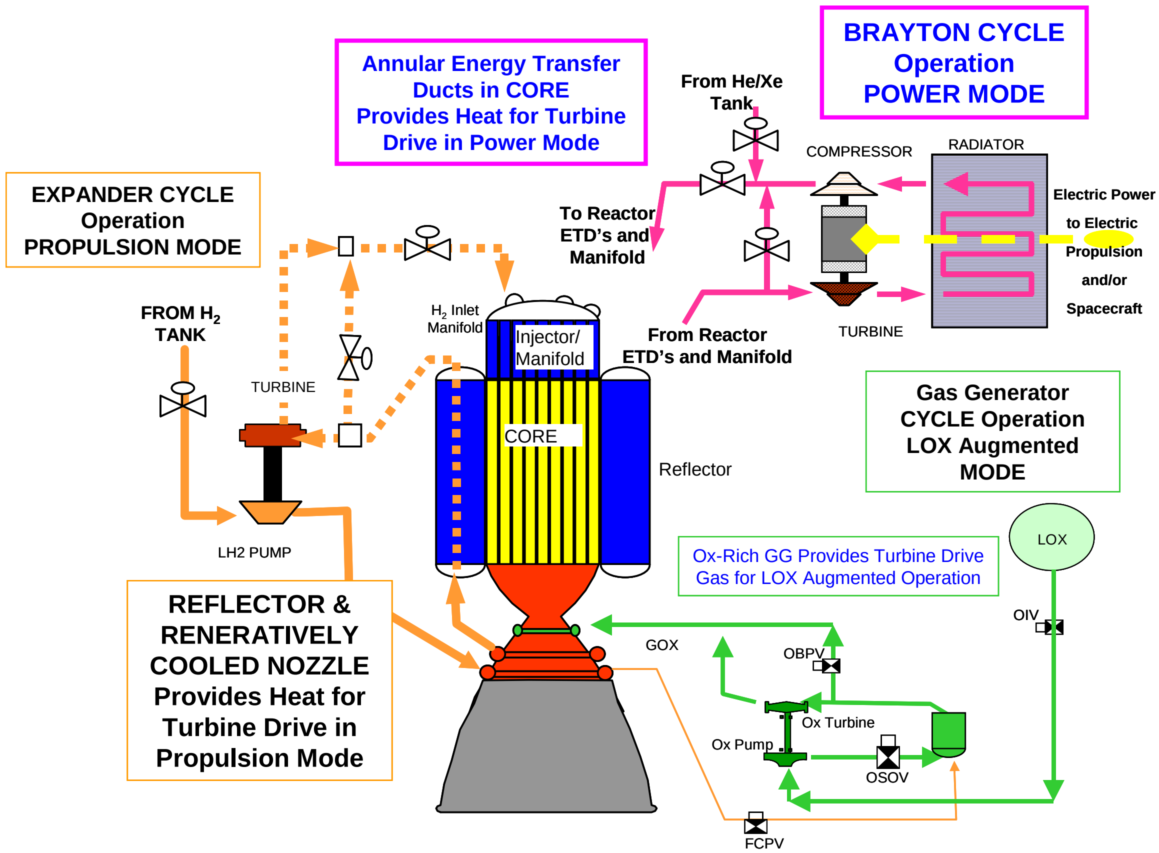

Figure 1 – TRITON Trimodal Schematic with Notional LANTR Gas Generator Flowpath.

In propulsive mode, the reactor is used to heat hot hydrogen to approximately 2,700 Kelvin, which is expanded through a converging/diverging nozzle to generate thrust. Heat pickup in the regeneratively cooled nozzle and the radial beryllium reflectors is used to drive the turbomachinery in the TRITON expander cycle. In electrical power generation mode, the reactor is used to heat a mixture of helium/xenon to drive a closed loop Brayton cycle in order to generate electrical energy. This closed loop system has the additional function of a decay heat removal system after the propulsive mode operation is discontinued.

The LANTR mode of the TRITON will operate by using a oxidizer-rich gas generator that "steals"less than 3% of the hydrogen flow to drive the gas generator. The gas generator will serve to drive the LOX turbopump to deliver gasified LOX to the injectors in the regeneratively cooled section of the nozzle. Since the LANTR mode operates at O/F ratios of 3 to 4, the TRITON augmented engine can produce thrust levels from 40,000 to 50,000-pounds at thrust-to-weights 8 and higher. The LANTR augmentation approach to the NTR design provides a superior way to get to high thrust levels without scaling up the reactor size which increases cost and the total fission product inventory at the end of life.

The ESCORT and TRITON propulsion and power systems have the advantage of using technology that has already matured from legacy liquid rocket engines. Much of the propellant feed system, combustion chamber and nozzle section, the carbon-carbon nozzle extension, and the valves are available as hardware that has already operated at the same conditions. The TRITON uses the same expander thermodynamic cycle for turbine drive power in the propulsion mode as the Pratt & Whitney RL10 liquid hydrogen-oxygen chemical engine used on today's expendable rockets. The cycle used by the RL10 family of engines provides added heritage and reduced technical risk. The primary benefit of the expander cycle is that it uses the latent available heat of the hydrogen fuel for starting and powering the turbopump to meet the design operating pressures. The expander cycle approach uses the cryogenic hydrogen that is flowed through the coolant passages to pick up enough heat to become vaporized to start drive the turbine of the turbopump. The cycle is started when the reactor is activated and starts providing additional heating to the hydrogen and then the turbopump speeds up to the full power level. For the baseline TRITON engine 15,000-pound thrust design, two turbopumps are used to support a "pump-out" failure mode. The turbopumps are connected in parallel from the hydrogen fuel tank to the reactor system so that if one turbopump has problems the other can "throttle-up" to maintain the propulsion-mode hydrogen flow at the require maximum.

As just described, the turbopump is driven by the hydrogen that becomes warmed as it acts as the coolant for the nozzle, reactor exit/chamber section, and the reflector/moderator. Based on the 15,000 pound thrust propulsion size, the liquid hydrogen turbopumps used on the TRITON design concept is the actual turbopump from a Pratt & Whitney liquid hydrogen upper stage engine that is currently under development.

III. Reactor Design Approach for the TRITON Engine

The reactor core and control system that are used for the TRITON engine concept was based on the ESCORT CERMET reactor design work. The TRITON point of departure reactor is capable of operation over a wide range of power levels and thedual-mode flow path fuel element design permits the electrical energy generation capability. In electrical power generation mode, the reactor is used to heat a mixture of helium/xenon to drive a closed loop CBC engine in order to generate electrical energy. The original ESCORT reactor design was configured for providing Bimodal capability as a propulsion and power system. The basis of the TRITON PCU and power mode analysis is taken from the ESCORT power generation mode engineering analkysis. Additional analysis has been performed on the TRITON to charaterize the maximum power capability for various thrust sizes for constant reactor fuel geometries. ***Figure 2*** provides a sample of some of the trades performed on the TRITON power mode operation.

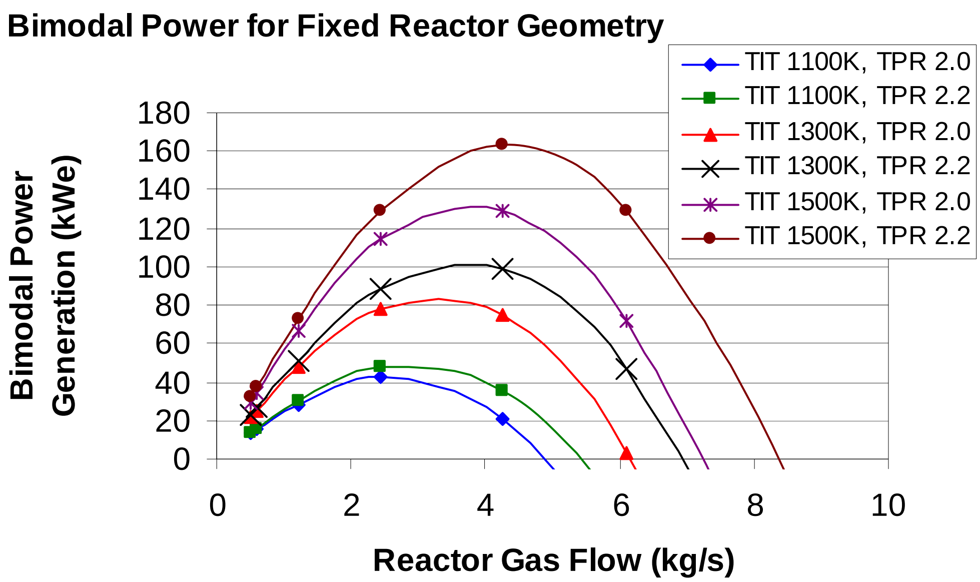

Figure 2 – TRITON power mode design sensitivies.

The CBC PCU operation provides the power generation and acts to augment the decay heat removal after the propulsive mode operation was discontinued. As can be seen by ***Figure 2***, if the turbine temperatures are maintained at a nominal 1300-K, a maximum power capability per 15,000-pound engine CBC PCU is near 100 kWe. Higher power is possible at higher turbine pressure ratios and increased turbine temperatures, but this would demand increases in materials technology for the turbine to withstand 1500-K and possibly the heat-pipe radiator in order to withstand the higher pressure losses. This data is based on a fixed reactor design geometry of the annular energy duct within the fuel element with 48 coolant holes along the perimeter for flowing the LH2 coolant. If the mission design requirements indicate a need for higher than 100 kWe per engine several other design options are possible. These include resizing the annular duct to increase the surface area, and scaling up the 15,000-pound thrust size to get a slightly larger reactor design and possibly adding an additional heat exchanger flowpaths just for the He-Xe gas flow.

The TRITON reactor core is comprised of nearly 110 hexagonal prismatic fuel elements surrounded radially by a beryllium reflector and on the top (axially) by a beryllium-oxide reflector. To produce the 25 kWe to the spacecraft propulsion and systems, the reactor needs to produce less than 250kWt and designed to operate for ten years. This is less than 1% of the maximum power capacity of the reactor.

The TRITON fuel element consists of a CERMET fuel matrix with both tubular hydrogen flow passages located concentrically around a annular flowpassage for the helium/xenon mixture used during power mode. The fuel matrix material is composed of a UO2-W-Gd2O3 mixture. This material was selected to support the high-temperature fast-spectrum characteristics of the ESCORT and now the TRITON reactor. The outer portion of the fuel element are clad with a high temperature refractory metal alloy (W-Re) to mitigate the release of fission products and fuel material from the reactor. The primary clad for the energy transport duct is also composed of the W-Re alloy. The energy transport duct also has a secondary clad material, which minimizes the release of material into the closed loop power generation system. A "Mo" alloy is chosen for an inner liner to reduce the weight penalty associated with "W" material systems. The inner tube of the annular energy transport duct (which provides the flow boundary separating the cylindrical down-flow region from the annular up-flow region) is composed of the same Mo-Re alloy.

The ESCORT reactor core was comprised of 91 hexagonal prismatic fuel elements of roughly 61cm in length. The TRITON reactor core has been updated to 110 hexagonal fuel elements to provide adequate criticality and to meet the propulsion mode operation and 7-10 year power mode operation fuel burnup requirements. The reactor is surrounded radially by a beryllium-oxide (BeO) reflector (~15-cm for conservatism) and on the top (axially) by a BeO reflector (20-cm). In the radial reflector surrounding the reactor core, eight rotating control drums with Boron-Carbide (B4C) absorber windows are used to control the reactor. To maintain safe shutdown of the reactor, the absorber material of each drum would be rotated to face the reactor core.

The general size of the reactor is independent of power level due to the sufficient excess reactivity designed into the system to support a wide range of burn ups. From an excess reactivity standpoint, the reactor is capable of supporting the thrust mode burn at 320-MWt for a period of several hours and the electrical power mode operation of <200 kWe for several years. The fuel element, however, was modified slightly to accommodate increased power requirements for the evolved ESCORT and the new TRITON design. These modifications were to the number and size of the hydrogen flow channels. The ESCORT and TRITON fuel elements have 48 hydrogen flow holes approximately 0.254 cm in diameter. These dimensions were set such that the peak fuel temperature limit of 2880 K for CERMET fuels is not violated. ***Figure 3*** shows the mechanical design and the resulting detailed CAD model of the TRITON bimodal NTP.

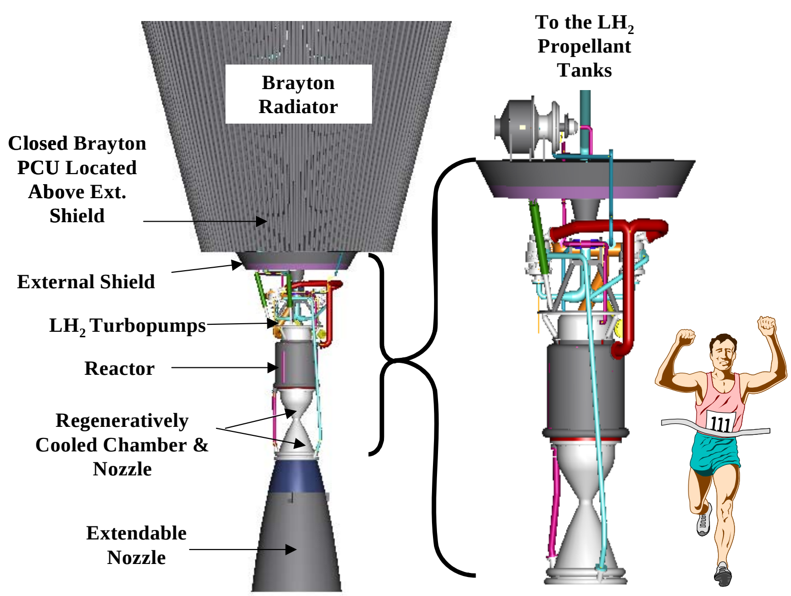

Figure 3 – TRITON CAD Design with CBC PCU and Radiator.

IV. Design Analysis of TRITON Engine

Using ROCETS hardware-anchored component models that had been evolved from early nuclear thermal propulsion and power system models, parametric design runs were used to examine the propulsion performance sensitivity for the Baseline LH2-fueled TRITON engine. The parametric data included thrust ranges from 5,000-pounds (22,240 N) to 75,000-pounds (333,600 N), reactor exit temperatures from 2,500-K to 3,000-K, nozzle area ratios from 100 to 500, reactor exit pressures from 750 psia (5.171 MPa) to 2,000 psia (13.789 MPa). Nozzle predicted performance was based on detailed two-dimensional kinetics calculations using TDK for the parametric temperature, pressure, and area ratios shown above. That data was then used to adjust the nozzle performance model in the ROCETS program for the TRITON engine. The ROCETS parametric data was provide to AEROJET for use in scaling and determining parametric performance for the LANTR operation of the baseline LH_2 TRITON NTP design. ***Figure 4*** provides a sample printout from the ROCETS bimodal propulsion and power thermodynamic cycle and reactor power balance model.

Also as part of the TRITON design activity a detailed mass properties model was developed that can provide the TRITON bimodal or trimodal system roll-up to obtain accurate estimates of the system thrust-to-weight, the external shield mass, the CBC PCU mass and the CBC PCU radiator mass. The model predicts 3.6 thrust-toweight for the 15,000-pound TRITON and a thrust-to-weight of 8.7 for the LANTR configuration of the TRITON.

```
                        PRATT & WHITNEY ROCETS MODEL
POINT: REV 2          ESCORT BNTR USING CURRENT HARDWARE
PAGE: 1/3            EXPANDER CYCLE WITH NO AUGMENTATION
VERSION:1.0     SIZED TO 15000 LBS THRUST AND 1000 PSIA CHAMBER

    ** ENGINE PERFORMANCE SUMMARY **
****************************************
THRUST                         (LBF)       15000.
NOZZLE GEOM AREA RATIO      (D-LESS)        300.0
TRUNCATED AREA RATIO        (D-LESS)        30.00
REACTOR DELTA P               (PSID)        430.0
TURBINE INLET TEMP           (DEG R)        533.7
REACTOR EXIT TEMPERATURE     (DEG R)        4860.
ISP                            (SEC)        910.7
HYDROGEN ROTOR SPEED           (RPM)       75235.
CHAMBER FLOW               (LBM/SEC)        16.47
TURBINE BYPASS FLOW        (LBM/SEC)        2.719
NOZZLE THROAT GEOM AREA       (IN^2)        8.478
PUMP DISCHARGE PRESSURE       (PSIA)        3236.
CHAMBER THROAT PRESSURE       (PSIA)        1000.
REGENERATOR DELTA P           (PSID)        90.87
REFLECTOR DELTA P             (PSID)        462.5
PUMP DISCHARGE TEMP          (DEG R)        80.55
REACTOR INLET TEMP           (DEG R)        485.5
REGEN INLET TEMP             (DEG R)        80.71
REFLECTOR INLET TEMP         (DEG R)        229.6
REFLECTOR EXIT TEMP          (DEG R)        533.6
REACTOR HEAT TO CHAMBER      (BTU/S)      275668.
REFLECTOR HEAT TO CYCLE      (BTU/S)       19848.
REGENERATIVE HEAT            (BTU/S)        8751.
TOTAL Q CORE + REFLECTOR     (BTU/S)      295516.
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                 REACTOR POWER MODE WITH BRAYTON CYCLE

REACTOR FUEL GEOMETRY - 107 ELEMENTS,  48 PROPELLANT HOLES,  1 TURNAROUND DUCT

                 BOUNDRY CONDITIONS

 TURBINE PRESSURE RATIO    =      2.20   REACTOR EXIT TEMPERATURE  =  1300.00

 SPACE SINK TEMPERATURE K  =    250.00   SYSTEM MASS FLOW KG       =     0.45

                 CALCULATED SYSTEM PARAMETERS

 HEAT ADDED TO GAS KW      =     82.58   RADIATOR HEAT REJECTED KW =    51.93
 SHAFT POWER KW            =     27.80   ELECTRIC POWER KW         =    25.02
 SHAFT WORK / HEAT ADDED   =    0.3366   ELECTRIC PWR / HEAT ADDED =   0.3029
 RADIATOR AREA M**2        =     19.56   RADIATOR MASS KG          =    97.80
 TOTAL MASS KG             =    821.74
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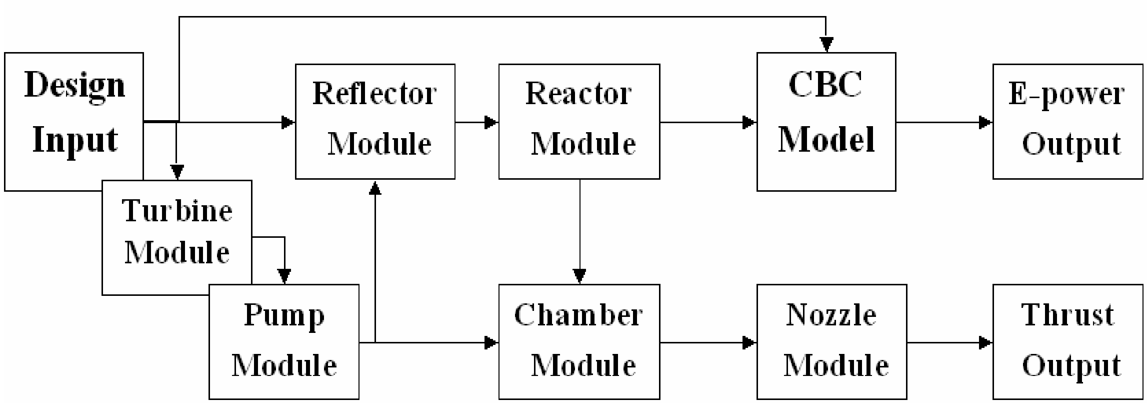

Figure 4 – Example of TRITON ROCETS Model Propulsion Mode for 15,000-pound Thrust Design and Power Mode Output for 25 kWe CBC Power Unit.

V. Follow-on TRITON Engine Design Analysis

Significant conceptual design work has been completed on the TRITON engine. It is anticipated that the TRITON design could be fully matured to FOC before 2018 in a "spiral" development approach. The first step to this development would be to restart CERMET NTP fuels qualification and to qualify what the actual mission driven design requirements are. Fuels work and detailed thermal-mechanical design work is needed now if fast, piloted Mars missions are to take place by 2020.

Pratt & Whitney, working with NASA Glenn research Center has defined a low risk, affordable development schedule that could mature the TRITON NTP to full flight capability in less than 15 years. This would make the bimodal NTP ready for human Mars missions and possibly even available for lunar reusable applications and robotic cargo missions to support deep space outposts. The TRITON NTP approach is technically feasible and builds off the legacy work of the NERVA and ROVER programs. It provides the lowest risk for transporting humans across the regions of space out beyond the Van Allen radiation belts.

VI. Summary

A Trimodal NTP concept, TRITON, that is capable of supporting the Exploration Enterprise mission architectures and deep space mission architectures has been defined based upon earlier bimodal ESCORT NTP work. A parametric design study effort has characterized a wide range of possible design solution paths for reactor operating temperature and pressure, system thrust range, nozzle exit area ratio performance, and LANTR mixture ratios for augmented thrust operation.

The turbopump, nozzle and chamber plenum elements, nozzle extension, and other propellant feed system components for both the propulsion modes are available directly from current liquid rocket engine hardware and the power conversion mode hardware is scalable from gas turbine brayton cycles and closed auxillary brayton power units already in operation. Current CBC PCU design study efforts underway in Project Prometheus are directly applicable to the CBC PCU on the TRITON.

The reactor core design for the TRITON combined power and propulsion system has a design technology heritage rooted in previous nuclear technology programs (i.e. GE710/ANL Program, NERVA). The design is ideal for use as combined propulsion and power system for manned missions to Mars and other Solar System expeditions. Once the NTP and bimodal NTP are in development with proven CERMET fuels, further refinements could be possible if the advanced high-temperature binary and ternary carbide fuels can have their TRL raised and they become fully qualified in a high temperature and pressure hydrogen enviroment.

Further technology and integration work is needed or long-life, high termperature fuel element in terms of qualification for TRITON-like NTP operating conditions. It is recommended that Project Prometheus and Project Constellation examine the NTP and bimodal NTP approaches within the architecture studies for the Exploration Enterprise. The prospects of developing only one nuclear system for both human and robotic missions, as well as having the NTP system available for Mars, lunar, and other solar system missions to reduce the total system of systems Life Cycle Cost (by reducing the number of expendable in-space elements) should not be ignored. A TRITON-like approach to in-space propulsion and power could provide the mechanism to have humans traveling through Space, and not just up to Space.

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