UCRL--95047-Rev.2

DE88 005220

Gas-Cooled Reactor Power Systems

Carl E. Walter

4th Symposium on Space Nuclear Power Systems
Albuquerque, New Mexico
January 12, 1987

January 1987

Lawrence Livermore National Laboratory

Log No. MM-3 17

GAS-COOLED REACTOR POWER SYSTEMS FOR SPACE

Carl E. Walter
Lawrence Livermore National Laboratory
Box 808 (L-144)
Livermore, CA 94550
(415) 422-1777

MANUSCRIPT prepared for:

OPEN SESSIONS
Fourth Symposium
on Space Nuclear Power Systems
Albuquerque, New Mexico
12-16 January 1987

Author running head: C. E. Walter

Title running head: GAS-COOLED REACTOR POWER SYSTEMS

Address all correspondence to: Mr. Carl E. Walter

MASTER

Log No. MM-3

GAS-COOLED REACTOR POWER SYSTEMS FOR SPACE

Carl E. Walter

Lawrence Livermore National Laboratory

Box 808 (L-144)

Livermore, CA 94550

ABSTRACT

Efficiency and mass characteristics for four gas-cooled reactor power system configurations in the 2- to 20-MWe power range are modeled. The configurations use direct and indirect Brayton cycles with and without regeneration in the power conversion loop. The prismatic ceramic core of the reactor consists of several thousand pencil-shaped tubes made from a homogeneous mixture of moderator and fuel. The heat rejection system is found to be the major contributor to system mass, particularly at high power levels. A direct, regenerated Brayton cycle with helium working fluid permits high efficiency and low specific mass for a 10-MWe system.

BACKGROUND

Large amounts of electric power are required for some systems envisioned in support of the nation's strategic defense. Because various applications are being considered, and an overall strategic defense power architecture study has not been completed, the required power levels and corresponding operating times for specific systems are not known. The operating conditions for selected arbitrary power levels were chosen on the basis of overall system considerations.

The reactor design described here benefits from earlier analyses of nuclear space power systems conducted at our Laboratory. Both gas- and liquid-cooled reactors were considered at that time. Pitts and Walter (1970) reported on the results of a detailed study of a 10-MWe lithium-cooled reactor in a potassium Rankine system. Results from a (unpublished) computer analysis performed in 1966 provided us details of an argon-cooled reactor in an argon Brayton system. We selected for further study a gas-cooled reactor design with a Brayton cycle. The reactor design draws heavily on the extensive development experience with the 500-MWt reactor for the Pluto nuclear ramjet shown in Figure 1 (Walter 1964). That development culminated in a successful (short time) full-power ground test (Reynolds 1964).

Gas-cooled reactors with thermal or near-thermal median fission energy are well suited for space power applications. They may be designed for a high power density as shown in Figure 2. Although there is no standard definition of a "compact reactor", high core power density should be a salient characteristic. High fuel utilization (high burnup) can be postulated for these reactors. For example, before operation the mass of highly enriched U-235 in the reference reactor of the present study is less than 5% of the mass of the moderator (BeO) in which it is homogeneously dispersed. Thus, the uranium atoms represent only about 0.5% of the atoms in the host moderator. Even for complete burnup, the fraction of atoms in the $BeO-UO_2$ fuel material which would be "altered" by the fission process is small compared to demonstrated burnup performance of fast reactor fuel. In addition, gas-cooled thermal or near-thermal reactors can also require a low U-235 inventory.

The goal of this study is to determine which of four thermodynamic configurations considered has the minimum system specific mass, while accommodating practical issues such as safeguards, fabricability, and reactor control.

SYSTEM PERFORMANCE ANALYSIS METHOD

The four cases investigated were indirect Brayton cycles with and without a regenerator in the power conversion loop (Cases 1 and 2, respectively) and direct Brayton cycles with and without a regenerator, (Cases 3 and 4, respectively). Figure 3 depicts the thermodynamic components for these cases, while Figures 4 and 5 show the physical arrangements of the components for Cases 1 and 4. All four cases have a conical configuration. In all cases heat is rejected from the power conversion loop by direct contact of the working gas with heat pipes. Because the radiator design is not specified in detail, a conservative value of mass per unit area is assumed. Use of a lighter radiator would significantly lower system specific mass. Results for five variations of Case 3 and two variations of Case 4 were obtained.

We modeled each system component using conventional equations and correlations to determine system performance and mass as a function of relevant system parameters, such as temperature, pressure, and working fluid. With a computer code which uses the Newton-Raphson process we solved simultaneously the many resulting equations for various combinations of cycle temperatures and turbine pressure ratios. The equation solver was then used near the "optimum" values (minimum system mass tempered by judgement of qualitative issues) of these ratios to evaluate the sensitivity of selected parameters in the equations. The method of solution permits the model equations to be listed in arbitrary order. Known (assumed) and unknown parameters can be easily interchanged during a parameter study provided that the resulting equation set is compatible. The code checks for compatibility and the computation proceeds as appropriate.

Models for the power conversion unit, shield, radiator, and connecting piping were simple algorithms; however, the heat exchanger and the reactor models were more detailed. Power conversion components and the associated piping were modularized to provide, for example, four or six parallel sets between the reactor and the radiator.

We prescribed specific mass coefficients for the turbine (0.1 kg/kW), compressor (0.15 kg/kW), and alternator (0.2 kg/kW). The output power of each device is multiplied by the above coefficients to obtain their individual masses. We determined physical dimensions (diameter and length) for each component from algorithms that included estimates of their homogenized density and (except for the alternator) gas molecular weight. The specific mass coefficient for the turbine-compressor-alternator unit is then calculated by summing the contributions for the three components and dividing the sum by the output electric power. Typical values of this coefficient are in general agreement with published data (Figure 6).

Since mission requirements are uncertain, only a shadow shield of lithium hydride 0.5-m thick located close to the reactor is considered. This shield provides neutron attenuation of approximately 10^{-6} in its conical shadow. No consideration was given to gamma attenuation. When that requirement is known, effective placement of power conversion components and heat exchangers can contribute to the gamma shield design. The effect of cone angle on system mass was studied as discussed with the study results below. These results should be reviewed when radiation attenuation requirements are known and gamma attenuation is properly provided.

Heat rejection in the system model is achieved by means of a heat pipe radiator having a reference specific mass of 20 kg/m^2 as suggested by Prenger and Sullivan (1982). Designs for much lighter radiators have been proposed, but their feasibility is not certain. The heat pipe radiator design is sufficiently redundant to survive meteoroid damage. We also assume that structural, rather than meteoroid considerations determine pressure vessel thicknesses. The working fluid pressure drop is fixed at 5% of the inlet pressure to the radiator, and the radiator surface temperature is assumed to be 50 K lower than the working fluid temperature at all points in the radiator. The assumed radiator temperature implies a variable heat transfer coefficient in the manifold where heat is transferred to the heat pipes. One means for varying the heat transfer coefficient is to vary the manifold dimensions thus changing the Reynolds number. A more exact assessment of the radiator temperature should be conducted to optimize heat transfer to the heat pipes. The sensitivity of these assumptions is discussed below (see Study Results).

We modeled the effect of connecting piping on mass and performance. Reactor exit piping was internally insulated, and for convenience, we assumed that heat was radiated from its outer (metal) surface. This feature would allow high temperature piping to be made from more readily fabricable alloys. Pipe diameter (0.25 m) was chosen arbitrarily and the number of parallel modules was chosen to reduce piping pressure loss to a negligible value.

We used heat exchangers of the compact counter-flow design (Figure 7) in three of the cases evaluated, either as a regenerator or as means of transferring heat from the reactor loop to the turbine loop. The heat exchanger equations calculate heat transfer, pressure drop and mass characteristics. The parameters of the heat exchanger were varied to achieve minimum specific system mass, thus optimizing the heat exchanger from the standpoint of mass, heat transfer, and pressure drop considerations. Effectiveness could be input or calculated as desired.

Material properties were expressed analytically based on published or projected material data. We wrote linear equations for the transport properties of helium and a mixture of helium and xenon having a molecular weight of 40 (same as argon). An allowable material strength for the system components as a function of temperature can be prescribed by correlating data and projections of 1% creep stress/density ratio for a series of increasingly refractory alloys. Figure 8 shows the continuous curves we derived for operating times of one and seven years. The equation for these curves in SI units, is C/T^3 where $C = 3.05 \times 10^{13}$ or 2.67×10^{13} for 1 or 7 y respectively, and T is the material temperature. Below about 800 K, we imposed an allowable stress/density value of 60,000 N m/kg. Assuming that the molybdenum and tungsten alloys shown in Figure 8 are successfully developed, this material strength model provides a convenient way of establishing component mass without specifying its material over a wide temperature range. Explicit density values are needed only to determine material thickness, since pressure vessel and pipe masses are determined by the stress/density ratio of the materials, not the density alone.

REACTOR CHARACTERISTICS

The reactor, configured as shown in Figure 9, has a prismatic ceramic core composed of several thousand "pencil shaped" tubes made from a homogeneous mixture of moderator and fuel. Radial compression forces exerted by girdle springs on the cylindrical surface of the core hold the tubes together. The reference core, 80-cm in diameter by 80-cm long, has a flow porosity of 30%. The reference core materials, also used in the Tory II-C (Pluto) reactor (Figure 10), are beryllium oxide and uranium dioxide. The Tory II-C reactor core (diameter, 1.2 m; height, 1.3 m) is considerably larger than the reference core used in this study. In the present designs, a layer of zirconia insulation between the fueled core and the girdle springs allows the inlet reactor gas to cool the springs and the reactor pressure vessel before the gas flows through the core. Spring force requirements are minimal since maneuver loads, if any, are very low, and gas pressure gradients are favorable. This may allow the springs and pressure vessel to be made from non-refractory metals. A ceramic dome at the outlet end, designed to experience only compressive stresses, supports the modest pressure drop through the core and also serves as a neutron reflector. Inlet and outlet reflectors are made from the same moderating material as is used in the core.

Several core material choices are possible. We evaluated beryllium oxide with uranium dioxide, boron carbide with uranium boride (boron-11 isotope), and carbon with uranium dicarbide. These materials all provide a thermal or epithermal neutron spectrum in the sizes considered. Based on their volatilities, we estimate these material combinations to be useful at temperatures up to about 1950 K, 2000 K, and 2200 K, respectively. Higher temperatures could be achieved with appropriate coatings. For conservatism, we limited the reactor coolant exit temperature in this study to 1625 K. Our results show that, for a given reactor geometry, the choice of core material causes only a negligible difference in system mass. However, study and experimental work is required to quantify fission product retention and irradiation effects at high burnup for all three material choices.

The beryllium oxide system is an outstanding candidate. This system is highly developed from the Pluto project, has good mechanical and physical properties, and results in the lowest critical mass (8.7 kg at 1400 K for the reference core) for the same size and porosity reactor. A possible drawback (which needs to be evaluated more fully) is the extent to which the toxicity of beryllium oxide represents a hazard to the public in the event of a launch accident. The reactor we modeled is based on a beryllium oxide core.

Its anticipated structural, chemical, and thermal properties make the boron system a leading candidate also, particularly for high burnup missions where a burnable poison (boron-10) would be desirable. Sufficiently pure boron-11 can be obtained at a reasonable cost with the desired amount of boron-10 for reactivity control if the design operating life is sufficiently long (7 y).

As in the case of beryllium oxide, the carbon system is also highly developed (it was developed for nuclear rockets), has the highest operating temperature capability, and has excellent thermal stress characteristics. Multiple-hole fuel elements are more feasible in the carbon system, should that be desirable. The major disadvantage of the carbon system is its relatively high critical mass (269 kg versus 44 kg for BeO in 68-cm diameter by 68-cm long cores having 30% flow porosity at 291 K). Nevertheless, all three material systems result in considerably lower fuel inventories than would be required for fast reactors.

Control of thermal (or near-thermal) reactors made from these material systems is accomplished by use of a burnable poison (not yet incorporated in the study), a variable-leakage reflector, and internal control rods. Reactivity swings of 10% are easily obtained with a dozen internal boron-10 rods for the core sizes studied, as shown in Figure 11. The radial reflector, which is worth about 5% in reactivity for the reference core despite the return coolant annulus surrounding the core, would be moved axially to effect control.

We preformed criticality calculations using the ALICE Monte Carlo code (Plechaty and Kimlinger 1976 and Kimlinger and Plechaty 1986). Core thermal-hydraulic calculations are straightforward since exit Mach numbers less than 0.1 are required. The inert gas flow may be treated as incompressible (at 5 MPa), and no flow instability mechanisms have been found.

STUDY RESULTS

We obtained a large amount of data from computations using the system models developed for the four cases. These cases were represented by the following number of equations and parameters:

Case	Equations	Parameters
1	220	317
2	162	247
3	175	259
4	117	189

The number of equations and parameters depends on the number of components in the system. For example, each interconnecting pipe contributed about two dozen parameters and a dozen equations.

We summarize our results in Table 1. Considerably more information could be obtained from further computations directed toward achieving minimum system mass, and toward quantifying the sensistivity of salient characteristics, such as mass and efficiency, to changes in "known" parameters. It is essential to insure that other system characteristics such as safety, safeguards, survivability, and reliability are not jeopordized in establishing the characteristics of the system which has "minimum" mass. These considerations have been made, but are judgemental in our analysis. More complete reporting is beyond the scope of this paper.

In general, we performed our computations for 10-MWe systems using helium as the reactor coolant/working fluid. Variations are included in Tables 1 and 2. Cases 3e and 4b represent 20-MWe and 2-MWe systems, respectively. Case 3d uses helium/xenon working fluid and should be compared with Case 3a, which uses pure helium for identical fixed cycle conditions (maximum and minimum temperatures, maximum pressure, turbine pressure ratio). Cases 3b and 3c differ only in their minimum cycle temperatures. None of the cases summarized here has been truly optimized for minimum system specific mass. Because the same reactor is used in each case, the reactor is "oversize" even for the highest reactor power core (Case 3e), where the core power density is only 170 MW/m^3. Except for Case 4b, a reasonable savings in reactor mass would not lower the system mass significantly. It does not seem prudent under these conditions to reduce the reactor size and incur penalties of higher fuel inventory and higher reactor pressure drop.

Although further effort is needed to optimize the cases of Table 1, the table shows that the direct-regenerated cycle configuration at 10-MWe minimizes specific system mass. The system represented by Case 3c would not only have low specific mass but would be more efficient than non-regenerated systems and thus requires a lower reactor fuel inventory. At the 2-MWe power level (Case 4b) the radiator no longer dominates system mass, and assumptions regarding other system components should be examined more closely. Final determination of reactor size and operating conditions should not be made without specifying application requirements. As shown in Table 1, the radiator contributes a major portion of the system mass. Radiator areas and lengths are large. For example, the conical surface area of the radiator for Case 3c is 2140 m^2. In the model, the radiator efficiency is increased by allowing heat to be radiated from the inside surface as well. The inside surface is represented as the area of the large base of the cone assumed to radiate at the same effective radiator temperature as the outside surface. As a result, increasing the cone angle decreases the mass of the radiator and the net mass of the system, because the corresponding increase in the neutron shield mass is smaller. (If a thick gamma shield is required, this conclusion may not be valid.) The optimum radiator would have a cone half-angle approaching 90 (a circular disk). Preliminary calculations indicate that scattered neutron radiation from a radiator located outside the shield cone angle may be acceptable for applications where the attenuation required is not great. For a given cone angle, the radiator mass is established by the assumptions regarding heat pipe radiator mass, piping and pressure vessel thickness, and working fluid pressure drop stated in the discussion of the system model. The effect on system specific mass obtained by improving the values of these assumptions by 10% is indicated below for Case 3c:

Radiator Parameter	Reference Value	Improvement
Mass/Area	20 kg/m^2	6.9%
Temperature bias	50 K	2.4%
Pressure drop	5 %	1.1%

An important consideration is the system operating pressure. A significant decrease in system mass results when operating pressure is increased. We did not increase system pressure above 5 MPa because we wanted to hold the thickness of the pressure vessel below about 10 mm. Heavier sections in this critical component made from refractory alloys may not be as reliable.

Comparison of pure helium and a mixture of helium and xenon having molecular weight equivalent to that of argon indicates a slight preference for pure helium, as shown in Cases 3a and 3d. At lower power levels, where the relative mass of the power conversion equipment is higher, a higher molecular weight gas than helium, but with good conductivity such as a mixture of helium and xenon may be preferred.

Since the radiator size appears to be extremely large for Brayton cycles at power levels of 10 MWe or above, it is appropriate to consider integrating gas-cooled reactors with other power conversion methods. The mass of intermediate heat exchangers and circulators for the reactor loop is seen to be low (Table 1, Cases 1 and 2). Thus, it appears reasonable that a gas-to-liquid heat exchanger could be provided for a small mass penalty, which would be more than compensated by the mass savings of a radiator operating at a higher effective temperature.

CONCLUSIONS

Although this study is not complete, general conclusions may be stated. Gas-cooled thermal or near-thermal reactors permit high-temperature power conversion and appear to provide reasonable multi-megawatt space power systems. The inherent high-temperature capability of the reactor design considered removes reactor technology as a limiting condition on system operating temperature. The low fuel inventories required, particularly for beryllium oxide reactors, make space power systems based on gas-cooled near-thermal reactors a lesser safeguard risk than those based on fast reactors. In particular:

- BeO-moderated, gas-cooled near-thermal reactors appear suitable for space power applications in the range of 2 to 20 MWe;

- A database exists for reactors of this design;
- Pure helium appears to be a good choice of working fluid;
- A direct regenerated cycle configuration results in low specific mass and retains high cycle efficiency at the 10-MWe level;
- Only one reactor need be developed for several applications in this power range;
- Brayton systems (in particular) would benefit greatly from a low mass radiator (of a practical design yet to be conceived);
- This reactor design coupled with a compact heat exchanger should also be considered with other means of power conversion. Although the mass of such a system may not be the lowest achievable, the reliability and safety aspects of gas-cooled thermal or near-thermal reactors should be considered before a system selection is made; and
- Many "optimum" power system features cannot be ascertained without a detailed knowledge of the system application.

Acknowledgments

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-

48. Significant technical contributions were made to this paper by D. Blackketter, J. Pearson, F. Kloverstrom, O. Krikorian, and P. Mohr.

References

Kimlinger, J. R. and E. F. Plechaty (1986) TART and ALICE Input Manual, UCID-17026, Lawrence Livermore National Laboratory, Livermore, CA.

Pitts, J. H. and C. E. Walter (1970) "Conceptual Design of a 10-MWe Nuclear Rankine System for Space Power", J. Spacecraft and Rockets, 7(3): 259-265.

Plechaty, E. F. and J. R. Kimlinger (1976) TARNP: A Coupled Neutron-photon Monte Carlo Transport Code, UCRL-50400, Vol. 14, Lawrence Livermore National Laboratory, Livermore, CA.

Prenger, F. C. and J. A. Sullivan (1982) Conceptual Designs for 100 MW Space Radiators, LA-UR 82-3279, Los Alamos Scientific Laboratory, Los Alamos, NM.

Reynolds, H. L., Ed. (1964) Tory II-C Reactor Test Report, UCRL-12069, Lawrence Livermore National Laboratory, Livermore, CA.

Walter, C. E., Ed. (1964) Engineering Design of the Tory II-C Nuclear Ramjet Reactor, UCRL-7679, Lawrence Livermore National Laboratory, Livermore, CA.

Table 1. Summary of the Principal Performance and Mass Characteristics of the Cases studied.[a,b,c]

	INDIRECT-REGENERATED	INDIRECT	DIRECT-REGENERATED					DIRECT	
Case	1	2	3a	3b	3c	3d	3e	4a	4b
P (MWe)	10	10	10	10	10	10	20	10	2
Cycle efficiency (%)	33	19	37	37	32	33	29	20	16
Reactor flowrate (kg/s)	19	16	14	11	12	15	32	11	4
Specific mass (Mg/MW)	10.3	10.7	8.4	6.9	6.2	9.0	6.8	7.7	7.9
Turbine press ratio	1.8	2.4	1.8	2.4	2.4	1.8	2.0	2.2	2.2
Min cycle temp (K)	500	500	500	500	550	500	550	500	675
Circulator[d]	1	e	—	—	—	—	—	—	—
Intermed heat exchanger[d]	3	1	—	—	—	—	—	—	—
Piping[d]	2	1	2	4	4	2	2	2	8
Reactor[d]	2	2	3	3	3	3	3	2	12
Shield[d]	3	3	4	5	5	4	2	4	21
Turb/Comp/Alt[d]	7	8	7	10	12	8	12	8	13
Regenerator[d]	12	—	14[f]	5	6	7	5	—	—
Radiator[d]	70	85	70	74	69	77	78	84	45

a. Reactor coolant (and working fluid) is helium in all cases except a mixture of He - Xe (mol. wt. = 40) is used in Case 3d.
b. Turbine inlet temperature is 1600 K in all cases.
c. The reactor outlet temperature is 1625 K in Cases 1 and 2.
d. Component mass contributions (%) to total system mass.
e. Negligible.
f. Regenerator design not optimized.

FIGURE CAPTIONS

Figure 1. Photograph of the Tory II-C Reactor Test System that was designed and tested for the Pluto Ramjet Application.

Figure 2. Relationship between Core Power Density and Thermal Power. High-Performance Gas-Cooled Reactors may be classed as Compact.

Figure 3. Schematic Diagrams of the Four Thermodynamic Configurations that were modeled and analyzed.

Figure 4. System Configuration for Case 1 (most complex) with the Payload located at the Far End of the Radiator.

Figure 5. System Configuration for Case 4 (least complex) is Simple by Comparison.

Figure 6. Dependence of the Specific Mass of Turbine-Compressor-Alternator Units on Power Level as determined by Various Investigators.

Figure 7. Schematic Diagram of the Counter Flow Heat Exchangers of Compact Design that were modeled for the Intermediate Heat Exchanger and Regenerator.

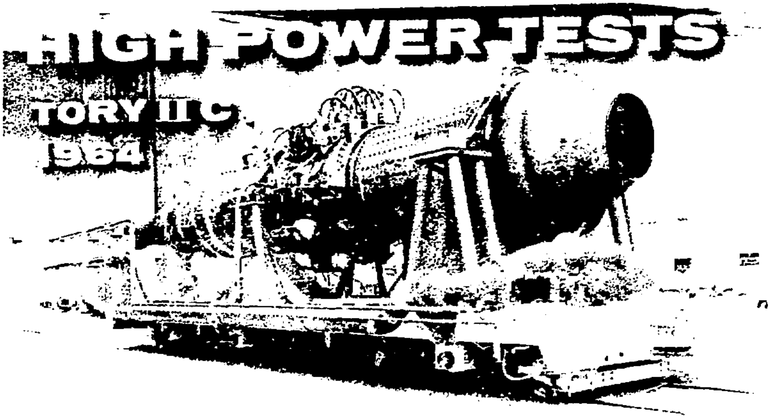
Figure 8. Temperature Dependence of Allowable Stress/Density Ratio for Structural Materials, based on Synthesis of 1% Creep Data and

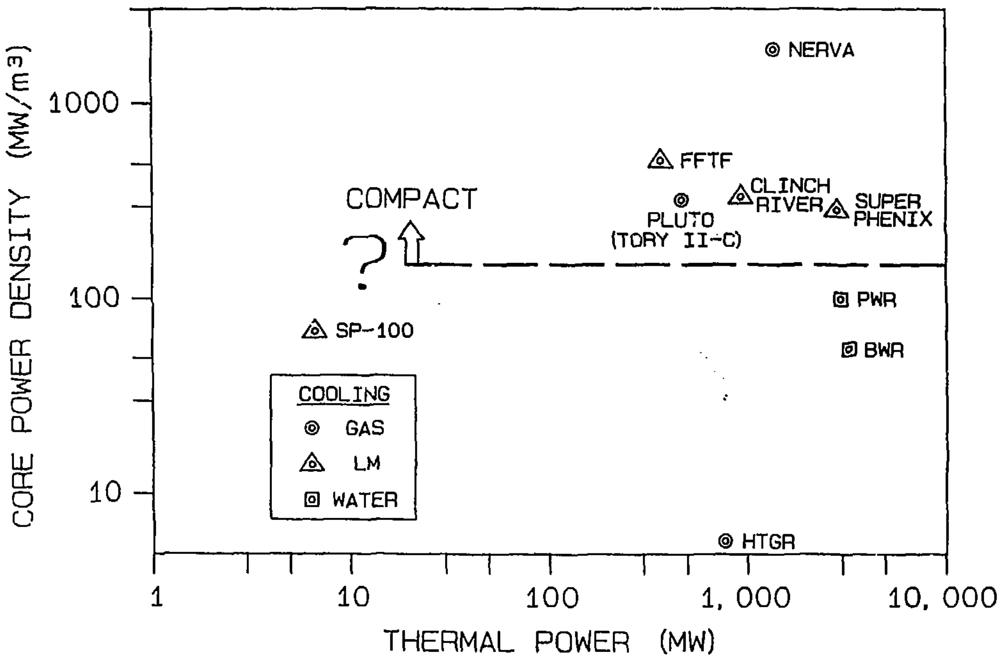
Projected Creep Behavior for Several Alloys.

Figure 9. Schematic Diagram of the Reactor which consists of a Ceramic Core supported in a Metal Pressure Vessel with an External Movable Radial Reflector and Internal Control Rods.

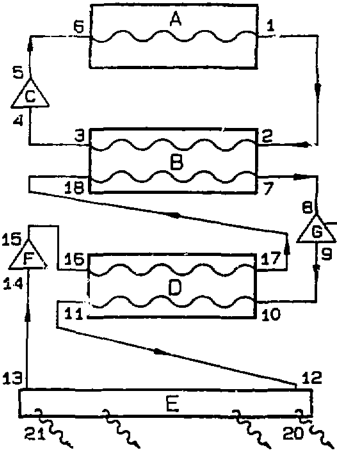
Figure 10. Photograph of the Assembled Tory II-C Reactor (Overall Dimensions: 1.4 m Diameter by 1.6 m High).

Figure 11. Dependence of Reactivity on the Number of Control Rods for BeO and B_4C cores.

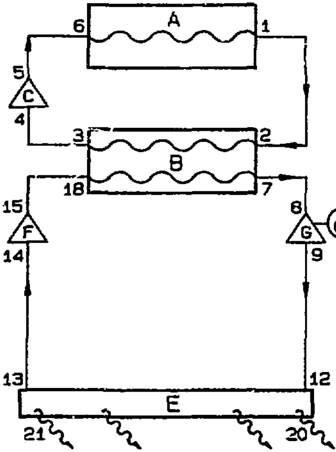

HIGH POWER TESTS
TORY II C
1964



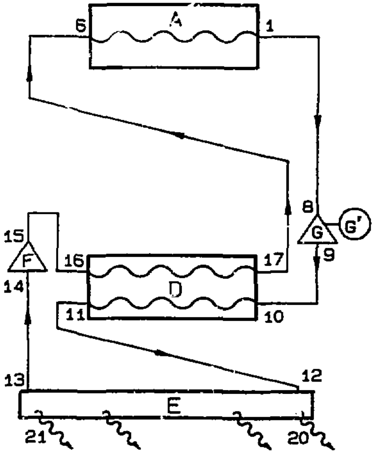
NERVA
1000
FFTF
COMPACT
CLINCH RIVER
SUPER PHENIX
PLUTO (TORY II-C)
?
100
PWR
SP-100
BWR
COOLING
GAS
LM
WATER
10
HTGR
1
10
100
1,000
10,000
THERMAL POWER (MW)
CORE POWER DENSITY (MW/m3)



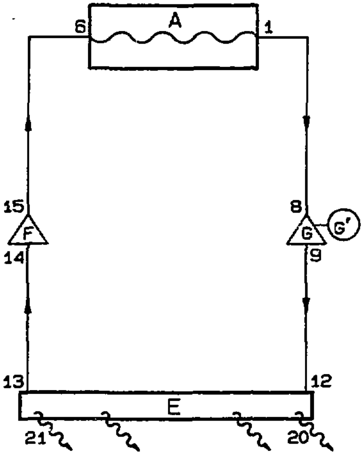
CASE 1



CASE 2

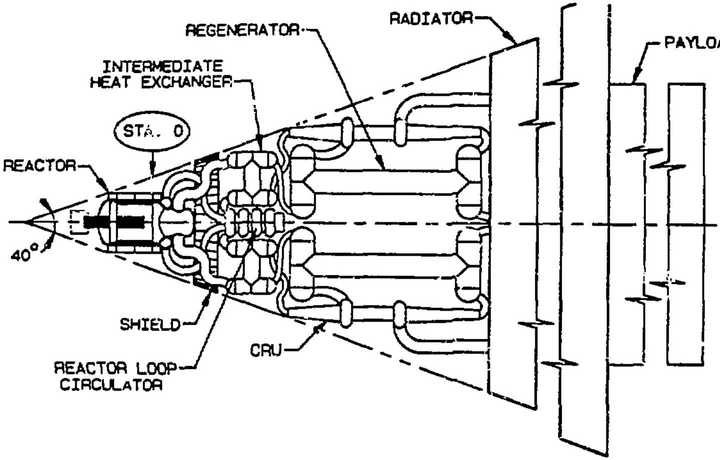


CASE 3

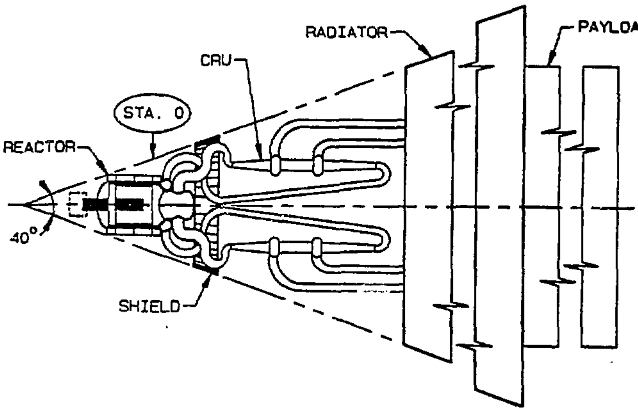


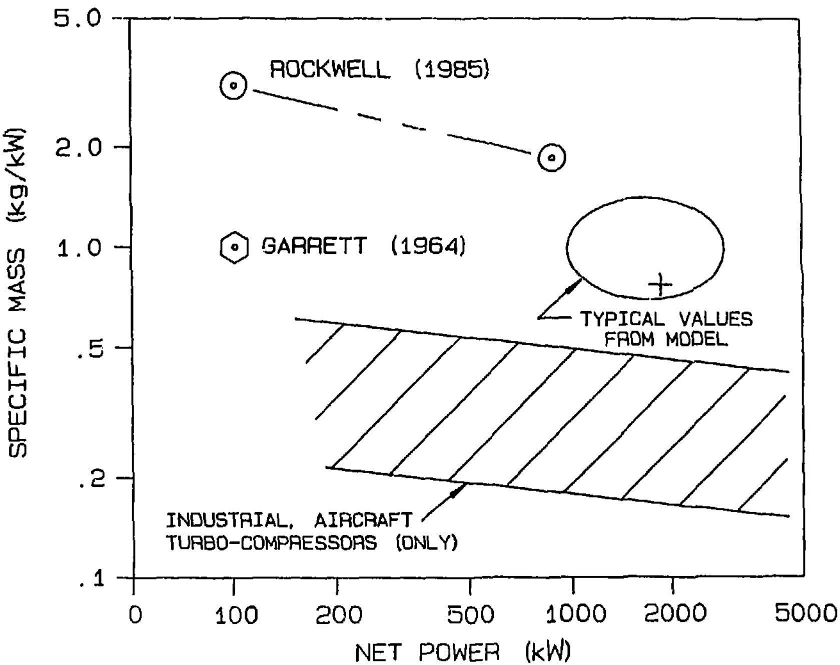
CASE 4

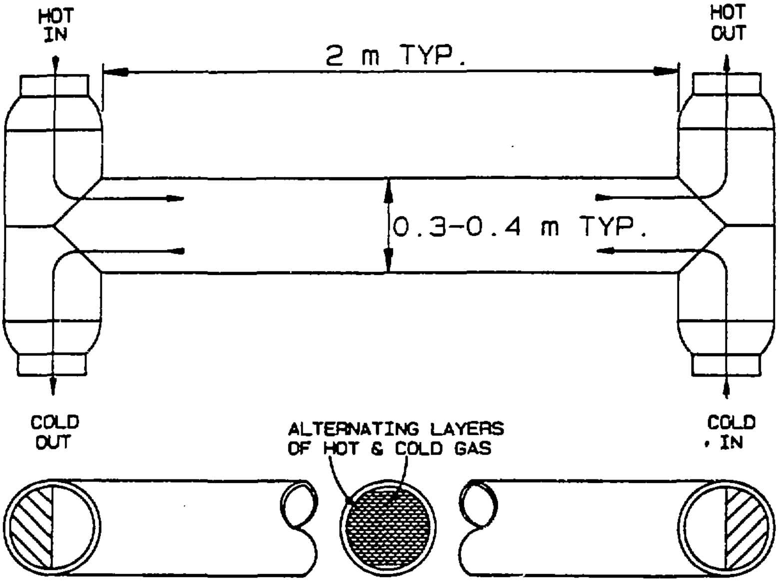
A =Reactor
B =Heat Exchanger
C =Circulator
D =Regenerator
E =Radiator
F =Compressor
G =Turbine
G'=Generator



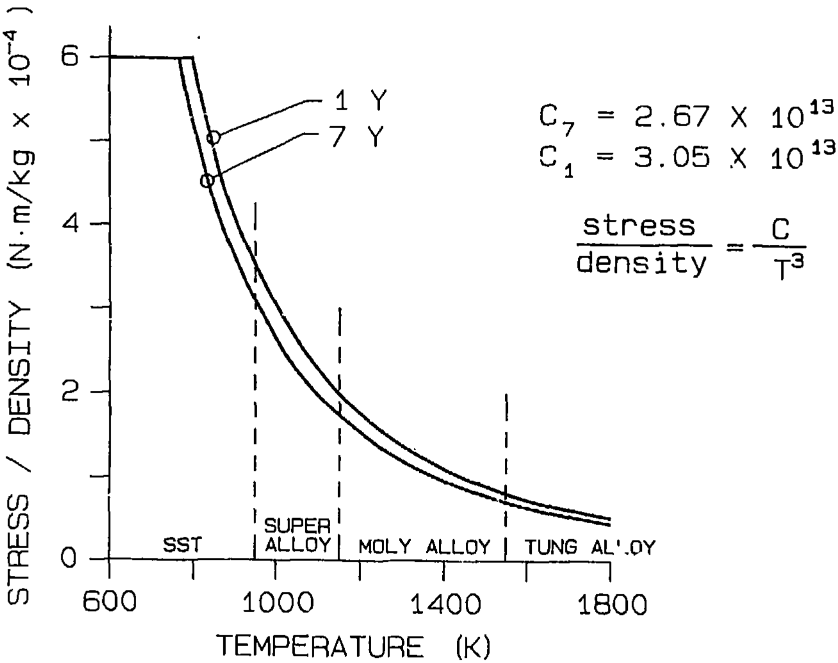
RADIATOR
REGENERATOR
PAYLOAD
INTERMEDIATE
HEAT EXCHANGER
STA. 0
REACTOR
40°
SHIELD
CRU
REACTOR LOOP
CIRCULATOR

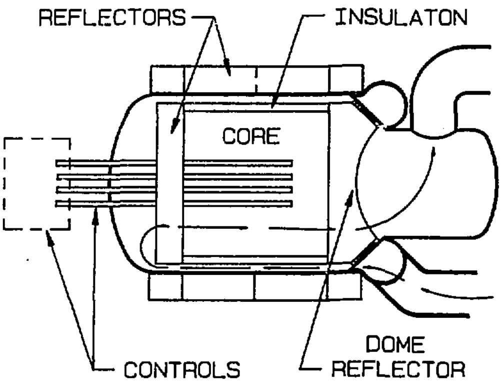

RADIATOR
PAYLOAD
CRU
STA. 0
REACTOR
40°
SHIELD


ROCKWELL (1985)
GARRETT (1964)
TYPICAL VALUES FROM MODEL
INDUSTRIAL, AIRCRAFT TURBO-COMPRESSORS (ONLY)
SPECIFIC MASS (kg/kW)
5.0
2.0
1.0
.5
.2
.1
0
100
200
500
1000
2000
5000
NET POWER (kW)



HOT IN
HOT OUT
2 m TYP.
0.3-0.4 m TYP.
COLD OUT
COLD IN
ALTERNATING LAYERS OF HOT & COLD GAS


STRESS / DENSITY (N·m/kg x 10^-4)
6
4
2
0
600
1000
1400
1800
TEMPERATURE (K)
1 Y
7 Y
C7 = 2.67 X 10^13
C1 = 3.05 X 10^13
stress / density = C / T^3
SST
SUPER ALLOY
MOLY ALLOY
TUNG AL'.OY


REFLECTORS
INSULATON
CORE
CONTROLS
DOME
REFLECTOR