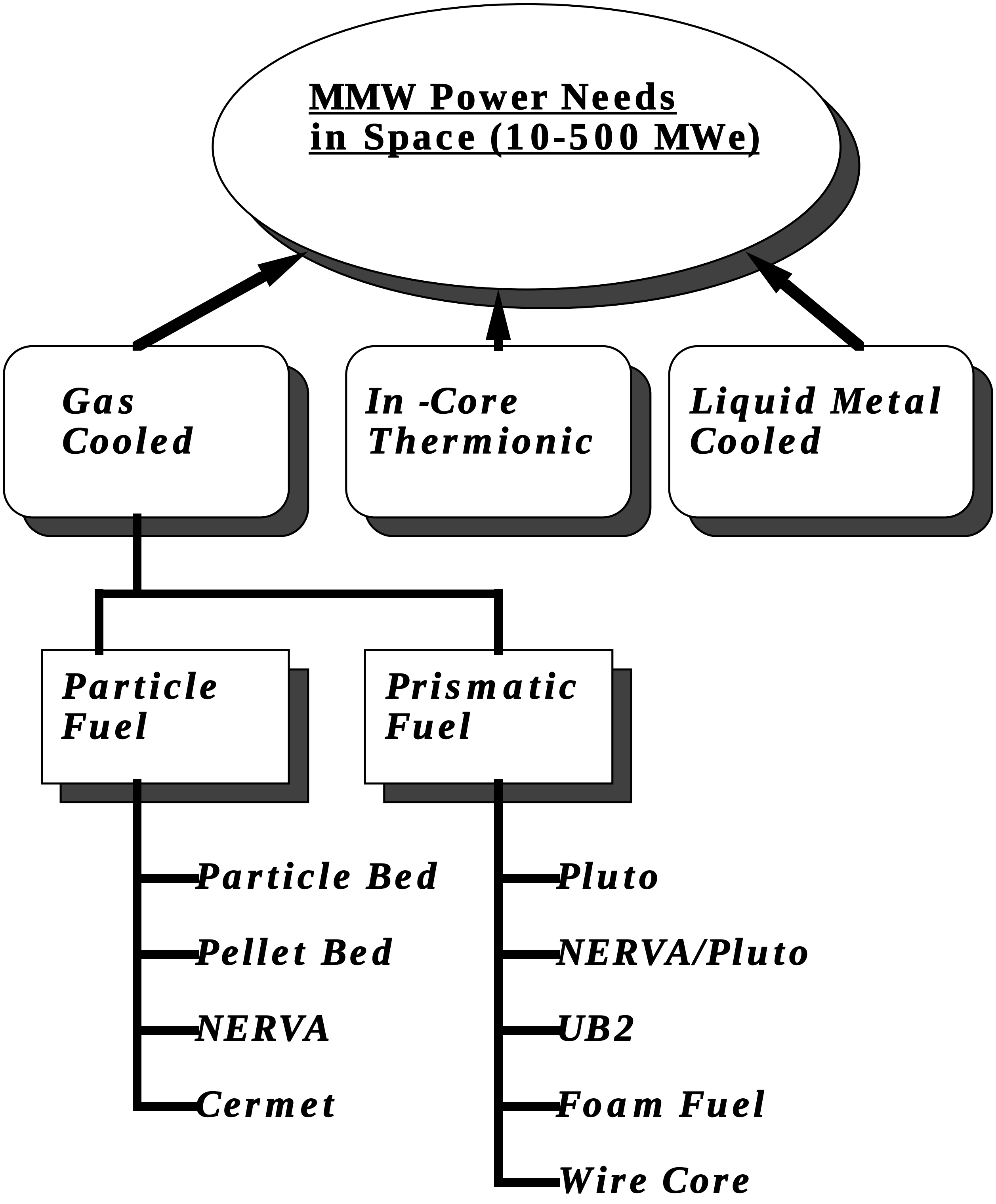
# Four Major Fission Reactor Concepts Which Have Survived the Screening for the Multi Megawatt Program



**MMW Power Needs in Space (10-500 MWe)**

- *Gas Cooled*
  - *Particle Fuel*
    - *Particle Bed*
    - *Pellet Bed*
    - *NERVA*
    - *Cermet*
  - *Prismatic Fuel*
    - *Pluto*
    - *NERVA/Pluto*
    - *UB2*
    - *Foam Fuel*
    - *Wire Core*
- *In -Core Thermionic*
- *Liquid Metal Cooled*

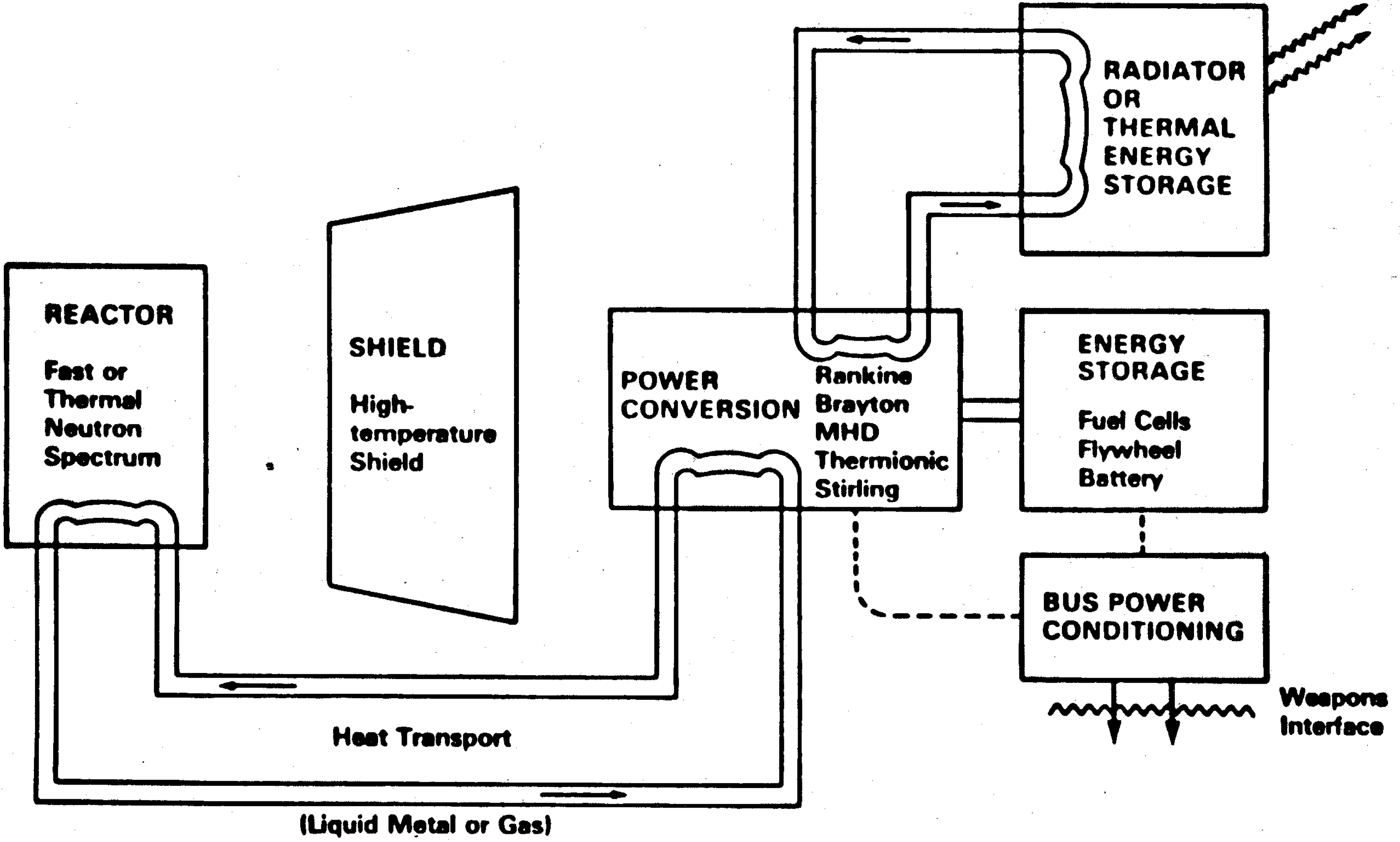


Figure 2.1 Schematic of Space Reactor Closed Cycle System Showing Possible Choices of Components (Open Cycle Systems Do Not Need A Mass Storage Sub-System)

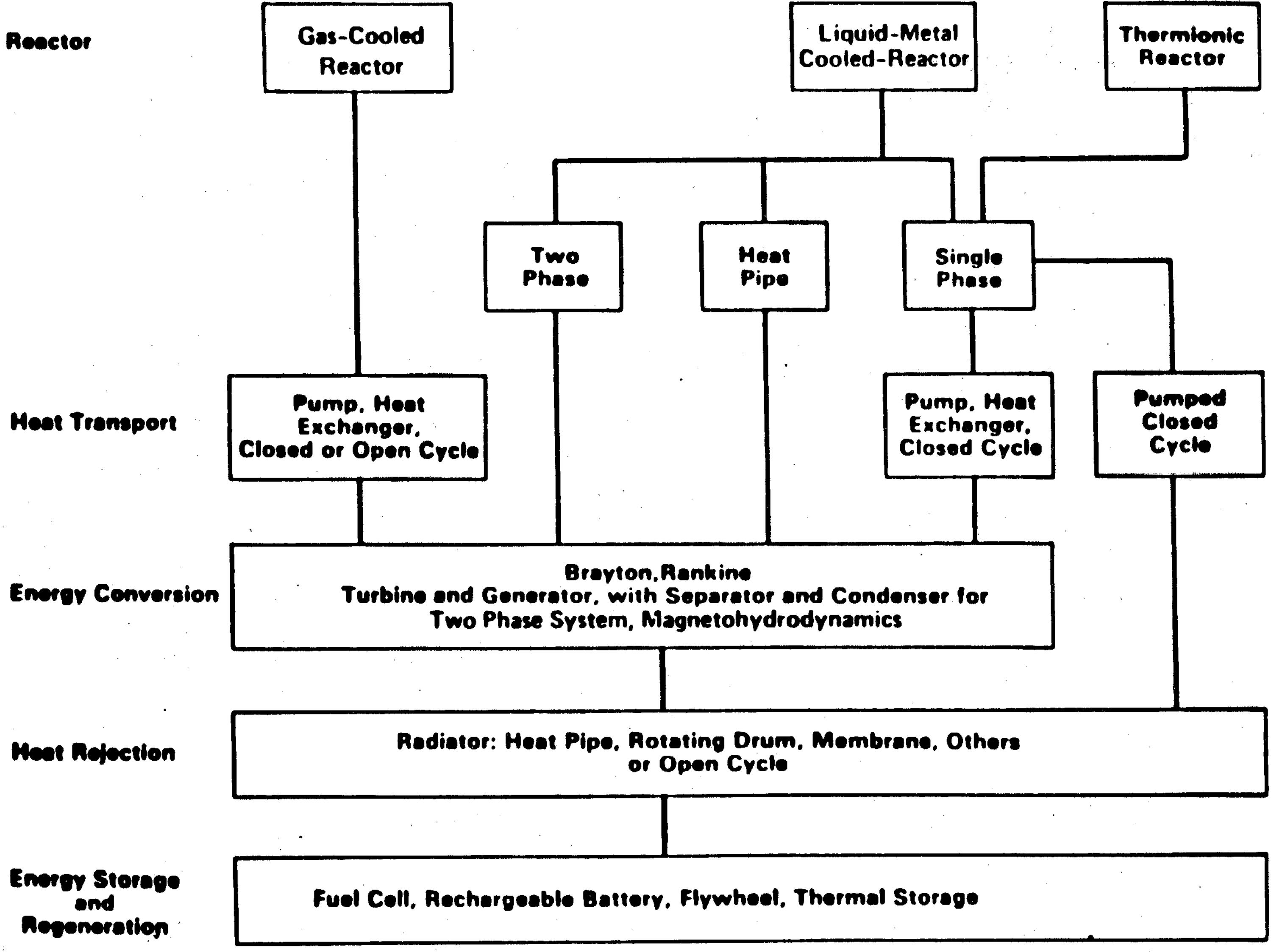


Figure 3.2 Generic Classes of Space Nuclear Power Systems

# General Comments on Space Power Reactor Designs

## A.) Fast Vs Thermal

### 1.) Reactor Mass

- *Thermal reactors require moderator*

- *Moderator/ Fuel molecular ratios ≈ 500:1*

- *Generally thermal reactors are bigger (size) and heavier than fast reactors*

### *2.)* Fissile Material Requirements

- $\sigma_{fiss}/\sigma_{capt}$ *for fast reactors is less than for thermal reactors, ===>more* $^{35}U$ *is required for fast reactors*

- *Control of thermal reactors is easier and less complicated;*
  - $\sigma_{absorption}$ *larger for thermal neutrons*
  - *delayed neutrons help control thermal reactors*

### *3.) Fission Product Poisoning*

- *Because of higher* $\sigma_{absorption}$ *for fission products in thermal reactors, more attention must be paid to FP buildup and decay (i.e., Xe)*

## B.) Direct vs Indirect Cycles

### *1.) In-Core Heat Transfer*

- *Liquid metal boiling in a micro -g environment has not been adequately explored (e.g., critical heat flux, flow instabilities, etc.)*

### *2.) Enhanced Erosion and Corrosion*

- *Due to In-core boiling and 2-phase flow*

### *3.) Contamination of Power Conversion System*

- *Occurs through coolant activation, FP release, and activated corrosion products*
    - *Indirect confines activation to primary loop*
    - *Direct cycle requires shielding to protect electronics from contamination*

### *4.) Working Fluid Optimization*

- *Indirect- both fluids can be, independently optimized for reactor and turbine*

- *Direct-Same working fluid used for all power system components*

*5.) Number of Components*

- *Indirect cycle requires at least a heat exchanger and an extra pump*

**C.) Liquid Metal vs Gas Cooling**

*1.) Heat Transfer Surface Area*

- *Because the heat transfer of liquid metals is much better than gases, the surface area required is much less ==> smaller size and less complicated fuel design*

*2.) Pump Requirements*

- *Electromagnetic pumps, with no moving parts can be used for liquid metals, not gases*

*3.) Coolant Freezing*

- *Thawing, space for expansion .*

*4.) High Temperature Material Compatibility*

- *More severe at MMW operating T*
  - *Trace impurities in gas (e.g., $O_2$, $N_2$, or hydrocarbons in He) may make these coolants incompatible with refractory alloys.*

*5.) Safety*

- *Gases better than liquid metals with regard to fire, explosions, and void coefficients.*

*6.) Neutron Activation*

- *Liquid metals present shielding problems ( both from activation of the coolant and because of activated corrosion product.)*

*7.) Two Phase Thermal/Hydraulics*

- *Boiling and 2 phase flow can be avoided with gases*

## *Related Technologies for Lead MMW Fission  Power Plants*

| Generic Concepts / Technolgy | Gas Cooled | | In-Core Thermionic | Liquid Metal System |
|---|---|---|---|---|
| | **Particle Fuel** | **Prismatic Fuel** | | |
| **Fuels** | UC | $UB_4$ -$B_4C$<br>99.9 % $^{11}B$ | • Cermets<br>• $UO_2$<br>UZrC | UN |
| **Materials** | SiC<br>MoRe<br>ZrC<br>Re | Ta Alloy<br>Mo Alloy<br>C Blocks | W-emitter<br>C-emitter<br>Refractory Alloys | Refractory Alloys<br>Ceramic Composite<br>Metal Composite |
| **Operating Temp/ Coolant** | 1500-2000 °K<br>He/Xe<br>$H_2$ | | 1000-1500 °K<br>NaK<br>or<br>Li | 1400-1700°K<br>Li |

# Comparison of System masses for Steady State Multimegawatt Power in Space

***Remember that these systems may have to generate a few MW's for a year or so.***

## This Means They will Be Closed!

**--------------------------**

**See table of masses for MMWSS**

**----------------------**

### General Comments

- **Even though the Rankine system is the lightest, the uncertainty with 2 phase flow in zero g is an inhibiting feature**

- **If the efficiency of Thermionic systems approaches 15-20%, then they can compete with Rankine cycles**

- **Closed cycle Brayton cycles avoids the flow problems and the need for more 'breakthrus'**

### 1.) Rankine Cycle

- **Used a single fluid system, K.**

- **Because of the difficulty in predicting the amount of fluid which will be entrained in K vapor, the turbine must be designed to handle significant erosion.**

- **Fires on the pad a potential problem**

- **Could go to an indirect cycle, but the heat exchanger mass would be equivalent to a vapor separator**

## 2.) Brayton System

- **Use He/Ne mixture, non-corrosive and inert**

- **Heavy, but simple and developed**

### 3.) Thermionic System

- **Heavy but has no moving parts**

- **Assumed technology is modest, and 1800 °K emitter give 10-12% efficiency. General Atomics has laboratory devices that exhibit much higher efficiencies (≈ 20 %)**

# Comparison of 10 $MW_e$ Steady State Mode Space Power Systems

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## Metric Tonnes for 1 Year

| Component | Therm-ionic | 1350 °K Rankine | 1500 °K Brayton |
|---|---|---|---|
| Reactor & Shield | 32.1 | 3.3 | 7.8 |
| Turbine | 0 | 0.9 | 1.2 |
| Generator | 0 | 1.1 | 1.1 |
| Compressor | 0 | 0 | 3.5 |
| Radiator & Condensor | 28.8 | 11.7 | 44.8 |
| Vapor Separ | 0 | 2.1 | 0 |
| Power Conditioning | 2.0 | 2.0 | 2.0 |
| PC & Gen Radiator | 1.1 | 2.3 | 2.3 |
| Mise | 6.4 | 2.3 | 6.3 |
| TOTAL | 70.4 | 25.7 | 69.0 |

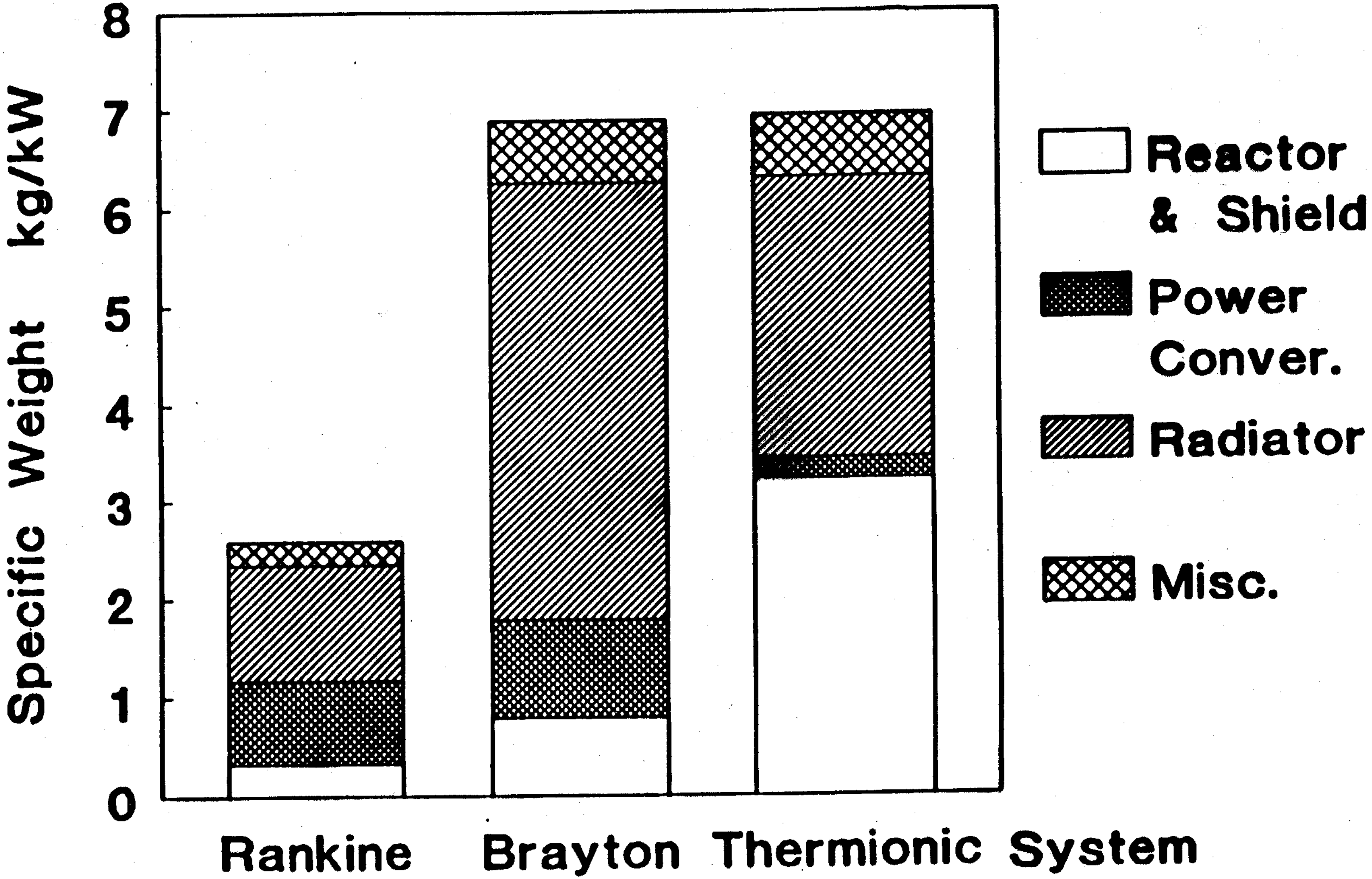
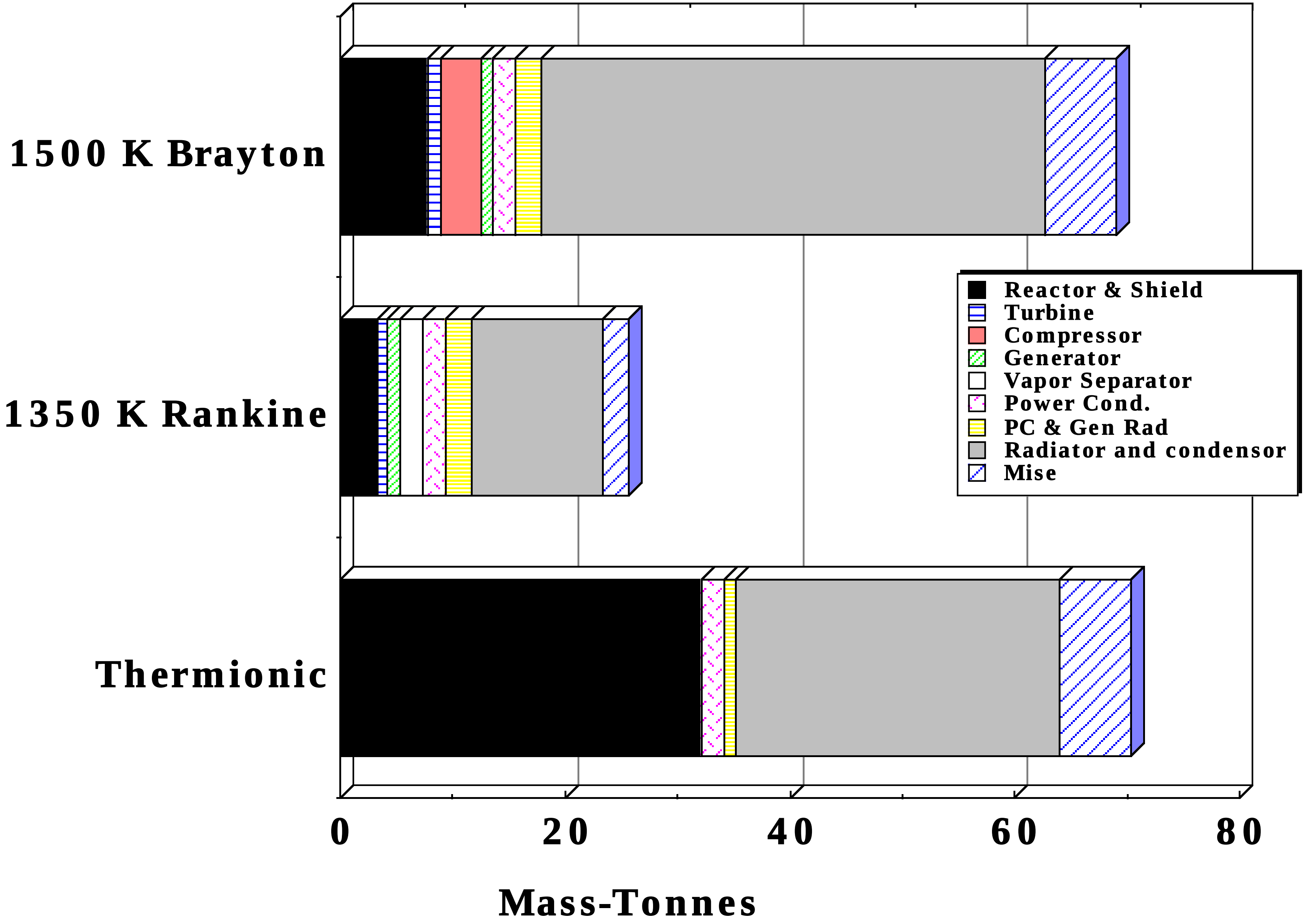


Figure 4-1. Comparison of Specific Weights of Multimegawatt Space Power Systems for the MMWSS Mode Assuming 10-MWe Power for 1 Year of Operation

Mass of Steady State 10 MWe Space Power System

1 Year Operating Time



# Comparison of Specific Masses for Multi Megawatt Space Power Sources

## A. ) Burst Mode

- **Within the range of 100-1000 MWe, the *specific* power density (kg/kWe) does not depend on the power level.**

- **General Assumptions:**
  **1.) The $H_2$ coolant from the weapon is used as a working fluid in the power source.**

  **2.) The weapons put out more $H_2$ than the power supply needs, therefore the $H_2$ is not included in the power supply mass.**

## *Compare*

| Reactors | • Batteries<br>• Fuel Cells | $O_2$-$H_2$ Combustion |
|---|---|---|
| • Open Gas | • 100 Wh/kg | • Open System |
| • Brayton | • 500 Wh/kg | |
| • Rankine | | |
| • Thermionic | | |

***See Figure***

**In general, open systems are lighter than closed systems, but the $H_2$ and $H_20$ effluent can interfere with the weapon system**

- ***Note: There is no advantage to a closed system if the cooling system of the weapon is open!***

## Table of Power System Weights

**General Observations**

**1.) Reactor mass is < 2 % of system mass in open gas cooled systems (< 4 % if the load specific power conditioning system is subtracted)**

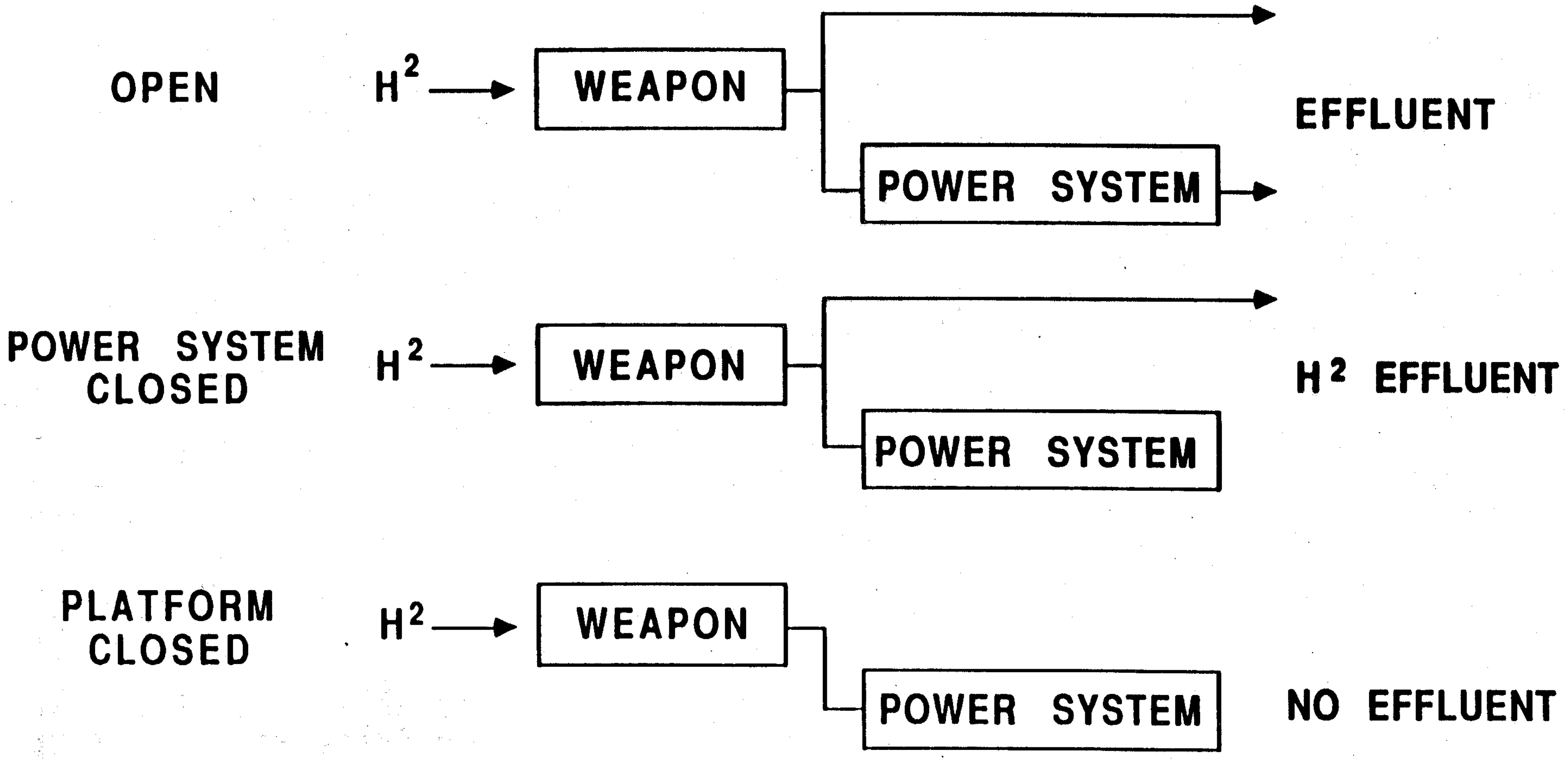
**2.) Power conditioning represents a significant portion of the total mass, and that system depends strongly on the load (weapon)**

**3.) Electromagnetic Launch weapons require almost no power conditioning (can use power directly from the power system)**

**4.) Free Electron Laser and Neutral Particle Beam weapons use substantial power conditioning to provide 1MV DC power for RF generation**

**5.) Closed Brayton and Rankine cycles dominated by radiator mass**

# SPAS POWER SYSTEMS



OPEN

$H^2$ → WEAPON → POWER SYSTEM

EFFLUENT

POWER SYSTEM CLOSED

$H^2$ → WEAPON → POWER SYSTEM

$H^2$ EFFLUENT

PLATFORM CLOSED

$H^2$ → WEAPON → POWER SYSTEM

NO EFFLUENT

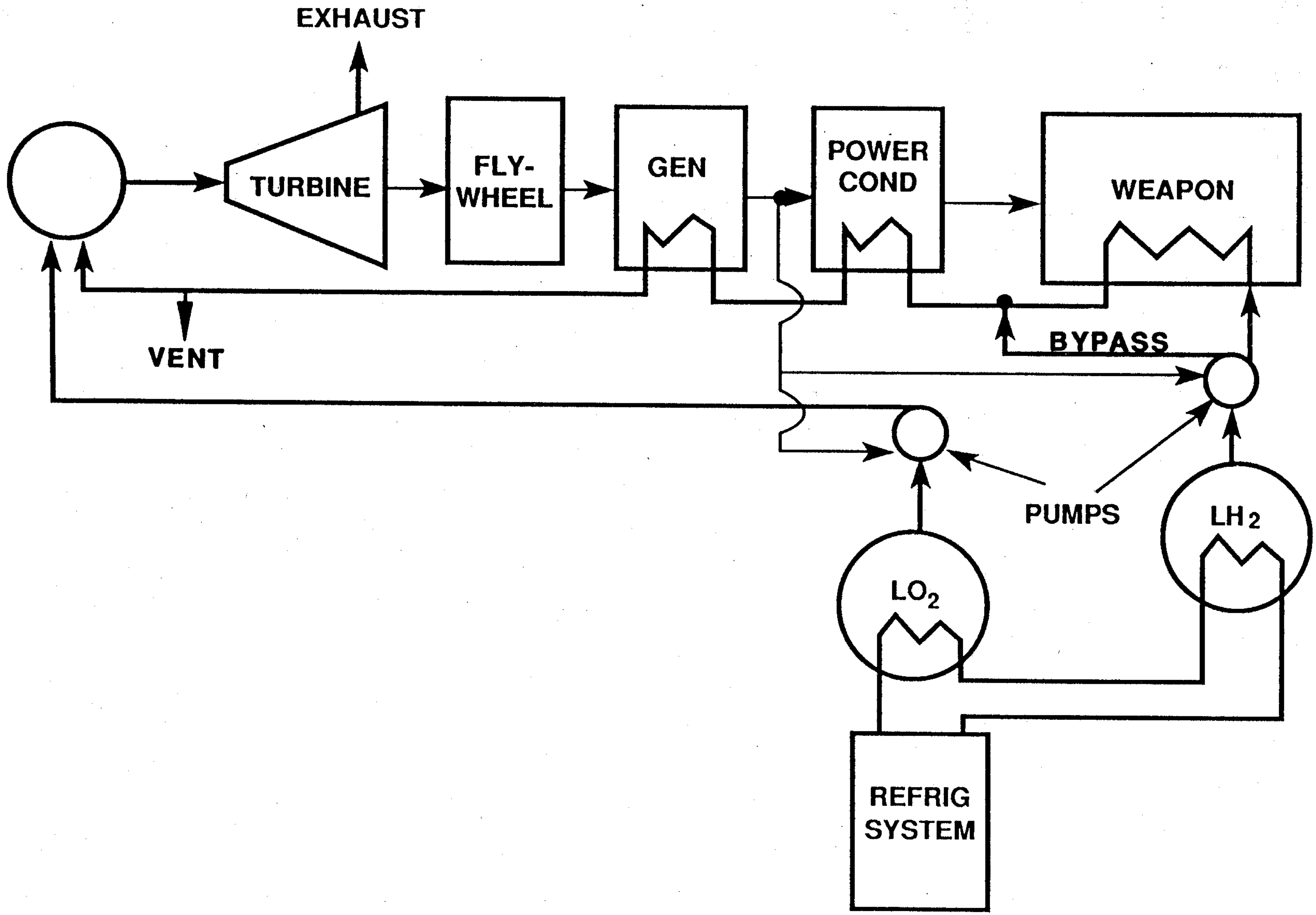
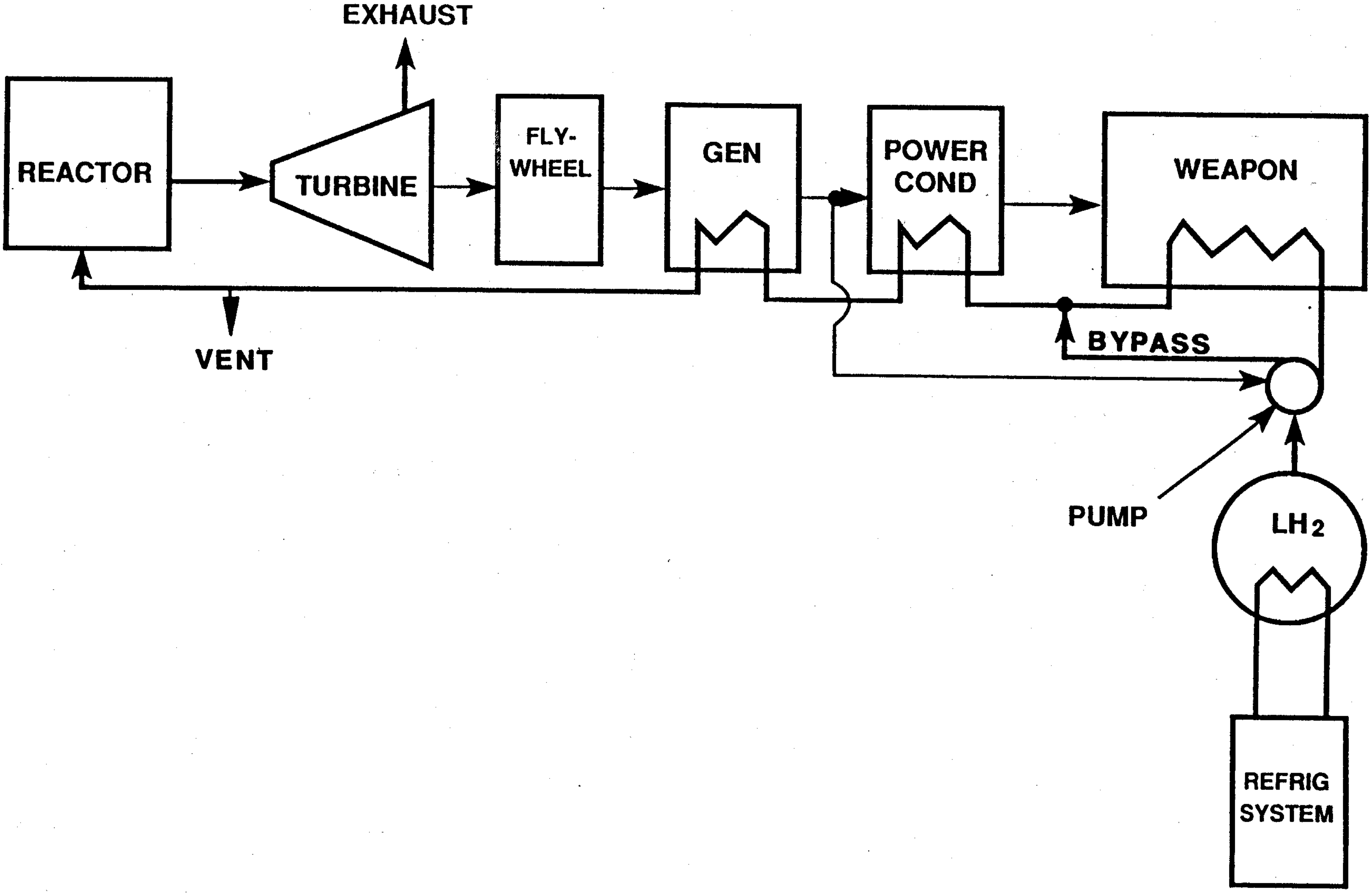
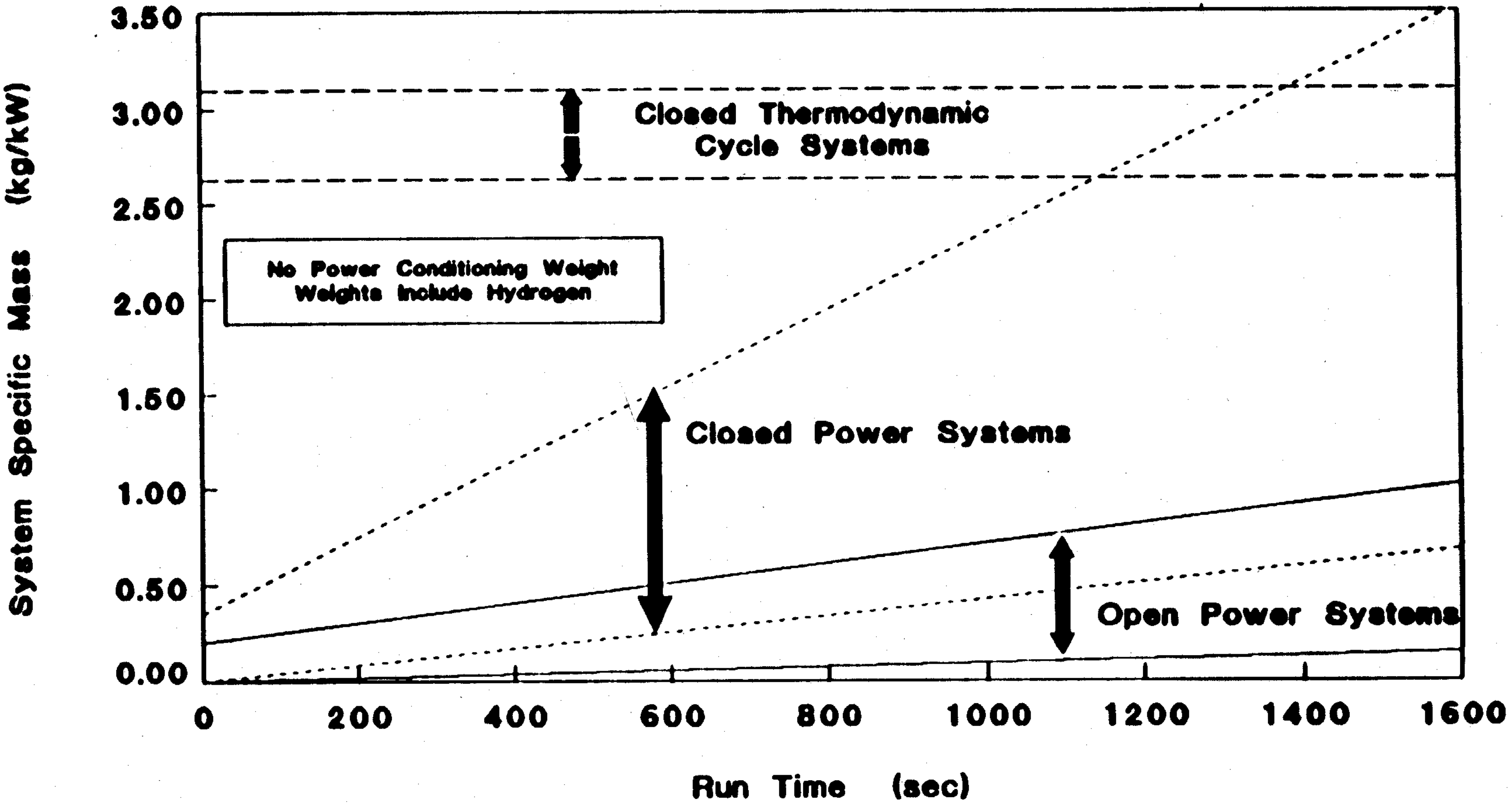


FIGURE 2. $H_2$-$O_2$ Combustion,


EXHAUST
REACTOR
TURBINE
FLY-WHEEL
GEN
POWER COND
WEAPON
VENT
BYPASS
PUMP
$LH_2$
REFRIG SYSTEM

alternal

# *Weight Depends on Whether the System is Open or Closed and on Run Time*



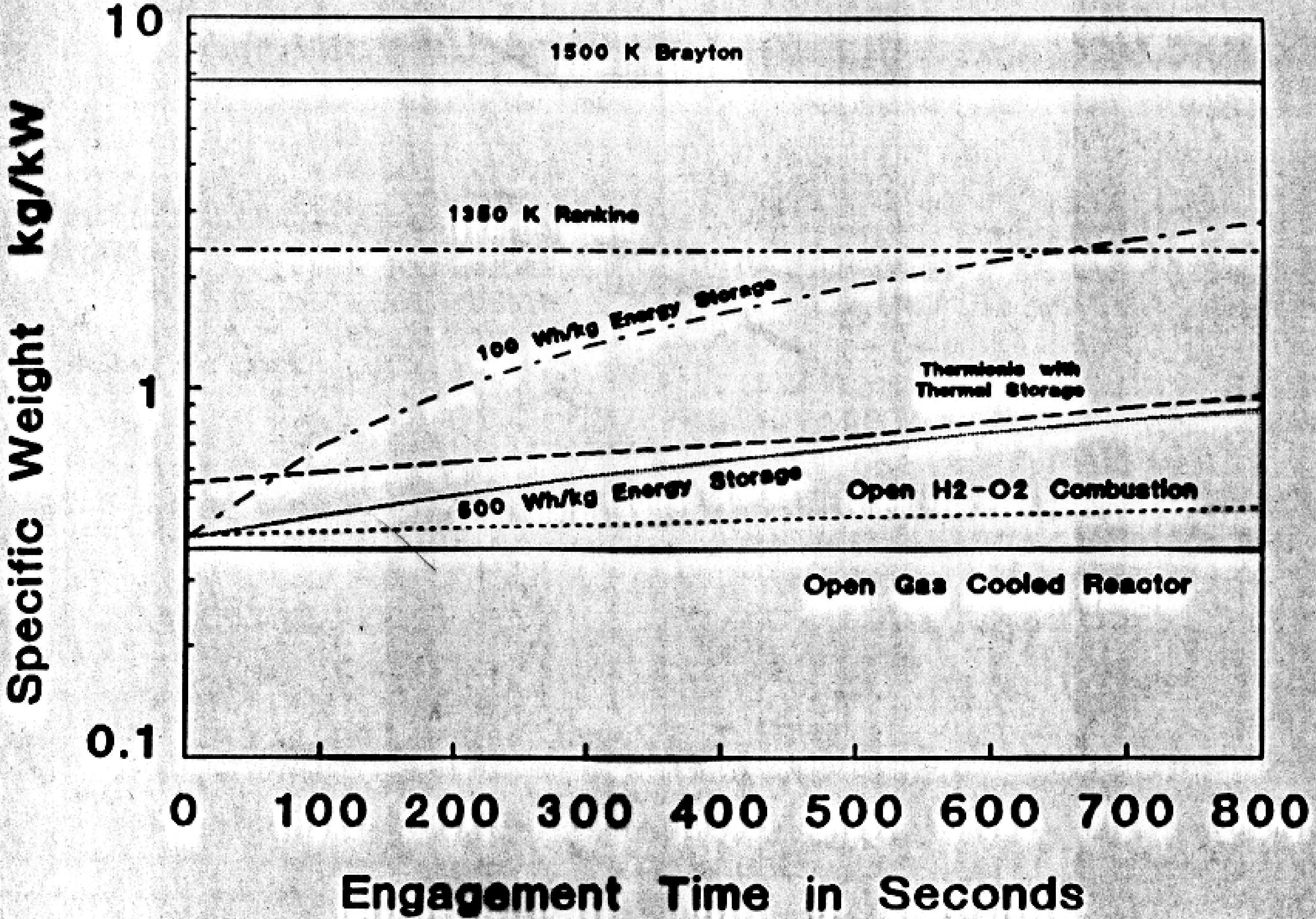


Figure A-1. Comparison of Specific Weights of Burst-Mode Space Power Systems