# NASA TECHNICAL MEMORANDUM

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# NUCLEAR POWER FOR MANNED
# ORBITING SPACE STATIONS

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## ABSTRACT

The impact of using nuclear (reactor and isotope) power systems on Space Station and Space Base is discussed, and candidate nuclear power systems are compared. Much of the information presented is derived from the current NASA Phase-B Space Station studies.

E-5605

## INTRODUCTION

Based on the Space Task Group recommendations (1) to the President, the NASA's space program of the 1970's includes the development of new capabilities for operations in space. As a part of this effort, the NASA is planning as one of its major objectives in the 1980's a large (≈50 men) autonomous Space Base. As the initial, but evolutionary step toward the Space Base, the NASA is presently conducting a Phase-B Definition Study of a Space Station (≈12 men) which would be launched in the late 1970's. In order to meet the lifetime and electrical power requirements of Space Station and Space Base, nuclear (reactor and isotope) power systems are attractive candidates.

Early manned spacecraft such as Mercury and Gemini were able to use battery power which was adequate for the short time and low powers required. For the extended flights of Gemini and Apollo (up to 2 wks duration) batteries were no longer acceptable and the hydrogen-oxygen fuel cell was developed to meet these requirements. The Apollo Applications Program, Orbital Workshop, will extend this duration to 56 days. For this application, a large solar array will be used. Because nuclear systems of the required power level (6 kWe) are not sufficiently advanced in their development cycle, this mission, scheduled for launch in 1973, is too early in time to permit consideration of a nuclear system.

The purpose of this paper is to describe the current concepts of Space Station and Space Base, discuss the impact of using nuclear power systems on Space Station and Space Base, and to compare the candidate Nuclear Power Systems.

Because the current definition studies are competitive, many details of the integration of nuclear power systems into space station and base cannot be discussed at this meeting. However, we will try to cover the major considerations. A description and status of the candidate Nuclear Power Systems can be found in Refs. 2 and 3.

## SPACE STATION/SPACE BASE DESCRIPTIONS AND REQUIREMENTS

The Space Station is defined as a completely self-contained module with systems and provisions for a 12-man crew with experimental programs. It is to be designed for a minimum operational life of 10 years and to be capable of being used as a module in the assembly of the Space Base. The Space Base is defined as an autonomous assembly of general purpose and specialized modules in low earth orbit capable of supporting a crew of 50 men (with growth beyond the 50-man size), multi-disciplinary experiments and applications program, and the orbital operations of other manned and unmanned spacecraft. It too shall have a minimum operational life of 10 years. Thus, Space Base would essentially be a laboratory in space where a broad range of physical and biological experiments would be performed.

Fig. 1 presents a brief summarization of Space Station and Space Base requirements, as specified in the current NASA Space Station Phase-B Definition study. The key points to be derived from Fig. 1 are the 10-year minimum operational life requirement; the varied orbital requirements; the zero and artificial gravity requirements; and the large estimated power requirements. A breakdown of the estimated electrical load requirements for Station and Base is shown in Fig. 2. The power necessary to support the crew and the experiments are the major loads. In the event of a power outage, most of these loads can be dropped except for the power required to sustain crew support and safety. Thus, in order to support the crew, backup power must be provided for the length of time necessary to maintain or replace the failed power system.

Another important consideration regarding Space Station is that at present its launch weight is limited to about 120,000 pounds which includes 10,000 pounds allocated to the experiments, but it does not include any payload allowance for the artificial-gravity capability. Furthermore, there is a requirement that a single launch be used to place the complete Station module in orbit. Both the weight limitation and the single launch requirement of Station, the variety of the mission orbital altitudes and inclinations, and the payload capability of the launch vehicle, all become important tradeoffs in the selection of the power system. The launch vehicle being considered for both Station and Base is a Saturn V derivative termed the INT-21 which uses the S-I-C and S-II stages with the payload in place of the SIVB and Apollo Command Service module. To illustrate the tradeoff problem, the payload capability of the INT-21 is shown in Fig. 3 for the mission orbits and inclinations. Currently, the orbit and inclination of prime interest for performing the many and various experiments is about 260 n. miles and 55°, where the payload capability is about 190,000 pounds. It is estimated that about 70,000 pounds will be required for the artificial-gravity equipment and launch vehicle margin, thus,

the 120,000-pound weight limitation for Station cannot be exceeded if the mission is to be performed at the orbit of interest. It is of interest to note that of the 120,000 pounds allocated to the Station module, about 20,000 pounds can be allocated to the power system.

## SPACE STATION/SPACE BASE CONCEPTS

Since September 1969, two Space Station Phase-B Definition Studies have been underway at McDonnell Douglas under contract with the NASA Marshall Space Flight Center and at North American Rockwell under contract with the NASA Manned Spacecraft Center. The following concepts for Space Station and Space Base, resulting from the Phase-B Study, are presented to provide perspective in the discussions of nuclear power systems that follow.

Fig. 4 shows a concept of a 12-man space station having five decks, a diameter of about 33 feet, and weighing approximately 120,000 pounds. As indicated, the station is capable of docking several "dependent and free-flying" experimental modules. A logistics vehicle is shown end docked. The power system depicted in this particular concept is a Solar Array/Battery system.

Two concepts of Space Base are shown in Figs. 5 and 6. These two concepts, although very similar, were arrived at independently by the two Phase-B study contractors. Both concepts show two reactor power systems located at the end of long booms approximately 200 to 300 feet in length. Long booms are used to minimize the cone angle for shielding and hence shield weight, which will be discussed in more detail later. In establishing the shield cone angle, consideration must be given to the direct dose and scatter dose that might be seen by logistics vehicles that approach the Space Base and by "free flying" experiment modules that will be docked to the Base. In order to insure Base autonomy and safety, two reactor power systems are used. Each power system is rated at 50 kWe in order to supply the required 100 kWe. In the event of a loss of one of the power systems, the other system would supply sufficient power to support the crew. Also, it could be increased in power to meet the total electrical load requirement for the period of time necessary to perform maintenance or until a replacement power system could be brought up and installed. It should be noted that each power system has its own radiator for rejection of the waste heat from the energy conversion cycle. In the concept shown in Fig. 5, the artificial gravity requirement is obtained in the spokes which rotate about the inertially stabilized hub. The concept shown in Fig. 6 uses two sets of rotating spokes, rotating in opposite directions, to meet the artificial gravity requirement. It is estimated that about five to six separate launches, of INT-21 Saturn class vehicles, are required to build the Space Base into the concepts shown.

# IMPACT OF USING NUCLEAR POWER SYSTEMS FOR SPACE STATION
## AND SPACE BASE

In order to meet the 25 kWe power requirement of Space Station, both a Solar Array/Battery Power System and Nuclear (isotope and reactor) Power Systems are being considered in the Phase-B Definition Study. At this time, only a Nuclear Reactor Power System is being considered to supply the 100 kWe required for Space Base. In any case, the selection of the power system is very important in meeting the mission objectives of Station and Base. For example, Station and Base must have both artificial and zero gravity operational capability. In addition, Station and Base must be capable of supporting a large number and variety of experiments ranging from earth survey experiments to astronomy experiments; some of which will be accomplished by manned "free flying experiment modules." Thus, all of the mission objectives and the 10-year minimum operational life of Station and Base must be considered in the selection of a particular power system. In terms of the preceding, there are several important advantages and disadvantages to using a Nuclear Power System when compared to a Solar Array/Battery Power System, and these are shown in Fig. 7.

In general, the nuclear power systems are relatively compact. Thus, the drag, physical interferences, and shadowing that would be imposed on the Station or Base by use of a large Solar Array would be minimized. (For example, a Solar Array system could require in excess of 10,000 sq. ft in array area to provide the 25 kWe needed for Space Station.) Low drag reflects itself in reduced station keeping propulsion requirements; and more important, having a relatively free spacecraft surface permits greater flexibility for mission operations and configuration optimization.

The performance of a nuclear electric power system is not dependent on the space environment, swings in solar activity, orbital altitude, or orbital inclination; all of which are major perturbations to a Solar Array System.

Once Space Station and/or Space Base are operational, it is reasonable to expect that the current estimated power requirements of 25 and 100 kWe will increase substantially. Here again the nuclear power system has a decided advantage. For example, as more advanced higher power reactors and energy conversion systems become available, they can be used without major modification to Station or Base configurations. The only way to achieve higher powers with the Solar Array system is to use larger and larger arrays.

The potential long useful life of a nuclear power system is important in order to minimize resupply requirements, overall cost, and also enhance independent operation.

Of course, there are two important disadvantages in using a Nuclear Power system - nuclear safety and the radiation environment. Safe utilization of the Nuclear Power System must be assured to some acceptable level for both operational and aerospace nuclear safety in order to minimize or eliminate any

hazards to the crew or the general population. A discussion of aerospace nuclear safety may be found in Ref. 4.

Now, having discussed several important advantages and disadvantages of Nuclear Power Systems compared to Solar Array Power Systems, the impact of using a Nuclear Power System on Space Station and/or Space Base will be discussed in terms of three important integration constraints; the radiation environment, maintenance and/or replacement of the power system, and the waste heat rejection radiator.

Radiation Environment

In order to understand the implications of integrating a Nuclear Power System on Station or Base, it is important to define the major elements that typically comprise a Nuclear Power Systems.

A Nuclear Power System is comprised of five major elements as illustrated in Fig. 8. The nuclear heat source may either be a liquid metal cooled reactor (Fig. 8(a)) or it may consist of isotope fueled capsules (Fig. 8(b)). Heat is transferred from the nuclear heat source to a power conversion system by means of a heat exchanger. For the Isotope Power System the heat is transferred by radiation; and for the Reactor Power System the heat is transferred to the heat exchanger by the pumped liquid metal. The power conversion system, which may be a static or a dynamic system, transfers its cycle waste heat to a radiator from where the waste heat is rejected to space by radiation. Finally, there is the shield required to reduce the radiation dose from the nuclear heat source to some permissible level.

In general, the shield will comprise the dominant weight for the Reactor Power System, weighing of the order of tens of thousands of pounds. Thus, in order to minimize shield weight, a combination of separation distance (i.e., distance from the reactor to the crew and/or experiment) and "shaped 4π" radiation shielding must be utilized. Since shielding calculations are very difficult and time consuming, it is important to establish crew tolerances, experiment tolerances, and the mission profile as soon as possible. Even then, the shield analyses will be iterative involving tradeoffs among the spacecraft configuration, radiation tolerance, the power system, and mission profile; and must also include the hazards to the crew and experiments from space radiation (i.e., galactic, solar, and Van Allen radiation).

At present, there are two radiation dose planning constraints for Station and Base crews. For the space environment it is 25 rem and for 6 months, whole body, 5 cm depth dose; and for any on-board nuclear source, it is 27 rem for 6 months. Both of these dose constraints are important considerations in determining the shielding required to protect the crew. The 25 rem space environment limitation has an important effect on orbital parameters. This effect is illustrated in Fig. 9 where the unshielded 50 percent probability depth dose (5 cm) from earth trapped radiation is shown for the mission orbital altitudes and inclinations. It can be seen that for altitudes up to about 270 n. miles and any inclination, the allowable dose is not exceeded and no

shielding is required. At 300 n. miles, however, shielding would have to be provided to the entire Space Station module to insure meeting the criteria. The shield required for this situation might exceed 10,000 pounds. Since, as discussed previously, Station weight is a critical parameter, radiation from the space environment tends to drive the mission to orbital altitudes below about 270 n. miles.

Now, using the 25 rem dose constraint for a Nuclear Power System; and considering the weight constraint for Station, the payload capability of the launch vehicle, and the fact that many "free flying experiment modules" and the Space Shuttle will fly in the vicinity of Station and Base or be docked; a shield geometry and shield weight can be established. In the case of a Reactor Power System, shielding must be provided in all directions. The effects of separation distance and shielded diameter on shield weight are illustrated in Fig. 10 for a Reactor Power System utilizing a 600-thermal kilowatt uranium-zirconium hydride fueled compact reactor. For dose constraints of 2 m-rem/hour at the dose plane, 200 m-rem/hour everywhere else around the reactor at a distance of 125 feet, and a gallery height of 20 inches (i.e., the gallery is that volume within the shield between the reactor and power conversion system as shown in Fig. 8), shield weight is very sensitive to both separation distance and shielded diameter. For example, increasing the separation distance from 50 to 200 feet for a shielded diameter of 50 feet results in a reduction in shield weight from about 110,000 to 40,000 pounds. To shield this reactor with a complete 4π shield so that the dose rate would be 2 m-rem/ hour at a distance of 65 feet everywhere around the shield would require a shield weight of about 137,000 pounds. For the Space Base configurations shown in Figs. 5 and 6, preliminary estimates indicate that the shield would weigh of the order of 40,000 to 50,000 pounds. These shields utilize lithium-hydride for neutron attenuation with tungsten and depleted uranium for gamma shielding.

Shielding for the Isotope Power System is simpler and the penalties are less severe than that for the reactor system. For example, preliminary estimates indicate that the shielding required for a 25 kWe Isotope (Plutonium-238 Heat Source) Brayton Power System would weigh of the order of a few thousand pounds.

## Maintenance and/or Replacement

At present, no existing reactor or power conversion system has demonstrated an operating life anywhere near the 10-year operational life required for Space Station and Space Base. The operating life of these two subsystems might be of the order of 2 to 5 years. Therefore, a requirement for integration of a Reactor Power System is the capability for easy maintainability and/or replacement. To date, the question of level of maintenance versus complete replacement of the power conversion system is undetermined. However, maintenance is facilitated by using an intermediate heat exchanger, as illustrated in Fig. 8, which prevents the transfer of activated liquid metal coolant from the reactor behind the shield into the power conversion system. Regardless of whether or not maintenance can be performed, it is likely that at some point in time the Reactor Power System will have to be replaced. Disposal of

the spent or replaced reactor system is a nuclear safety problem.  At present, three means of reactor disposal are being considered; boost into higher orbit, and Earth or ocean impact with recovery.

The same considerations just discussed for the Reactor Power System apply to the Isotope Power System with a few noteworthy exceptions.  For example, if maintenance is performed on the power conversion system, it is facilitated by the low radiation dose levels from the isotope heat source and by the fact that the heat generated by the isotope is transferred to the heat exchanger by radiation (see Fig. 8).  This radiation coupling between the isotope heat source and the Brayton heat exchanger permits the heat source to be pivoted away from the power conversion system during maintenance or replacement.  Since the isotope most likely to be used is Plutonium-238 and its half life is 87 years, planned replacement of the isotope heat source would not be contemplated during the 10-year mission.

Another factor to be considered regarding Nuclear Power System replacement is the time required to launch a replacement power system, and the size and availability of the launch vehicle.  That is, time is reflected in the requirements of an adequate backup power supply on Station and Base to provide power to support the crews; and the weight of the replacement power system will dictate the size of launch vehicle required.

It should be noted that maintenance and replacement are also a requirement for a Solar Array/Battery Power System.  For example, replacement of the solar array panels must be considered since the system may degrade, experience has shown, more than 30 percent in power in 5 years due to the space environment.  Also, the batteries (which are the dominant weight of the system) will have to be replaced on some regular time basis.

Waste Heat Rejection Radiator

The last major area of integration impact of the Nuclear Power System is the waste heat rejection radiator.  At the required power levels of Space Station and Space Base, and due to the characteristics of the candidate power conversion system that might be used, large radiator areas will be required.  At the 50 kWe power level, radiator areas can range from about 2300 to 5000 square feet depending on the power conversion system.  Large radiator area requirements not only present problems to the spacecraft designer, but they also create problems of integration in the launch vehicle.

## NUCLEAR POWER SYSTEM COMPARISONS

At present, there is only one reactor heat source that may be considered for application to Space Station and Space Base, and that is the uranium-zirconium hydride (SNAP-8) reactor under development by the AEC.  This reactor is designed for a thermal power of 600 kW at a 1300° F liquid metal (NaK) coolant outlet temperature.

Based on their current development programs and technological status, there are only three power conversion systems, which when mated to the uranium-zirconium hydride reactor, are candidates for application to Space Station and Space Base starting in the late 1970's. These systems are the mercury Rankine, inert gas Brayton, and thermoelectric, which are discussed by English (2) and Wilson (3).

In the case of an Isotope Power System, only one system, the Isotope Brayton Power System which utilizes a Plutonium-238 heat source and is currently under development, is the only candidate for application to Space Station and Space Base.

In order to select a power system for application to Space Station and/or Space Base, selection criteria must be established. At the risk of oversimplification, these criteria can be stated as shown in Fig. 11. Other factors being equal, these criteria state the obvious - a power system that embodies the least constraints, with the greatest operational flexibility, and at a minimum cost is desired.

Launch Vehicle Constraint: As noted earlier, the Space Station module including the experiments is limited to approximately 120,000 pounds for the initial launch weight. Of this, about 20,000 pounds can be allocated to the power system. The requirement that Space Station be capable of use in polar and sun-synchronous orbits also presents a weight constraint. Regarding Space Base, it is not so severely weight limited. As noted earlier, five to six Saturn class launches will be required to assemble Space Base. One of the launches is allocated to the power system. However, this launch must not exceed the total launch vehicle payload capability. Thus, this particular criteria drives the selection toward a low weight system.

Operational Flexibility: The power system should minimize interference with the Space Station or Base logistics operations in the near vicinity of the spacecraft. The primary effect to considere here, for the nuclear system, is the radiation environment which could dictate angles of approach, loiter time and location, rendezvous corridors, and docking positions. In the case of Space Station, the power system must permit operation in both a zero-G and artificial-G mode. In the Space Base, this is not such a distinct driver since both artificial-G and zero-G are simultaneously provided while multiple reactor systems and physical size minimize effects on logistics operations. However, for Space Base it is necessary to provide additional flexibility to accommodate increasing capability, and hence, power levels. This drives the selection toward the system with growth capability and minimum effect on configuration.

Cost Effectiveness: This criteria impacts two characteristics of system selection as shown in Fig. 11. The development of any of these nuclear power systems or a large Solar Array to flight qualified status will be costly; perhaps several hundred million dollars. To minimize development costs it would therefore be desirable to select a common power conversion system for station and base which could meet all of the various mission requirements, thus avoiding a multiplicity of costly development efforts.

Operating life of the power system is also an important factor. Replacement of the nuclear heat source or complete power system will be difficult, complex, potentially hazardous, and hence costly. The requirement for replacement should then be minimized by emphasizing long life. Since replacement is, however, inevitable for either the power conversion system or heat source, the system selected should lend itself to maintenance and/or replacement utilizing the logistics vehicle if possible. This would avoid the necessity of a separate launch vehicle. Payload costs to orbit by separate launch are approximately $1000 per pound while for the re-usable logistics vehicle these costs are anticipated to be of the order of $100 per pound. The logistics vehicle or Space Shuttle imposes both weight and volume limitations, approximately 15,000 to 40,000 pounds and volume to fit within a 15-foot diameter by 60-foot length.

Thus, in order to keep the total Station and Base program costs to a minimum, the cost effectiveness criteria tends to drive the power system selection toward a single (i.e., application to both Station and Base), long-lived, and easily replaceable power system.

## COMPARISON

It is now possible to compare the various candidate nuclear power systems against the criteria given above. Fig. 12 shows these systems compared at the 50 kWe power level for Space Base. Since at present, a reactor thermoelectric power system is not a candidate at the 50 kWe power level, only the Mercury Rankine and Brayton systems are shown. It is apparent that the weights of the two reactor systems are comparable and dominated by the shield. Either system would, however, meet the weight requirements for separate launch of a 100 kWe system using two reactors. When considering power system replacement, both reactor systems exceed the Space Shuttle payload capability of about 40,000 pounds. However, it is possible that only partial shield replacement would be necessary, making it possible that the Space Shuttle could be utilized. Radiator areas are shown to give an idea of surface requirements for waste heat rejection. From the dimensions of the Space Shuttle payload given above it would appear that the maximum cylindrical radiator that could be accommodated would be 2500 square feet. It is possible that a deployable radiator could be used which would ameliorate this problem if practical.

Another important factor shown is the wide variation in thermal power required for the two reactor systems. This reflects the inherent power conversion efficiencies which are of the order of 8 and 20 percent, respectively, for the Rankine and Brayton systems. The isotope Brayton is 25 percent efficient due to its higher turbine inlet temperature. Assuming that both of the reactor systems are capable of operation at the same reactor coolant outlet temperature, reactor life will be strongly influenced by thermal power level. As this power level is reduced, life will increase and frequency of replacement and hence cost will be reduced. It is therefore, proper to infer that reactor life would bias the selection toward the lowest thermal power.

Caution should be used in drawing any conclusion relative to the isotope system. Though it is the lightest and should be the longest lived (87 yr half life) there are two mitigating factors not included in this somewhat simplified comparison. These are safety and availability. Present planning seems to indicate a multiplicity of heat sources (approximately four or more in this case) and conversion systems (four at 12.5 kWe each). It is therefore, likely that this type of system would be modularized for integral rather than separate launch. The isotope Plutonium-238 is not available in unlimited quantities. The quantity of fuel available would have to be assessed against other requirements for the fuel in the time frame of interest.

The same comparison, but at 25 kWe is shown in Fig. 13 for Space Station. Since the reactor system weight is dominated by its shield, which is roughly equal for any of the conversion systems, this comparison treats a typical reactor system. It should be noted that the weight shown is also typical for the reactor thermoelectric system which is a candidate at the 25 kWe power level. Using a typical weight is warranted, since only weight is necessary for this comparison, based on the selection criteria. A Solar Array/Battery system is also shown for perspective.

The shield weight shown in Fig. 13 is somewhat lower than the shield weights shown for Space Base in Fig. 12. This reflects the reduced dose plane diameter for Station since no rotating arms are present as they are in Base. However, in order to keep shield weight to a minimum and stay within the 25 rem dose constraint, a deployment boom is used to separate the Reactor Power System from the Station module. It is estimated that the boom may weigh about 10,000 pounds, and therefore, this weight penalty is included in the system weight shown in Fig. 13.

It is clear from Fig. 13 that the reactor system cannot meet the single launch criteria for Station (i.e., about 20,000 pounds is allocated to the Station power system). Further, there is little difference in weight between the isotope system and the Solar Array.

Summary: Space Station/Base requirements have been shown, the characteristics of Nuclear Power Systems discussed, and comparisons of the candidate power systems were made against a set of simplified criteria. Obviously the trade-offs involved in the actual selection process are far more complex and encompass many factors not included in this discussion. However, it is inevitable that the reader will draw conclusions as to which systems fit best the criteria given.

At this time, the Space Station/Base contractors have selected the Reactor Brayton as the preferred power system for Space Base. The recommendation for Space Station has not yet been made. In any event, these are tentative recommendations only. Final selection will not be made for some time and must take into account changing requirements, technology, and development status, as well as overall NASA objectives.

## REFERENCES

1. ANON., "The Post-Apollo Space Program:  Directions for the Future; Space Task Group Report to the President" (September 1969).

2. R. E. ENGLISH, "Technology for Nuclear Dynamic Space Power Systems," ANS Conference on Aerospace Nuclear Applications (April 1970), to be presented.

3. R. F. WILSON, "ZrH Reactor and Thermoelectric Conversion System," ANS Conference on Aerospace Nuclear Applications (April 1970), to be presented.

4. G. P. DIX, "Nuclear Safety of Space Nuclear Systems," ANS Conference on Aerospace Nuclear Applications (April 1970), to be presented.

| MISSION | CREW | OPERATIONAL LIFE | ORBIT, N MI | ORBITAL INCLINATION | POWER |
|---|---|---|---|---|---|
| SPACE STATION [1] | 12 | 10 YR MIN | 200 - 300[3] | 28.5° - 55° | 25 kWe |
| SPACE BASE[2] | 50 | 10 YR MIN | 200 - 300 | 28.5° - 55° | 100 kWe + |

[1]SHALL BE DESIGNED FOR ARTIFICIAL AND ZERO GRAVITY OPERATIONS.

[2]SHALL PROVIDE ARTIFICIAL AND ZERO GRAVITY ENVIRONMENTS IN SEPARATE VOLUME SIMULTANEOUSLY.

[3]ALSO BE CAPABLE OF USE IN POLAR AND SUN-SYNCHRONOUS ORBITS.

Figure 1. - Space station/space base requirements.

|  | SPACE STATION 12 MEN, kWe | SPACE BASE 50 MEN, kWe |
|---|---|---|
| CREW SUPPORT | 12 | 50 |
| EXPERIMENTS | 8 | 35 |
| GUIDANCE AND CONTROL | 3 | 10 |
| COMMUNICATIONS | 1 | 3 |
| OTHER | 1 | 2 |
| TOTAL | 25 | 100 |

Figure 2. - Typical average electrical load requirements.
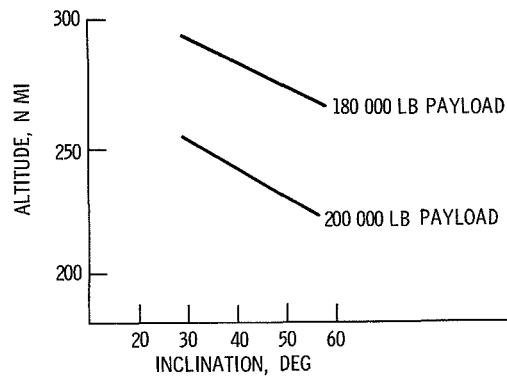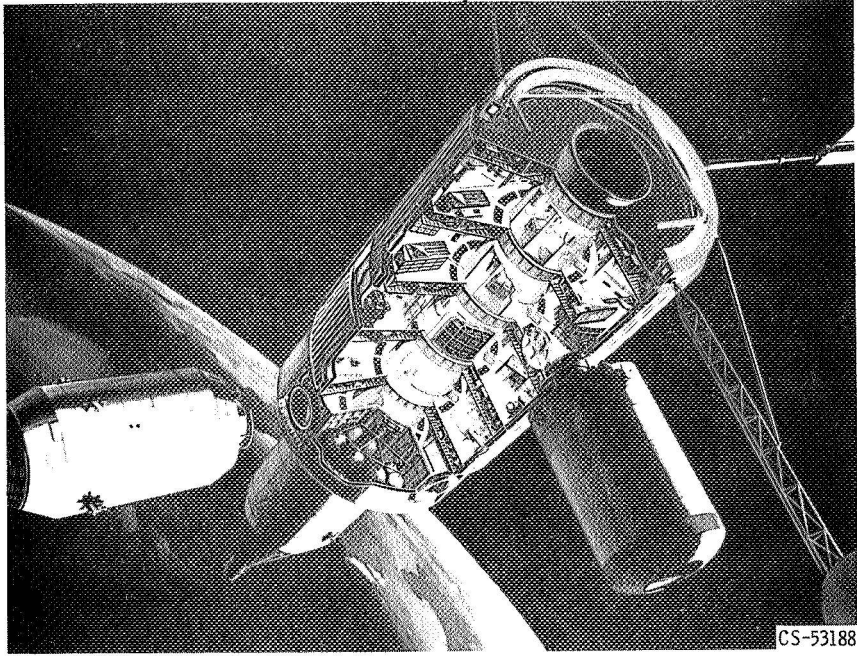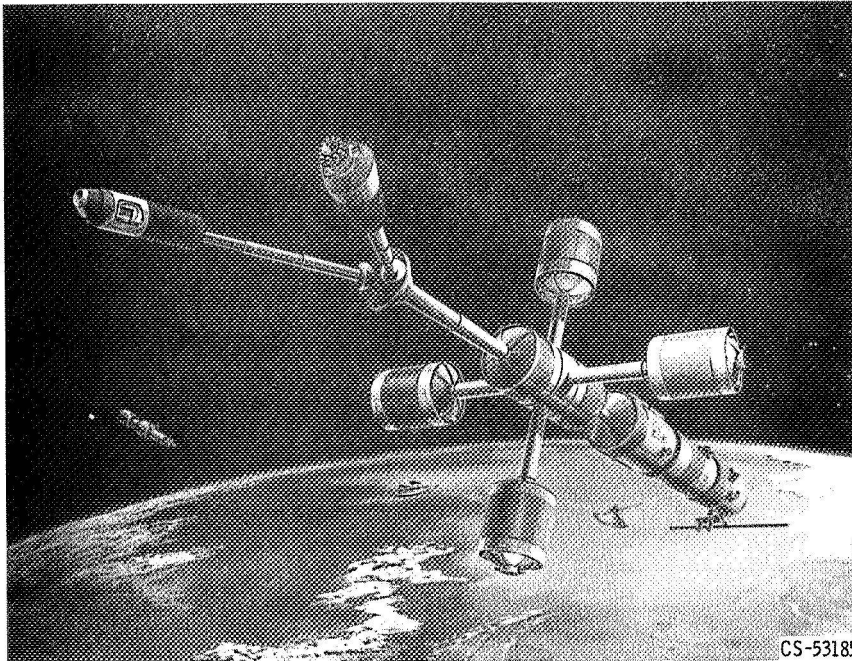


Figure 3. - INT.-21    Payload   Capability Direct ascent.

CS-53188

Figure 4. - Space station concept.
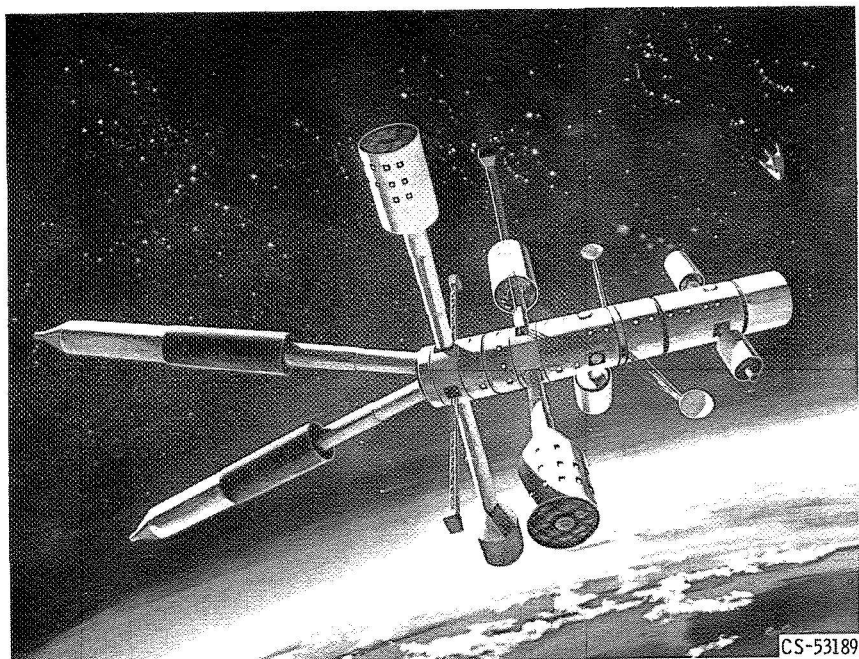


CS-53185

Figure 5. - Space base concept.

Figure 6. - Space base concept.

| ADVANTAGES | DISADVANTAGES |
|---|---|
| COMPACT | NUCLEAR SAFETY |
| INDEPENDENT OF SPACE ENVIR. | RADIATION ENVIRONMENT |
| NO ORIENTATION REQUIREMENT | |
| GROWTH POTENTIAL | |
| LONG POTENTIAL LIFE | |

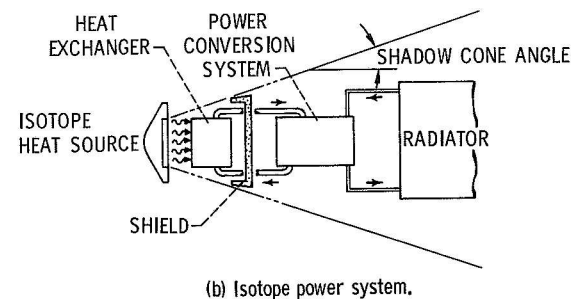Figure 7. - Nuclear power system features.



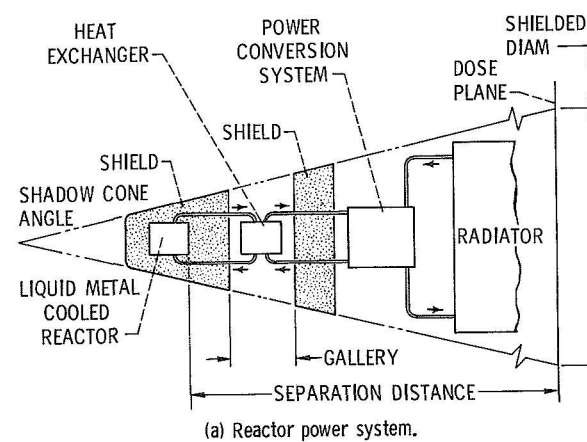(a) Reactor power system.



(b) Isotope power system.

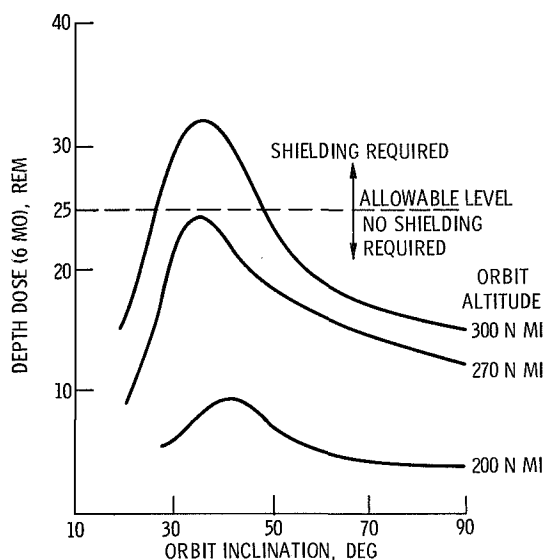Figure 8. - Nuclear power systems.

Figure 9. - Earth-trapped radiation. 50 Percent proba-
bility depth dose (ref. 5).

CONSTRAINTS:

200/HR SIDE DOSE AT 125 FT
2 MR/HR DOSE RATE AT DOSE PLANE
20 IN. GALLERY HEIGHT
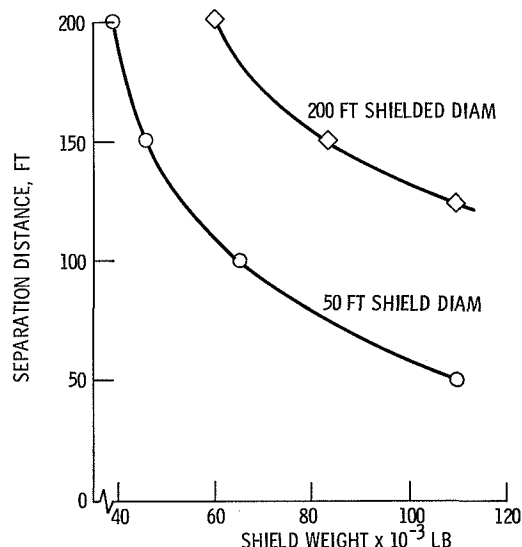REACTOR OPERATING AT 600 kWt



Figure 10. - Shield weight sensitivity. Separation
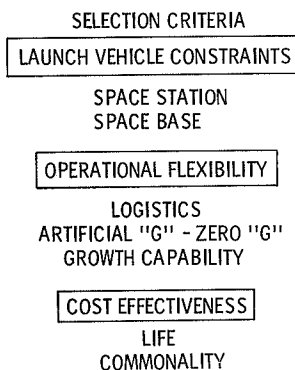distribution and shielded diameter.

SELECTION CRITERIA

LAUNCH VEHICLE CONSTRAINTS

SPACE STATION
SPACE BASE

OPERATIONAL FLEXIBILITY

LOGISTICS
ARTIFICIAL "G" - ZERO "G"
GROWTH CAPABILITY

COST EFFECTIVENESS
LIFE
COMMONALITY

Figure 11

| POWER SYSTEM | THERMAL POWER, kWt | SYSTEM WT. (NO SHIELD) LB | SHIELD WT, LB | RADIATOR AREA, FT$^2$ | TOTAL WEIGHT, LB |
|---|---|---|---|---|---|
| MERCURY RANKINE | 600 | 16 000 | 40 000 | 2300 | 56 000 |
| BRAYTON | 250 | 14 000 | 40 000 | 3000 | 54 000 |
| ISOTOPE BRAYTON | 200 | 22 000 | 6 000 | 3000 | 28 000 |

Figure 12. - Reactor power systems comparison for space base. 50 kWe
net output.

| POWER SYSTEM | SYSTEM WT. (NO SHIELD), LB | SHIELD WT, LB | RADIATOR AREA, FT$^2$ | TOTAL WEIGHT, LB |
|---|---|---|---|---|
| REACTOR (U-ZrH) | 15 000 | 30 000 | 1500 - 2500 | 55 000[1] |
| ISOTOPE | 12 000 | 3 000 | 1500 | 15 000 |
| SOLAR ARRAY | 17 000 | ----- | 10 000[2] | 17 000 |

[1]INCLUDES 10 000 LB FOR DEPLOYMENT BOOM

[2]SOLAR ARRAY AREA

Figure 13. - Power system comparison for space station. 25 kWe
net output.