NASA Technical Memorandum 102064

Space Nuclear Reactor Shields for Manned and Unmanned Applications

Barbara I. McKissock and Harvey S. Bloomfield
Lewis Research Center
Cleveland, Ohio

(NASA-TM-102064) SPACE NUCLEAR REACTOR SHIELDS FOR MANNED AND UNMANNED APPLICATIONS (NASA. Lewis Research Center) 16 p CSCL 10B

N89-25272

Unclas
G3/20 0211980

Prepared for the
International Conference on Space Power
sponsored by the International Astronautical Federation
Cleveland, Ohio, June 5-7, 1989

NASA

SPACE NUCLEAR REACTOR SHIELDS FOR MANNED AND UNMANNED APPLICATIONS

Barbara I. McKissock and Harvey S. Bloomfield
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-4821

ABSTRACT

Missions which use nuclear reactor power systems require radiation shielding of payload and/or crew areas to predetermined dose rates. Since shielding can become a significant fraction of the total mass of the system, it is of interest to show the effect of various parameters on shield thickness and mass for manned and unmanned applications. Algorithms were developed to give the thicknesses needed if reactor thermal power, separation distances, and dose rates are given as input. The thickness algorithms were combined with models for four different shield geometries to allow tradeoff studies of shield volume and mass for a variety of manned and unmanned missions. Shield design tradeoffs presented in this study include the effects of: higher allowable dose rates; radiation hardened electronics; shorter crew exposure times; shield geometry; distance of the payload and/or crew from the reactor; and changes in the size of the shielded area. Specific NASA missions that were considered in this study include unmanned outer planetary exploration, manned advanced/evolutionary space station, and advanced manned lunar base.

INTRODUCTION

Potential mission options as identified and studied by NASA [1,2] to expand human presence in space and increase scientific knowledge of our solar system require power sources with capabilities beyond those launched to date. Nuclear reactor power systems enable or enhance many missions that require high capacity and long operational lifetimes, as well as providing independence from variations in solar energy availability.

Nuclear reactor power systems include shielding to reduce radiation doses at the payload and/or crew areas to allowable levels. This shielding can be a significant portion of the total power system mass, especially for manned missions. Due to this potentially large impact on system mass, and therefore on launch capability and cost, shield design and analysis is done with an emphasis on finding a minimum mass configuration that meets radiation dose requirements.

The design of minimum mass nuclear reactor shielding for manned and unmanned space mission applications is a complex undertaking that requires detailed design considerations of reactor source spectrum, power plant and payload geometry, as well as a knowledge of the particular mission application constraints. Application and comparative studies of space nuclear power plant applications will, however, require only a first-cut or system level estimate of shield mass to provide mission planners with preliminary estimates.

Thickness Algorithms

The NASA Lewis Research Center has been conducting feasibility studies and trade-off analyses of space nuclear reactor power system applications since the early 1960's. These studies were primarily focussed on manned interplanetary missions where shield mass is a significant fraction of total power plant mass. In an attempt to more accurately estimate shield mass an extensive development of Monte Carlo shielding codes was undertaken to replace the point kernel methods previously used [3]. Further attempts to refine estimates of shield thickness and mass in optically thick manned shields were directed toward optimization of shield geometry and increased confidence in radiation attenuation calculations with the incorporation of a variety of variance reduction techniques [4].

These efforts resulted in the development of a simple algorithm for shield thickness as a function of reactor power level. The algorithm is based on a thermal reactor spectrum, and a combined neutron and gamma biological dose constraint. A six layer shield configuration, composed of three layers each of tungsten and lithium hydride slabs, was required to meet the dose constraint which included secondary gamma ray production within the shield.

A similar algorithm for "instrument rated" or unmanned shield thickness was developed from a series of MCNP and TWODANT computer code calculations carried out by the Los Alamos National Laboratory [5] for a two layer shield composed of tungsten and lithium hydride slabs. Reactor leakage source terms were based on a fast spectrum SP-100 reactor core and payload radiation constraints are in terms of neutron fluence and absorbed gamma dose.

Application of these algorithms to estimate shield thickness for other dose constraints or separation distances is accomplished by use of the exponential attenuation law and the inverse distance squared law, respectively.

Geometry Considerations

Shield thickness estimates must be combined with geometrical considerations to provide the shield mass estimates required for mission planning studies. Geometrical considerations and constraints for instrument rated shields differ from those of man rated shields. Typically, instrument rated shield configurations must satisfy a constant dose constraint for radiation sensitive instruments and electronics that are located on the power plant side of the reactor source. Therefore, shielding configurations that protect the power plant side of the reactor source would be required. In the case of man-rated shielding, typical configurations must satisfy a dose constraint that varies with location of specific manned activities. These activities are generally not limited to a single hemisphere or side of the reactor source.

In order to accommodate the wide range of possible manned and unmanned shield configurations that may be encountered, a variety of shield geometry options are employed. The ones discussed in this paper are: the cone; the truncated cone; the

$4-\pi$; and the $4-\pi$ with a conical insert. The cone geometry, shown in Fig. 1, consists of a frustum of a right circular cone. This geometry can be used with either the manned or unmanned thickness algorithms for cases with only one dose constraint. The truncated cone geometry, shown in Fig. 2, is a frustum of a right circular cone that has been cut flat perpendicular and tangent to the surface of its narrow base. This geometry, a variant of the cone geometry, is used for cases involving surface applications with one dose constraint. The $4-\pi$ geometry, shown in Fig. 3, consists of two hemispherical shells of differing thicknesses. This configuration is used for manned applications that have different dose constraints for two halves of space. The $4-\pi$ with a conical insert geometry, shown in Fig. 4, is also for manned applications that have two areas with differing dose constraints and consists of a spherical shell with a cone geometry plug inserted into it. The area with the more rigorous dose constraint is smaller and more defined for the $4-\pi$ with a conical insert geometry as compared to the $4-\pi$ geometry. In addition, both the cone geometry and the truncated cone geometry can have "winglet" shields (Fig. 5) added on to enlarge the protected area at the payload. These additional "winglets" can impose a different dose constraint than the rest of the shield and could be used to shield various objects which protrude outside of the main area of shielding (i.e., antennas).

Unmanned Missions

One of the unmanned spacecraft/mission applications considered for small reactors is the Mariner Mark II Cassini spacecraft and mission [6]. Since the radiation hardness for the electronics and instrumentation was undefined, a range of integrated gamma and neutron exposures from 7.5 krad and 1.5×10^{11} nvt to 300 krad and 6×10^{12} nvt were studied. Unmanned conical shield masses for shielded spot size diameters of 8 to 18 m and a range of separation distances from 10 to 40 m were compared using a 20 kWt fast spectrum reactor. The shield masses needed at the two dose extremes for the range of shielded spot size diameters are shown in Fig. 6 for a payload separation distance of 20 m. Figure 7 shows the effect of different payload separation distances on shield mass at the two dose extremes for a 10 m shielded spot size diameter.

Manned Missions

Two manned missions that have been considered for possible applications of nuclear power are a manned lunar base [7] and a growth space station [8]. Different shielding options were considered for each of these applications which will be discussed separately.

The shielding for the lunar base is a truncated conical shadow shield with a half angle determined by the separation distance and the size of the shielded area to which manned activities would be limited. Analytically, it is treated as a shadow shield, neglecting surface backscattering and secondary radiation effects. Results from a preliminary study of attenuation and scattering by the lunar surface material showed negligible backscattering effects and sufficient attenuation to produce shield equivalent doses within 7 m of soil. Dose rates of 5 and 25 rem/30 days were considered for a range of reactor to base separation distances of 20 to 100 m and a range of reactor powers from 333 kWt to 2.5 MWt. The doses represent a total exposure to both natural (uncontrollable) and manmade (controllable) radiation sources. Currently, guidelines have been established allowing a 5 rem dose from controllable radiation sources with a 25 rem total dose from controllable plus uncontrollable radiation sources for a 30 day exposure period. Manned truncated conical shadow shield masses for a 500 kWt reactor and a 5 m high shielded area are shown in Fig. 8 for shielded area widths of 40 and 160 m using dose extremes of 5 and 25 rem/30 days. The shielded area that can be used for manned operations can be enlarged by extending the shield into a 360° ring. Due to the much higher masses as compared to shielding a more limited area, longer separation distances were studied for the same doses. Figure 9 shows shield mass for reactor powers of 333 kWt and 2.5 MWt and dose rates of 5 and 25 rem/30 days for a range of separation distances from 100 to 1000 m.

Three concepts were included in the growth space station application study: (1) two 150 kWe boom mounted reactor power systems, (2) one 300 kWe boom mounted reactor power system, and (3) one 300 kWe tether mounted reactor power system. The first of the boom mounted concepts consisted of two 150 kWe reactor based power systems each mounted 165 m from the centerline of the station. The second of the boom mounted concepts used one 300 kWe reactor based power system 60 m from the bottom boom of the space station. Two types of shielding were considered for the boom mounted concepts: the 4-π, and the 4-π with conical insert. The tether concept used one 300 kWe reactor based power system tethered 2 km from the centerline of the station and used a conical shield with "winglet" extensions. Figure 10 compares the shield masses needed for each concept.

SUMMARY OF RESULTS

Masses required for shielding are greatly dependent on mission requirements such as: dose requirements for the areas to be shielded, the size of the shielded areas, and payload separation distance from the reactor. The simplified algorithms discussed above, which were based on extensive Monte Carlo modeling, provide a first guess estimate to use in preliminary system tradeoffs so that a specific configuration can be chosen for further study.

REFERENCES

1. Ride, S.K.: Leadership and America's Future in Space. NASA TM-89638, Aug. 1987.
2. Exploration Studies Technical Report, FY 1988 status. Vol. I: Technical Summary and Vol. II: Study Approach and Results, NASA TM-4075-VOL-1; -2, 1988.
3. Soffer, L.; and Clemons, L.C., Jr.: COHORT-II - A Monte Carlo General Purpose Shielding Computer Code. NASA TM X-52561, 1969.
4. Bloomfield, H.S.; and Clemons, L.C., Jr.: Evaluation of the COHORT II Monte Carlo Shielding Code: Gamma Ray Transport Using Source Direction Biasing, NASA TM X-1877, 1969.

5. Carlson, D.: Personal Communication, Los Alamos National Laboratory.
6. Bloomfield, H.S.: Small Space Reactor Power Systems for Unmanned Solar System Exploration Missions. NASA TM-100228, 1987.
7. Bloomfield, H.S.: Nuclear Reactor Power Systems for Lunar and Planetary Bases. Presented at the 2nd Symposium on Lunar Bases and Space Activities in the 21st Century, Symposium Paper No. LBS-88-251, Houston, TX, Apr. 5-7, 1988.
8. Bloomfield, H.S.; and Heller, J.A.: A Feasibility Assessment of Installation, Operation, and Disposal Options for Nuclear Reactor Power System Concepts for a NASA Growth Space Station. NASA TM-89923, 1987.

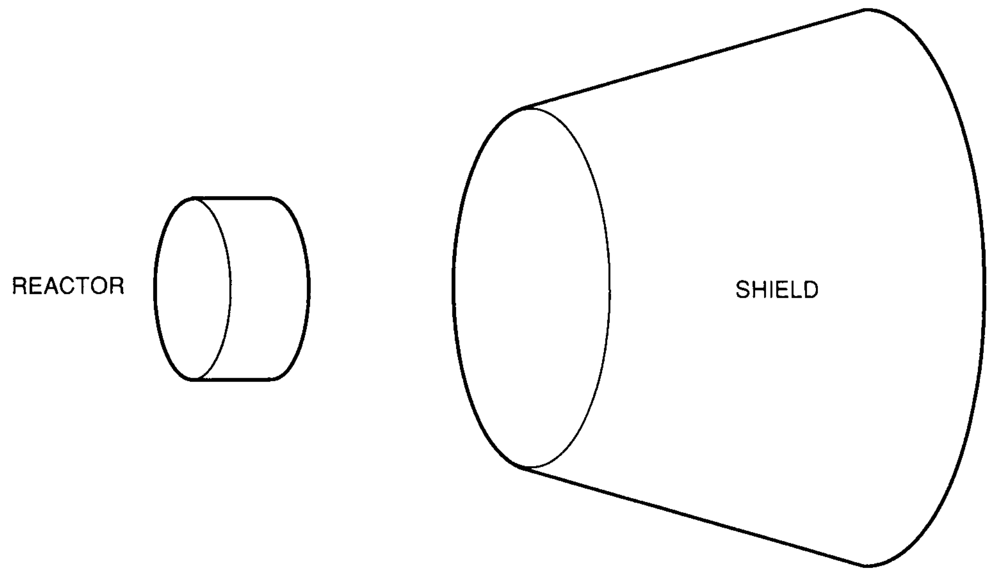

Figure 1. - Conical shield geometry.

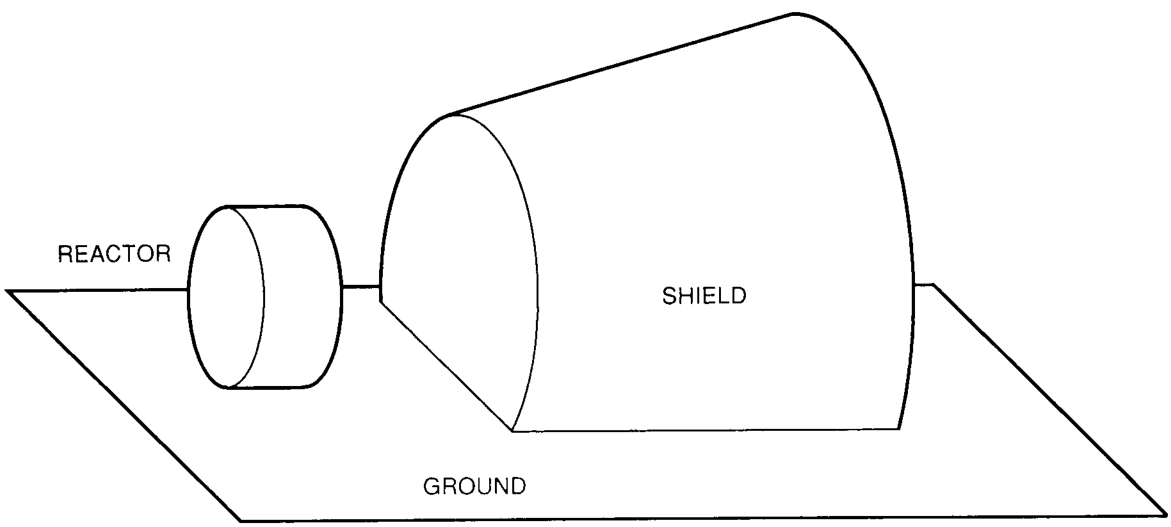

Figure 2. - Truncated cone geometry.

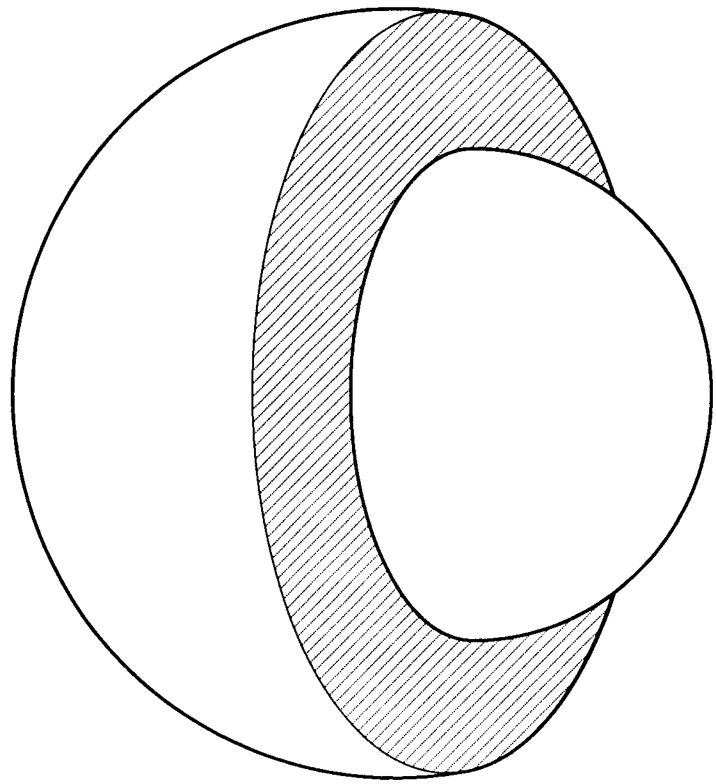

Figure 3. - 4 π shield geometry.

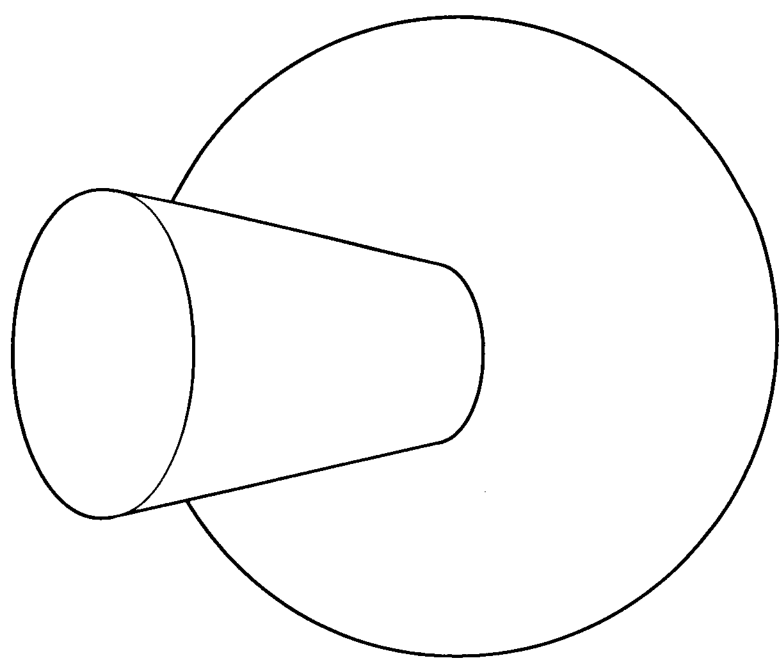

Figure 4. - 4 π with conical plug shield geometry.

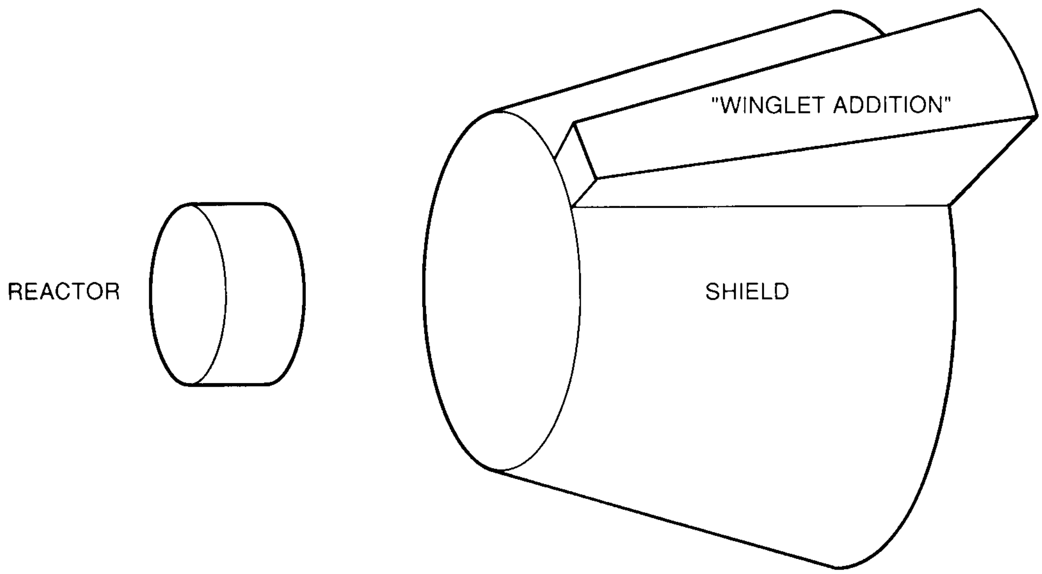

Figure 5. - Conical shield geometry with "Winglet" addition.

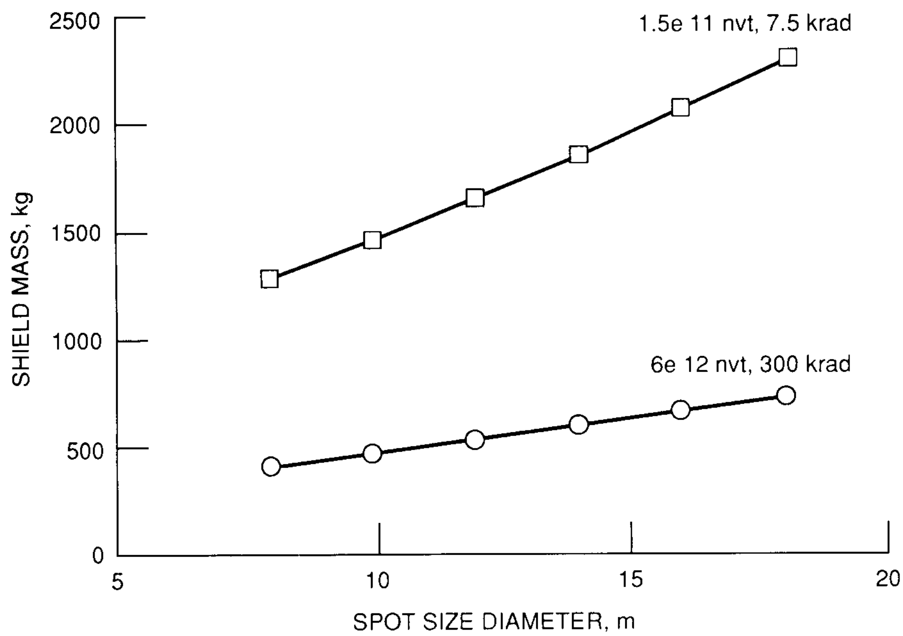

Figure 6. - Effect of shielded spot size diameter on shield mass, 20 m payload separation distance.

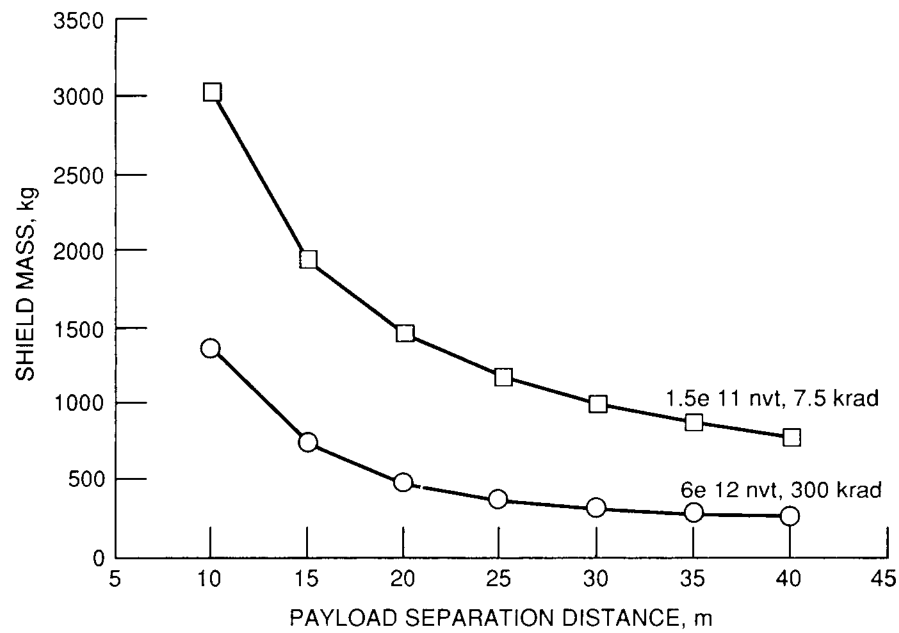

Figure 7. - Effect of payload separation distance on shield mass for a 10 m shielded spot size.

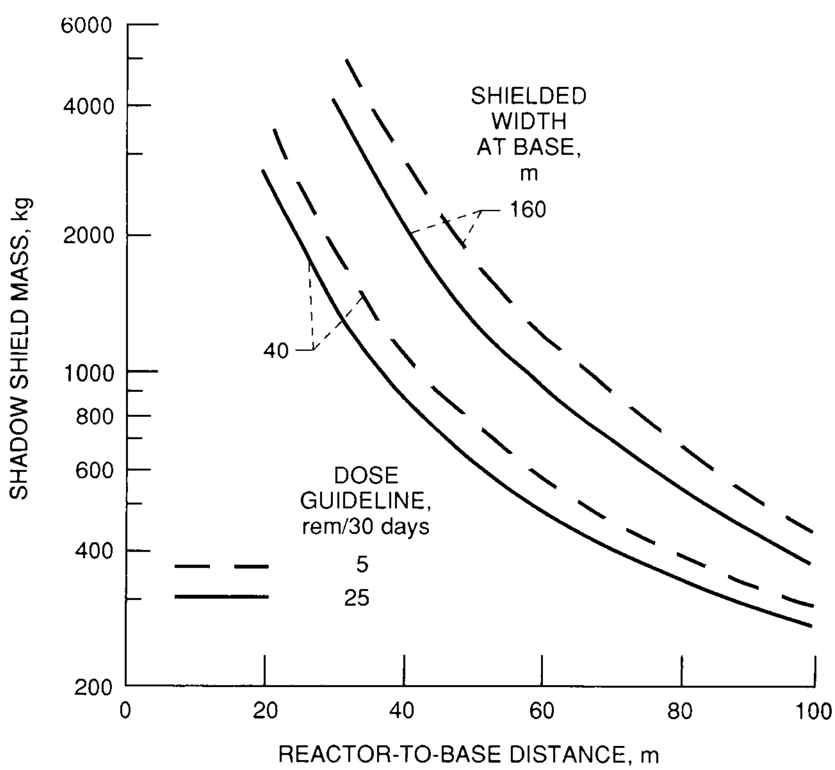

Figure 8. - Nuclear reactor surface power shadow shield, reactor thermal power, 500 kWt; base height, 5 m.

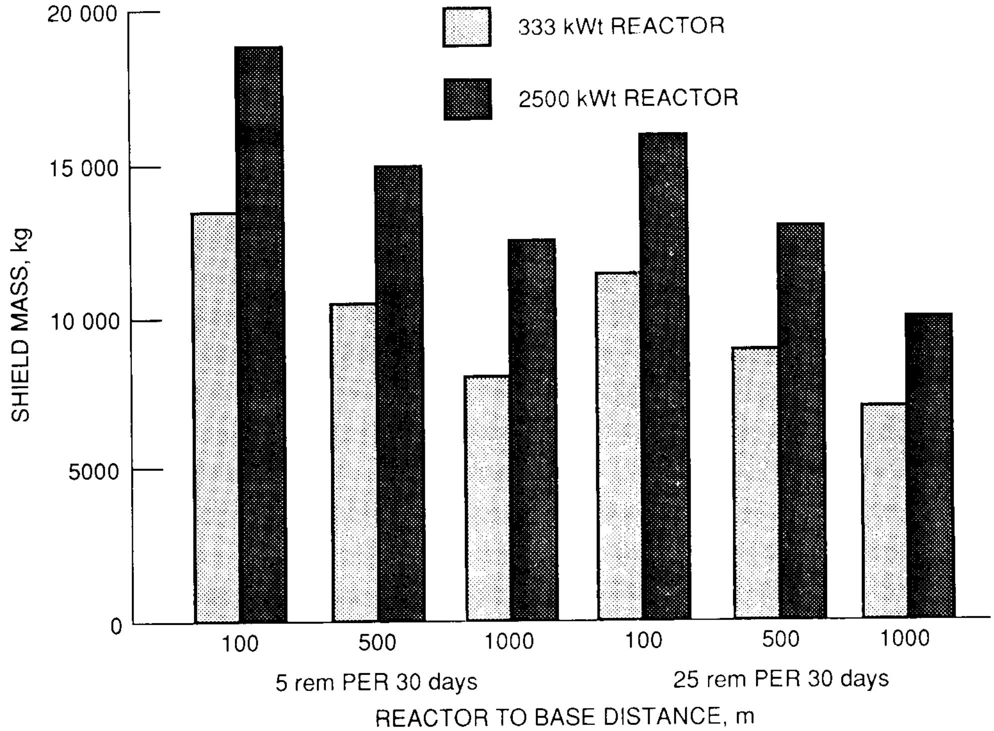

Figure 9. - Nuclear reactor surface power 360° shield mass.

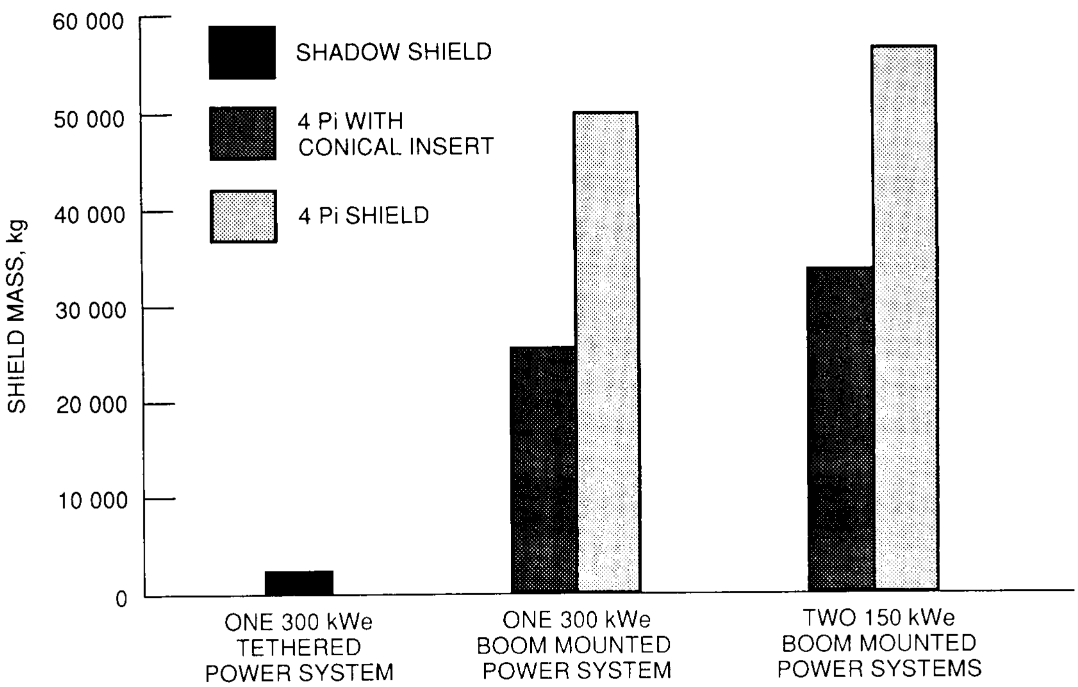

Figure 10. - Shield mass for growth space station.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102064		

4. Title and Subtitle	5. Report Date
Space Nuclear Reactor Shields for Manned and Unmanned Applications	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Barbara I. McKissock and Harvey S. Bloomfield	E-4821
	10. Work Unit No.
	586-01-11
9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the International Conference on Space Power sponsored by the International Astronautical Federation, Cleveland, Ohio, June 5-7, 1989.

16. Abstract

Missions which use nuclear reactor power systems require radiation shielding of payload and/or crew areas to predetermined dose rates. Since shielding can become a significant fraction of the total mass of the system, it is of interest to show the effect of various parameters on shield thickness and mass for manned and unmanned applications. Algorithms were developed to give the thicknesses needed if reactor thermal power, separation distances, and dose rates are given as input. The thickness algorithms were combined with models for four different shield geometries to allow tradeoff studies of shield volume and mass for a variety of manned and unmanned missions. Shield design tradeoffs presented in this study include the effects of: higher allowable dose rates; radiation hardened electronics; shorter crew exposure times; shield geometry; distance of the payload and/or crew from the reactor; and changes in the size of the shielded area. Specific NASA missions that were considered in this study include unmanned outer planetary exploration, manned advanced/evolutionary space station, and advanced manned lunar base.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Shielding Nuclear power systems	Unclassified – Unlimited Subject Category 20

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	16	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161