SHIELD DESIGN FOR SNAP REACTORS*

V. Keshishian†
Atomics International
A Division of North American Aviation, Inc.
Canoga Park, California

ABSTRACT

A survey has been made of reactor shield requirements in a satellite with nuclear auxiliary power. The payloads range from rugged equipment through radiation sensitive electronic gear. A number of system layouts from compact to greatly extended, have been analyzed. Dependent upon reactor power, system layout, and degree of payload protection required, the shield weight requirements are found to extend from zero to several thousand pounds.

The radiation originating from a space nuclear auxiliary power system of the SNAP type may be reduced to acceptable payload protection limits by proper vehicle, component, and shielding arrangement. Studies have shown that, depending on this arrangement, shield weights can vary from zero to a few thousand pounds. Since few details of the vehicle or its mission are known at the present time, it is only possible to point out the high degree of interdependence between the shield and the vehicle, and to show how widely the shield can vary, depending on the arrangement.

There are three main approaches which may be taken in the design of the shield:

1) Place all shielding around the reactor.
2) Place all shielding around the payload.
3) Use a split shield, i.e., use part of shield around the reactor and part around the payload.

---

*Presented at the Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. Work done under AEC Contract: AT(11-1)-GEN-8

†Compact Power Systems Department

Since the SNAP series of reactors are very small in size, it is advantageous to place all of the shield around the reactor in order to achieve a minimum system weight.

It was assumed in this study that the reactor would be in a satellite in orbit, and that the reactor and the remainder of the system would be in operation continuously for one year. This required determination of the dose tolerances of system components most sensitive to radiation. A compilation of available data on radiation damage thresholds of electronic components showed that transistors are the most sensitive to radiation damage. This survey lead to the selection of 10^{12} fast neutrons/cm^2 and 10^7 roentgens of gamma radiation as reasonable lifetime exposures. It is quite possible that these values may be conservative as thresholds of radiation damage, however, it is possible that noise generation rather than damage may be the limiting consideration. Since little information on this subject is available, it is believed that the above thresholds for radiation damage for transistors are realistic values. Thus the reactor shield was designed so that transistors would have a useful life of one full year.

In order to show the effect of vehicle layout on shield weight, a variety of cases were considered. While shield weight may not be the most urgent problem confronting the system at the present time, the ultimate feasibility, of at least some missions, may depend on it. At this time, a reactor and its associated components cannot be regarded as an incidental part of a reactor containing satellite, but must be regarded as one of its central features. The design of the entire vehicle must be influenced and, perhaps, dominated by both the accomplishment of the mission and the presence of the reactor. It appears necessary, therefore, to maintain an open mind on vehicle configurations.

In all the shielding calculations that were performed for the various configurations, the same assumptions were used and are given below:

1) The reactor, including the reflector, is cylindrical in shape, D = H = 15.5 inches.
2) The reactor is in operation at full power (250 kw thermal) for a period of one year.
3) The core composition is similar to a typical SNAP reactor.
4) The dose rates at the payload were set at the most pessimistic levels which appear consistent with transistor operation:
    a. 3×10^4 fast neutrons/cm^2-sec.
    b. 10^3 roentgens/hr for gamma radiation.

(These dose rates correspond to 10^{12} fast neutrons/cm^2 and 10^7 roentgens for gamma radiation for a period of one year continuous operation.)

5) The shield is made of lithium hydride, and in weight computations it is assumed to have a density of 0.90 gm/cm^3.
6) In the calculation of the neutrons scattered from the radiator, it is assumed that the aluminum radiator has an effective thickness of 28 mils.
7) In the calculations it is assumed that the direct dose and the scattered doses are equal.
8) The radiator has an area of approximately 400 ft^2.

In all the configurations, the gamma ray dose at the payload integrated over a period of one year is less than 10^7 roentgens. Thus, all the shield designs were based on the fast neutron contribution. It should be noted that at very high altitudes, the air density is extremely low and as a result, the air scattering contribution is negligible.

Figures 1 to 9 illustrate the various configurations with the resulting shield weights.

Figure 1

The reactor is located between the payload and the last stage booster, and all the shield is placed in front of the payload. The shield weight is calculated to be 11,000 pounds. In the remainder of this discussion the shields are around reactor and shield weights are much less than 11,000 pounds.

Figure 2

The reactor is again located between the payload, which is in the nose of the missile, and last stage booster. The total shield weight is 3720 pounds instead of 11,000 pounds, as in the arrangement of Figure 1. The shield for the neutrons scattering off the radiator weighs 2840 pounds, whereas the direct shield weighs only 880 pounds. Calculations indicate that ratio of the radiator scattered to unscattered (or direct) neutron flux at the payload is approximately 0.72%. This value corresponds to an aluminum radiator thickness of 28 mils. Actually, the radiator is only 14 mils thick, however, the radiator steel pipes that contain the mercury vapor, represent an effective additional 14 mils of aluminum for neutron scattering calculations.

The most important item in this figure is the large amount of shield that is required for the radiator-scattered neutrons.

Figure 3

This arrangement is very similar to Figure 2, except that the radiator is placed below the reactor. Note that the direct shield weight is not changed, whereas the scattering shield is 1463 pounds instead of the 2840 pounds in Figure 2. A disadvantage of this design is that the outer skin between the payload and the radiator must be ejected when the system is in orbit to prevent additional neutron scatter. Also, the structure that holds the payload must be in the solid angle of the direct shield, and this becomes a difficult structural problem.

Figure 4

The radiator folds outward to one side in four quadrants, which further reduces shield weight. However, due to the required folding action, reliability is decreased and it results in a difficult structural design.

Figure 5

Reactor and radiator are extended backwards 100 feet after orbit is achieved and shield weight is further reduced to 636 pounds. However, the extending mechanism weight has not been included and system reliability is decreased

Figure 6

A single fin radiator is used in this design. The total shield weight is 552 pounds. The cylindrical skin around reactor and radiator must be ejected, when the system is in orbit. In addition, structural reinforcement is necessary to prevent oscillation or flexure and the consequent increase in scattered neutron flux at the payload.

Figure 7

This design is similar to the previous design, except that it has a 3 fin radiator. The same problems exist in this design, however it is stronger structurally.

Figure 8

In this design the reactor and shield are moved back about 9 feet after achieving orbit. The direct shield weight decreases to only 465 pounds, however, the radiator scattering shield weight increases to 587 pounds due to the cylindrical radiator. It can be seen that if the radiator were positioned along the dotted lines, the total shield weight could be reduced to that of the direct shield only. However, the last stage booster would have to be ejected, and an additional cylindrical skin would have to be placed around the new radiator section during launch. On the other hand, if the reactor is placed above the payload as shown in Figure 9, these problems would be overcome.

Figure 9
In this design the reactor is placed in the nose cone with the shield located directly below it. Note that no radiator scattering shield is necessary and that the total shield weight is only 450 pounds. The radiator is in the form of a frustum of a cone having the required area of 400 ft^2. This arrangement is very attractive due to its structural simplicity and lack of scattering surface which leads to its high weight efficiency.

It should be realized that the shielding weights given in the 9 arrangements are only approximate, and that they are used only for design comparison purposes. If the last design is used for SNAP 2 and SNAP 8, the total shield weight would be approximately 300 and 450 pounds respectively.

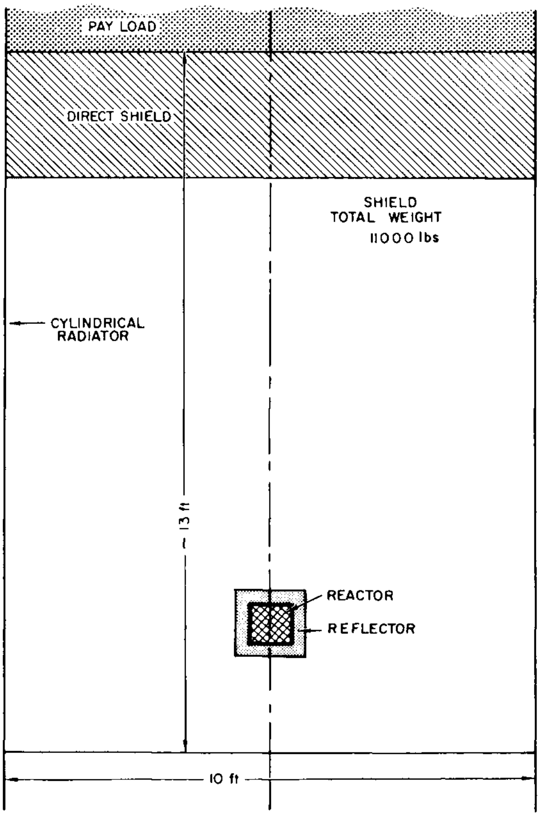

Fig. 1.

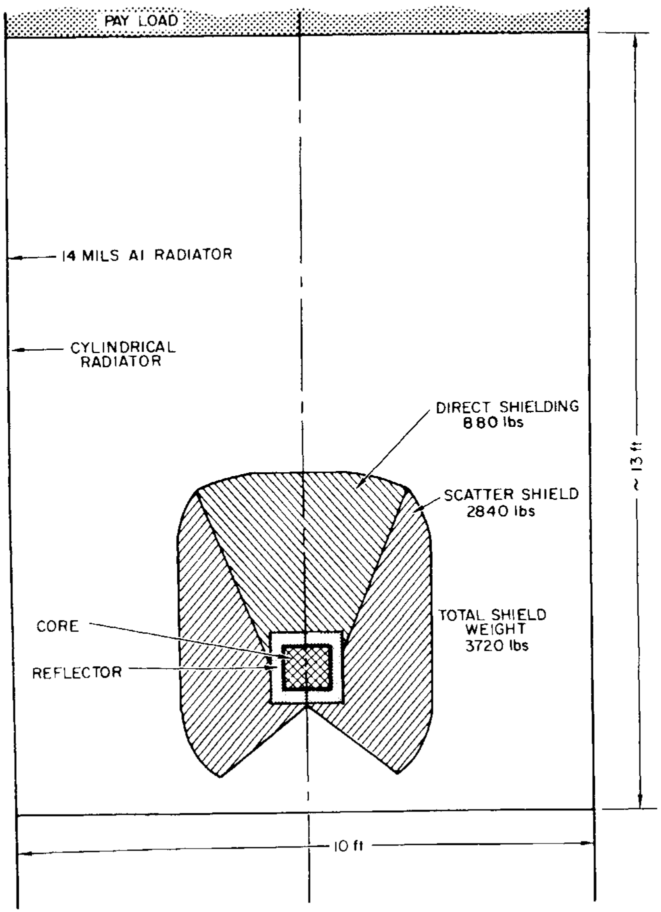
PAY LOAD
14 MILS Al RADIATOR
CYLINDRICAL RADIATOR
DIRECT SHIELDING 880 lbs
SCATTER SHIELD 2840 lbs
TOTAL SHIELD WEIGHT 3720 lbs
CORE
REFLECTOR
~ 13 ft
10 ft

Fig. 2.

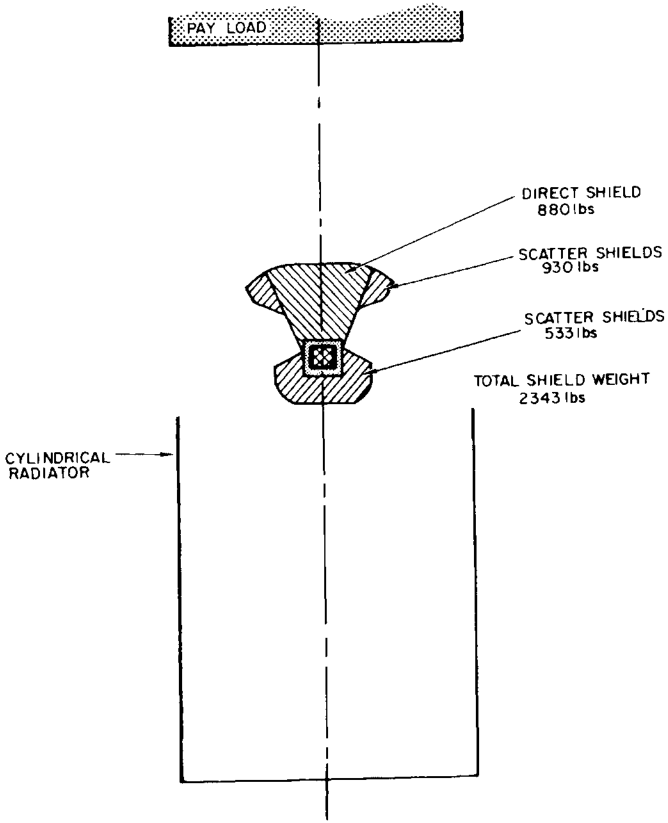
PAY LOAD
DIRECT SHIELD 880 lbs
SCATTER SHIELDS 930 lbs
SCATTER SHIELDS 533 lbs
TOTAL SHIELD WEIGHT 2343 lbs
CYLINDRICAL RADIATOR

Fig. 3.

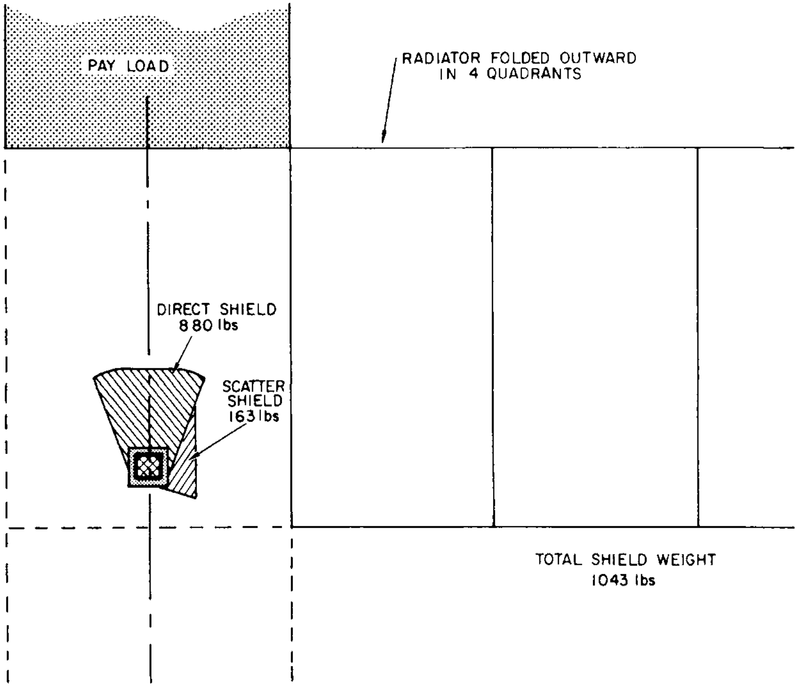
PAY LOAD
RADIATOR FOLDED OUTWARD IN 4 QUADRANTS
DIRECT SHIELD 880 lbs
SCATTER SHIELD 163 lbs
TOTAL SHIELD WEIGHT 1043 lbs

Fig. 4.

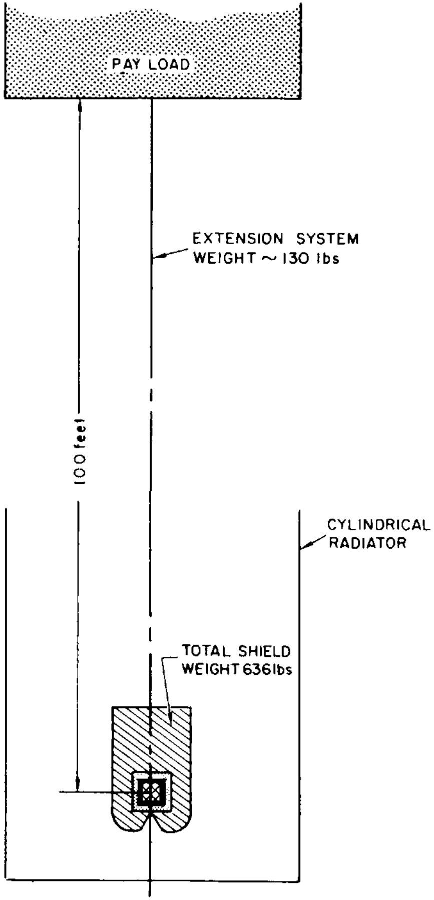
PAY LOAD
EXTENSION SYSTEM WEIGHT ~ 130 lbs
100 feet
CYLINDRICAL RADIATOR
TOTAL SHIELD WEIGHT 636 lbs

Fig. 5.

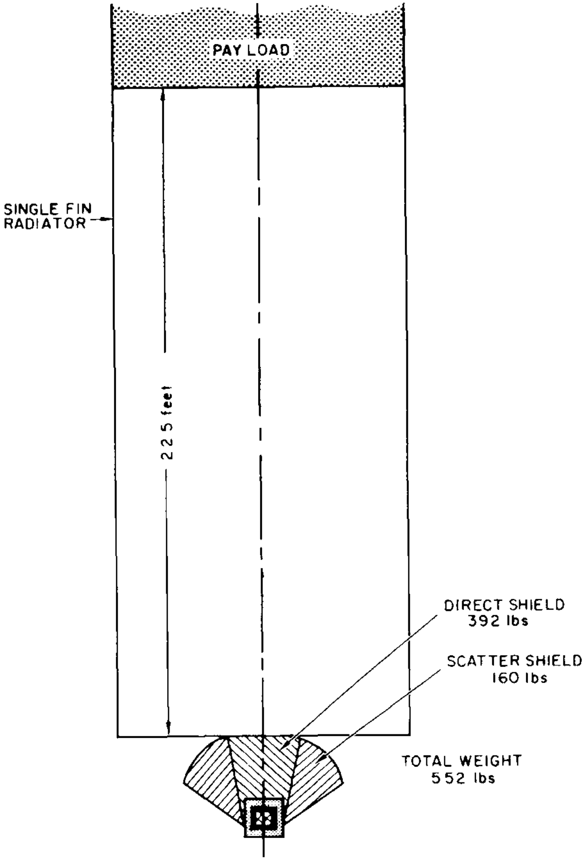
PAY LOAD
SINGLE FIN RADIATOR
225 feet
DIRECT SHIELD 392 lbs
SCATTER SHIELD 160 lbs
TOTAL WEIGHT 552 lbs

Fig. 6.

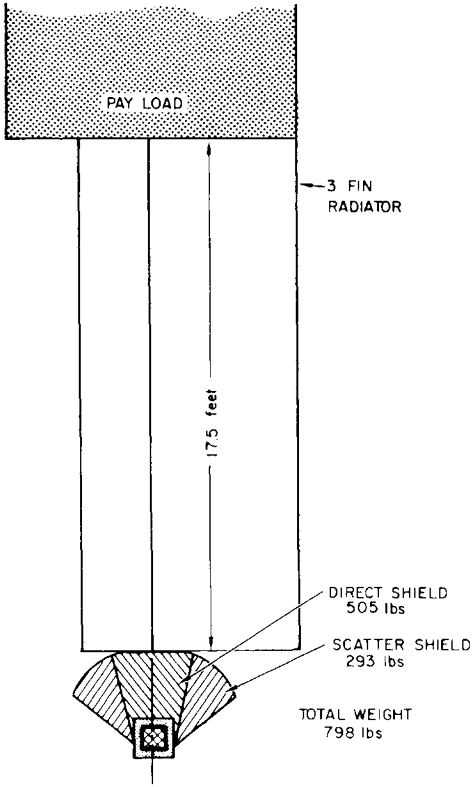
PAY LOAD
3 FIN RADIATOR
17.5 feet
DIRECT SHIELD 505 lbs
SCATTER SHIELD 293 lbs
TOTAL WEIGHT 798 lbs

Fig. 7.

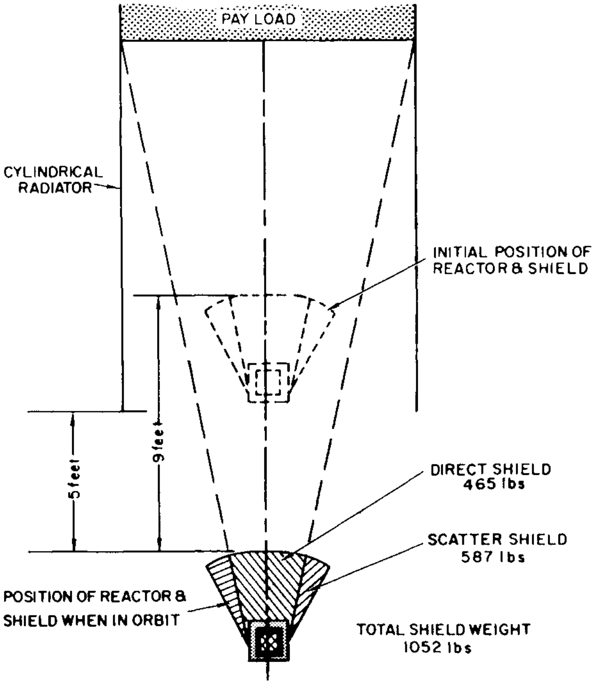
PAY LOAD
CYLINDRICAL RADIATOR
INITIAL POSITION OF REACTOR & SHIELD
5 feet
9 feet
DIRECT SHIELD 465 lbs
SCATTER SHIELD 587 lbs
POSITION OF REACTOR & SHIELD WHEN IN ORBIT
TOTAL SHIELD WEIGHT 1052 lbs

Fig. 8.

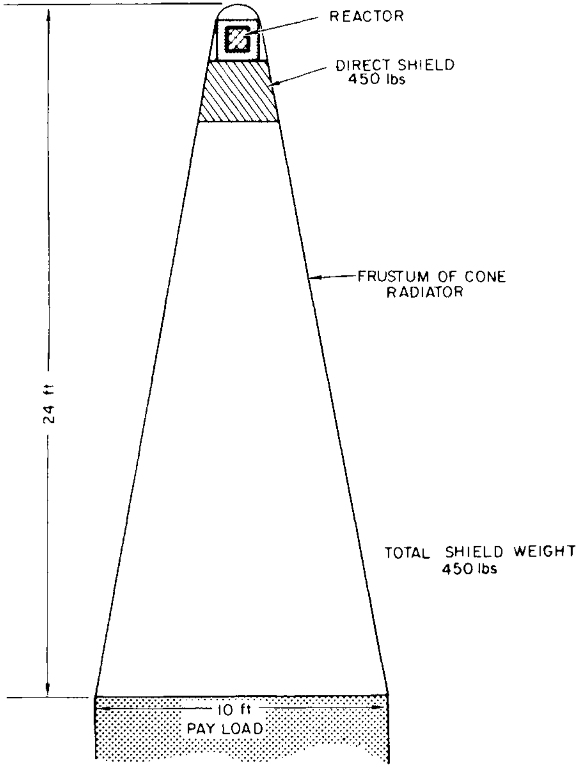
REACTOR
DIRECT SHIELD 450 lbs
FRUSTUM OF CONE RADIATOR
24 ft
TOTAL SHIELD WEIGHT 450 lbs
10 ft
PAY LOAD

Fig. 9.