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Plutonia Aerodynamic Disk (PAD) Summary Report

by

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ABSTRACT

Work on the Plutonia Aerodynamic Disk (PAD) fuel capsule concept began at the Los Alamos Scientific Laboratory the summer of 1971. This work was performed in cooperation with NASA's Ames Research Center and the NUS Corporation. Our objective is to develop a modular heat source for radioisotope thermoelectric generators (RTGs), with primary consideration for nuclear safety.

Analytical effort has been directed to areas such as generator integration, launch abort, reentry, and postimpact. Experimental efforts have included air drop, hypersonic wind tunnel, and impact testing. Progress was also made in vent development, clad compatibility, and fuel processing. Results are summarized in this report, particularly because the results identify basic fuel capsule characteristics that are desirable from a safety standpoint. Recommendations for future efforts are also included.

I. INTRODUCTION

This report outlines the status of the Plutonia Aerodynamic Disk (PAD) development work as of October 1, 1973. Burns et al.¹ published a detailed safety feasibility study of a PAD design sized specifically for use in the Multi-Hundred Watt (MHW) Radioisotope Thermoelectric Generator (RTG). The material covered in Ref. 1 is summarized here as is other more generalized material that has resulted from the PAD development effort.

The PAD concept is more a general approach to fuel capsule design than it is to a specific set of dimensions or hardware configuration. This general approach is described in Sec. II. In Secs. III and IV we summarize the status of various analytical and experimental investigations of the general PAD design approach. Section V covers the efforts that remain to be completed.

II. THE GENERAL PAD CONCEPT

The PAD fuel capsule evolves from a consideration of the various accident environments that may result in release of nuclear fuel from the capsule. Numerous configurations were considered during the PAD study. At its present state of development, the preferred PAD configuration is as shown in Fig. 1.

Plutonium was considered in all areas of the PAD study. In some instances, curium was also considered. The fuel pellets were studied in both cylindrical and spherical shapes, but in all cases the pellets were small (~15 W). Figure 1 shows 15-W spherical plutonium fuel pellets. Presently, the spherical pellet seems to be the best choice based on superior impact survivability.

Each fuel pellet is encapsulated in a single 0.020-in.-thick vented metal clad. Various noble metals

Fig. 1.
PAD reference design.

and noble metal alloys were considered. The Oak Ridge National Laboratory (ORNL) Pt/Rh/W alloy appears to be acceptable. Iridium should also be acceptable, but not required, and its low-temperature impact characteristics have not been determined. In many cases Pt/25 Ir was considered, mainly because of its availability at the Los Alamos Scientific Laboratory (LASL) for experimental uses. All of these materials and other noble metals and noble metal alloys have essentially the same densities and thermal characteristics allowing them to be considered interchangeably in most PAD analytical studies. Although the ORNL Pt/Rh/W alloy now seems to be the best candidate, the ultimate material selection for the clad must await demonstration of compatibility with the other materials in the system and final definition of generator operating temperature requirements. The clad vent is fabricated from a combination of clad material screen and powder, as described in Sec. IV.D.

Figure 1 shows 16 fuel pellets (240 W). PAD studies have covered fuel capsule inventories from 45 to 300 W. An optimum inventory has not been found, but it appears that the inventory can be varied as desired to best integrate the fuel capsule with the generator or, possibly, to improve the postimpact recovery situation.

The encapsulated fuel pellets in Fig. 1 are embedded directly into the graphite reentry heat shield. In many of the PAD analytical studies, the fuel pellets were embedded into a single large strength member. However, subsequent impact tests indicated that this strength member was unnecessary. The use of a strength member also adds another material to the compatibility test matrix and another gap to the heat source, thus raising its operating

temperature gradient. The strength member also increased the PAD's weight, impact velocity, and reentry heating rate.

Many different graphites were considered for the reentry heat shield, including molded graphites such as POCO and ATJ, two-dimensional composites such as Carbitex, and three-dimensional composites such as Avco's MOD 3. All appear to be acceptable, with MOD 3 the best. Tests indicate that the two-dimensional composite considerably increases the survivable impact velocity over the use of molded graphites. Therefore, the preferred material for the reentry shield of Fig. 1 is a composite graphite.

We cannot be more specific about the PAD configuration as to dimensions, weights, etc., without integrating the heat source to a specific generator. However, the PAD can be described as having certain additional characteristics as follows.

Low Ballistic Coefficient—A low ballistic coefficient ($W/C_D A$) results in many desirable features. First, reentry heating depends directly on the ballistic coefficient. Thus, a low ballistic coefficient generally will lead to lower capsule component temperatures during reentry. A low ballistic coefficient is not the only way to assure reentry survival, but the other available methods have undesirable side effects. For example, a fuel capsule with large thermal capacitance can absorb high heating rates without excessive component temperatures. However, such systems have high terminal velocities making impact survival more difficult, and they are plagued by thermal stress problems. Another method involves the use of insulation that will cause high surface temperatures on the capsule during reentry. The high surface temperatures in turn result in high energy losses by either reradiation or ablation. However, in most systems this method results in high steady-state component temperatures that intensify long-term materials problems that are quite sensitive to temperature. PAD can benefit from the use of additional reentry insulation when the reentry heat flow path is different from the steady-state heat flow path, but additional insulation for reentry protection will probably not be required if the ballistic coefficient is low.

The second important result of low ballistic coefficient is low terminal velocity. Appendix G of Ref. 1 shows the dependency of terminal velocity on ballistic coefficient. Tests indicate that bare, single pellet capsules survive intact at impact velocities of ~ 150 ft/sec or less on steel targets. The use of an energy absorbing material around the fuel may also assure impact survival; however, at this time this technology is without sufficient analytical or experimental basis to permit accurate trade-off against other system requirements. Presently, it appears that the

low impact velocity that results from a low ballistic coefficient is the best way to assure impact survival.

PAD designs having ballistic coefficients between 2 and 10 lb/ft² appear to be sufficiently low to attain the above desirable results. Values between 10 and 20 lb/ft² are marginal.

Limited Fuel Dimensions—The source of numerous fuel problems can be traced to the fuel dimensions. For instance, the rates of undesirable chemical reactions increase with temperature. In turn, the maximum fuel temperature is dependent on the *square* of the fuel dimensions. Further, fuel fabricators found that fuel cracking can be minimized and dimensional stability and production yield improved by reducing fuel dimensions.

Although analysts will disagree on postimpact thermal modeling, they agree that reducing the number of watts of fuel per unit area of container will result in a lower postimpact temperature. This can be accomplished by a change in configuration (i.e., sphere to cylinder) or a reduction in dimensions. The wattage contained in a sphere is proportional to the diameter cubed (volume), whereas the surface area of the sphere is proportional to its diameter to the second power. Thus, the surface flux (watts per unit area) of the capsule can be reduced by decreasing the sphere's diameter. Thus, a PAD will have relatively small fuel dimensions with a surface area as large as possible.

Regardless of the capsule designer's efforts to protect the fuel, it is possible to postulate a set of circumstances that will breach the fuel container. If all fuel capsule concepts are compared on the basis that a breach has occurred, the container with the least amount of fuel will be superior, assuming all other things (i.e., probabilities) are equal.

This advantage is particularly apparent when the launch pad abort environment is considered. Here, both the size and the velocity of potential blast fragments are uncertain and critical for a single container fuel capsule. If the fuel is divided into many containers, the exact characteristics of the fragments become less important because one can rely on the low probability of the fragments impacting more than a few of the containers.

Also, for a solid propellant fire, standard practice is to investigate analytically and experimentally the capsule's response to the credible worst case situation where few if any capsules can survive. Again, one can rely on the low probability of more than a few containers in a multiple container system being breached in this worst case environment.

Postreentry recovery is also critical to the consideration of a multiple container PAD system. Here there is no standard model that can be used to compare various

systems. The area of possible impact that must be searched following an orbital decay reentry of any system is usually extremely large. The area of actual impact of a multiple container fuel capsule system is much smaller by orders of magnitude. The area of actual impact of a single container system is the smallest. From this perspective the larger actual impact area of a PAD system is an advantage permitting rapid concentration of the search force because its footprint should be easier to find. The only time the larger PAD impact area could be a disadvantage is when the circumstances of the reentry are such as to permit accurate prediction of the impact of a single container system in an area smaller than the PAD footprint. Another possible disadvantage might exist if all PADs do not release from the generator at approximately the same time during reentry. The RTG design must provide against this event.

Another PAD disadvantage may exist if a large single container system could be designed to assure impact survival. Here the large inventory of the single container system may make it much easier to detect. No analysis has been done in this area. However, this could only be considered a disadvantage if the large single container system had the same probability of impact survival as the PAD.

In addition to the system's operational and safety advantages to be realized by using fuel in small modular packages, developmental and safety qualification testing is facilitated. If the modules are small enough to permit safe handling in the laboratory or available test facilities, realistic tests, close to the actual environments, can be conducted with live fuel instead of simulants. Thus, full-scale compatibility or impact tests can be conducted readily and real system response defined so that improvements can be directed from a knowledge of actual system performance. This should result in a better design and will promote increased confidence in the necessary safety analysis.

III. ANALYTICAL PAD EFFORT

A. Generator Integration

Considerable analytical effort has been directed toward determining the adaptability of PAD fuel capsules to various generator designs. The basic modular building block has been a 15-W fuel pellet encapsulated in a vented noble metal container 0.02 to 0.03 in. thick. Designs incorporating various quantities of these encapsulated pellets embedded in graphite heat shields (MOD 3 or POCO) with and without strength members were

analyzed. While other areas of PAD experimental effort are determining optimum fuel geometry and the need for a strength member, the analytical effort has progressed in a manner that is felt to be generic to the complete range of possibilities. Thus, if impact testing indicated that spherical fuel geometry is superior to cylindrical fuel geometry, or that a strength member was not required, the conclusions of the analytical effort would not change significantly, although the detailed analysis might change considerably.

Further, the exact specification of the fuel clad material should not significantly change the conclusions within certain limits. The PAD's low impact temperature requires a clad material that is ductile at temperatures slightly above ambient. Most noble metals and their alloys (Pt/Ir, Pt/Rh, Pt/Rh/W) have essentially the same thermal properties and densities making them analytically interchangeable. Therefore, the exact specification of the clad material can await completion of lengthy fuel compatibility testing.

Heat sources have been dimensionally sized for MHW, Pioneer, Transit, and HPG generators. No thermal or dimensional incompatibilities were found, but there were significant safety advantages. For the Pioneer and HPG generators, we found that the PAD safety characteristics could be substantially improved by changing the generator from a 6- to a 10-sided unit. This reduced the PAD's ballistic coefficients for these generators below the marginal value of 10.

In all cases the PAD had both weight and steady-state thermal advantages over other fuel capsule designs. For these studies, a helium management system was not designed, thus its weight could not be included. A typical steady-state thermal distribution is shown in Fig. 2, which was taken from Ref. 1. Figure 2 shows that the temperature gradients in a PAD heat source are relatively low. The basic reasons for this are the small fuel dimensions, low internal capsule heat fluxes, reduced number of gaps, and the small dimensions for materials between the fuel and the thermoelectrics since reentry and impact protection requirements are minimal. Additional reentry and launch pad fire insulation on the flat faces of the PAD would not significantly affect the steady-state temperatures shown in Fig. 2. Also, the loss of helium in the heat source gaps does not affect the distribution as much as in other systems because the number of gaps have been minimized and the heat flux across the gaps is smaller. For the model in Fig. 2, the helium loss in the gaps between the fuel clad and the PAD surface about doubles the temperature gradient. The reduced temperature gradients in a PAD heat source are particularly significant when considering capsule material problems. Here even a few degrees reduction in operating temperatures can be critical.

Fig. 2.
PAD thermal model steady-state temperature.

As a further part of this effort, dimensional and ballistic characteristics were determined for about 500 different PAD heat source configurations using both plutonium and curium. Our initial intent was to determine whether an optimum heat source fuel inventory existed from a safety standpoint. No such optimum was found, but it appears that there is a proportionality between various safety problems and heat source power density.

A basic PAD geometry without strength member was selected to simplify the study. The fuel was in the form of 15-W cylinders of either plutonia or curia. Each fuel cylinder was encapsulated in a 0.02-in.-thick noble metal container. The encapsulated fuel cylinders were embedded in a graphite (1.65 g/cm^3) heat shield.

A computer code was written to determine the characteristics of PADs containing various quantities of fuel from 45 to 300 W in steps of 15 W. For each inventory, the heat shield diameter was varied in steps of 0.200 in. to permit examination of various ballistic coefficients for each fuel loading.

Computer code printouts are included in Appendix A. For each inventory, PAD dimensions and weights are listed together with ballistic coefficients, impact velocity, and power density.

After completing the plutonium study, we plotted the maximum values of these variables against the fuel inventory, as shown in Fig. 3. All variables peak at an inventory of 105-W, indicating that from a safety standpoint, a

Fig. 3.

PAD fuel capsule characteristics vs fuel inventory.

105-W pure plutonium oxide (PPO) PAD is the least desirable. However, the high-power density of the 105-W PAD is the most desirable from a system analysis standpoint, as shown in Fig. 4. Here impact velocity is plotted against heat source power density for all inventories from 45 to 300 W. A similar plot would result if ballistic coefficient (or maximum reentry heat rate) was substituted for impact velocity. Thus it appears that heat source power density rather than total inventory is the significant parameter from the standpoint of impact velocity and maximum reentry heating rate.

Intuitively, it appears that a similar situation exists in regard to a number of other safety problems. For instance, if a fuel capsule's power density is increased by removing a portion of its reentry shield, then its probability of surviving a launch pad fire, or impact, (and possibly reentry) will be reduced. Also, if shape (i.e., spherical, cylindrical, or flat plate) is used as a parameter, the postimpact temperature will also be found to be proportional to power density.

B. Reentry Analysis

The detailed results of the reentry analysis are reported in Refs. 1 and 2, where a 240-W unit having a strength

Fig. 4.

Impact velocity vs power density for PAD fuel capsule.

member and sized for the MHW generator was considered. During analyses the need for a strength member was uncertain. However, its inclusion made the analysis more conservative because it raises the PAD's ballistic coefficient.

Because reentry experiments are prohibitively expensive, considerable effort was expended in manpower and computer time to generate and exercise mathematical models that would yield believable predictions of the modular disk heat source response to various reentry environments.

The trajectories were calculated in two ways. First, for most of the calculations, the modular disk heat source was assumed to be a single reentry body independent of the spacecraft and generator at an initial altitude of 400,000 ft. Second, to investigate the effects of spacecraft breakup on heat source survivability, a near-vertical entry at 33,400 ft/sec was calculated using the ballistic coefficient of an intact generator as the initial condition. In this calculation, the ballistic coefficient was instantly changed to that of the modular disk heat source at various assumed breakup altitudes. This sudden exposure resulted in an increase in deceleration and a sudden onset of aerodynamic heating. This calculation showed little sensitivity of response to breakup altitude, but it did yield the maximum thermal stress condition.

The ablation of the graphite heat shield was investigated for many trajectories, including single and multipass

entries. The calculations used the ablation equations of Metzger et al.³ in the reaction limited regime, of Scala and Gilbert⁴ in the diffusion limited regime, and of Scala and Gilbert⁵ in the sublimation regime. The ablation was found to be significant only in two cases. For the entry at -88° and 33,400 ft/sec, the ablation during the subsonic and hypersonic portions of the flight was 0.033 and 0.010 in., respectively, for a total of 0.043 in. The range of entry angles that results in multiple passes through the earth's atmosphere was investigated. We found that only 0.100 in. of graphite would be ablated from the original 0.175 in. of material for the worst multipass entry condition. The maximum component temperature trajectory ($V = 35,700$ ft/sec, $\gamma = -25^\circ$) yielded peak component temperatures that were below their melting points. This included the Pt/Ir fuel clad. Additional reentry insulation reduces these temperatures considerably without paying steady-state penalties. Calculations for steep angle reentries ($V = 33,400$ ft/sec, $\gamma = -88^\circ$) and low-altitude generator breakup, where thermal stress is most severe, showed that peak stress was 39% of the ultimate strength for a POCO heat shield. For a MOD 3 heat shield, peak stress was 23% of ultimate strength. Impact testing shows that carbon composites are superior to molded graphites for impact protection. However, the low PAD terminal velocities do not require graphite for impact protection. Thus, either type of graphite is acceptable provided excessive fuel capsule power density with resulting high-impact velocities is not required to adequately integrate the PAD with the generator.

We concluded from the reentry studies that the PAD concept is generally confirmed. Choice of heat shield material is not critical. If the application is such as to allow the steady-state heat flow to be radial and thus normal to the direction of reentry heat flow (which is the case for PAD heat sources in current RTGs), component temperatures on reentry can be reduced further while maintaining the advantage of low operating temperature gradients.

C. Launch Abort

The only analysis in this area is reported in Ref. 1. Essential conclusions are that the PAD capsule would survive a Pioneer fireball and liquid residual fire with good margin and would probably survive a Pioneer solid propellant fire, but not a double proximity MHW solid propellant fire.

The fire analysis presents numerous modeling difficulties associated with the boundary definition. Thus, we cannot make firm statements about the PAD's response to

this environment, but it appears highly probable that the PAD would not survive the so-called double proximity fire without some additional protection. As mentioned above, one must rely on the low probability of breaching a large quantity of PAD fuel in the extreme environment of a double proximity fire. Also, the improvements that might be available from using additional "reentry" insulation have not been fully explored.

D. Postimpact Analysis

Here again a standard thermal analysis model does not exist. Reference 1 reports the results of a very conservative analysis on a 240-W PAD with a molybdenum strength member. The reported temperature was 400°C . Removing the strength member will increase the temperature of the individual clad fuel pellets, but not beyond the oxidation capabilities of the noble metal clad.

Postimpact temperatures are quite sensitive to variations in environments caused by surrounding objects, winds, and degree of capsule burial. The lack of a standard boundary makes it impossible to compare different fuel capsule designs based on absolute temperatures. However, a good guide is the total capsule inventory divided by the surface area of the capsule (surface heat flux). If all capsules were in the same environment, their temperatures would differ almost exactly as the surface heat flux differed. The figures for a number of capsules are given in Table I.

Based on the surface heat flux comparison, the PAD 15-W sphere would have a surface temperature about half that of the MHW sphere. Experimental observations of MHW spheres show a surface temperature of $\sim 600^\circ\text{C}$, depending on conditions. Thus an approximate surface temperature of 200 to 300°C is projected for a 15-W spherical pellet.

TABLE I
SURFACE FLUX OF FUEL CAPSULES

Fuel Capsule	Surface Flux (W/in. ²)	Comments
Pioneer	17.8	Heat shield removed
Transit	20.2	Heat shield removed
MHW	14.8	No graphite
PAD (Ref. 1)	3.9	Heat shield removed
PAD 15-W cylinder	5.8	No graphite
PAD 15-W sphere	7.6	No graphite

IV. EXPERIMENTAL PAD EFFORT

A. Air Drop Tests

Ten models of a PAD heat source module were released from an aircraft and observed by radar. The initial launch attitude, spin rate, and mass of the models were varied. Significant mode of flight and terminal velocity differences were observed among models of different mass and different launch attitudes. Surprisingly, the models launched edge down and spinning had a lower terminal velocity than models of the same size and mass launched at other attitudes. The mean drag coefficient and lift-to-drag ratio were found to be 1.18 and 0.285, respectively. The total sea-level velocity of the models was found to be well correlated as a function of mass per unit frontal area. The demonstrated terminal velocity of the modular disk heat source, about 88 ft/sec for the Ref. 1 design, is only about 33% of that of existing heat source designs. Other test details can be found in Ref. 6.

B. Hypersonic Wind Tunnel Testing

Before the aerodynamic advantages of the disk module design can be realized, two events must occur after the disk pack is separated from its container: the disks must separate from one another, and each must assume a stable, flat-face-forward attitude. To determine whether both events will occur, the separation conditions were simulated in the Ames Hypervelocity Free-Flight Aerodynamic facility. In this facility, models are fired from a light gas gun into a long chamber held at a controlled pressure. A careful study of sequential photographs taken at different stations in the long chamber revealed that the disks quickly separate and fly as if they had been released as single bodies. These same photographs also show that the disks soon seek a stable, flat-faced-forward attitude in hypersonic flight.

C. Impact Testing

Developmental impact testing is now in progress with 15-W UO_2 fuel simulant pellets (90-95% theoretical density). Both the cylinders and the spheres are being tested with and without graphite protection. All pellets have had 0.020-in. Pt/Ir containers. Drawings of the test components are included in Appendix B.

Testing has been done with both an air gun and explosively driven steel plates. The air gun permits good high-speed camera coverage of the impact. Gases from the

explosion tend to blur camera coverage. However, the explosive technique has no significant size limitation, permits "soft" recovery, and offers the potential for instrumenting the stationary models.

Because of the high cost of using the MOD-3 graphite, Carbitex was substituted. The impact models contain only one clad fuel pellet. When graphite was used, its dimensions were 0.6 in. thick radially and 0.14 in. thick axially. Tests with multiple fuel pellets will be conducted later. The testing was done at room temperature, which is on the conservative side of the expected impact temperature. Initial tests used a steel target with "as-rolled" hardness. Later, a hardened steel target was used.

For each cylinder test in the air gun, it was intended that the model impact "edge-on." However, the models usually turned slightly before impact so that the model's center of gravity and corner were approximately aligned with the velocity vector at impact. Most of these "corner" impacts were directly on the weld, but in no case did the weld break.

Table II is a summary of the tests run to date. Survival in the table is defined as impact without any breach of the clad.

The impacts were recorded on high-speed film. To establish the timing for the film, preliminary shots were fired using an inexpensive molded graphite. These preliminary tests indicated that the graphite absorbed negligible energy during the impact. However, the tests using Carbitex gave the opposite indication. To illustrate this, the clad in the sixth test had much less permanent deformation than the clad in the first test. The energy of the model in the first test was about one-fifth of the model energy in the sixth test.

The cylindrical clad failures in tests 4 and 5 appeared to be the result of excessive strain in the axial direction. The clad geometry had little internal resistance to axial deformation of the clad wall as compared with circumferential deformation. This indicates that a cylinder with a larger length-to-diameter ratio or even a sphere would probably have higher impact resistance. Tests 11 through 14 confirmed this indication.

All spherical models thus far have had defective welds. Test models 11 and 12 had large openings in the weld before testing. However, if it is assumed that a satisfactory weld can be developed, these test results can be useful. For instance, the breach in the weld of test 14 was only a hairline crack in the weld. However, there was sufficient clad deformation to indicate that even if the weld were sound, the clad was near the threshold of failure in other areas. The clad in test 13 had no perceptible permanent deformation after impact, indicating that a sphere with composite graphite protection probably has a much higher velocity capability.

TABLE II
PAD IMPACT TESTS (15-W PELLETS)

<u>Test No.</u>	<u>Velocity (ft/sec)</u>	<u>Shape</u>	<u>Target</u>	<u>Graphite</u>	<u>Test Equipment</u>	<u>Survival?</u>
1	78	Cylinder	Cold rolled steel	None	Air gun	Yes
2	108	Cylinder	Cold rolled steel	None	Air gun	Yes
3	155	Cylinder	Cold rolled steel	None	Air gun	Yes
4	219	Cylinder	Hardened steel	None	Air gun	No
5	172	Cylinder	Hardened steel	None	Air gun	No
6	172	Cylinder	Hardened steel	Carbitex 1 ^a	Air gun	Yes
7	230	Cylinder	Hardened steel	Carbitex 1 ^a	Air gun	No
8	230	Cylinder	Hardened steel	Carbitex 1 ^a	Air gun	Yes
9	155	Cylinder	Hardened steel	None	Air gun	No
10	230	Cylinder	Hardened steel	Carbitex 2 ^b	Air gun	Yes
11	205	Sphere	Hardened steel	None	Explosive	No ^c
12	155	Sphere	Hardened steel	None	Explosive	No ^c
13	205	Sphere	Hardened steel	Carbitex 2 ^b	Explosive	Yes
14	220	Sphere	Hardened steel	None	Air gun	No ^c

^aLaminations parallel to velocity vector.

^bLaminations perpendicular to velocity vector.

^cModels had defective clad welds. Clad breaches, if any, occurred in weld area well away from the impact zone.

Based on these tests, it appears that the 15-W PAD fuel pellet will have a very high probability of impact survival without a strength member at the expected impact velocities (≤ 100 ft/sec). Additional planned effort in this area is described in Sec. V.

D. Vent Development

Development work has started on a new vent concept that combines clad screen and powder. LASL has fabricated numerous "frit" type vents for plutonium glovebox lines and shipping containers. Some of these vents were made with layers of screen and others by standard powder metallurgy techniques. In the first case, layers of screen are pressed together at high temperatures to produce diffusion bond joints between adjacent layers of screen. The vents were made with steel, copper, and noble metals. The screen vents have higher mechanical strengths, whereas the powder vents result in smaller particle retention. A plain screen vent for fuel capsule applications would require a screen with extremely small openings and would be prohibitively expensive, if obtainable.

For the PAD application, a screen with a more-or-less standard (~ 100) mesh and spheroidized powder will be tested. The diameters of the powder particles will be about the size of the openings in the screen (~ 0.003 in.). A particle of powder will be positioned in each screen opening of each layer of screen before the pressure/temperature bonding of the layers. The finished vents will then be diffusion bonded into openings in the fuel clads.

The fabrication feasibility of the combined screen and powder vent has been demonstrated. Actual vents were fabricated using copper, which included both the screen to powder bonds and the vent to clad bonds. Commercial sources for noble metal screen and spheroidized powder have been found. Also, a helium test loop was constructed around a Granville-Phillips automatic pressure controller. This loop will determine the flow rate-pressure drop characteristics of test vents. The test vents will be made from copper until the proper combination of screen and powder sizes has been determined.

The flow specification for these vents has been set assuming a 15-W PPO fuel helium release at between 6×10^{-7} and 6×10^{-4} standard cm^3/sec , with a minimum pressure drop of 0.1 atm.

E. Clad Compatibility

Because thermodynamic data pertaining to intermetallic compounds of plutonium and precious metals are not available, we cannot predict whether or not a system consisting of graphite, platinum-25 iridium, and plutonia is compatible at the projected operating temperatures.

Experimental testing of the system graphite-iridium-plutonia in support of the MHW program indicates that iridium metal is an acceptable container material for plutonia at 1450°C. However, reaction of platinum and platinum-rhodium alloys with plutonia has been observed in reducing atmospheres at 1000°C (see Ref. 7).

We examined two test assemblies consisting of an unvented, two-compartment capsule of platinum-25 iridium containing a pellet of stoichiometric plutonia and a pellet of graphite separated by a partition with a 0.003-in.-diam. hole, heated at 1150°C. No reaction between the test components was observed after 985 h. These results should not be considered conclusive because the capsule was not vented to vacuum and reactions may have been limited by attainment of equilibrium gas-phase compositions in the very small free volume in the assembly. Additional testing is required as described in Sec. V.

F. Fuel Pellet Production

Eight fabrications of cylindrical plutonium PAD pellets were completed. Each fabrication involved a simultaneous pressing of eight pellets. Although all pellet dimensions are ~0.90-in. diam by 0.34 in. thick, varying die designs were used to form some of the specimens with the desired chamfers.

These developmental fabrications explored differences in pre- and postpressing thermal equilibrations by microstructural and chemical characterization of the product. Dimensional variations among the simultaneously fabricated pellets were acceptably low, averaging ± 0.004 in. Typical immersion densities of 85-90% were attained.

Some cracking was observed in these prototype pellets, particularly in those with asymmetric chamfers. Further studies are in progress to eliminate this effect. It may be necessary to vary the length-to-diameter ratio to ensure higher production yields.

One simultaneous pressing of four 15-W spherical pellets was also completed. Although some of the pellets had surface cracks after heat treatment at 1600°C, initial indications are that these pellets have satisfactory properties.

G. Platinum-Iridium Fabrications

In support of the impact testing, experience was gained in the fabrication and welding of both Pt/Ir cylindrical and spherical clads (0.02 in. thick). Drawings for these parts are included in Appendix B.

The cylindrical configuration consists of a cup and a flat lid, whereas the spherical configuration consists of two hemishells. All parts were formed from fully annealed sheet material. Some thinning (0.002 to 0.003 in.) was noted in both the walls of the cups and near the poles of the hemishells. The weld joints were machined after forming. The material appears to machine similar to tool steel.

About 20 cylindrical assemblies were TIG welded. After a few test welds, the proper set of weld parameters was found, resulting in full weld penetration without damage to the UO₂ simulant fuel pellets. The drawings in Appendix B show a 0.032 by 45° chamfer at both ends of the UO₂ fuel cylinders. The chamfer had to be increased to 0.06 by 45° adjacent to the weld to assure that the UO₂ pellet did not crack during welding. This weld was quite successful in that it has never failed during 10 impact tests, although most of the tests impacted directly on the weld.

The weld development of the spherical system is incomplete. A completely satisfactory weld has yet to be made after five attempts. The difficulties were attributed to the difference in material thicknesses between the male and female hemishells. New male shells are being fabricated with simple step joints in an effort to eliminate the welding problems.

V. ADDITIONAL PAD EFFORT

The following outlines additional PAD effort required to complete the generalized PAD development. The completion of the following, together with work done to date, should yield a sufficient data base so that we can proceed with the design and development of a PAD fuel capsule for a specific generator. Items such as the generator operating temperature and the required fuel capsule power density will greatly influence any specific fuel capsule design. Until such items are specified, only a limited amount of additional effort will be profitable.

A. Capsule Materials

More fuel compatibility testing is needed. Present data suggest that noble metals or their alloys will probably be

compatible if appropriate temperatures are used. However, temperature ranges of usefulness need to be defined for each potential alloy, unexpected reactions sought, and long-term tests done to verify the chemical and metallurgical stability of proposed configurations.

Experiments currently in progress or being planned that will contribute additional information include:

(1) An assembly consisting of a vented, full-sized Pt-25 Ir PAD fuel module contained in a graphite capsule is being exposed in vacuum at 1150°C.

(2) A limited number of small capsule, compatibility tests are being assembled to compare the compatibility characteristics of plutonia with commercially pure platinum, platinum-25 iridium, and platinum-30 rhodium-8 tungsten. This series of tests is designed to be conducted in a sealed capsule of molybdenum with a zirconium getter to provide an atmosphere of low oxygen partial pressure. Initially, an assembly of each alloy will be heated at 1000°C for about 1 month. Pending these exposure results, a duplicate assembly will either be given a longer term exposure at the same temperature or another temperature will be selected.

B. Weld Development

Additional effort will be required to develop a satisfactory weld joint and, hopefully, to prevent cracking of the fuel during the welding of a spherical clad. This will require the fabrication of additional noble metal clads for test welds and, possibly, the evaluation of an internal weld shield. The success with the cylindrical weld also suggests the possibility of fabricating and encapsulating hemispheres, or fabricating the fuel sphere with a cylindrical section adjacent to the weld so that there will be additional clearance in this area. These approaches to preventing fuel cracking may also be investigated. Weld parameters for other candidate clad materials such as Pt/Rh should also be determined. Completion of this effort is a prerequisite to completing the impact testing effort.

C. Vent Development

Vents are being fabricated from copper to determine the mesh and powder sizes required to obtain the proper flow characteristics. Ultimately, these vents will have to be made from Pt/Ir or other candidate materials. After the flow characteristics have been determined, these vents will be heated above typical operating temperature for

extended periods to check for changes in flow characteristics. Also, tests should be conducted to determine the particle retention capability of the vents. Finally, impact tests of vented clads will be required to assure that the vents do not cause clad breaches at expected impact velocities.

D. Impact Testing

Based on present tests, spherical geometry is probably far superior to cylindrical geometry at impact. However, this conclusion cannot be definite until spherical weld development has been completed, at which time additional impact tests will be conducted.

In addition, impact tests with actual PPO fuel and multiple fuel pellet models are required. PPO fuel will require some changes in testing techniques. Multiple fuel pellet models will determine whether there is any adverse interaction between the pellets at impact.

Impact tests of vented clads and clads with alternate materials will also be required. Also required will be some data on the effect of impact on the clad emissive coating.

E. Fire Test

Analytical work on the solid propellant fire is uncertain. Any safety review will rely heavily on empirical data in this area. This is especially true for a PAD capsule, because any credible worst case will have a significant probability of fuel release. Thus, it is desirable to conduct solid propellant fire tests on PAD models.

These tests will determine the capability of PAD components in the fire environment, that is, how long they can survive or how large a piece of fuel is required to cause a breach in the clad. These data, together with data on solid propellant breakup (such as in Ref. 8), should be sufficient to compute source terms for this environment.

F. Fuel Pellet Development

As with any new fuel configuration, some trial fabrications will be required. These fabrications will be aimed at selecting the proper fabrication parameters (i.e., feed material, die design, etc.) to assure the highest possible production yield and dimensional stability for the PAD pellets. The limited dimensions of the PAD pellets should result in a relatively short development cycle in this area.

REFERENCES

1. J. J. Burns, J. W. Vorreiter, W. C. Pitts, and T. W. Conway, "Plutonium Aerodynamic Disc (PAD) Safety Feasibility Study," AEC-Space Nuclear Systems Division report SNS-975 (November 1972).
2. J. W. Vorreiter, J. J. Burns, W. C. Pitts, and H. A. Stine, "Atmosphere-Entry Behavior of a Modular, Disk-Shaped Isotope Heat Source," Eighth Intersociety Energy Conversion Engineering Conference, Philadelphia, PA, August 13-17, 1973.
3. J. W. Metzger, M. J. Engel, and N. S. Diaconis, "The Oxidation and Sublimation of Graphite in Simulated Re-Entry Environments," AIAA Thermophysics Specialists Conference, Monterey, CA, September 13, 1965, Paper 65-643.
4. S. M. Scala and L. M. Gilbert, "Aerothermochemical Behavior of Graphite at Elevated Temperatures," General Electric report R63SD89 (November 1965).
5. S. M. Scala and L. M. Gilbert, "Sublimation of Graphite at Hypersonic Speeds," AIAA Journal, 3, No. 9, 1635-1644 (1965).
6. J. W. Vorreiter and D. L. Tate, "Observations of Disk-Shaped Bodies in Free Flight at Terminal Velocity," NASA report TMX-62, 262 (March 1973).
7. J. E. Selle, J. R. McDougal, and D. R. Schaefer, "The Compatibility of Plutonium-238 Dioxide with Platinum and Platinum-Rhodium Alloys Interim Report," Mound Laboratory report MLM 1684 (January 1970).
8. R. Coffey and T. W. Conway, "A Model of the Solid Propellant Fragments From a Launch Abort of a Titan III C Launch Vehicle," NUS Corporation report NUS-TM-S-148 (November 1972).

APPENDIX A

PAD FUEL CAPSULE DESIGN SYNTHESIS

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

45 WATTS:

3 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 3.745

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .2440#
CLAD WEIGHT = .1157#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(lb)/POUND
		EDGE	FACE	WEIGHT				
3.745	.704	.75	.154	.407	.767	5.57	90.7	58.621
3.945	.697	.85	.151	.453	.812	5.32	88.6	55.351
4.145	.690	.95	.147	.500	.860	5.10	86.7	52.201
4.345	.685	1.05	.145	.550	.910	4.91	85.1	49.429
4.545	.680	1.15	.142	.602	.962	4.74	83.6	46.755
4.745	.675	1.25	.140	.657	1.016	4.59	82.3	44.256
4.945	.671	1.35	.138	.713	1.073	4.47	81.2	41.923
5.145	.668	1.45	.136	.772	1.132	4.35	80.1	39.743
5.345	.665	1.55	.135	.833	1.193	4.25	79.2	37.707
5.545	.662	1.65	.133	.897	1.256	4.16	78.3	35.804
5.745	.659	1.75	.132	.962	1.322	4.08	77.6	34.025
5.945	.657	1.85	.131	1.030	1.390	4.00	76.9	32.361
6.145	.655	1.95	.130	1.101	1.460	3.94	76.2	30.824
6.345	.653	2.05	.129	1.173	1.533	3.87	75.6	29.366
6.545	.651	2.15	.128	1.248	1.608	3.82	75.1	27.980
6.745	.649	2.25	.127	1.325	1.685	3.77	74.6	26.699
6.945	.647	2.35	.126	1.405	1.764	3.72	74.1	25.497
7.145	.646	2.45	.125	1.486	1.846	3.68	73.7	24.368
7.345	.645	2.55	.125	1.570	1.930	3.64	73.3	23.307
7.545	.643	2.65	.124	1.657	2.017	3.60	72.9	22.309

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

60 WATTS:

4 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 4.030

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .3253#
CLAD WEIGHT = .1542#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(lb)/POUND
		EDGE	FACE	WEIGHT				
4.030	.714	.75	.159	.471	.950	5.96	93.8	63.100
4.230	.707	.85	.156	.520	.999	5.68	91.6	60.013
4.430	.700	.95	.152	.571	1.050	5.45	89.7	57.093
4.630	.695	1.05	.150	.624	1.104	5.24	87.9	54.333
4.830	.689	1.15	.147	.680	1.159	5.06	86.4	51.720
5.030	.685	1.25	.145	.738	1.217	4.90	85.0	49.271
5.230	.680	1.35	.142	.798	1.277	4.75	83.7	46.953
5.430	.676	1.45	.140	.860	1.340	4.62	82.6	44.769
5.630	.673	1.55	.139	.925	1.404	4.51	81.6	42.709
5.830	.670	1.65	.137	.992	1.471	4.40	80.6	40.765
6.030	.667	1.75	.136	1.061	1.540	4.31	79.8	38.938
6.230	.664	1.85	.134	1.132	1.612	4.23	79.0	37.212
6.430	.661	1.95	.133	1.206	1.686	4.15	78.2	35.585
6.630	.659	2.05	.132	1.282	1.762	4.08	77.6	34.050
6.830	.657	2.15	.131	1.360	1.840	4.01	77.0	32.601
7.030	.655	2.25	.130	1.441	1.920	3.95	76.4	31.234
7.230	.653	2.35	.129	1.524	2.003	3.90	75.9	29.942
7.430	.652	2.45	.128	1.609	2.089	3.85	75.4	28.721
7.630	.650	2.55	.127	1.696	2.176	3.80	74.9	27.567
7.830	.649	2.65	.127	1.786	2.266	3.76	74.5	26.475
8.030	.647	2.75	.126	1.878	2.358	3.72	74.1	25.442
8.230	.646	2.85	.125	1.973	2.452	3.68	73.7	24.463
8.430	.645	2.95	.125	2.069	2.549	3.65	73.4	23.535
8.630	.644	3.05	.124	2.168	2.649	3.62	73.1	22.656
8.830	.643	3.15	.124	2.269	2.749	3.59	72.8	21.822

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

75 WATTS:

3 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 4.346

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .40679

CLAD WEIGHT = .19288

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE		WEIGHT	TOTAL PAD WEIGHT	BAL COEF	IMPACT V	VELOCITY	WATT(Th)/POUND
		EDGE	FACE						
4.346	.720	.75	.162	.546	1.546	6.18	95.5		65.414
4.546	.713	.85	.159	.599	1.599	5.91	93.3		61.535
4.746	.706	.95	.155	.654	1.754	5.67	91.4		59.792
4.946	.701	1.05	.153	.712	1.911	5.46	89.7		57.183
5.146	.695	1.15	.150	.771	1.971	5.27	88.2		54.704
5.346	.690	1.25	.147	.833	1.872	5.10	86.8		52.348
5.546	.686	1.35	.145	.897	1.496	4.95	85.5		50.112
5.746	.682	1.45	.143	.963	1.362	4.82	84.3		47.989
5.946	.678	1.55	.141	1.031	1.631	4.69	83.2		45.778
6.146	.675	1.65	.140	1.102	1.701	4.58	82.2		44.066
6.346	.672	1.75	.138	1.175	1.774	4.48	81.3		42.254
6.546	.669	1.85	.137	1.250	1.850	4.39	80.5		40.536
6.746	.667	1.95	.136	1.328	1.927	4.31	79.7		38.906
6.946	.664	2.05	.134	1.407	2.007	4.23	79.0		37.359
7.146	.662	2.15	.133	1.490	2.089	4.16	78.4		35.892
7.346	.660	2.25	.132	1.574	2.173	4.10	77.8		34.499
7.546	.658	2.35	.131	1.661	2.260	4.04	77.2		33.177
7.746	.656	2.45	.130	1.749	2.349	3.98	76.7		31.921
7.946	.654	2.55	.129	1.841	2.440	3.93	76.2		30.728
8.146	.653	2.65	.129	1.934	2.534	3.88	75.7		29.595
8.346	.651	2.75	.128	2.030	2.630	3.84	75.3		28.517
8.546	.650	2.85	.127	2.128	2.728	3.80	74.9		27.491
8.746	.649	2.95	.127	2.228	2.828	3.76	74.5		26.515
8.946	.648	3.05	.126	2.331	2.931	3.73	74.2		25.586
9.146	.646	3.15	.125	2.436	3.036	3.69	73.8		24.702

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

90 WATTS:

6 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 4.675

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .48809

CLAD WEIGHT = .23149

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE		WEIGHT	TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE					
4.675	.723	.75	.164	.632	1.351	6.29	96.4	66.596
4.875	.716	.85	.160	.688	1.408	6.03	94.3	63.902
5.075	.710	.95	.157	.747	1.467	5.80	92.5	61.333
5.275	.704	1.05	.154	.809	1.528	5.59	90.8	58.878
5.475	.699	1.15	.152	.872	1.591	5.40	89.3	56.532
5.675	.694	1.25	.149	.938	1.657	5.24	87.9	54.293
5.875	.690	1.35	.147	1.006	1.725	5.09	86.6	52.157
6.075	.686	1.45	.145	1.076	1.795	4.95	85.5	50.120
6.275	.682	1.55	.143	1.148	1.868	4.83	84.4	48.178
6.475	.679	1.65	.142	1.223	1.942	4.71	83.4	46.326
6.675	.676	1.75	.140	1.300	2.019	4.61	82.5	44.562
6.875	.673	1.85	.139	1.379	2.098	4.52	81.7	42.881
7.075	.670	1.95	.137	1.460	2.180	4.43	80.9	41.280
7.275	.668	2.05	.136	1.544	2.263	4.35	80.1	39.753
7.475	.666	2.15	.135	1.630	2.349	4.28	79.5	38.295
7.675	.663	2.25	.134	1.718	2.433	4.21	78.8	36.912
7.875	.661	2.35	.133	1.809	2.520	4.15	78.2	35.591
8.075	.660	2.45	.132	1.902	2.621	4.09	77.7	34.330
8.275	.658	2.55	.131	1.997	2.716	4.04	77.2	33.128
8.475	.656	2.65	.130	2.094	2.814	3.99	76.7	31.982
8.675	.655	2.75	.130	2.194	2.917	3.94	76.2	30.888
8.875	.653	2.85	.129	2.296	3.015	3.90	75.8	29.843
9.075	.652	2.95	.128	2.400	3.120	3.85	75.4	28.846

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

105 WATTS:

7 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 5.010

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .5693#
CLAD WEIGHT = .2699#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
5.010	.725	.75	.165	.825	1.565	6.35	96.0	67.090
5.210	.718	.85	.161	.786	1.625	6.10	94.8	64.561
5.410	.712	.95	.150	.640	1.625	5.77	93.1	62.172
5.610	.707	1.05	.156	.914	1.754	5.67	91.3	59.860
5.810	.702	1.15	.153	.982	1.821	5.49	90.0	57.644
6.010	.697	1.25	.151	1.051	1.891	5.33	88.7	55.520
6.210	.693	1.35	.149	1.123	1.963	5.19	87.4	53.487
6.410	.689	1.45	.147	1.197	2.037	5.03	86.3	51.540
6.610	.685	1.55	.145	1.274	2.113	4.92	85.2	49.677
6.810	.682	1.65	.143	1.352	2.192	4.81	84.3	47.895
7.010	.679	1.75	.142	1.433	2.273	4.71	83.3	46.191
7.210	.676	1.85	.140	1.516	2.356	4.61	82.5	44.560
7.410	.673	1.95	.139	1.602	2.441	4.52	81.7	43.002
7.610	.671	2.05	.138	1.690	2.529	4.44	81.0	41.511
7.810	.668	2.15	.136	1.780	2.619	4.37	80.3	40.085
8.010	.666	2.25	.135	1.872	2.711	4.30	79.7	38.721
8.210	.664	2.35	.134	1.966	2.806	4.24	79.1	37.417
8.410	.662	2.45	.133	2.063	2.902	4.18	78.5	36.170
8.610	.661	2.55	.133	2.162	3.002	4.12	78.0	34.974
8.810	.659	2.65	.132	2.264	3.103	4.07	77.5	33.834
9.010	.657	2.75	.131	2.367	3.207	4.02	77.0	32.740

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

120 WATTS:

8 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 5.340

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .6507#
CLAD WEIGHT = .3085#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
5.340	.725	.75	.165	.827	1.786	6.35	96.0	67.170
5.540	.719	.85	.162	.892	1.851	6.12	95.0	64.817
5.740	.713	.95	.159	.959	1.916	5.91	93.4	62.551
5.940	.708	1.05	.156	1.028	1.987	5.72	91.8	60.372
6.140	.703	1.15	.154	1.099	2.059	5.54	90.4	58.276
6.340	.699	1.25	.152	1.175	2.132	5.38	89.1	56.262
6.540	.695	1.35	.150	1.249	2.208	5.24	87.9	54.328
6.740	.691	1.45	.148	1.327	2.286	5.11	86.8	52.470
6.940	.687	1.55	.146	1.408	2.367	4.99	85.8	50.688
7.140	.684	1.65	.144	1.490	2.450	4.88	84.8	48.977
7.340	.681	1.75	.143	1.575	2.535	4.78	84.0	47.336
7.540	.678	1.85	.141	1.662	2.622	4.68	83.1	45.763
7.740	.675	1.95	.140	1.752	2.711	4.59	82.3	44.253
7.940	.673	2.05	.139	1.844	2.803	4.51	81.6	42.805
8.140	.671	2.15	.138	1.938	2.897	4.44	80.9	41.417
8.340	.668	2.25	.136	2.034	2.993	4.37	80.3	40.085
8.540	.666	2.35	.135	2.132	3.092	4.30	79.7	38.808
8.740	.665	2.45	.135	2.233	3.192	4.24	79.1	37.583
8.940	.663	2.55	.134	2.336	3.296	4.19	78.6	36.407
9.140	.661	2.65	.133	2.442	3.401	4.13	78.1	35.279

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

135 WATTS:

9 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 5.691

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .7320#
CLAD WEIGHT = .3471#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
5.691	.724	.75	.164	.936	2.015	6.33	96.7	66.973
5.891	.719	.85	.162	1.005	2.084	6.11	95.0	64.760
6.091	.713	.95	.159	1.076	2.155	5.91	93.4	62.624
6.291	.708	1.05	.156	1.149	2.228	5.73	92.0	60.564
6.491	.704	1.15	.154	1.225	2.304	5.57	90.6	58.578
6.691	.699	1.25	.152	1.303	2.382	5.42	89.4	56.666
6.891	.696	1.35	.150	1.383	2.462	5.28	88.2	54.825
7.091	.692	1.45	.148	1.465	2.544	5.15	87.2	53.053
7.291	.689	1.55	.147	1.549	2.629	5.03	86.2	51.349
7.491	.685	1.65	.145	1.636	2.715	4.92	85.2	49.709
7.691	.682	1.75	.143	1.725	2.804	4.82	84.4	48.132
7.891	.680	1.85	.142	1.816	2.895	4.73	83.6	46.616
8.091	.677	1.95	.141	1.910	2.989	4.65	82.8	45.158
8.291	.675	2.05	.140	2.006	3.085	4.57	82.1	43.756
8.491	.672	2.15	.138	2.104	3.183	4.49	81.4	42.409
8.691	.670	2.25	.137	2.204	3.283	4.42	80.8	41.113
8.891	.668	2.35	.136	2.306	3.386	4.36	80.2	39.868
9.091	.666	2.45	.135	2.411	3.490	4.30	79.6	38.671

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

150 WATTS:

10 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 6.034

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .8134#

CLAD WEIGHT = .3857#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
6.034	.723	.75	.164	1.053	2.252	6.30	96.4	66.595
6.234	.718	.85	.161	1.126	2.325	6.09	94.8	64.505
6.434	.713	.95	.159	1.201	2.400	5.90	93.1	62.489
6.634	.708	1.05	.156	1.278	2.477	5.73	91.9	60.534
6.834	.704	1.15	.154	1.358	2.557	5.57	90.7	58.650
7.034	.700	1.25	.152	1.440	2.639	5.43	89.5	56.831
7.234	.696	1.35	.150	1.524	2.723	5.30	88.4	55.077
7.434	.693	1.45	.149	1.610	2.809	5.17	87.4	53.386
7.634	.689	1.55	.147	1.699	2.897	5.06	86.4	51.755
7.834	.686	1.65	.145	1.789	2.987	4.96	85.5	50.181
8.034	.683	1.75	.144	1.882	3.082	4.86	84.7	48.668
8.234	.681	1.85	.143	1.978	3.177	4.77	83.9	47.209
8.434	.678	1.95	.142	2.073	3.274	4.68	83.1	45.802
8.634	.676	2.05	.140	2.175	3.374	4.61	82.4	44.448
8.834	.674	2.15	.139	2.277	3.476	4.53	81.8	43.143
9.034	.671	2.25	.138	2.382	3.581	4.46	81.2	41.886

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

165 WATTS:

11 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 6.379

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .8947#

CLAD WEIGHT = .4242#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
6.379	.722	.75	.163	1.177	2.496	6.24	96.0	66.088
6.579	.717	.85	.161	1.254	2.573	6.05	94.5	64.110
6.779	.712	.95	.158	1.333	2.652	5.87	93.1	62.195
6.979	.708	1.05	.156	1.415	2.734	5.71	91.8	60.343
7.179	.704	1.15	.154	1.499	2.818	5.56	90.6	58.551
7.379	.700	1.25	.152	1.584	2.903	5.43	89.5	56.820
7.579	.696	1.35	.150	1.673	2.992	5.30	88.4	55.146
7.779	.693	1.45	.149	1.763	3.082	5.18	87.5	53.529
7.979	.690	1.55	.147	1.855	3.174	5.07	86.5	51.968
8.179	.687	1.65	.146	1.950	3.269	4.97	85.7	50.461
8.379	.684	1.75	.144	2.047	3.366	4.88	84.9	49.008
8.579	.681	1.85	.143	2.147	3.466	4.79	84.1	47.601
8.779	.679	1.95	.142	2.248	3.567	4.71	83.4	46.245
8.979	.677	2.05	.141	2.352	3.671	4.63	82.7	44.937
9.179	.674	2.15	.139	2.458	3.777	4.56	82.1	43.675

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

180 WATTS:

12 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 6.724

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .9760#

CLAD WEIGHT = .4628#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
6.724	.720	.75	.162	1.309	2.748	6.13	95.5	65.495
6.924	.716	.85	.160	1.390	2.822	6.00	94.1	63.618
7.124	.712	.95	.158	1.473	2.902	5.86	92.8	61.799
7.324	.707	1.05	.156	1.559	2.988	5.69	91.6	60.036
7.524	.703	1.15	.154	1.646	3.085	5.55	90.5	58.329
7.724	.700	1.25	.152	1.736	3.175	5.42	89.4	56.677
7.924	.696	1.35	.150	1.829	3.269	5.30	88.4	55.078
8.124	.693	1.45	.149	1.923	3.362	5.18	87.5	53.532
8.324	.690	1.55	.147	2.020	3.459	5.08	86.6	52.036
8.524	.687	1.65	.146	2.119	3.558	4.98	85.7	50.589
8.724	.684	1.75	.144	2.220	3.659	4.89	85.0	49.191
8.924	.682	1.85	.143	2.323	3.762	4.81	84.2	47.839
9.124	.679	1.95	.142	2.429	3.868	4.73	83.5	46.532

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

195 WATTS:

13 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 7.070

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = 1.0574#
CLAD WEIGHT = .5014#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
7.070	.719	.75	.162	1.447	3.006	6.12	95.0	64.852
7.270	.714	.85	.159	1.533	3.091	5.95	93.7	63.066
7.470	.710	.95	.157	1.620	3.179	5.80	92.5	61.334
7.670	.706	1.05	.155	1.710	3.268	5.65	91.3	59.654
7.870	.702	1.15	.153	1.801	3.360	5.52	90.1	58.024
8.070	.699	1.25	.152	1.895	3.454	5.40	89.3	56.445
8.270	.696	1.35	.150	1.992	3.550	5.29	88.3	54.916
8.470	.693	1.45	.149	2.090	3.649	5.18	87.4	53.434
8.670	.690	1.55	.147	2.191	3.750	5.08	86.6	51.999
8.870	.687	1.65	.146	2.294	3.853	4.98	85.8	50.609
9.070	.685	1.75	.145	2.399	3.958	4.90	85.0	49.264

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

210 WATTS:

14 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 7.421

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = 1.1387#
CLAD WEIGHT = .5399#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
7.421	.717	.75	.161	1.596	3.274	6.05	94.5	64.123
7.621	.713	.85	.159	1.685	3.364	5.89	93.3	62.422
7.821	.709	.95	.157	1.776	3.455	5.75	92.1	60.770
8.021	.705	1.05	.155	1.870	3.549	5.61	91.0	59.167
8.221	.702	1.15	.153	1.966	3.645	5.49	90.0	57.610
8.421	.698	1.25	.151	2.064	3.743	5.37	89.0	56.100
8.621	.695	1.35	.150	2.164	3.843	5.26	88.1	54.636
8.821	.692	1.45	.148	2.267	3.946	5.16	87.3	53.215
9.021	.689	1.55	.147	2.372	4.051	5.07	86.5	51.838
9.221	.687	1.65	.146	2.479	4.158	4.98	85.7	50.504
9.421	.684	1.75	.144	2.588	4.267	4.89	85.0	49.211

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

225 WATTS:

15 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 7.765

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = 1.2201#
CLAD WEIGHT = .5785#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
7.765	.715	.75	.160	1.748	3.547	5.99	94.0	63.425
7.965	.711	.85	.158	1.842	3.640	5.84	92.8	61.801
8.165	.707	.95	.156	1.937	3.736	5.70	91.7	60.222
8.365	.704	1.05	.154	2.035	3.833	5.57	90.7	58.687
8.565	.701	1.15	.153	2.135	3.933	5.46	89.7	57.197
8.765	.698	1.25	.151	2.237	4.035	5.35	88.8	55.749
8.965	.695	1.35	.150	2.341	4.140	5.24	87.9	54.344
9.165	.692	1.45	.148	2.448	4.246	5.14	87.1	52.979
9.365	.689	1.55	.147	2.557	4.355	5.05	86.4	51.655
9.565	.687	1.65	.146	2.668	4.466	4.97	85.6	50.370
9.765	.684	1.75	.144	2.781	4.580	4.89	84.9	49.124
9.965	.682	1.85	.143	2.897	4.695	4.81	84.3	47.914

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

240 WATTS:

16 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 8.113

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = 1.3014#

CLAD WEIGHT = .6171#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/FOUND
		EDGE	FACE	WEIGHT				
8.113	.713	.75	.159	1.909	3.828	5.92	93.5	62.688
8.313	.710	.85	.157	2.007	3.925	5.78	92.4	61.134
8.513	.706	.95	.155	2.106	4.025	5.65	91.3	59.623
8.713	.703	1.05	.154	2.203	4.127	5.53	90.4	58.153
8.913	.700	1.15	.152	2.312	4.230	5.42	89.4	56.724
9.113	.697	1.25	.151	2.418	4.337	5.31	88.6	55.335
9.313	.694	1.35	.149	2.527	4.445	5.22	87.7	53.985
9.513	.691	1.45	.148	2.637	4.556	5.12	86.9	52.674
9.713	.689	1.55	.147	2.750	4.669	5.04	86.2	51.400
9.913	.686	1.65	.145	2.865	4.784	4.95	85.5	50.163

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

255 WATTS:

17 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 8.464

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = 1.3827#

CLAD WEIGHT = .6556#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/FOUND
		EDGE	FACE	WEIGHT				
8.464	.711	.75	.158	2.079	4.118	5.85	92.9	61.921
8.664	.708	.85	.156	2.181	4.219	5.72	91.9	60.431
8.864	.705	.95	.155	2.284	4.323	5.60	90.9	58.985
9.064	.701	1.05	.153	2.390	4.428	5.49	90.0	57.575
9.264	.698	1.15	.151	2.498	4.536	5.38	89.1	56.204
9.464	.696	1.25	.150	2.608	4.647	5.28	88.3	54.870
9.664	.693	1.35	.149	2.721	4.759	5.19	87.5	53.573
9.864	.690	1.45	.147	2.836	4.874	5.10	86.7	52.312

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

270 WATTS:

18 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 8.809

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = 1.4641#

CLAD WEIGHT = .6942#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/FOUND
		EDGE	FACE	WEIGHT				
8.809	.710	.75	.157	2.253	4.412	5.79	92.4	61.192
9.009	.706	.85	.155	2.359	4.517	5.66	91.4	59.764
9.209	.703	.95	.154	2.466	4.625	5.55	90.5	58.374
9.409	.700	1.05	.152	2.576	4.735	5.44	89.6	57.020
9.609	.697	1.15	.151	2.688	4.847	5.34	88.8	55.701
9.809	.695	1.25	.150	2.803	4.961	5.25	88.0	54.418

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

285 WATTS:

19 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 9.163

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = 1.5454#

CLAD WEIGHT = .7328#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/FOUND
		EDGE	FACE	WEIGHT				
9.163	.708	.75	.156	2.439	4.717	5.72	91.9	60.410
9.363	.705	.85	.155	2.548	4.827	5.60	90.9	59.039
9.563	.702	.95	.153	2.660	4.938	5.50	90.1	57.704
9.763	.699	1.05	.152	2.774	5.052	5.39	89.2	56.403
9.963	.696	1.15	.150	2.890	5.169	5.30	88.4	55.135

PAD FUEL CAPSULE (WITHOUT STRENGTH MEMBER)

300 WATTS:

20 FUEL CYL @ 15 WATTS

(.90 Dia x .341 Lg)

MIN PAD DIA = 9.506

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = 1.62680

CLAD WEIGHT = .77140

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
9.506	.706	.75	.155	2.626	5.025	5.66	91.4	59.699
9.706	.703	.85	.154	2.740	5.138	5.85	90.5	58.381
9.906	.700	.95	.152	2.856	5.254	5.45	89.7	57.095

PAD FUEL CAPSULE (WITH CURIUM)

75 WATTS:

3 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 3.265

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .07300

CLAD WEIGHT = .06500

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
3.265	.666	.75	.135	.311	.449	4.29	79.5	166.910
3.465	.661	.85	.133	.350	.488	4.14	78.1	153.515
3.665	.657	.95	.131	.392	.530	4.01	77.0	141.498
3.865	.654	1.05	.129	.435	.573	3.91	75.9	130.702
4.065	.651	1.15	.128	.481	.619	3.81	75.0	120.908
4.265	.648	1.25	.126	.530	.668	3.74	74.3	112.231
4.465	.646	1.35	.125	.580	.718	3.67	73.6	104.322
4.665	.643	1.45	.124	.633	.771	3.61	73.0	97.163
4.865	.642	1.55	.123	.687	.827	3.55	72.4	90.671
5.065	.640	1.65	.122	.746	.884	3.51	71.9	84.771
5.265	.639	1.75	.122	.806	.944	3.46	71.5	79.397
5.465	.637	1.85	.121	.868	1.006	3.43	71.1	74.493
5.665	.636	1.95	.120	.933	1.071	3.39	70.8	70.008
5.865	.635	2.05	.120	1.000	1.138	3.36	70.5	65.899
6.065	.634	2.15	.119	1.069	1.207	3.34	70.2	62.126
6.265	.633	2.25	.119	1.140	1.278	3.31	69.9	58.636
6.465	.632	2.35	.118	1.214	1.352	3.29	69.7	55.458
6.665	.632	2.45	.116	1.290	1.428	3.27	69.5	52.506
6.865	.631	2.55	.118	1.368	1.506	3.25	69.3	49.775
7.065	.630	2.65	.117	1.449	1.587	3.23	69.1	47.246
7.265	.630	2.75	.117	1.532	1.670	3.22	68.9	44.899
7.465	.629	2.85	.117	1.617	1.755	3.20	68.8	42.718

PAD FUEL CAPSULE (WITH CURIUM)

90 WATTS:

6 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 3.475

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .08760

CLAD WEIGHT = .07800

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
3.475	.668	.75	.136	.352	.518	4.37	80.3	173.706
3.675	.664	.85	.134	.394	.559	4.22	78.9	160.775
3.875	.660	.95	.132	.438	.603	4.09	77.7	149.071
4.075	.656	1.05	.130	.484	.649	3.98	76.7	138.467
4.275	.653	1.15	.129	.532	.698	3.89	75.8	128.847
4.475	.650	1.25	.127	.583	.749	3.81	75.0	120.109
4.675	.648	1.35	.126	.636	.802	3.73	74.2	112.158
4.875	.646	1.45	.125	.692	.857	3.67	73.6	104.913
5.075	.644	1.55	.124	.749	.915	3.62	73.1	98.300
5.275	.642	1.65	.123	.809	.975	3.57	72.6	92.252
5.475	.641	1.75	.123	.872	1.037	3.52	72.1	86.713
5.675	.639	1.85	.122	.936	1.102	3.48	71.7	81.630
5.875	.638	1.95	.121	1.003	1.169	3.45	71.3	76.958
6.075	.637	2.05	.121	1.073	1.238	3.41	71.0	72.656
6.275	.636	2.15	.120	1.144	1.310	3.38	70.7	68.689
6.475	.635	2.25	.120	1.218	1.384	3.36	70.4	65.024
6.675	.634	2.35	.119	1.294	1.460	3.33	70.1	61.632
6.875	.633	2.45	.119	1.373	1.538	3.31	69.9	58.489
7.075	.632	2.55	.118	1.453	1.619	3.29	69.7	55.571
7.275	.632	2.65	.118	1.537	1.702	3.27	69.5	52.859
7.475	.631	2.75	.118	1.622	1.788	3.25	69.3	50.334
7.675	.630	2.85	.117	1.710	1.875	3.24	69.1	47.980
7.875	.630	2.95	.117	1.800	1.965	3.22	69.0	45.783

PAD FUEL CAPSULE (WITH CURIUM)

105 WATTS:

7 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 3.686

MIN GRAPHITE DIMENS :

EDGE TK = .730"

FACE TK = .100"

FUEL WEIGHT = .1022#

CLAD WEIGHT = .0910#

(.020Thick)

FUEL CYL CLAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
3.688	.670	.75	.137	.397	.590	4.42	80.7	177.871
3.688	.665	.85	.135	.441	.634	4.27	79.4	165.487
4.088	.661	.95	.133	.487	.680	4.14	78.2	154.197
4.288	.658	1.05	.131	.536	.729	4.04	77.2	143.898
4.488	.655	1.15	.130	.587	.780	3.94	76.3	134.493
4.688	.652	1.25	.128	.640	.834	3.86	75.5	125.895
4.888	.650	1.35	.127	.696	.889	3.79	74.8	118.026
5.088	.647	1.45	.126	.754	.947	3.72	74.1	110.813
5.288	.645	1.55	.125	.814	1.007	3.67	73.6	104.192
5.488	.644	1.65	.124	.877	1.070	3.61	73.0	98.107
5.683	.642	1.75	.123	.941	1.135	3.57	72.6	92.505
5.888	.641	1.85	.123	1.008	1.202	3.53	72.2	87.341
6.088	.639	1.95	.122	1.078	1.271	3.49	71.8	82.573
6.288	.638	2.05	.121	1.150	1.343	3.46	71.4	78.164
6.488	.637	2.15	.121	1.224	1.417	3.42	71.1	74.081
6.688	.636	2.25	.120	1.300	1.493	3.40	70.8	70.295
6.888	.635	2.35	.120	1.379	1.572	3.37	70.5	66.779
7.088	.634	2.45	.119	1.460	1.653	3.35	70.3	63.509
7.288	.634	2.55	.119	1.543	1.736	3.33	70.1	60.464
7.488	.633	2.65	.119	1.628	1.822	3.30	69.8	57.624
7.688	.632	2.75	.118	1.716	1.910	3.29	69.7	54.973
7.888	.632	2.85	.118	1.807	2.000	3.27	69.5	52.494
8.088	.631	2.95	.118	1.899	2.092	3.25	69.3	50.173
8.288	.630	3.05	.117	1.994	2.187	3.24	69.1	47.998
8.488	.630	3.15	.117	2.091	2.284	3.22	69.0	45.958
8.688	.629	3.25	.117	2.190	2.384	3.21	68.9	44.041
8.888	.629	3.35	.117	2.292	2.485	3.20	68.7	42.238

PAD FUEL CAPSULE (WITH CURIUM)

120 WATTS:

8 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 3.904

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .1168#

CLAD WEIGHT = .1040#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
3.904	.671	.75	.138	.444	.665	4.44	81.0	180.243
4.104	.666	.85	.135	.491	.712	4.30	79.7	168.427
4.304	.663	.95	.134	.540	.761	4.18	78.6	157.592
4.504	.659	1.05	.132	.591	.812	4.08	77.6	147.651
4.704	.656	1.15	.130	.645	.866	3.98	76.7	138.524
4.904	.653	1.25	.129	.701	.922	3.90	75.9	130.135
5.104	.651	1.35	.128	.759	.980	3.83	75.2	122.417
5.304	.649	1.45	.127	.819	1.040	3.76	74.5	115.309
5.504	.647	1.55	.126	.882	1.103	3.70	73.9	108.754
5.704	.645	1.65	.125	.947	1.168	3.65	73.4	102.701
5.904	.643	1.75	.124	1.014	1.235	3.61	73.0	97.106
6.104	.642	1.85	.123	1.084	1.305	3.56	72.5	91.926
6.304	.641	1.95	.123	1.156	1.377	3.53	72.1	87.125
6.504	.639	2.05	.122	1.230	1.451	3.49	71.8	82.669
6.704	.638	2.15	.121	1.307	1.528	3.46	71.4	78.528
6.904	.637	2.25	.121	1.386	1.606	3.43	71.1	74.675
7.104	.636	2.35	.120	1.467	1.688	3.40	70.9	71.085
7.304	.635	2.45	.120	1.550	1.771	3.38	70.6	67.735
7.504	.635	2.55	.120	1.636	1.857	3.35	70.4	64.607
7.704	.634	2.65	.119	1.724	1.945	3.33	70.1	61.682
7.904	.633	2.75	.119	1.815	2.035	3.31	69.9	58.943
8.104	.633	2.85	.119	1.907	2.128	3.30	69.8	56.376
8.304	.632	2.95	.118	2.002	2.223	3.29	69.6	53.967

PAD FUEL CAPSULE (WITH CURIUM)

135 WATTS:

9 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 4.121
MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .1314#
CLAD WEIGHT = .1170#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
4.121	.671	.75	.138	.495	.744	4.46	81.1	181.368
4.321	.667	.85	.136	.545	.793	4.32	79.9	179.112
4.521	.663	.95	.134	.596	.845	4.21	78.8	159.740
4.721	.660	1.05	.132	.650	.898	4.10	77.8	150.178
4.921	.657	1.15	.131	.706	.955	4.01	76.9	141.357
5.121	.654	1.25	.129	.765	1.013	3.93	76.2	133.213
5.321	.652	1.35	.128	.825	1.074	3.86	75.5	125.688
5.521	.650	1.45	.127	.888	1.137	3.79	74.8	118.728
5.721	.648	1.55	.126	.953	1.202	3.74	74.3	112.283
5.921	.646	1.65	.125	1.021	1.269	3.68	73.7	106.309
6.121	.644	1.75	.124	1.091	1.339	3.64	73.3	100.765
6.321	.643	1.85	.124	1.163	1.411	3.59	72.8	95.615
6.521	.642	1.95	.123	1.237	1.486	3.55	72.4	90.824
6.721	.640	2.05	.122	1.314	1.563	3.52	72.1	86.364
6.921	.639	2.15	.122	1.393	1.642	3.49	71.7	82.205
7.121	.638	2.25	.121	1.475	1.723	3.46	71.4	78.324
7.321	.637	2.35	.121	1.558	1.807	3.43	71.1	74.707
7.521	.636	2.45	.120	1.644	1.893	3.40	70.8	71.306
7.721	.636	2.55	.120	1.733	1.981	3.38	70.6	68.126
7.921	.635	2.65	.120	1.823	2.072	3.36	70.4	65.147
8.121	.634	2.75	.119	1.916	2.165	3.34	70.2	62.351
8.321	.633	2.85	.119	2.011	2.260	3.32	70.0	59.724
8.521	.633	2.95	.119	2.109	2.357	3.30	69.8	57.253

PAD FUEL CAPSULE (WITH CURIUM)

150 WATTS:

10 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 4.340
MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .1460#
CLAD WEIGHT = .1300#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
4.340	.671	.75	.138	.549	.825	4.46	81.1	181.613
4.540	.667	.85	.136	.601	.877	4.33	80.0	170.894
4.740	.664	.95	.134	.655	.931	4.22	78.9	160.976
4.940	.661	1.05	.133	.712	.986	4.12	78.0	151.794
5.140	.658	1.15	.131	.770	1.046	4.03	77.1	143.291
5.340	.655	1.25	.130	.831	1.107	3.95	76.4	135.409
5.540	.653	1.35	.129	.894	1.170	3.88	75.7	128.098
5.740	.651	1.45	.128	.960	1.236	3.82	75.1	121.310
5.940	.649	1.55	.127	1.028	1.304	3.76	74.5	115.003
6.140	.647	1.65	.126	1.098	1.374	3.71	74.0	109.137
6.340	.645	1.75	.125	1.170	1.446	3.66	73.5	103.675
6.540	.644	1.85	.124	1.245	1.521	3.62	73.1	98.584
6.740	.643	1.95	.124	1.322	1.598	3.58	72.7	93.835
6.940	.641	2.05	.123	1.403	1.677	3.54	72.3	89.399
7.140	.640	2.15	.122	1.483	1.759	3.51	72.0	85.252
7.340	.639	2.25	.122	1.567	1.843	3.49	71.7	81.370
7.540	.638	2.35	.121	1.653	1.929	3.45	71.4	77.734
7.740	.637	2.45	.121	1.742	2.019	3.43	71.1	74.324
7.940	.636	2.55	.120	1.833	2.109	3.40	70.9	71.122
8.140	.636	2.65	.120	1.926	2.202	3.38	70.6	68.114
8.340	.635	2.75	.120	2.021	2.297	3.36	70.4	65.284
8.540	.634	2.85	.119	2.119	2.395	3.34	70.2	62.619
8.740	.633	2.95	.119	2.219	2.495	3.32	70.0	60.107
8.940	.633	3.05	.119	2.321	2.597	3.31	69.9	57.738
9.140	.632	3.15	.118	2.426	2.702	3.29	69.7	55.501

PAD FUEL CAPSULE (WITH CURIUM)

180 WATTS:

12 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 4.779

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .1752#

CLAD WEIGHT = .1560#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
4.779	.671	.75	.138	.666	.998	4.45	81.0	180.344
4.979	.667	.85	.136	.723	1.055	4.33	79.9	170.613
5.179	.664	.95	.134	.783	1.114	4.23	79.0	161.548
5.379	.661	1.05	.133	.844	1.175	4.13	78.1	153.100
5.579	.658	1.15	.131	.908	1.239	4.05	77.3	145.224
5.779	.656	1.25	.130	.974	1.305	3.98	76.6	137.876
5.979	.654	1.35	.129	1.042	1.373	3.91	76.0	131.017
6.179	.652	1.45	.128	1.113	1.444	3.85	75.4	124.611
6.379	.650	1.55	.127	1.186	1.517	3.79	74.8	118.622
6.579	.648	1.65	.126	1.261	1.592	3.74	74.3	113.019
6.779	.647	1.75	.126	1.338	1.670	3.70	73.9	107.773
6.979	.645	1.85	.125	1.418	1.749	3.65	73.4	102.857
7.179	.644	1.95	.124	1.500	1.832	3.62	73.1	98.246
7.379	.643	2.05	.124	1.585	1.916	3.58	72.7	93.918
7.579	.641	2.15	.123	1.672	2.003	3.55	72.4	89.852
7.779	.640	2.25	.122	1.761	2.092	3.52	72.0	86.029
7.979	.639	2.35	.122	1.852	2.183	3.49	71.8	82.430
8.179	.638	2.45	.121	1.946	2.277	3.46	71.5	79.041
8.379	.638	2.55	.121	2.042	2.373	3.44	71.2	75.845
8.579	.637	2.65	.121	2.140	2.471	3.42	71.0	72.829
8.779	.636	2.75	.120	2.240	2.572	3.39	70.8	69.982
8.979	.635	2.85	.120	2.343	2.674	3.37	70.6	67.290
9.179	.635	2.95	.120	2.448	2.780	3.36	70.4	64.744
9.379	.634	3.05	.119	2.556	2.887	3.34	70.2	62.344
9.579	.633	3.15	.119	2.666	2.997	3.32	70.0	60.051
9.779	.633	3.25	.119	2.778	3.109	3.31	69.9	57.885
9.979	.632	3.35	.118	2.892	3.223	3.29	69.7	55.831

PAD FUEL CAPSULE (WITH CURIUM)

210 WATTS:

14 FUEL CYL @ 15 WATTS

(.50 Dia x .200 Lg)

MIN PAD DIA = 5.222

MIN GRAPHITE DIMENS :

EDGE TK = .750"

FACE TK = .100"

FUEL WEIGHT = .2044#

CLAD WEIGHT = .1820#

(.020Thick)

FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
5.222	.670	.75	.137	.796	1.182	4.41	80.7	177.571
5.422	.667	.85	.136	.858	1.244	4.31	79.7	168.715
5.622	.664	.95	.134	.922	1.309	4.21	78.9	160.421
5.822	.661	1.05	.133	.989	1.375	4.13	78.1	152.650
6.022	.658	1.15	.131	1.058	1.444	4.05	77.3	145.368
6.222	.656	1.25	.130	1.129	1.515	3.98	76.7	138.539
6.422	.654	1.35	.129	1.202	1.589	3.92	76.1	132.132
6.622	.652	1.45	.128	1.278	1.665	3.86	75.5	126.118
6.822	.650	1.55	.127	1.356	1.743	3.81	75.0	120.469
7.022	.649	1.65	.127	1.437	1.823	3.76	74.5	115.159
7.222	.647	1.75	.126	1.519	1.906	3.72	74.1	110.164
7.422	.646	1.85	.125	1.604	1.991	3.68	73.7	105.463
7.622	.645	1.95	.125	1.692	2.078	3.64	73.3	101.035
7.822	.643	2.05	.124	1.781	2.168	3.60	72.9	96.860
8.022	.642	2.15	.123	1.873	2.259	3.57	72.6	92.922
8.222	.641	2.25	.123	1.967	2.354	3.54	72.3	89.205
8.422	.640	2.35	.122	2.064	2.450	3.51	72.0	85.693
8.622	.639	2.45	.122	2.162	2.549	3.49	71.8	82.372
8.822	.638	2.55	.121	2.264	2.650	3.46	71.5	79.230
9.022	.638	2.65	.121	2.367	2.753	3.44	71.3	76.255
9.222	.637	2.75	.121	2.473	2.859	3.42	71.0	73.436
9.422	.636	2.85	.120	2.581	2.967	3.40	70.8	70.763
9.622	.636	2.95	.120	2.691	3.077	3.38	70.6	68.226
9.822	.635	3.05	.120	2.804	3.190	3.36	70.5	65.818

PAD FUEL CAPSULE (WITH CURIUM)

240 WATTS:

16 FUEL CYL @ 15 WATTS

MIN PAD DIA = 5.663

(.50 Dia x .200 Lg)

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .2336#
CLAD WEIGHT = .2080#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
5.663	.669	.75	.137	.936	1.377	4.37	80.3	174.189
5.863	.666	.85	.135	1.003	1.445	4.28	79.4	166.089
6.063	.673	.95	.134	1.072	1.514	4.19	78.7	158.470
6.263	.680	1.05	.132	1.144	1.586	4.11	77.9	151.302
6.463	.658	1.15	.131	1.218	1.660	4.04	77.3	144.554
6.663	.656	1.25	.130	1.294	1.736	3.98	76.6	138.201
6.863	.654	1.35	.129	1.373	1.815	3.92	76.1	132.215
7.063	.652	1.45	.128	1.454	1.896	3.87	75.5	126.574
7.263	.651	1.55	.128	1.537	1.979	3.82	75.1	121.253
7.463	.649	1.65	.127	1.623	2.064	3.77	74.6	116.232
7.663	.648	1.75	.126	1.711	2.152	3.73	74.2	111.492
7.863	.646	1.85	.125	1.801	2.242	3.69	73.8	107.013
8.063	.645	1.95	.125	1.893	2.335	3.65	73.4	102.779
8.263	.644	2.05	.124	1.988	2.429	3.62	73.1	98.773
8.463	.643	2.15	.124	2.085	2.526	3.59	72.8	94.981
8.663	.642	2.25	.123	2.184	2.626	3.56	72.5	91.390
8.863	.641	2.35	.123	2.286	2.727	3.53	72.2	87.986
9.063	.640	2.45	.122	2.390	2.831	3.51	71.9	84.757
9.263	.639	2.55	.122	2.496	2.937	3.48	71.7	81.693
9.463	.638	2.65	.121	2.604	3.046	3.46	71.5	78.782
9.663	.638	2.75	.121	2.715	3.157	3.44	71.2	76.017
9.863	.637	2.85	.121	2.828	3.270	3.42	71.0	73.387

PAD FUEL CAPSULE (WITH CURIUM)

270 WATTS:

18 FUEL CYL @ 15 WATTS

MIN PAD DIA = 6.106

(.50 Dia x .200 Lg)

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .2628#
CLAD WEIGHT = .2340#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
6.106	.667	.75	.136	1.088	1.585	4.33	79.9	170.325
6.306	.664	.85	.134	1.160	1.657	4.24	79.1	162.892
6.506	.662	.95	.133	1.235	1.732	4.16	78.4	155.875
6.706	.660	1.05	.132	1.312	1.809	4.09	77.7	149.249
6.906	.658	1.15	.131	1.391	1.888	4.03	77.1	142.990
7.106	.656	1.25	.130	1.472	1.969	3.97	76.5	137.076
7.306	.654	1.35	.129	1.556	2.053	3.91	76.0	131.485
7.506	.652	1.45	.128	1.642	2.139	3.86	75.5	126.198
7.706	.651	1.55	.128	1.731	2.227	3.82	75.1	121.192
7.906	.649	1.65	.127	1.821	2.318	3.77	74.6	116.454
8.106	.648	1.75	.126	1.914	2.411	3.73	74.2	111.965
8.306	.647	1.85	.126	2.009	2.506	3.70	73.9	107.711
8.506	.645	1.95	.125	2.107	2.604	3.66	73.5	103.677
8.706	.644	2.05	.124	2.207	2.704	3.63	73.2	99.849
8.906	.643	2.15	.124	2.309	2.806	3.60	72.9	96.215
9.106	.642	2.25	.123	2.413	2.910	3.57	72.6	92.762
9.306	.641	2.35	.123	2.520	3.017	3.54	72.3	89.480
9.506	.640	2.45	.122	2.629	3.126	3.52	72.1	86.359
9.706	.640	2.55	.122	2.741	3.237	3.50	71.8	83.369
9.906	.639	2.65	.122	2.854	3.351	3.47	71.6	80.561

PAD FUEL CAPSULE (WITH CURIUM)

300 WATTS:

20 FUEL CYL @ 15 WATTS

MIN PAD DIA = 6.549

(.50 Dia x .200 Lg)

MIN GRAPHITE DIMENS :
EDGE TK = .750"
FACE TK = .100"
FUEL WEIGHT = .2920#
CLAD WEIGHT = .2690#
(.020Thick)
FUEL CYL CLEAR = .125"

PAD DIA	PAD THICK	GRAPHITE			TOTAL PAD WEIGHT	BAL COEF	IMPACT VELOCITY	WATT(Th)/POUND
		EDGE	FACE	WEIGHT				
6.549	.666	.75	.135	1.252	1.804	4.26	79.5	166.277
6.749	.663	.85	.134	1.329	1.881	4.20	78.8	159.431
6.949	.661	.95	.133	1.409	1.961	4.13	78.1	152.948
7.149	.659	1.05	.132	1.491	2.043	4.07	77.5	146.807
7.349	.657	1.15	.131	1.575	2.127	4.01	76.9	140.989
7.549	.655	1.25	.130	1.662	2.214	3.95	76.4	135.474
7.749	.653	1.35	.129	1.751	2.303	3.90	75.9	130.245
7.949	.652	1.45	.128	1.842	2.394	3.85	75.4	125.284
8.149	.650	1.55	.127	1.936	2.488	3.81	75.0	120.576
8.349	.649	1.65	.127	2.031	2.583	3.77	74.6	116.106
8.549	.648	1.75	.126	2.129	2.681	3.73	74.2	111.859
8.749	.647	1.85	.126	2.230	2.782	3.70	73.9	107.823
8.949	.645	1.95	.125	2.332	2.886	3.66	73.5	103.986
9.149	.644	2.05	.124	2.437	2.993	3.63	73.2	100.334
9.349	.643	2.15	.124	2.545	3.097	3.60	72.9	96.859
9.549	.642	2.25	.123	2.654	3.206	3.58	72.7	93.549
9.749	.642	2.35	.123	2.766	3.318	3.55	72.4	90.395
9.949	.641	2.45	.123	2.880	3.432	3.53	72.2	87.387

APPENDIX B

PAD IMPACT TEST COMPONENT DRAWINGS

1. Material UO_2 - 90-95% TD
 2. Inspect and record diam and length
 3. Record weight to nearest 0.001 g
 4. Radiograph
 5. Bag and tag - serialize P/N CMB5-106-XXX
- SK-CMB5-106

Impact Fuel Simulant Cylinder

1. Material: Pt-25 Ir fully annealed
 2. Make from P/N CMB5-109
 3. Sandblast P/N CMB5-108-XXX
 4. Inspect and record dimensions A, B, C and D and wall thickness and flatness
 5. Record weight to nearest 0.001 g
 6. 32 finish all over
 7. Diameter A circular to within 0.002 TIR
- SK-CMB5-108

Impact Container

1. Material: Pt-25 Ir fully annealed
 2. 32 finish all over
 3. Inspect and record diam and thickness
 4. Record weight to nearest 0.001 g
 5. Sandblast P/N CMB5-107-XXX
- SK-CMB5-107

Lid-Impact Container

1. Material: graphite (to be determined)
 2. Inspect and record thickness
- SK-CMB5-109

Lid-Impact Shell

Section A-A

1. Material: Graphite (to be determined)
2. Inspect and record all wall thickness
SK-CMB5-110

Impact Shell

Inspection report

Weight, wall thickness, and pole height
Sandblast P/N CMB-5-113-A-001, etc.
Sandblast P/N CMB-5-113-B-001, etc.
Material: Pt-25 Ir fully annealed
SK-CMB-5-113

Fuel Impact Sphere Containers