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AN ADVANCED ABSORBER ASSEMBLY DESIGN FOR BREEDER REACTORS

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By

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I. INTRODUCTION

The development of the reference absorber assembly design for the Fast Flux Test Facility (FFTF) was based on a very conservative approach due primarily to incomplete irradiation performance data for boron carbide. To ensure that the goal lifetime of 300 full power days (FPD) could be achieved, the selected absorber assembly design employed small diameter pins with thick-walled cladding and relatively large gas plena to accommodate anticipated helium release quantities.(1) Subsequent developmental testing has assured that the reference assemblies will satisfy all design requirements. Results obtained in this testing, however, also revealed that design options were available to improve in-reactor performance of FFTF absorber assemblies, and also to reduce their fabrication costs.

Slight modifications to the FFTF reference absorber assembly design have been successful in extending the useful lifetime of these components. The revised design, designated Series 2, is capable of a 600 FPD lifetime in FFTF. Nonetheless, these assemblies incorporate most of the basic features of the reference design, and are relatively expensive to fabricate. An advanced design has been developed which promises improved in-reactor performance, longer lifetimes, and substantially reduced fabrication costs. Following proof testing of two prototypes in FFTF, it is intended to replace the entire complement of absorber assemblies in the reactor with this advanced design. The pin design should be adaptable to larger breeder reactor core concepts as well.

II. DESIGN FEATURES

The principal design changes adopted in evolving from the FFTF reference absorber assembly design to the advanced design are depicted in Figure 1. Whereas the reference design is comprised of 61 sealed boron carbide pins arranged in a hexagonal configuration, the advanced design incorporates 19 vented pins arrayed in a circular pattern inside of round duct tubes. Also, in lieu of AISI Type 316 stainless steel reference duct and cladding material, the advanced design makes use of a modified Type 316 stainless steel alloy in the fabrication of these structural components. The design is presented in more detail in Figure 2. The design changes implemented lead to a number of improvements in both performance and economics.

A. Vented Pins

Boron carbide is the accepted reference absorber material for breeder reactor control element applications. Its selection in this capacity was based on its excellent neutronic properties, enrichment capability, adequate resistance to irradiation damage, and commercial availability. One disadvantageous aspect of this material is that helium is generated in substantial quantities from the $^{10}B(n,\alpha)^{7}Li$ reaction during irradiation. Release of helium from the boron carbide to the plena of sealed absorber pins can result in significant gas pressure buildup, and ultimately limit the lifetime of these components. In the design of the FFTF reference absorber assemblies, accommodation of anticipated helium release quantities required the utilization of small diameter pins with thick cladding and large gas plena. Venting of the helium from the absorber pins eliminates gas pressure-limiting concerns and provides design latitude to improve the performance and economics of absorber assemblies.

An apparent advantage of a vented pin concept is that gas pressure is no longer a limiting phenomenon with regard to cladding strain or rupture. This allows cladding thickness to be reduced substantially. The increased volume made available by this modification can be used to increase the pellet-to-clad gap to enhance swelling-limited lifetimes. Increased absorber loadings can also be accommodated to improve reactivity worth.

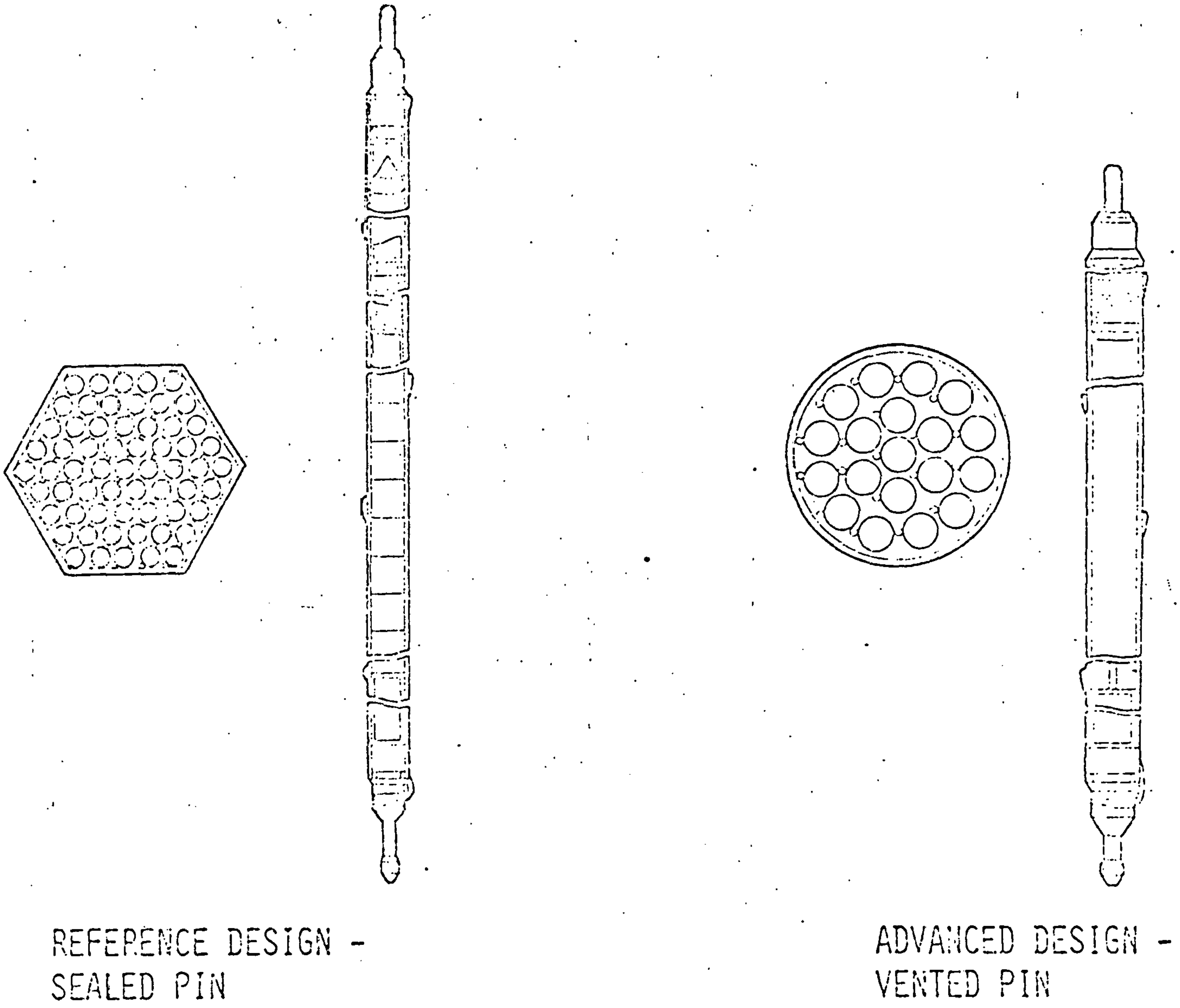

FIGURE 1. Comparison of FFTF Reference and Advanced Absorber Assembly Designs.

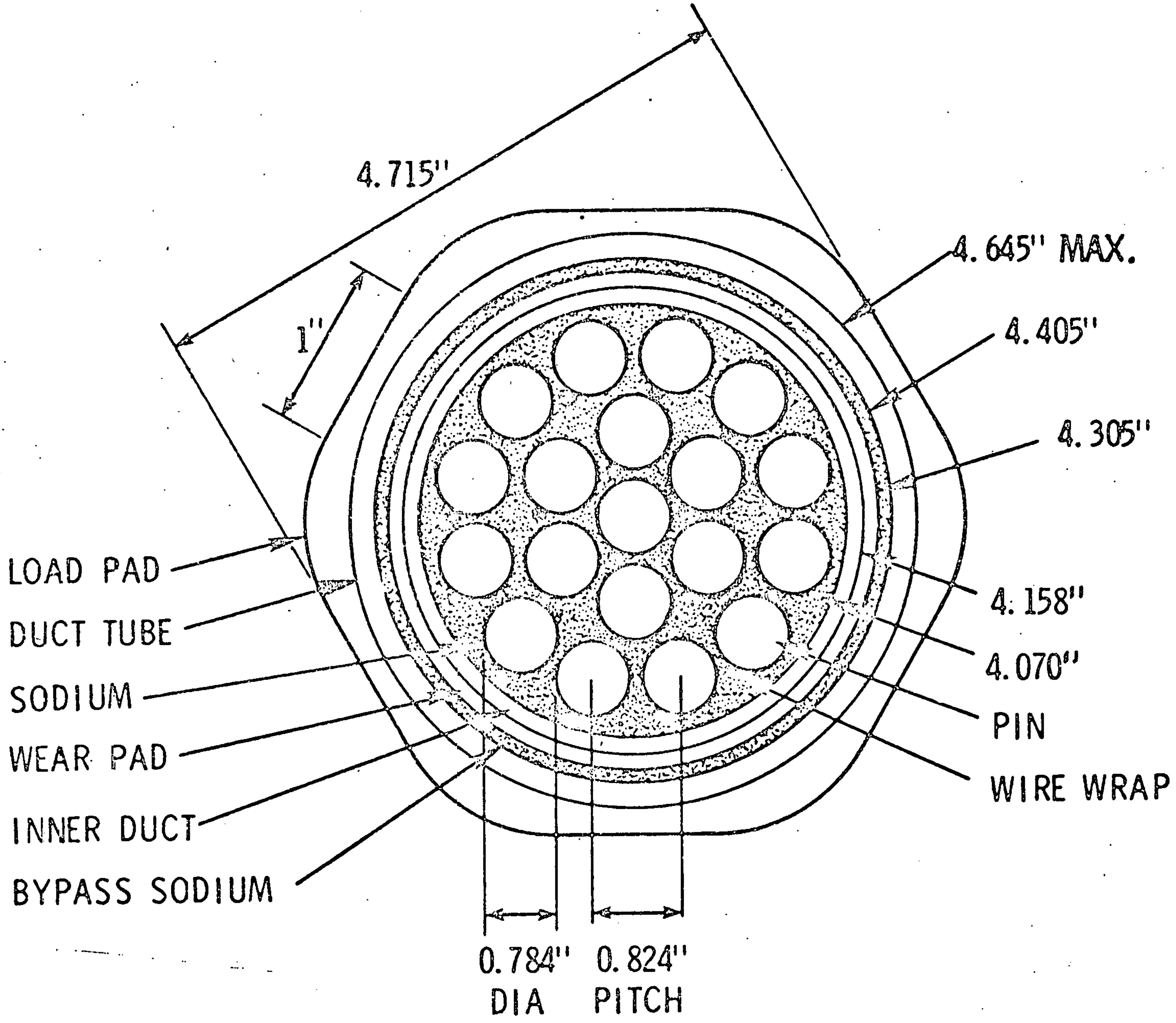

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FIGURE 2. Advanced Absorber Assembly Design Details.

Since gas plena are no longer required in vented absorber pins, shorter elements can be constructed. This contributes to some cost saving and improves flow hyraulics through the pin bundle. Also, shorter assemblies are less susceptible to bowing problems induced by thermal and flux gradients in the reactor. Use of vents in the advanced absorber design permits the pin bundle assembly in FFTF to be shortened by ∿25%.

The physical configuration of the vent assembly is shown in Figure 3. This assembly is located at the bottom of the absorber pin, and is comprised of a flow restrictor vent used in conjunction with a diving bell. This design concept was selected to provide adequate venting capacity and to suppress sodium ingress to the absorber section of the pin. The diving bell works on a pressure balance principle; helium is vented out the vent ports into the reactor coolant when gas pressure exceeds the sodium coolant pressure. The diving bell is included to defer sodium wetting of the flow restrictor vent.

The flow restrictor portion of the vent is located at the top of the bottom end cap. It consists of a vent body, coarse filter, porous plug, and protective cap all attached by electron beam (EB) welds. The B_4C absorber stack is located directly above the vent assembly, and is normally separated from it by an insulator pellet. The coarse filter serves to screen out any particulate material that may find its way to the bottom of the pin, thus protecting the porous plug frit. The porous plug regulates the flow of helium and is composed of sintered stainless steel of graded porosity. The protective cap at the bottom of the vent body provides physical protection for the porous plug and also functions as a splash guard in the event sodium should be forced upward during a control rod scram.

The vent ports are sealed with sodium soluble plugs prior to reactor insertion to maintain in inert gas atmosphere in the absorber pin. Once immersed in hot sodium, these plugs dissolve rapidly to provide helium release apertures.

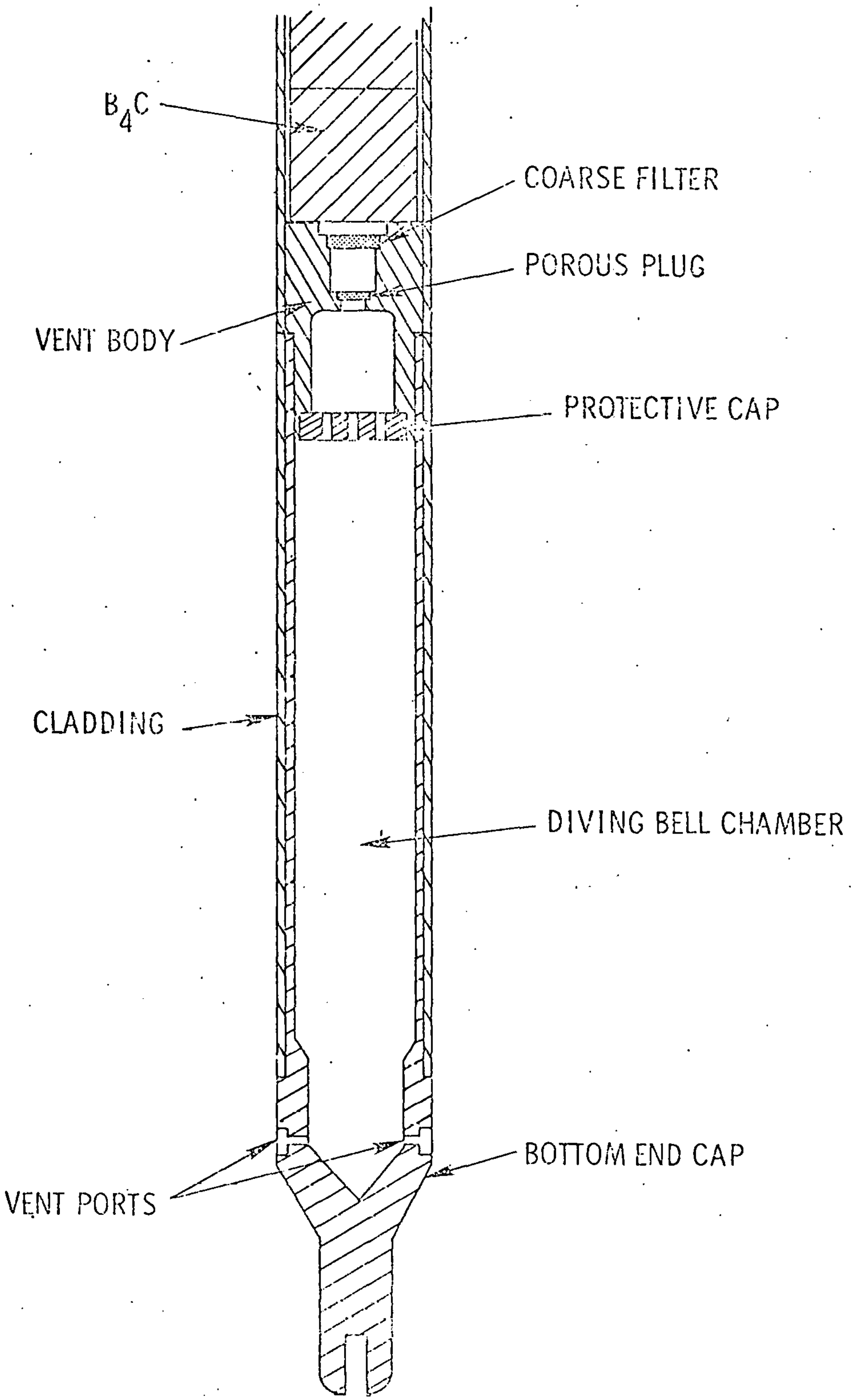

FIGURE 3. Vent Assembly Configuration.

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B. Geometry

With vented pins, cladding stresses associated with gas pressure buildup are no longer a concern; therefore, larger diameter pin concepts can be considered. Pin size then is limited primarily by thermal considerations. For the advanced design, the pin diameter has been increased from 0.474 inch (1.204cm) to 0.784 inch (1.991cm). B_4C operating temperatures remain under 2500°F (1371 °C) with this design, which is substantially below the 4440°F (2449 °C) melting temperature of this material. The larger pin size allows a reduction in the number of pins required to comprise the absorber assembly, from 61 pins for the reference assembly to 19 pins for the advanced design. The overall reduction in cladding volume effected by this revision also provides additional space for absorber loading, and the advanced assembly contains 12.5% more boron carbide than the reference assembly.

During the Environmental Life Test for the FFTF Control Rod Systems,(2) it was noted that some material transfer occurred between the inner surface of the outer duct tube and the pin bundle wear pads. It was determined that this condition was a result of torque imparted to the driveline by the control rod drive mechanism during rod withdrawal, thereby causing the affected components to interact. Although the observed wear effects caused no deterioration in scram performance, it is preferable to eliminate this potential for galling. This is accomplished by changing the duct tubes from a hexagonal to round configuration. With round duct tubes, there are no contact points to react to inter-component torque, and wear potential is eliminated. Also, round duct tubes are simpler to fabricate than hexagonal duct tubes.

The incorporation of round duct tubes in the advanced design necessitates the implementation of a circular pin array pattern inside the inner duct tube. If a conventional triangular array were employed, excessive flow maldistribution would occur due to the large spacing between the pin bundle periphery and the inner duct tube. The circular pin array chosen provides acceptably uniform coolant flow through the pin bundle assembly. The selected configuration also improves the volume of total coolant flow through the pin bundle. With the reference design, only 60% of the coolant passes through the pin bundle, with the remaining 40% flowing through annulus between the inner and outer duct tubes. With the advanced design, the flow split is improved to 75%/25%.

C. Advanced Alloy

A major concern in developing a long-lived absorber assembly design is the irradiation-induced bowing of the duct tubes that occurs at high neutron fluences. This bowing results from thermal and flux gradients that exist within the reactor system. Excessive bowing could cause interference in the axial travel of the absorber assembly, and thereby limit its useful lifetime. The goal lifetime for the advanced absorber assembly design is 900 FPD, corresponding to fast neutron fluences in excess of 2×10^{23} n/cm^2 (E >0.1 MeV) in all absorber assembly locations. Many alloys exhibit substantial swelling at these fluence levels, and the resultant bowing effects eliminate them from consideration as duct material. The alloy chosen for the advanced design is a modified Type 316 stainless steel alloy. This alloy displays very low predicted swelling rates at absorber assembly temperatures, thus effectively eliminating problems related to duct bowing. Physical and mechanical properties of this alloy are very similar to those of the reference FFTF duct material, 20% cold-worked Type 316 stainless steel.

III. SCRAM PERFORMANCE

Essentially all the design changes introduced in the transition to the advanced design tend toward improved scram performance. The advanced absorber assembly weighs $\sim$ 30 pounds (13.6 kg) less than the reference assembly, and therefore, responds faster to accelerating spring forces. The reduced length of the pin bundle decreases shear forces on the assembly, and the volume change associated with the shorter bundle reduces buoyancy by $\sim$ 5 pounds (22 N). Also, the pressure drop through the pin bundle is reduced from 2.8 psi (19.3 kPa) for the reference design to 1.2 psi (8.3 kPa) for the advanced design, and the hydraulic lifting force is $\sim$ 26 pounds (116 N) less. Therefore, by all measures, scram times for the advanced design would be expected to be less than for the reference design.

Scram times were calculated using the SCRAM computer code.(3) This code was developed specifically for the scram analysis of FFTF absorber assemblies. Calculated scram times for the reference absorber assemblies were in excellent agreement with measured data obtained from out-of-reactor scram testing.(2) Only geometrical modifications were made to the SCRAM code to account for the advanced assembly design changes. The calculated results for the reference and advanced assemblies, along with the technical requirements, are shown in Figure 4. The scram is effectively complete at the 27-inch level, after

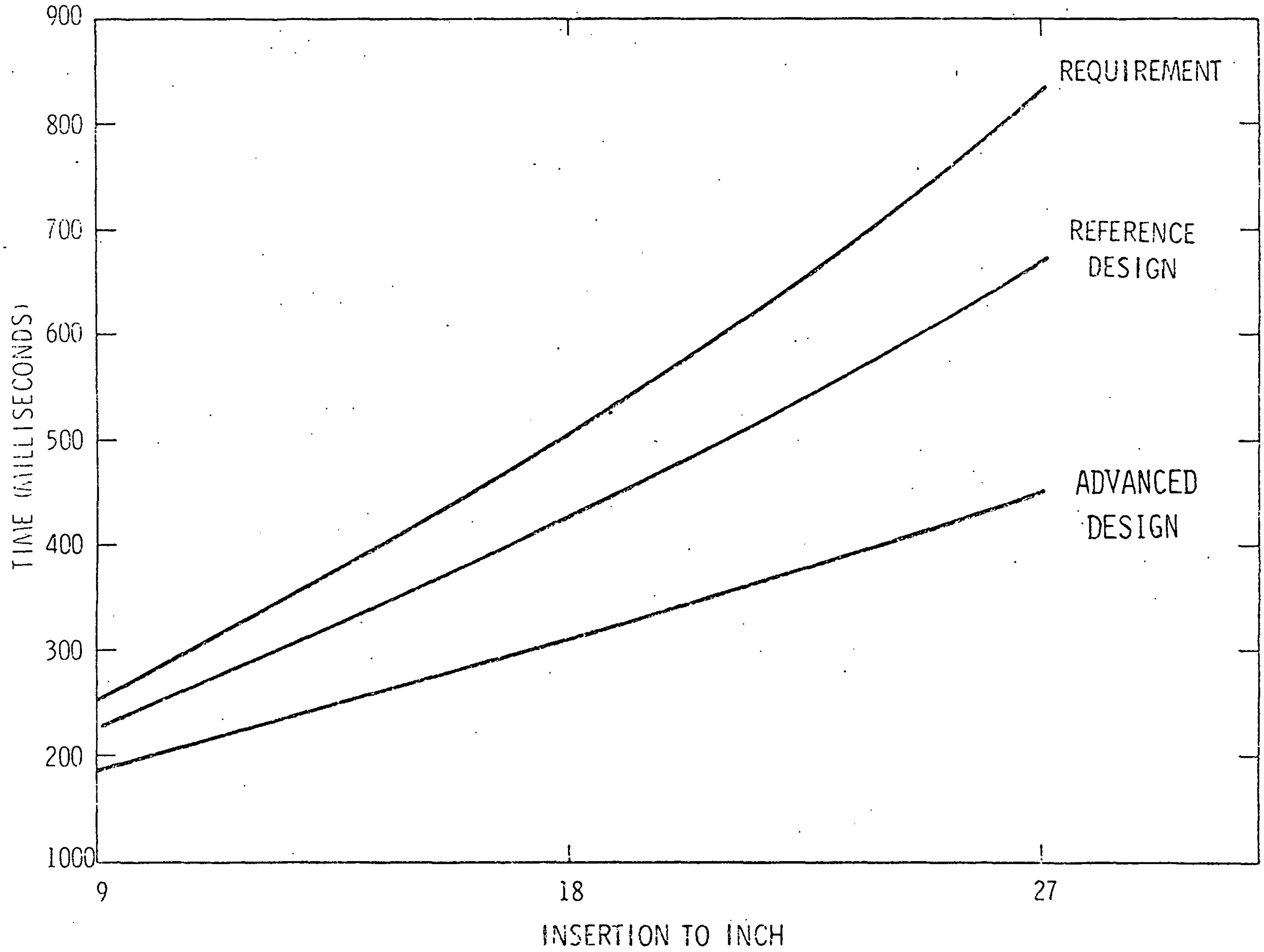

FIGURE 4. Required and Predicted Scram Performance.

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which point a dashpot acts to decelerate the assembly. While the reference design adequately satisfies scram requirements, the predicted scram times for the advanced design are notably improved. The predicted scram times for the advanced absorber assembly are only about half the allowance per the scram requirement.

The shutdown capability of a control rod system relates to the speed of scram response combined with the reactivity worth of the control rods. While scram time performance of a control rod is not expected to change appreciably with reactor service, its reactivity worth will decrease due to burnup of the absorber material. The advanced absorber assembly has a design lifetime of 900 FPD; whereas, the Series 2 absorber assembly lifetime is only 600 FPD. The relative peak burnup values will be 110×10^{20} captures/cm^3 and 85×10^{20} captures/cm^3, respectively. Thus, burnup effects will be more severe in the advanced assembly, and this consequence must be considered with regard to overall shutdown capabilities.

The FFTF control rods will operate in a partially-inserted to fully-withdrawn mode. The greatest burnup, therefore, occurs toward the lower end of the absorber column. The effect of burnup on the integrated reactivity worth is shown in Figure 5, where the values presented are normalized to the full reactivity worth of a new assembly. The net effect is that additional insertion is required to obtain the same reactivity worth as burnup increases, which is reflected in decreased reactivity insertion rates during scram events. These results were combined with the speed of response to obtain the plots shown in Figure 6, where the effect of burnup on scram reactivity insertion is shown for the reference design and the advanced design. The notable result is that even at the end of its 900 FPD lifetime, the advanced design introduces negative reactivity into the core faster than the reference design at beginning-of-life. Thus, the advanced design is expected to provide improved reactivity insertion capability throughout its 900 FPD lifetime.

IV. LIFETIME

The primary lifetime-limiting phenomena associated with absorber assemblies are B_4C swelling, helium release, reactivity worth depletion, pin bundle/duct

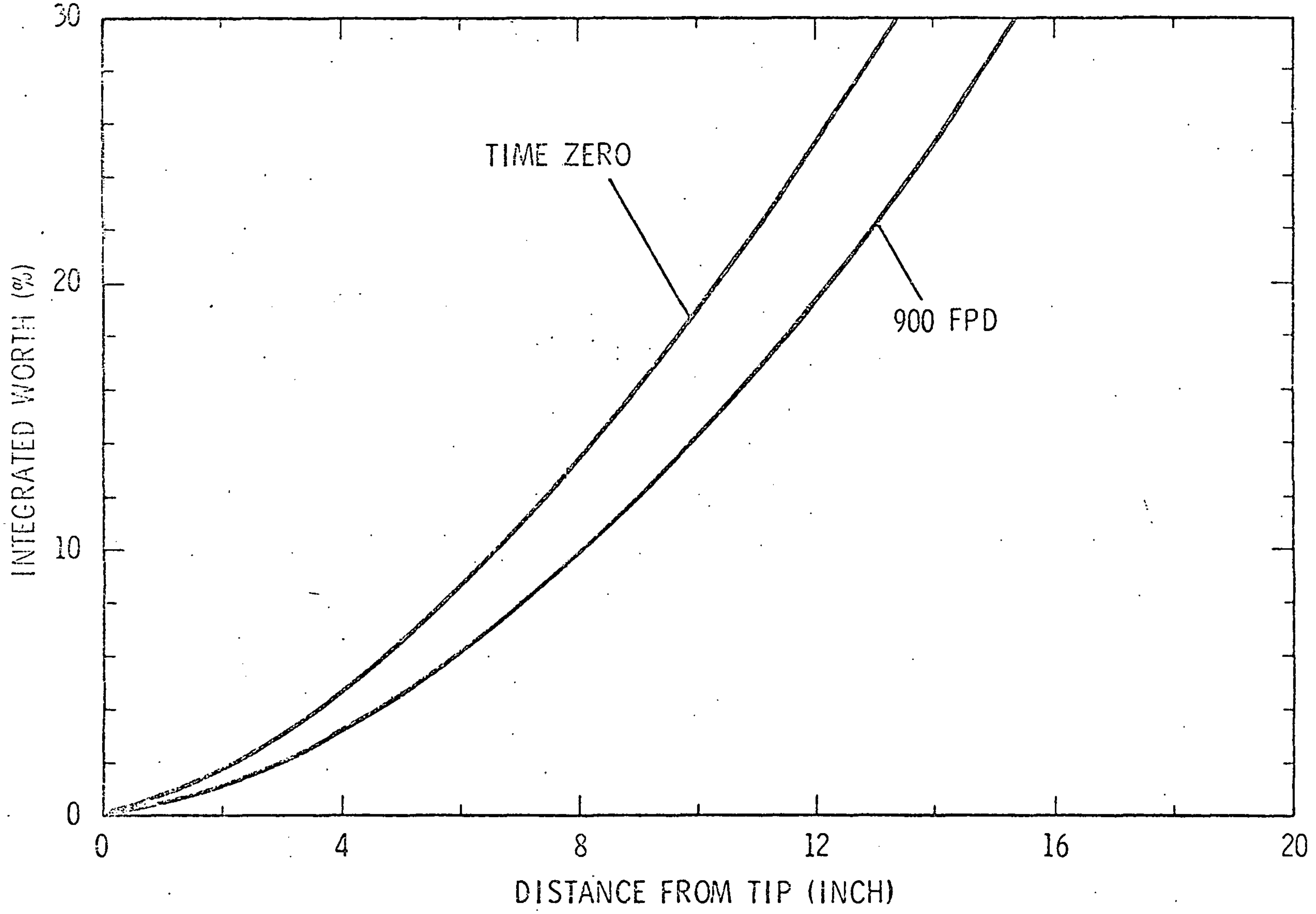

FIGURE 5. Effect of Burnup on Scram Response.

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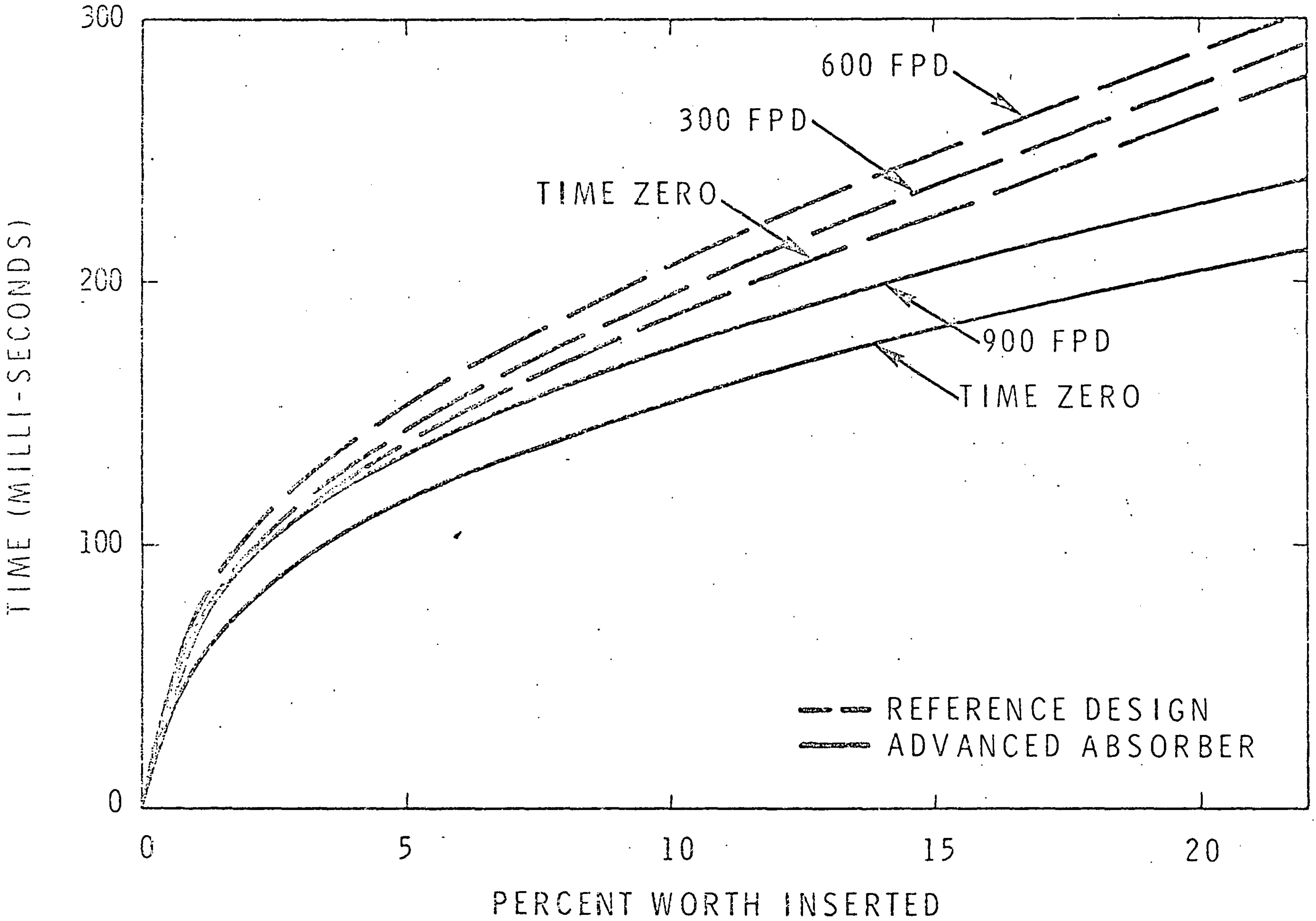

FIGURE 6. Reactivity Insertion for the Reference and Advanced Absorber Assembly Designs. HEDL 7805-020.19

interaction, and duct bowing. Specifically, end-of-life conditions are defined as follows:

- Swelling - Closure of the diametral pellet/cladding gap to 0.002 inch (0.005 cm).
- Gas Release - Permanent cladding strain of 0.2% for steady-state conditions (0.3% including transients).
- Worth Depletion - Reduction in worth to a value 90% of that of a new reference absorber assembly.
- Pin Bundle/Duct - Closure of the 0.022 inch (0.056 cm) clearance allowance between the pin bundle and inner duct tube.
- Bowing - Forced 3-point contact between the pin bundle assembly and outer duct tube.

Bowing behavior was analyzed using the CRPBOW code.(4) This computer program performs calculations for irradiation swelling, irradiation-induced creep, thermal elongation, and beam centerline displacement as a function of operating time and pin bundle axial position. The remaining lifetime-limiting phenomena were analyzed using the CONROD code.(5) This is a computer program developed for the design analysis of LMFBR control elements.

Lifetime analyses are performed on a worst-case basis. This includes maximum tolerance allowances, upper confidence limits on design correlations, and hot-channel conditions where applicable. Design margin is defined as the additional lifetime attainable if nominal conditions and correlations are applied. Lifetime results and design margins for the advanced absorber assembly are given in Table 1. In all cases, the required 900 FPD lifetime is satisfied with substantial design margin. The long lifetimes indicated for pin bundle/duct interaction and bowing are a consequence of the very low swelling behavior of the modified alloy.

TABLE 1

ABSORBER ASSEMBLY LIFETIMES AND MARGINS (FPD)

Limit	Lifetime	Design Margin
Swelling	920	270
Gas Release	>1200	Vented
Reactivity	920	180
Pin Bundle/Duct	>1200	-
Bowing	>1200	-

V. ECONOMICS

Fabrication costs for the advanced design are substantially reduced from those of the reference FFTF absorber assembly. This benefit derives primarily from the reduced number of pins in the advanced design, but some cost savings are also incurred in the simplified fabrication of the round duct tubes. It is anticipated that fabrication costs for the advanced assembly will be 40% less than for the reference assembly.

The longer lifetime of the advanced design also contributes to cost savings in the sense that annual absorber assembly replacement costs are reduced. The annual costs for absorber assemblies in the FFTF are compared in Figure 7 for the reference (Series 1), Series 2, and advanced design. Replacement costs for a full complement of advanced absorber assemblies would be approximately a factor of four less than for the reference design, and a factor of two less than for the Series 2 design. For the FFTF, this translates into savings of nearly a million dollars per year when comparing the advanced and reference designs. Similar economic benefits should be achievable in large core breeder reactor designs as well.

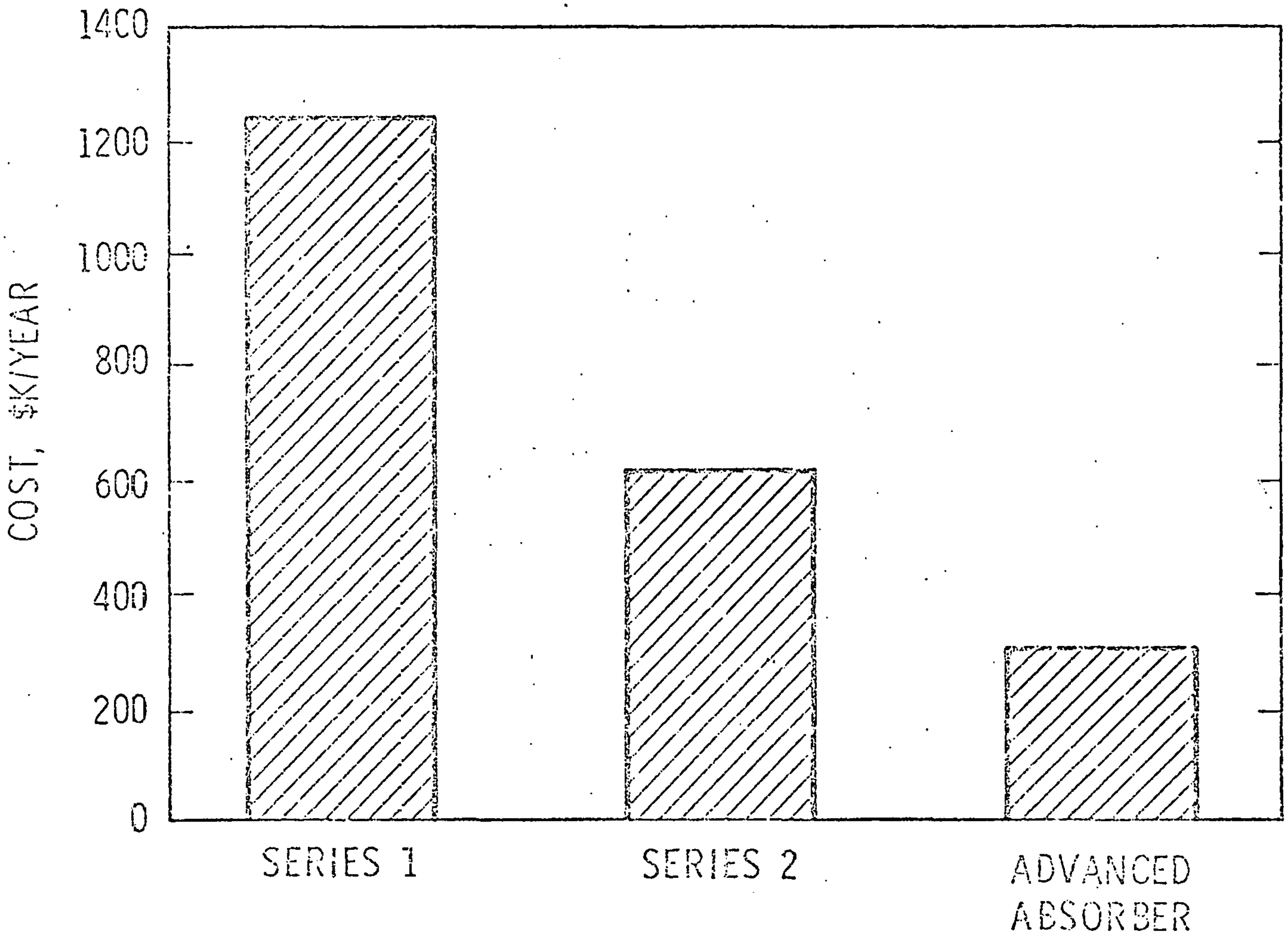

FIGURE 7. Absorber Assembly Cost Comparison.

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VI. CONCLUSIONS

An advanced absorber assembly design has been developed for breeder reactor control rod applications that provides for improved in-reactor performance, longer lifetimes, and reduced fabrication costs. The design comprises 19 vented pins arranged in a circular array inside of round duct tubes. The absorber material is boron carbide; cladding and duct components are constructed from the modified Type 316 stainless steel alloy. Analyses indicate that this design will scram 30 to 40% faster than the reference FFTF absorber assembly. The reduced fabrication costs and extended lifetime of the advanced design would save nearly one million dollars annually in absorber assembly replacement cost in FFTF if this design replaced the reference absorber assembly complement. The basic design characteristics of this advanced FFTF absorber assembly are applicable to large core breeder reactor design concepts.

REFERENCES

1. Final Safety Analysis Report, Fast Flux Test Facility, HEDL-TI-75001, December 1975.

2. J. L. McKinney and N. J. Kleiss, FFTF Control Rod Systems Environmental Life Test Report, WARD-SCT-9, December 1976.

3. R. D. Bourquin and K. R. Birney, SCRAM--A Computer Program for Calculating Scram Times for LMFBR Control Rods, HEDL-TME 75-83, August, 1975.

4. K. R. Birney and R. D. Bourquin, CRPBOW User's Manual, HEDL-TME 77-7, June 1977.

5. K. R. Birney and A. L. Pitner, User's Manual for CONROD - A Computer Program for the Design Analysis of LMFBR Control Elements, HEDL-TME 75-131, December 1975.