DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

FLUIDIZED-BED DESIGN FOR ICF REACTOR BLANKETS USING SOLID-LITHIUM COMPOUNDS

CONF-830406--41

DE83 012454

E. W. Suvov, P. S. Malick, L. Green, B. O. Hall
Westinghouse Electric Corporation
Madison, PA 15663
(412/722-5206)

ABSTRACT

A fluidized-bed concept for blankets of dry or wetted first-wall ICF reactors using solid-lithium compounds is described. The reaction chamber is a right cylinder, 32 m high and 20 m in diameter; the blanket is composed of 36 steel tanks, 32 m high, which carry the sintered Li_2O particles in the fluidizing helium gas. Each tank has a radial thickness of 2 m which generates a tritium breeding ratio (TBR) of 1.27 and absorbs over 98% of the neutron energy; reducing the thickness to 1.2 m produces a TBR of 1.2 and energy absorption of 97% which satisfy the design goals. Calculations of tritium diffusion through the grains and heat removal from the grains showed that neither could be removed by the carrier gas; tritium and heat are therefore removed by removing the grains themselves by varying the helium flow rate. The particles are continuously fed into the bottom of the tanks at 300°C and removed at the top at 475°C. Tritium and heat extraction are easily and conveniently done outside the reactor. Compared to blanket designs which use flowing liquid metals or packed beds of solid lithium compounds, this concept is safer, simpler, cheaper, easier to maintain and less likely to break down. In addition, this concept is compatible with both wetted wall and dry wall first wall designs. Finally, deleterious thermal expansion effects due to absorption of the neutron pulse in liquid lithium or the packed bed disappear because of the decoupling of the particles in the helium stream.

INTRODUCTION

The purpose of the work reported here was to devise a safe, practical and feasible design for an ICF reactor blanket using solid lithium compounds, which could be evaluated as an alternate to the original design for the Westinghouse¹ ICF reactor first wall and blanket. In contrast to most other ICF reactor designs^{2,3,4}, which place liquid lithium inside the reactor chamber between the explosion and the first wall, the Westinghouse design utilizes a "dry" tantalum coated steel first wall with heat removal and tritium breeding performed behind the wall in liquid lithium flowing through pipes and channels as shown in Figure 1.

Figure 1. Schematic Representation of Ta Coating Dry Wall Concept

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

MASTER

EBB

Approximately 30% of the energy in each pellet explosion is in the form of x-rays and ions which are absorbed in a very thin layer of material causing very high temperature transients. Tantalum was selected to absorb this surface energy because it had a high melting and vaporization temperature, was ductile and could be easily applied. Calculations using the CHART D code showed⁵ that the maximum temperature reached was 400°C below the melt temperature, that evaporation did not occur and that the internal stresses generated by absorbing this energy pulse did not cause spallation. This design concept separates the surface heat removal function in the first wall from the volume heat removal function in the blanket. Consequently, solid forms of lithium can be considered for the blanket.

FLUIDIZED BED BLANKET DESIGN

The issues to be resolved by the new design are volume heat removal and tritium breeding and removal. In this design the neutrons are absorbed directly in the grain clusters of the solid lithium compound floating in the helium gas stream which then acquire the desired temperature rise from 300°C to 475°C. The 475°C was set by the need to retain adequate strength in the structural material while the 300°C was set by the desire for an efficient steam cycle for power conversion. The tritium inventory in the grains was calculated using a time-dependent bulk diffusion model. This analysis showed that tritium could not be removed from the grains in the gas phase because of the low diffusion rates at the operating temperature of the grains; tritium removal had to be accomplished by removing the grains themselves. This is very easily accomplished in a fluidized bed by varying the helium flow rate. The fluidized bed concept thus provides for continuous heat and tritium removal and avoids the problems of tritium diffusion path blockage and complex piping system for heat removal identified in the stationary packed bed design.⁶

Since a fluidized bed operates at uniform temperature throughout because of rapid thermal mixing, the energy absorbed at one side is distributed, and local hot spots do not occur. The major disadvantage of a fluidized bed blanket is its low power density. The grain clusters are porous, about 70% solid, because of the sintering method used to create the clusters. The void fraction in the fluidized bed made up of these particles will be about 50%. The effective density of the solids is thus only 35% of the material density. It is inherent in fluidized bed devices that considerable free space exist

above the surface of the fluidized bed. If this is not done, there will be excessive carryover of solid particles with the exhausting helium. This is shown in the elevation view of the fluidized bed blanket, Figure 2.

Figure 2. Elevation View of Fluidized Bed Blanket.

1. Horizontal tank fluidized beds;
2. Free board height above the surface of the fluidized bed, 3. Upper surface of fluidized beds, 4. Lithium compound particles out at 475°C, 5. Screw conveyor inserts particles at 300°C, 6. Inlet plenum for vertical tanks, 7. Distributor plate for vertical tanks, 8. Fuel pellet explosion point, 9. Vertical tank fluidized bed, 10. Distributor plate for horizontal tanks.

The reaction chamber is a right circular cylinder standing on end. The blanket which forms the cylindrical wall of the chamber is made up of 36 tall steel tanks which run the full 32 m height of the chamber. Each of these tanks forms the containment for an individual fluidized bed of sintered lithium oxide pellets (which have a maximum diameter of one mm) suspended in helium gas at 345 kPa (50 psi). The blanket has an average radial thickness of 2 m. Horizontal fluidized beds 2 m deep, contained in tanks 2 m wide, form the top and bottom of the cylindrical reaction chamber. Neutrons give up their energy to the suspended particles which are continuously withdrawn at 475°C from the top of each tank; these carry the heat to the fluidized bed heat exchangers shown in Figure 3 which serve as steam generators. The cooled particles at

300°C are then returned to the bottom of the fluidized bed tank by a screw feeder. A small portion of the circulating particle stream will be withdrawn continuously for heating to a high temperature to drive off the tritium. These particles will be pulverized, mixed with the fines separated from the fluidizing gas and resintered into particles of the size required for proper operation of the fluidized beds.

Figure 3. Fluidized Cooler for Hot Alumina Particles

The use of individual tanks is essential for maintenance and repair. While the blanket is designed to last the life of the plant, provision must always be made for the unplanned failure which requires the replacement of a major component. In this design an individual tank with its contents weight only 100 tons so that it can easily be transported by an overhead crane. All connections to the individual fluidized beds are made at the outer periphery of the blanket where they can be disconnected remotely.

NEUTRONIC ANALYSIS

One dimensional spherical geometry coupled neutron-photon transport calculations were performed for the fluidized bed blanket design. The primary objective of these calculations was to provide blanket dimensional requirements for adequate tritium breeding and neutron energy deposition. A tritium breeding ratio (TBR) goal of about 1.2 was established to account for calculational uncertainties, chamber penetrations, and tritium losses. The energy loss rate goal was set at 1%. An additional goal is a first wall lifetime of at least five years. This would insure a first wall replacement schedule consistent with the utility maintenance cycle for major plant shutdown and overhaul.

The calculations were performed with the codes and cross section data base described in Reference 5. The burning pellet was approximated by an equimolar mixture of deuterium and tritium with a density-radius product of 3g/cm^2 . Neutrons were started uniformly and isotropically inside this source. This source provides a neutron energy fraction of approximately 68%, with the remaining 32% appearing as a surface heat load to the first wall.

The ICF fluidized bed design has a separately cooled and supported first wall structure. The first wall consists of pressurized water cooled corrugated panels, and is an adaptation of the STARFIRE⁶ design. The average surface heat load is 0.7 MW/m^2 for STARFIRE, close to the present value of 0.6 MW/m^2 . The dimensions of the STARFIRE first wall were therefore retained in the neutronic calculations. In particular, the corrugated surface, which faces the explosion, consists of a 1.5 mm HT-9 substrate coated with a 1.0mm layer of tantalum.⁷ The 0.7 mm thick first wall zone then consists of 32 v/o water, 21 v/o HT-9, 14 v/o tantalum and 23 v/o void. A plenum zone approximately 50 cm wide is included behind the first wall structure to contain all of the piping and manifolding required for the pressurized water coolant distribution system. Lithium oxide (Li_2O) at 70% of theoretical density and 50% packing fraction was selected for the fluidizing bed material. The side walls and front nose structure of the fluidizing bed tanks were assumed to be 3.635 cm thick HT-9, with the noses hemispherical in shape and having a diameter of 2 m. No other structure was included in the fluidized bed zones. A 20 cm thick graphite reflector with 5 v/o HT-9 structure was included in the calculation. Void space was included for coolant, but no coolant was specified. The choice of coolant will depend upon a decision regarding energy recovery in the reflector zone. The reflector was followed by a 3 m thick ordinary concrete shield. This was shown in earlier studies to provide an adequate bulk biological shield for the reference chamber size and D-T power output.

The solid angle weighted global TBR is 1.27, exceeding the design goal of 1.2 by a substantial margin. One reason for this good breeding performance, is the low structural volume fraction. This results in a parasitic absorption rate of less than 10%. Figure 4 shows the cumulative tritium breeding ratio through the side wall fluidized bed. Similar curves apply to the top and bottom beds. It can be seen that the TBR rises rapidly at first, slowing down above about 80 cm in bed thickness, and then approaching the full bed thickness (300 cm) value of 1.28 in a near asymptotic fashion. The target value of 1.2

occurs at a thickness of approximately 120 cm. Thus, on the basis of TBE requirements, it appears that a considerable reduction in fluidized bed thickness is possible. Analysis of the energy deposition distribution in the various chamber components shows that only 4.5 MW, or about 0.1% of the total available energy is deposited outside of the first wall and blanket. This is much lower than the goal of 1% and suggests, in a fashion analogous to that for tritium breeding, that the blanket thickness can be reduced. At a blanket thickness of 120 cm, which is adequate for tritium breeding, nearly 97% of the available neutron energy is deposited in the first wall and blanket. If the surface heat deposition of 1120 MW is included, 98% of the total energy is deposited. Moving the graphite reflector adjacent to this thinner blanket would raise this close to the 99% goal.

Figure 4. Tritium Breeding Ratio vs. Fluidized Bed Thickness

The average first wall neutron loading is 1.3 MW/m^2 , rising to a maximum value of 1.9 MW/m^2 at the surfaces nearest to the chamber center. Fluence lifetime under ICF reactor conditions for HT-9 is not well defined, but we can probably assume it to be close to that of titanium modified 316-SS (prime candidate alloy). Under low thermal stress steady state conditions this has been estimated to be 20 MWy/m^2 . These conditions are reasonably well satisfied in the present case. The wall thickness has been chosen to be that identical to the thin walled STARFIRE design, and temperature fluctuations between pellet

microexplosions has been estimated to be less than 50°C . On this basis the expected first wall lifetime is therefore approximately 10 years. Another basis for estimating radiation damage lifetime is to examine displacement damage and helium production rates. These were calculated to be 10.7 DPA/year and 104 appm He/year, respectively, at 70% plant availability. Assuming again that we may use results for 20% cold worked 316 SS, limits of 165 DPA and 500 appm He at an operating temperature of 500°C have been suggested.⁸ This results in a first wall lifetime of 15 years due to displacement damage and 5 years due to helium production. However, the ENDF/S-IV helium production cross sections used in the calculations are probably high. Calculations by Meier⁹ for the HYLIFE concept gave helium production rates a factor of two lower when the ENDL library was used. From the above considerations we may conclude that, based on available data and calculations, the first wall radiation lifetime damage goal of five years is satisfied for the present ICF fluidized bed dry wall design.

ACKNOWLEDGEMENT

This research was sponsored by the U.S. Department of Energy, Office of Inertial Fusion, under Contract No. DE-AC08-81DP40146.

REFERENCES

1. E. W. SUCOV, et al., "The Westinghouse ICF Power Plant Design Study," Proc. Fourth Top. Meeting on Tech. Contr. Nucl. Fusion, 1980.
2. J. A. MANISCALCO, et al., "A Lesser Fusion Power Plant Based on a Fluid Wall Reactor Concept," Proc. Third Top. Mtg. on Tech. Contr. Nucl. Fusion, 1978.
3. G. KULCINSKI, et al., "HIBALL, A Conceptual Heavy Ion Beam Driven Fusion Reactor Study," U. Wisc. UWFD-450, 1981.
4. J. H. PENDERGRASS, et al., "A Modified Watted Wall ICF Reactor Concept," Proc. Fourth Top. Meeting on Tech. Contr. Nucl. Fusion, October 1980, p. 1131.
5. E. W. SUCOV, et al., "Inertial Confinement Fusion Reactor Dry Wall Study," DOE/DP/40146-4, WARD FP-83-15, January 1983.
6. C. C. BAKER, et al., "An Overview of the STARFIRE Reference Commercial Tokamak Fusion Power Reactor Design," Proc. Fourth Top. Meeting on Tech. of Contr. Nucl. Fusion, 1980.

7. L. H. TAYLOR and E. W. SUCOV, "Coating Requirements for an ICF Dry Wall Design," J. Nucl. Mat. 103, 245 (1982).
8. G. L. KULCINSKI, et al., "Protection of CTR Metallic First Walls by Neutron Spectral Shifting," UWDM-127, University of Wisconsin, 1975.
9. W. E. MEIER, Laser Program Annual Report, 1977, UCRL-50021-77, pp. 8-21 to 8-25.