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SUBJECT: Nuclear Characteristics of Cylindrical Breeder Reactors
Containing Thorium in Pellet Form

TO: Distribution

FROM: D. R. Vondy

SUMMARY

The results of nuclear calculations for aqueous homogeneous reactors containing blanket thorium in pellet form are presented. Critical core fuel concentrations, gross breeding ratios, power densities, multiplication as dependent on core fuel concentration and neutron balances are included. Critical U^{233} core concentration for a 24-in.-dia core was 8.4 gm/l when U/Th was 0.003 in the blanket and the relative power density at the core wall was 1.04 kw/l/Mw; a 48-in.-dia core required 1.6 gm U^{233} /l in the core and the relative power density at the core wall was 0.095 kw/l/Mw. The above reactors had gross breeding ratios of 1.12 and 1.09, respectively.

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NUCLEAR CHARACTERISTICS OF CYLINDRICAL BREEDER REACTORS
CONTAINING THORIUM IN PELLET FORM

D. R. Vondy

Introduction

This material is submitted in reply to the letter of December 28, 1959 from I. Spiewak to P. R. Kasten requesting nuclear computations of reactors with pellet blankets. The specific reactors calculated are indicated in Table 1. The 24-in.-dia cores were associated with a 10-ft-long reactor having a 6-ft-long core with an 18-in. diameter x 2-ft-long neck, a 3/8-in.-thick zirconium core tank, three annular cylindrical regions of fertile material separated by regions of D_2O moderators, and a 4-in. stainless steel shell. The 48-in.-dia cores were associated with a 16-ft-long reactor having a 12-ft-long core with a 36-in. diameter x 2-ft neck, a 1/2-in.-thick zirconium core tank, three annular cylindrical regions of fertile material separated by regions of D_2O , and a 6-in. stainless steel shell. Radial identification of regions is given in Table 2.

Method of Calculation

Two-group, one-dimensional WANDA calculations were made to obtain estimates of critical core fuel concentrations. These results also provided radial flux distributions. These distributions were of particular interest in the region near the shell.

Two-group, two-dimensional Equipoise calculations were made to obtain neutron balances for the cases under study.

For comparison purposes, one-dimensional calculations were made for homogeneous blankets containing 1000 gm/l of Th²³² and 3 gm/l of U²³³.

Gross breeding ratios were calculated with no allowance made for higher isotope build-up nor Pa losses.

Discussion of Results

Principal results are presented in tables 3 and 4 which include neutron balances by region. Figures 1 and 2 show multiplication as dependent on core fuel concentration. Midplane thermal flux in the reactor having a 48-in.-dia core is shown in Fig. 3. Figures 4 and 5 present local power densities along the midplane for the cases studied. Figure 6 is a plot of the blanket power level relative to core power as a function of fuel in the blanket. Multiplication in reactors of the size under study having homogeneous blankets containing 1000 gm/l thorium is shown in Fig. 7 as a function of core fuel concentration.

The following additional comments may be noted:

1. The 2-ft-dia core reactor required a fuel concentration less than 10 g U²³³/l. About 75% of the absorptions in fertile material occur in the inboard blanket region.
2. The blanket-to-core power ratio in the 4-ft-dia core reactor exceeded 0.25 when the blanket fuel-to-thorium ratio was greater than 3 g U²³³/kg Th. In this reactor, 85% of the absorptions in thorium occurred in the inboard region.
3. The ratio of local absorptions in thorium to local absorptions in uranium was found to be 0.0129/C (where C is gms U/gms Th), independent of position.

4. A rough comparison of gross breeding ratios expected for homogeneous blankets with those for the pellet beds under consideration was made, and the results are given in Table 5. These one-dimensional results differ from the two-dimensional results primarily because these one-dimensional calculations consider the fuel region length to be the same as that of the blanket.

Table 1. Conditions Associated with Cases Studied

24-in.-Diameter Core

- Case 1. No fuel in blanket, no poison in core
 Case 2. $U/Th = 0.003$ in region D (3_1), core poison fraction 0.03
 Case 3. No fuel nor thorium in blanket, but empty pellets. No poison in core

48-in.-Diameter Core: Core poison fraction 0.06

- Case 1. U/Th in region D(3_1) = 0.001
 Case 2. U/Th in region D(3_1) = 0.003
 Case 3. U/Th in region D(3_1) = 0.005
 U/Th in region F(3_2) = 0.001

General

Fertile Region: thorium, 5300 gm/l

D_2O 350 gm/l

$\Sigma_a (Zr)/\Sigma_a (Th) = 0.01$

Temperatures:

Core 280°C

Core tank 260°C

Pellets 260°C

D_2O 250°C

Shell (24-in. core) 250°C

Shell (48-in. core) 270°C

Table 2. Dimensions and Composition of Reactor Regions

Core Size, diameter, in.		24	48
Region *	Material	Radial Thickness of Region, in.	
A	U^{233} in D_2O Solution	12	24
B	Zirconium core tank	3/8	1/2
C	D_2O moderator	1	2
D (3_1)	Fertile material in pellets	3	3
E	D_2O moderator	7.6	8.16
F (3_2)	Fertile material in pellets	1.8	2.18
G	D_2O moderator	9.58	4.3
H (3_3)	Fertile material in pellets	1.24	1.86
I	D_2O moderator	2	2
J	Shell	4	6
K	Extrapolation	1.0 cm	1.0 cm

* Refers to Fig. 8 for schematic placement of these regions.

Table 3. Summary of Calculations for 10-ft-long Reactor

Having 24-in.-Dia Core

Case	1	2	3
U/Th in Region D (3_1)	0	0.003	0
U/Th in Regions F and H (3_2 and 3_3)	0	0	0
Th in Regions D, F, and H gm/l	5300	5300	0
Critical Core Fuel Concentration, gm/l	9.4	8.4	3.3
Gross Breeding Ratio	1.13	1.12	0
Blanket Power/Core Power	0	0.218	0
Power Density, relative, kw/l/Mw			
Max in core	3.33	2.68	2.27
Max core wall	1.27	1.04	1.77
Max in blanket	0	0.928	0
Power Density at 40 Mw Total, kw/l			
Average in core	63	52	63
Max in core	133	107	91
Max core wall	51	42	71
Max in blanket	0	37	0
Fast Absorption ÷ Thermal Absorption			
Core Fuel	0.3492	0.3126	0.0857
Blanket Fuel	-	0.2420	-
Blanket Thorium	0.1930	0.1933	-
Fast Leakage ÷ Thermal Leakage	18.29	18.73	1.31
Relative Absorption in thorium, Region D (3_1)	0.7562	0.7116	-
Region F (3_2)	0.2080	0.2446	-
Region H (3_3)	<u>0.0358</u>	<u>0.0438</u>	-
Total	1.0000	1.1000	-

Table 3 - cont'd

Case	1	2	3
Neutron Balance (Two Group)			
Core Fuel	1.0000	0.8183	1.000
Core Poison	-	0.0190	-
Core Moderator	0.0036	0.0074	0.0129
Blanket Moderator	0.0027	0.0029	0.0532
Blanket Fuel	-	0.1817	-
Blanket Thorium	1.1349	1.1190	-
Blanket Zirconium	0.0095	0.0092	0.1813
Core Tank Zirconium	0.0147	0.0136	0.0924
(Shell top)	0.0131	0.0141	0.0905
Shell Bottom	0.0024	0.0036	0.0525
Circumferential Shell	<u>0.0242</u>	<u>0.0289</u>	<u>0.7551</u>
Total absorptions	2.2051	2.2177	2.2379
Leakage	<u>0.0171</u>	<u>0.0204</u>	<u>0.0256</u>
Gross Account	2.2222	2.2381	2.2635

Table 4. Summary of Calculations for 16-ft-Long Reactor
Having 48-in.-Dia Core

Case	1	2	3
U/Th in Region D (3_1)	0.001	0.003	0.005
U/Th in Region F (3_2)	0	0	0.001
U/Th in Region H (3_3)	0	0	0
Critical Core Fuel Concentration, gm/l	1.70	1.57	1.47
Gross Breeding Ratio	1.09	1.09	1.09
Blanket Power/Core Power	0.081	0.267	0.532
Power Density, Relative, kw/l/Mw			
Max in Core	0.490	0.409	0.328
Max Core Wall	0.113	0.095	0.087
Max in Blanket	0.142	0.391	0.603
Power Density at 400 Mw Total, kw/l			
Average in Core	76	68	56
Max in Core	196	164	131
Max Core Wall	45	38	35
Max in Blanket	57	156	241
Fast Absorption ÷ Thermal Absorption			
Core Fuel	0.0721	0.0713	0.0697
Blanket Fuel	0.0860	0.1125	0.1334
Blanket Thorium	0.0848	0.1142	0.1403
Fast Leakage ÷ Thermal Leakage	14.67	21.14	30.15
Relative Absorption in Thorium			
Region D (3_1)	0.8684	0.8262	0.7829
Region F (3_2)	0.1097	0.1430	0.1744
Region H (3_3)	0.0219	0.0308	0.0427
Total	1.0000	1.0000	1.0000

Table 4. cont'd

Case	1	2	3
Neutron Balance			
Core Fuel	0.9264	0.7905	0.6553
Core Poison	0.0518	0.0442	0.0369
Core Moderator	0.0239	0.0218	0.0199
Blanket Moderator	0.0029	0.0029	0.0029
Blanket Fuel	0.0736	0.2095	0.3447
Blanket Thorium	1.0945	1.0948	1.0931
Blanket Zirconium	0.0102	0.0100	0.0095
Core Tank Zirconium	0.0475	0.0449	0.0421
(Shell top)	0.0198	0.0184	0.0174
Shell Bottom	0.0027	0.0034	0.0043
Circumferential Shell	<u>0.0109</u>	<u>0.0156</u>	<u>0.0222</u>
Total Absorptions	2.2642	2.2560	2.2483
Leakage	<u>0.0084</u>	<u>0.0116</u>	<u>0.0165</u>
Gross Account	2.2726	2.2676	2.2648

Table 5. Effect of Thorium Placement upon Breeding Ratio

Core Diameter, in.	Fertile Material (U/Th 0.003)	Critical Core Fuel Concentration, g/l	Gross Breeding Ratio
24	5300 g/l Th, pellets	8.0	1.053
24	1000 g/l Th, homogeneous	6.9	1.066
48	5300 g/l Th, pellets	1.55	1.056
48	1000 g/l Th, homogeneous	1.59	1.069

ACKNOWLEDGMENT

The recommendations of M. Tobias and his participation in this work are recognized and appreciated.

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FIG. 1.
MULTIPLICATION IN
24 IN. DIA. CORE, 10 FT.
LONG REACTOR

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FIG. 2
MULTIPLICATION IN
48 IN. DIA. CORE, 16 FT.
LONG REACTOR

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FIG. 8: SKETCH OF REACTORS
(NOT TO SCALE)

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