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NUCLEAR CHARACTERISTICS OF A FISSIONING URANIUM PLASMA TEST REACTOR WITH LIGHT-WATER COOLING

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16. Abstract

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SUMMARY

An analytical study was performed to determine a design configuration for a cavity test reactor. Test section criteria were that an average flux of 10^{15} neutrons/cm^2/sec ($E \leq 0.12$ eV) be supplied to a 61-centimeter-diameter spherical cavity at 200 atmospheres pressure. Design objectives were to minimize required driver power, to use existing fuel-element technology, and to obtain fuel-element life of 10 to 100 full-power hours.

Parametric calculations were made on moderator region size and material, driver fuel arrangement, control system, and structure in order to determine a feasible configuration. Although not optimized, a configuration was selected which would meet design criteria. The driver fuel region was a cylindrical annular region, one element thick, of 33 Materials Testing Reactor (MTR)-type H_2O-cooled fuel elements (aluminum-uranium fuel plate configuration), each 101 centimeters long. The region between the spherical test cavity and the cylindrical driver fuel region was beryllium (10 vol. % H_2O coolant) with a midplane dimension of 8 centimeters. Exterior to the driver fuel, the 25-centimeter-thick cylindrical and axial reflectors were also beryllium with 10 volume percent H_2O coolant. The entire reactor was contained in a 10-centimeter-thick steel pressure vessel, and the 200 atmospheres cavity pressure was equalized throughout the driver reactor. Fuel-element life was 50 hours at the required driver power of 200 megawatts. Reactor control would be achieved with rotating poison drums located in the cylindrical reflector region. A control range of about 18 percent $\Delta k/k$ was required for reactor operation.

INTRODUCTION

A recent study was conducted which proposed a heavy-water-moderated and -cooled cavity reactor (ref. 1) to test the gas-core nuclear rocket concept (refs. 2 and 3). Although this test reactor concept provided the lowest power split (least driver or throwaway power) of any considered, the potential cost and complexity of handling heavy water warranted a more thorough investigation of alternate reactor systems. This report describes the conceptual design of a light-water-cooled cavity test reactor.

As indicated previously (ref. 1), major constraints of the study were that existing fuel-element technology be used in the driver core and that the capability exist for gas-core tests in the cavity. Thus, we designed the driver core around MTR fuel elements, thereby utilizing considerable reactor operating experience at the NASA Plum Brook Reactor (PBR).

The test cavity will be spherical with a 60.96-centimeter diameter. Under a particular set of test conditions the cavity would contain 572 grams of enriched uranium (an update of expected experimental conditions) during a typical test at a pressure of 200 atmospheres, and it would generate 2.7 megawatts of power. To provide sufficient cavity power generation to maintain cavity fuel edge temperatures greater than the condensation temperature, an average cavity flux of 10^{15} neutrons/cm^2/sec ($E \leq 0.12$ eV) is required (as measured in a void cavity). The corresponding flux in a fueled cavity would be approximately 3×10^{14} neutrons/cm^2/sec.

This report presents the neutronics information generated in a study to define a light-water-cooled cavity test reactor. Design objectives were to minimize required power production in the driver core (throwaway power) and to provide the fuel capability for reasonable operating times (10 to 100 full-power hours), in addition to providing the aforementioned experimental conditions. Analysis procedures were preliminary in nature and have not been verified experimentally for the particular system being considered.

ANALYSIS

Procedure

Based on previous data (ref. 1), a cylindrical beryllium (Be) reflector thickness of 10.24 centimeters was used for all models. The moderator thickness and the material and fuel arrangement were varied in an effort to minimize required driver power and to meet driver power density limitations. Parametric calculations were run using a spherical model. Calculated multiplication factors k were then adjusted to two-dimensional S_4P_1 14-group accuracy by the use of reactivity correction factors. Each configuration was normalized to a driver multiplication factor k_D of 1.075 with a fueled cavity (or $k_D = 1.099$ with a void cavity) by adjusting the fuel loading (uranium per element). The corresponding power split was determined from the ratio of the driver to the cavity multiplication factors k_D/k_C. Unless otherwise noted, all power splits were calculated after the multiplication factors were normalized to $2DS_4P_1$ 14-group accuracy.

All reactor calculations were performed with multigroup neutron transport codes: TDSN (ref. 4) and ANISN (ref. 5) for one-dimensional models, and DOT (ref. 6) for two-dimensional models. Cross sections were generated with GAM-II (ref. 7) and GATHER-II (ref. 8) codes for energy groups above and below 2.38 electron volts, respectively. Group structure is described in previous reports (refs. 1 and 9).

Calculation Model

The cavity test reactor consists of a spherical test cavity surrounded by a neutron-moderating region, a cylindrical driver fuel region, a reflector, and a pressure vessel. In the cavity a central fuel region is surrounded by propellant hydrogen. Some hydrogen (40 percent partial pressure) is mixed into the fuel region and uranium-238 (^{238}U) is included in the propellant as seed material for thermal radiation absorption. A spherical plenum around the cavity is provided for distribution of the propellant before it enters the cavity through the porous cavity liner.

The configuration from which the one- and two-dimensional analytical models were derived is shown in figure 1 and table I. For one-dimensional models the cylindrical

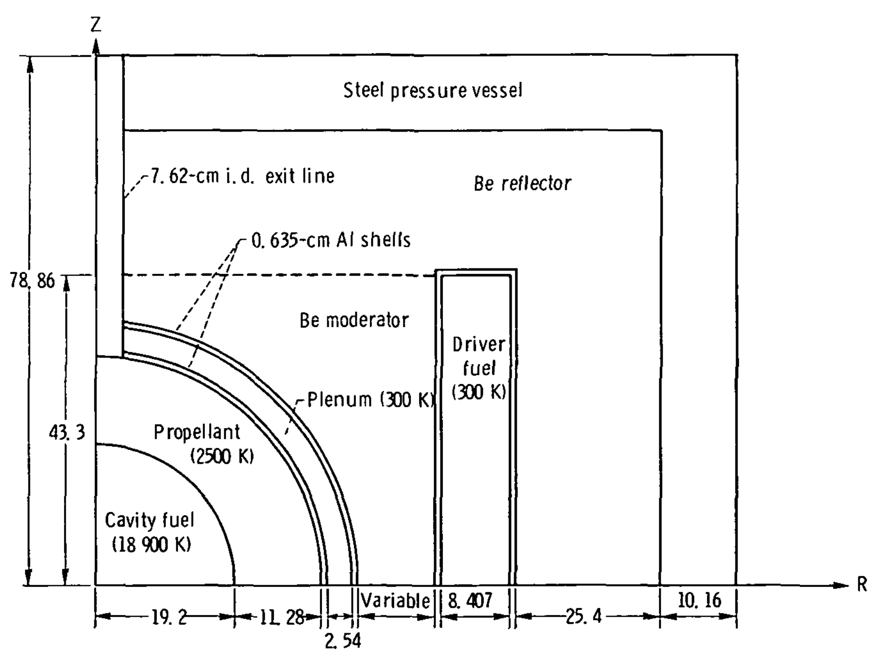

Figure 1. - Analytical model for beryllium-moderated cavity test reactor. Pressure, 200 atmospheres. (All dimensions are in cm.)

TABLE I. - REGION COMPOSITIONS FOR BERYLLIUM-MODERATED ANALYTICAL MODEL OF CAVITY TEST REACTOR

Region	Composition, vol. %
Cavity fuel	572 g enriched (0.932^{235}U) uranium 1.38 g H_2 (40 percent partial pressure)
Propellant	75 Percent H_2 25 Percent ^{238}U (seed)
Driver fuel	Variable[a]
Moderator	90 Percent Be 10 Percent H_2O or H_2 coolant
Reflector	90 Percent Be 10 Percent H_2O coolant
Plenum	75 Percent H_2 25 Percent ^{238}U

[a]A maximum number of MTR fuel elements (ref. 1) were fitted into a cylindrical channel. The remaining volume was H_2O coolant.

regions were converted to spherical shells with corresponding volumes. For two-dimensional R-Z models the spherical regions were converted to cylinders (height-length ratio of 1) with the same volume.

The moderator region with inner spherical boundary and outer cylindrical boundary presented a special problem. Zero moderator thickness at the radial midplane was equivalent to a spherical shell about 4 centimeters thick. Therefore, when thin moderator regions were required, it was necessary to provide a cylindrical region adjacent to the spherical plenum. The configuration for a water-moderated system is shown in figure 2. The fillet region, volume between the spherical plenum boundary and the cylindrical moderator boundary, has been filled with hydrogen to equalize system pressure. Any material in this region is detrimental to the water-moderated configuration; even a moderating material would create an overmoderated condition for the cavity source flux.

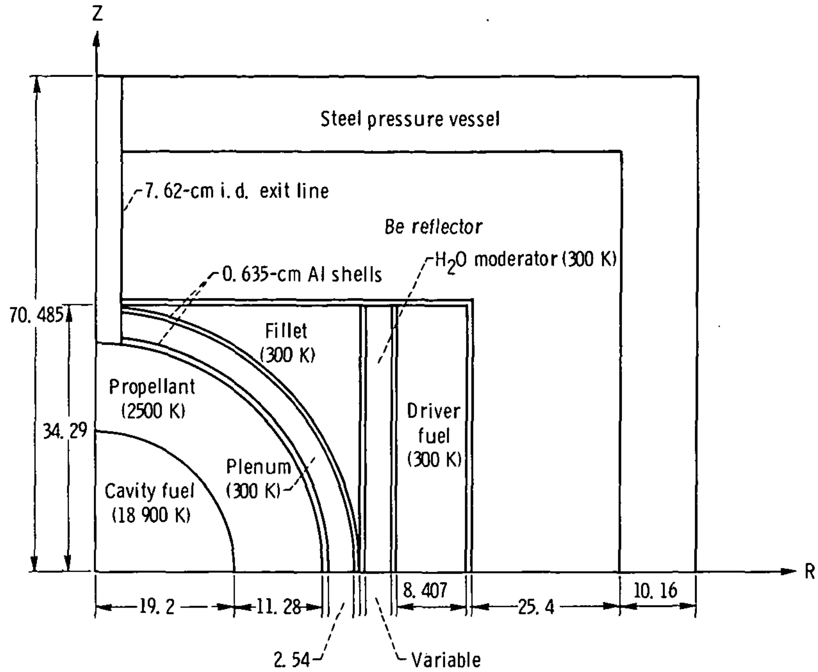

Figure 2. - Analytical model for light-water-moderated cavity test reactor. Pressure, 200 atmospheres. (All dimensions are in cm.)

Moderator

Two moderator materials were considered, H_2O and Be. Parametric calculations in spherical geometry were used to optimize moderator volume. In each case the fuel loading was adjusted to provide a k_D of 1.120 with a test cavity containing 572 grams of U. The results, presented in table II, indicate an H_2O moderator should be about 2 centimeters thick and a Be moderator about 10 centimeters thick. At smaller thicknesses, insufficient moderation occurs between the driver fuel and the cavity. At larger thicknesses, the greater fuel loading tends to decrease the driver flux required for criticality and therefore lessens the source to the cavity.

The power splits from table II have not been normalized to the recommended two-dimensional model and therefore should be used only to indicate trends. Also, the calculational model differed somewhat from the recommended configuration.

Beryllium-moderated reactors appear to offer the advantage of a somewhat (~15 percent) lower power split. Another factor favoring Be as the moderator material is that an accident to a water-moderated reactor could cause a loss of water (or gas) from the moderator region. Data in table III indicate that a positive reactivity effect (6.17 percent $\Delta k/k$) occurs when water is removed from a region between the driver fuel and the cavity. Use of H_2O-cooled Be reduces the effect to +3.2 percent $\Delta k/k$, and H_2-cooled Be would essentially eliminate the consequences of this accident.

TABLE II. - EFFECT OF MODERATOR THICKNESS ON

POWER SPLIT

[Calculation model: spherical; 1/3 of driver fuel channels filled with H_2O to simulate withdrawn control rods; $k_D = 1.120$; 10 vol. % coolant in solid moderator and reflectors.]

Shell thickness		Moderator material	Moderator coolant	Power split, k_D/k_C	Driver fuel loading, kg U	Moderator volume, cm^3
cm	in.					
0	---	----	----	41.8	5.2	-------
1.27	0.5	H_2O	----	34.1	6.25	1.9×10^4
2.54	1	H_2O	----	35.0	7.65	5.1×10^4
3.81	1.5	H_2O	----	38.8	9.3	6.3×10^4
3.81	1.5	Be	H_2	35.7	5.46	6.3×10^4
10.16	4	↓	H_2	29.2	6.09	2.0×10^5
16.76	6.6	↓	H_2	35.8	7.96	3.9×10^5
10.16	4	↓	H_2O	32.2	7.66	2.0×10^5
16.76	6.6	↓	H_2O	48.6	10.1	3.9×10^5

TABLE III. - EFFECT OF LOSS-OF-MODERATOR

(OR MODERATOR COOLANT) ACCIDENT

Moderator material	Moderator coolant[a]	Reactivity change, % Δk/k
H_2O	----	+6.1
Be	H_2O	+3.2

[a]10 Vol. % of moderator region.

Fuel

Variations of the driver fuel arrangement were investigated in an effort to reduce power density. The driver power required to produce an average thermal flux of 10^{15} neutrons/cm^2/sec in a void test cavity exceeded an acceptable value for MTR fuel elements based on the reference configuration. From both PBR and Advanced Test Reactor (ATR) operating data, maximum acceptable average power densities were determined to be 3.35 and 2.5 kW/cm^3 for 10 and 100 hours full-power operation, respectively, based on fuel-element volume.

The reference configuration contained a single row of fuel elements arranged in a cylindrical annulus around the test cavity. The fuel length of 68.6 centimeters was selected early in the study as a sufficient length to provide a uniform flux to the cavity.

Data in table IV show that extending fuel-element length to 91.4 centimeters necessitates a higher power output from the driver reactor in order to maintain a flux of 10^{15} neutrons/cm^2/sec in the cavity. This follows from the fact that fuel is located in lower flux regions. However, average power density decreases to 2.97 kW/cm^3 because the addition of fuel more than compensates for the increase in power.

TABLE IV. - EFFECT OF FUEL ARRANGEMENT ON DRIVER POWER IN A BERYLLIUM-MODERATED AND -REFLECTED, LIGHT-WATER-COOLED, MTR-FUELED CAVITY TEST REACTOR

Configuration		Fuel mass, kg ^{235}U	Power split	Power, MW	Power density, kW/cm^3
Number of fuel elements	Fuel-element length, cm				
[a]35	68.6	8.0	20.1	170	3.54
35	91.4	9.3	22.4	190	2.97
57	68.6	9.5	22.4	220	2.66

[a]Reference configuration.

Inclusion of a second row of fuel elements (57 total elements) has a similar effect - power increased to 220 megawatts and power density decreased to 2.66 kW/cm^3. Again fuel was moved to a lower flux region. The assumption has been made in the preceding analysis that changes in power shape are sufficiently small that peak-to-average ratios are relatively constant. In a more detailed analysis these power-shape effects would have to be considered.

Obviously, a trade-off exists between power, power density, and fuel life. Data in figure 3 show the penalty (power increase) as a function of power density for varying the fuel arrangement to increase fuel volume. As power increases, cooling system and effluent handling problems increase; as power density decreases, fuel lifetime increases. The resulting net effect on cost must be determined to establish the "best" design configuration.

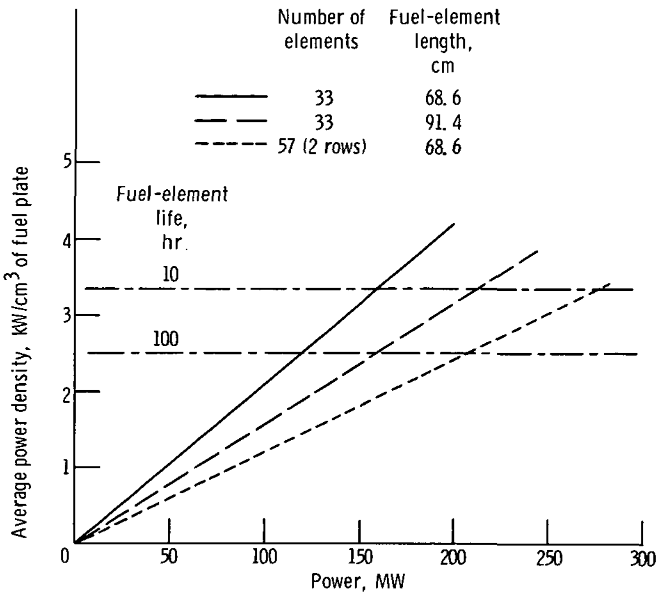

Figure 3. - Required power density in cavity test reactor models with various fuel arrangements.

Control System

Although reactivity control requirements are a function of such variables as driver power, cavity power, operating time, and configuration, no significant change is expected for the range of conditions considered in this study. Therefore, data were calculated for a typical system and are presented in table V.

The planned startup procedure is to flood the cavity with 200-atmosphere, 300 K hydrogen prior to the introduction of cavity fuel. The reactivity worth of this hydrogen, -0.039 $\Delta k/k$, must be compensated for by the control system so that the reactor remains critical. Other excess reactivity requirements were 0.027 $\Delta k/k$ for the fuel depletion during 18 000 MW-hr (est.) of operation, 0.01 $\Delta k/k$ for xenon-135 (^{135}Xe) buildup during a 1-hour run, 0.002 $\Delta k/k$ for an H_2O temperature rise from 300 to 325 K, 0.01 $\Delta k/k$ (est.) for other fission product buildup, and 0.002 $\Delta k/k$ allowance for contingencies. The total 0.09 $\Delta k/k$ requires an effective multiplication factor (k_{eff}) of 1.099 for a reactor with a void test cavity.

When 572 grams of fuel is added to the cavity, its worth is 0.042 $\Delta k/k$. However, the -0.019 $\Delta k/k$ effect on the driver fuel reduces the net effect on the reactor to +0.023 $\Delta k/k$. Sufficient shutdown reactivity must be available to override this effect at any time. An additional margin of 0.067 $\Delta k/k$ below critical was considered a reasonable estimate in view of the many uncertainties at this stage of the design.

Two types of control systems were considered - rods and drums containing a neutron poison. Previous work (ref. 1) indicated that a reactivity worth of 50 to 60 percent

TABLE V. - REACTIVITY REQUIREMENTS OF CONTROL SYSTEM FOR A 180-MW-DRIVER, 2.7-MW CAVITY TEST REACTOR

[Effective multiplication factor, k_{eff} = 1.099 (empty cavity); shutdown multiplication factor, k_s = 0.917.]

	Reactivity, $\Delta k/k$
Excess reactivity:	
Initial hydrogen in cavity	0.039
Fuel depletion (18 000 MW-hr)	.027
Xenon-135 production	.01
Temperature defect (300 to 325 K)	.002
Other fission products (estimated)	.01
Contingency	.002
	0.09
Shutdown reactivity:	
Cavity fuel override	0.023
Margin (estimated)	.067
	0.09
Total control range	0.18

$\Delta k/k$ could be achieved in a similar reactor using cadmium - stainless-steel control rods interspersed in the driver fuel region. Subsequent calculations have been made for a drum control system. As a first approximation fourteen 25-centimeter-diameter drums were arranged adjacent to the outer periphery of the driver fuel region, as shown in figure 4. These drums were made of Be and had a 0.5-centimeter-thick poison strip attached to 30 percent of the drum periphery. The poison was a mixture of boron-10 (^{10}B) and copper (Cu), with respective atom densities of 0.0237×10^{24} and 0.0662×10^{24} atoms/cm^3.

Calculational results, itemized in table VI, indicate that the required range of approximately 18 percent $\Delta k/k$ should be achievable with either drums or rods. The R-θ results are considered the more accurate. These data were obtained by using a two-dimensional model with the inclusion of sufficient mesh points to eliminate significant errors caused by a rapidly changing flux in the poison region. The spherical model was calculated to determine how well a simplified model could approximate the R-θ model. In the spherical model a spherical shell was located at the centroid position of the poison strips, and its thickness was adjusted to preserve total poison atoms. A con-

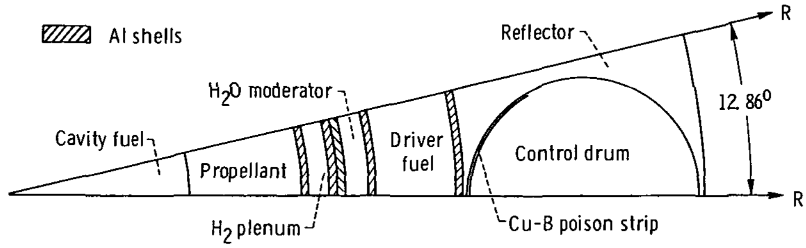

Figure 4. - Calculational model of cavity test reactor with poison drum control. Symmetric portion of midplane. Cross section of light-water-moderated configuration with drums rotated in (shutdown position).

TABLE VI. - REACTIVITY WORTHS OF SEVERAL CONTROL SYSTEM MODELS

Model	Reactivity worth	
	% $\Delta k/k$	% Δk
Drum controlled (25.4-cm diam), R-θ	21	21
Drum controlled (25.4-cm diam), spherical	(a)	25
Drum controlled (17.8-cm diam), spherical	(a)	23
Rod controlled (ref. 1)	50 to 60	50 to 60

[a]Multiplication factor k deviated from 1 by so much that a $\Delta k/k$ value was meaningless.

trol range was calculated from the difference between multiplication factors for the poison rotated from full in to full out. A geometric conversion factor of 0.655 (ratio of outer surface area of the cylindrical driver fuel region to the corresponding area in the spherical model) was then applied to convert the results to cylindrical geometry.

Reactivity coefficients were calculated to facilitate dynamic analyses. The data, shown in table VII, indicate that a positive temperature effect in the reflector and moderator regions is smaller than a negative effect in the driver fuel region. The net temperature coefficient is therefore negative. The pressure coefficient was also shown to be negative. Although the model used in these calculations was H_2O moderated and

TABLE VII. - REACTIVITY COEFFICIENTS FOR A LIGHT-WATER-MODERATED AND -COOLED TEST REACTOR

Variable, P	Range	Reactivity change, $\Delta k/k$	Coefficient $\Delta k/k$/deg K	$\frac{\Delta k/k}{\Delta P/\overline{P}}$
Driver fuel coolant temperature	300 to 325 K	-0.0060	-2.4×10^{-4}	-0.075
Moderator temperature	300 to 325 K	+.0038	$+1.5\times10^{-4}$	+.048
Reflector coolant temperature[a]	300 to 325 K	+.0008	$+3.2\times10^{-5}$	+.010
Reactor pressure	1 to 200 atm	-.0018	[b] -9×10^{-6}	(c)

[a]10 Vol. % of reflector.
[b]$\Delta k/k$/atm.
[c]Not applicable because of large value of $\Delta P/\overline{P}$, the ratio of the change in a physical property to the average value of that property.

cooled, it is unlikely that any configuration changes contemplated in this report would significantly affect the results in table VII other than changing the moderator to H_2O-cooled Be. In that case the change would be toward a more negative net temperature coefficient.

Design Variations

Effects of several contemplated changes to the reference design are listed in table VIII.

Argon appears to be a desirable gas for certain planned cavity experiments from the standpoints of heat transfer and buoyancy. Neutronically, an advantage also exists because power split Q_D/Q_C is reduced to 14. Thus, driver power could be 35 percent less and still produce the required cavity flux. The lower absorption cross section of argon accounts for less parasitic absorptions of neutrons in the region between the moderator and the cavity fuel. The increased fraction of neutrons being absorbed in the cavity fuel (lower Q_D/Q_C) tends to increase the driver fuel mass required for criticality. Since argon cross sections were not available in a usable format at the time, calculations were performed using zero values for argon. The results should be reasonably accurate, however, because of the low measured values for argon cross sections (ref. 10).

The use of General Atomic Reactor for Training, Research and Isotope Production (TRIGA) fuel elements was considered because of their safer operating characteris-

TABLE VIII. - EFFECT OF DESIGN VARIATIONS ON REFERENCE

MODEL TEST REACTOR

Parameter	Driver fuel critical mass, kg ^{235}U	Power split Q_D/Q_C
Reference model test reactor	8.8	21
Argon used as cavity gas	9	14
MTR fuel elements replaced with TRIGA fuel elements	11	24
Addition of 2.54-cm-thick Al shell plus 2.54-cm-thick H_2 buffer zone for pressure barrier	10.4	31
In pressure barrier model, all Al shells except cavity liner replaced by ^4Zr shells	10.1	29

tics and flux burst capability. Power split (and therefore driver power) was increased about 14 percent. In this case, increased parasitic absorption in the driver fuel (more cladding per unit fuel) caused the required critical mass to increase. Increased driver fuel mass leads to a lower flux and a higher power split (ref. 1). Simply stated,

$$Q_D \approx M_D \varphi_D \tag{1}$$

$$Q_C \approx M_C \varphi_D \tag{2}$$

$$\frac{Q_D}{Q_C} \approx \frac{M_D}{M_C} \tag{3}$$

where Q_C is cavity power, Q_D is driver power, M_C is cavity fuel mass, M_D is driver fuel mass, and φ_D is the neutron flux resulting from driver fuel fissions. The major assumptions are that no spectral changes occur and that $\varphi_C << \varphi_D$. In this calculation, a counteracting effect (on critical mass) is the increased moderation of the uranium - zirconium hydride (U-ZrH) fuel matrix. Unfortunately, the power density that will be required in the test reactor will exceed the maximum allowable in TRIGA fuel by a factor of 2 or 3.

Operation of the driver reactor at low pressure while the cavity is at 200 atmospheres would be advantageous. Inclusion of a 2.54-centimeter-thick Al pressure vessel and a 2.54-centimeter-thick H_2 buffer zone to withstand a 200-atmosphere pressure drop caused the required driver power to be increased by 50 percent. The inclusion of these regions not only increased parasitic absorption, but it also pushed the driver fuel further from the cavity fuel, as shown in figure 5. Since fuel density and region thickness were relatively constant, the amount of driver fuel required for criticality increased. As before, this increase caused the power split to increase.

In an effort to reduce parasitic absorption, Al was replaced by Zircaloy-4 in all shells. Only a small reduction of power split (6 percent from the pressure barrier model) occurred. Apparently, a significant part of the pressure barrier penalty was

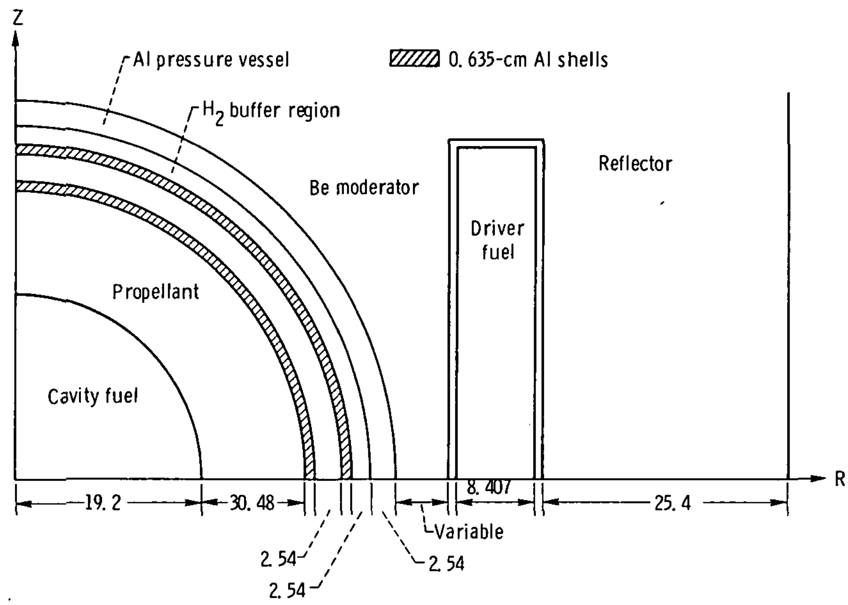

Figure 5. - Model of cavity test reactor with a pressure barrier between test cavity and driver reactor.

movement of the driver fuel away from cavity. This was corroborated in a subsequent calculation with a void in place of the pressure barrier material ($Q_D/Q_C = 26$). Possibly, significant reductions in power split could be achieved by reducing the test cavity diameter.

CONFIGURATION SELECTION

Within the limits of this study it was possible to select a number of defining characteristics of the cavity test reactor. Based on a previous analysis (ref. 1) the following general configuration was selected: a 61-centimeter-diameter spherical cavity surrounded by a moderator region, a cylindrical driver fuel region of MTR-type fuel elements, a cylindrical Be reflector with a nominal thickness of 25.4 centimeters, axial slab reflectors of 25.4-centimeter-thick Be, and a steel pressure vessel nominally 10 centimeters thick. The moderator material was limited to Be and H_2O from parametric analyses that used minimum driver power as the criterion. Optimum moderator thicknesses (minimum driver power) were about 10 and 2 centimeters for Be and H_2O, respectively, from spherical calculations. When these dimensions are translated to real geometry (spherical cavity and cylindrical driver fuel region), thicknesses along the radial midplane are 8 and 2.5 centimeters for Be and H_2O, respectively. (The H_2O moderator is retained in a cylindrical annulus, whereas the Be moderator fills the region between the spherical cavity structure and the cylindrical driver fuel.) Beryllium was selected as the moderator material because the potential results of a loss-of-moderator (liquid) accident would be less severe and a somewhat better power split could be achieved. Loss of H_2O coolant in the Be moderator (10 percent by volume) resulted in an increase of 3.2 percent $\Delta k/k$, whereas loss of H_2O moderator increased reactivity by 6.1 percent $\Delta k/k$.

Rotating drums were selected as the control system. A drum control system was shown to provide a 21-percent $\Delta k/k$ range, which provided a sufficient margin over the 18 percent $\Delta k/k$ required for operation. The use of drums, as opposed to rods, allowed more driver fuel elements to be included in the fuel annulus, thereby reducing power density. Rods would probably require channels in the fuel annulus.

Determination of the driver fuel arrangement (number of fuel elements and their length) will require further study. The compromise between power level and fuel life will require an evaluation using operating costs and possibly a better definition of the problems associated with core replacement and variations in the cavity flux requirement. Data from figure 3 have been crossplotted in figure 6 to show the effect on attainable cavity flux as a function of power level and fuel life. For the present requirement of 10^{15} neutrons/cm^2/sec in the cavity, 100-hour life was not attainable in the calculated configurations. Extrapolation of the lifetime curve is risky because of its decreasing slope, which results from the fact that power split decreases as fuel volume increases.

For this study the assumption is made that a fuel-element life of 50 hours represents an acceptable condition. Interpolation of data in figure 6 gives a required driver power of 200 megawatts to supply a flux of 10^{15} neutrons/cm^2/sec to the test cavity. Driver fuel volume will be about 8.8×10^4 cubic centimeters, which could be achieved by lengthening a single row (33 elements in an annulus) of fuel elements to 101 centimeters.

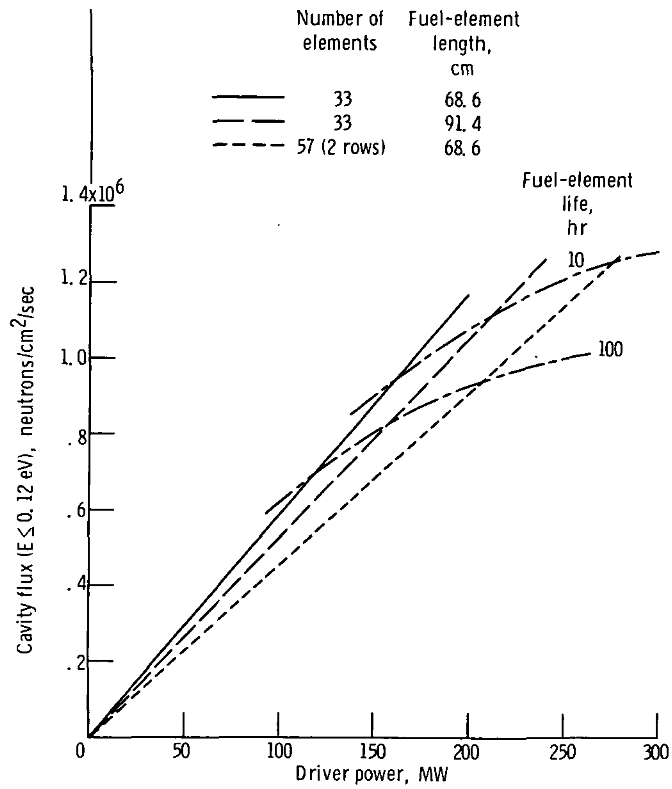

Figure 6. - Cavity flux in a cavity test reactor as function of driver power for various driver fuel arrangements.

SUMMARY OF RESULTS

Data from this study plus previous work led to the selection of a configuration for a cavity test reactor. The basic criteria were that a 61-centimeter-diameter test cavity with an average flux of 10^{15} neutrons/cm^2/sec ($E \leq 0.12$ eV) operate at a pressure of 200 atmospheres. The criteria can be achieved by a reactor composed of a spherical test cavity surrounded by a moderator region, a cylindrical annulus of H_2O-cooled Mockup Test Reactor (MTR)-type fuel elements as the driver fuel, 25.4-centimeter-thick beryllium (Be) radial and axial reflectors, and a 10-centimeter-thick steel pressure vessel. The moderator material is the same as the reflector, Be with 10 percent by volume H_2O coolant, and the moderator thickness along a radial midplane is 8 centimeters. The entire reactor will operate at 200 atmospheres. Although a definite driver fuel arrangement was not determined, one capable of a 50-hour fuel-element lifetime would be a single row (33) of elements 101 centimeters in length. Required driver power would be 200 megawatts. Control would be achieved with rotating poison drums.

Specific results from this study are as follows:

1. Optimum thicknesses for spherical shell regions of H_2O and Be moderator materials are about 2 and 10 centimeters, respectively.

2. Required driver power increases as the driver fuel arrangement is varied to increase volume compared to the single-row-annulus (33 elements), 68.6-centimeter-long configuration.

3. A range of 18 percent $\Delta k/k$ is required for the control system. Poison drums located adjacent to the outer fuel boundary can produce a 21-percent $\Delta k/k$ range.

4. Reactivity coefficients were calculated for reactor temperature and pressure changes which show a net negative temperature coefficient and a negative pressure coefficient.

5. Effects of several design variations were determined: (a) argon as the cavity gas would decrease required driver power by about 35 percent; (b) General Atomic Reactor for Training, Research, and Isotope Production (GARTRIP) fuel elements as driver fuel would cause a 15-percent increase in required power, but their power density limit is exceeded; (c) inclusion of a pressure barrier in order to operate the driver reactor at low pressure would increase required power by 50 percent; and (d) use of Zircaloy-4 in place of aluminum in the reactor structure would decrease required power by 6 percent.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 22, 1973,
503-04.

APPENDIX - CALCULATIONAL MODEL GEOMETRY

Parametric calculations were performed with a spherical model to simplify problem setup and to reduce machine time. Comparison with the more geometrically correct two-dimensional cylindrical model is shown in table IX. Region volumes and material densities were preserved when the spherical model was synthesized. Both the multiplication factors and the power split are sufficiently close to warrant the use of the spherical model.

The 91.4-centimeter-fuel-length case was included to indicate that the accuracy of the spherical model power split decreases as the length of the cylindrical fuel element increases.

TABLE IX. - EFFECT OF CALCULATIONAL MODEL ON MULTIPLICATION FACTOR

Model	Fuel length, cm	Multiplication factor		Power split, k_D/k_C
		Cavity, k_C	Driver, k_D	
Sphere S_4P_0 10-group	[a]68.6	0.0615	1.0892	17.7
R-Z S_2P_0 10-group	68.6	.0520	1.0840	20.8
R-Z S_2P_0 10-group	91.4	.0473	1.0766	22.8

[a]Spherical shell volume equal to 68.6-cm length in cylindrical geometry.

REFERENCES

1. Whitmarsh, Charles L., Jr.: Preliminary Neutronic Analysis of a Cavity Test Reactor. NASA TM X-2743, 1973.
2. Rom, Frank E.: Comments on the Feasibility of Developing Gas-Core Nuclear Reactors. NASA TM X-52644, 1969.
3. Clement, J. D.; and Williams, J. R.: Gas-Core Reactor Technology. Reactor Tech., vol. 13, no. 3, Summer 1970, pp. 226-251.
4. Barber, Clayton E.: A Fortran IV Two-Dimensional Discrete Angular Segmentation Transport Program. NASA TN D-3573, 1966.
5. Engle, Ward W., Jr.: A Users Manual for ANISN: A One Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering. Rep. K-1693, Union Carbide Corp., Mar. 30, 1967.
6. Soltesz, G. D.; Disney, R. K.; and Collier, G.: User's Manual for the DOT-IIW Discrete Ordinates Transport Computer Code. Rep. WANL-TME-1982, Westinghouse Electric Corp., Dec. 1969.
7. Joanou, G. D.; and Dudek, J. S.: GAM-II. A B_3 Code for the Calculation of Fast-Neutron Spectra and Associated Multigroup Constants. Rep. GA-4265, General Atomic Div., General Dynamics Corp., Sept. 16, 1963.
8. Joanou, G. D.; Smith, C. V.; and Vieweg, H. A.: GATHER-II. An IBM-7090 FORTRAN-IV Program for the Computation of Thermal-Neutron Spectra and Associated Multigroup Cross Sections. Rep. GA-4132, General Atomics Div., General Dynamics Corp., July 8, 1963.
9. Hyland, Robert E.: Evaluation of Critical Mass for Open-Cycle Gas-Core Rocket Reactors. Nucl. Tech., vol. 12, no. 2, Oct. 1971, pp. 152-161.
10. Hughes, Donald J.; and Schwartz, Robert B.: Neutron Cross Sections. Second ed. Rep. BNL-325, 2nd ed., Brookhaven National Lab., July 1, 1958.

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