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INFORMAL AEC RESEARCH & DEVELOPMENT REPORT

AN ANALYSIS TO DETERMINE THE PERCENTAGE OF HELIUM BYPASSING
THE CORE DUE TO THE REFLECTOR SEALING SYSTEM
DURING NORMAL OPERATION OF THE H T G R

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TABLE OF CONTENTS

	ii
TITLE PAGE	i
ABSTRACT	iii
LIST OF ILLUSTRATIONS.	iv
REFERENCES	v
NOMENCLATURE	vi
I INTRODUCTION	1
II ANALYSIS	4
III DISCUSSION AND CONCLUSIONS	7
IV RECOMMENDATIONS FOR FUTURE WORK.	8
APPENDIX A ANALYSIS TO DETERMINE THE AVERAGE EFFECTIVE GAP BETWEEN SEALING SURFACES, Z	A-1
APPENDIX B ANALYSIS TO DETERMINE THE AMOUNT OF BOWING OF THE TOP SEALS DUE TO THE TEMPERATURE GRADIENT ACROSS THEM	B-1

ABSTRACT

The primary purpose of this report is to predict the percentage of helium which will bypass the core if the reflector system shown in Figure 1 is used. It is estimated that nominally about 0.1 to 0.2% of the total flow will bypass the core, which is not considered excessive. The most difficult parameter to determine was Z the gap between the sealing surfaces. The method used to predict Z is presented in Appendix A. In Appendix B the effect of bowing due to a temperature gradient across the seals is discussed.

LIST OF ILLUSTRATIONS

iv

FIGURE 1	SCHEMATIC OF TEETER-TOTTER SYSTEM	2
FIGURE 2	TOP VIEW OF CORE	3
FIGURE 3	SCHEMATIC OF THE TOP OF THE VERTICAL SEAL	6
FIGURE 4	SCHEMATIC OF THE TOP SEAL	6
FIGURE A-1	SCHEMATIC OF TEST APPARATUS	A-2
FIGURE A-2	DETAIL OF PLATE AND BLOCK	A-3
FIGURE A-3	FLOW VS PRESSURE DROP	A-5
FIGURE A-4	RESULTS OF TESTS (Z, EFFECTIVE GAPS)	A-6
FIGURE B-1	SKETCH FOR EQUATION (B-2)	B-2

REFERENCES

v

1. Fluid Mechanics, R. C. Binder, Second Edition, Third Printing
2. Thermodynamic and Transport Properties of Helium, M. P. Wilson, Jr., GA-1355, TID-4500 (15th Ed.), Department of Commerce, Washington 25, D. C.
3. GAMD-1375, Design Criterion of Plenum to Reflector Block Seal for HTGR Reactor Vessel
4. GAMD-449, Recommended High Temperature Helium Properties
5. Formulas for Stress and Strain, R. J. Roark, Third Edition
6. Handbook of Chemistry and Physics, Hodgeman and Lange, 14th Edition
7. Strength of Materials Part II, Timoshenko, 2nd Edition
8. Heat Transmission, McAdams, Third Edition

N O M E N C L A T U R E

vi

A = cross-sectional opening, ft^2

b = dimension shown in Figure B-1, in.

d = dimension shown in Figure B-1, in.

D = hydraulic diameter, ft

g = constant $4.18 \times 10^8 \text{ ft/hr}^2$

h = dimension shown in Figure B-1, in.

k = length around inside of block, ft

L = width of the opening, ft

N_r = Reynolds number

Δp = pressure difference across surfaces, lb/ft^2

Q = total quantity of flow ft^3/hr

r = radius of curvature, in.

R = hydraulic radius, ft

μ = viscosity, lb/hr-ft

V = velocity, ft/hr

w = specific weight, lb/ft^3

Z = the average effective gap between sealing surfaces, ft

The object of this report is to predict the percentage of helium that will bypass the core due to the reflector sealing system, shown in Figure 1, during normal operation of the HTGR.

The primary object of the reflectors is to reflect neutrons back into the core. Secondly, they are being used to hold the core during operation of the reactor. This holding is accomplished by forces the reflectors exert on the core from differential pressure across the reflectors. This differential pressure is caused by the pressure drop due to friction and expansion of the helium as the helium is forced through the core. Various other systems of holding the core were analyzed but it appeared that this system would be the best. When the helium gas is turned off there is no load on the core which allows easy removal of all core elements.

To allow the reflectors to move in and out in order to hold the core, it is necessary that they be segmented. At the present time there are 30 inner reflectors (see Figure 2). If the reflectors are to move in and out in order to hold the core, it is necessary to place seals between the plenum and reflector blocks and between the reflector blocks themselves to restrict the amount of helium bypassing the core. This report will show the method used to determine the amount of helium that will bypass the core during normal operation for the system shown in Figure 1. It will be noted that the magnitude of the leak rate is very sensitive to the gap between sealing surfaces (see II Analysis). Because of this sensitivity, it is impossible to make an accurate prediction of the amount of leakage through the seals. It is, however, possible to make a reasonable estimate of the leakage that will occur. Tests were performed to determine the average effective gap between sealing surfaces. It was determined (see Appendix A) that an average effective gap width of 0.002 inches would be reasonable to expect. On the basis of this evaluation of the

FIGURE I - SCHEMATIC OF TEETER-TOTTER SYSTEM

FIGURE 2 - TOP VIEW OF CORE

test data, the prediction as to the amount of leakage through the teeter-totter reflector system was made. Appendix A discusses the method used to determine the average effective gap, Z and Appendix B discusses the possible bowing of the top seals due to the temperature gradient across them. These appendices were written in order to simplify the main report and clarify the points mentioned.

II. ANALYSIS

As stated in the introduction, the purpose of this report is to predict within reasonable limits, the amount of helium bypassing the core. By referring to Appendix A and the equations shown, the following calculations can be made:

It will be assumed to start that the flow is laminar (this will be checked later in the calculations). To determine the amount of flow (if laminar) Equation A-6 is used

$$Q = \frac{\Delta p Z^3}{12 L \mu} \text{ kg} \quad (\text{ref Appendix A}) \quad (\text{A-6})$$

It can be seen from the equation that the accuracy of the calculations is highly dependent on Z. If this term varies by a factor from 1 to 2 (which can be the case), the flow rate varies by a factor from 1 to 8. The gap Z is difficult to determine because it is dependent on many things; the finish, the surface flatness or waviness, effect of temperature, the effect of radiation, etc. The test samples run, although small in number, should allow a reasonable prediction to be made. Additional losses other than those included in the test data (entrance, exit, expansion, etc.) are ignored. These losses will not affect the accuracy of the final results significantly due to the magnitude of the possible

variation in Z. The following assumptions are made:

1. The top seal blocks are straight rectangular pieces (the blocks are actually curved in one direction but for calculations of leakage and bowing due to temperature (Appendix B) this is not important since the curvature is small and the blocks will be made to be flush against the curved surface).
2. The Δp across the reflector blocks varies uniformly from 3.5 psi at the top to 0 psi at the bottom.
3. The sealing surfaces are parallel and have an average gap of 0.002 in. between them due to surface irregularities. (see Appendix A)

Once the temperature distribution at various points in the area of the seals is determined, the seals should be designed so that an average gap of .002 inches would be maintained during normal operation. A temperature gradient across the graphite blocks of 700°F (a conservative average gradient) will cause them to bow about .006 inches (see Appendix B). If the amount the seal blocks will bow is known they can be machined so that at operating conditions they will be flat against the sealing surfaces.

The sealing system is shown schematically in Figures 1 and 2. Figures 3 and 4 show a schematic of the top and vertical seals. For the 30 reflector blocks there would be the following leak surfaces:

- A. 30 vertical seals
- B. 30 large top seal pieces
- C. 30 small top seal pieces

For A, the Average $\Delta p = 1.75$ psi, $Z = .002$ in, $k = (30)(144)(2) \approx 8640$ in, $g = 4.18 \times 10^8$ ft/hr², $L = 1$ in and $\mu = .081$ lb/hr-ft (Ref. 4 at 700°F). Using Equation (A-6) and these values $Q \approx 4350$ ft³/hr.

If the vertical seal pieces were made of graphite instead of sheet metal (which might be the case), the pieces would be approximately

FIGURE 3 - SCHEMATIC OF THE TOP OF THE VERTICAL SEAL

FIGURE 4 - SCHEMATIC OF THE TOP SEAL

.25 inches thick and 4 inches long. The length of 4 in. is determined due to a limit imposed by the geometry at the top of the blocks when removing these pieces. This means there would be 36 pieces per vertical seal. To determine this leak rate, the average $\Delta p = 1.75$ psi, $k = (36)(30)(2.25) \cong 2430$ in. and $L = .25$ in., Z , g and μ are as above. Using Equation (A-6) and these values $Q \cong 4880$ ft³/hr.

For B and C, the average $\Delta p = 3.5$ psi, $k = (2)(2\pi)(65) \cong 816$ in., $L = 1.00$ in. (a conservative average, Z , g and μ are as above). Using Equation (A-6) and these values, $Q \cong 818$ ft³/hr. It should be noted that the top seals are actually more complicated than the calculation shows, but again due to the possible variation in Z this should be a good approximation.

In order to be sure that the flow is laminar equations (A-1), (A-2), (A-3) and A-4) can be combined eliminating D , R and V to produce

$$N_r = \frac{2w Z Q}{\mu A} \quad (1)$$

Using equation (1) and the values indicated in the calculations shown above it can be seen that the flow across all the seals is laminar.

For example in A, $w = 0.116$ lb/ft³ (at 350 psi and 650°F ref 4), $Z = .002$ in, $Q = 4350$ ft³/hr, $\mu = .078$ lb/hr-ft (at 650° ref 4), and $A = (.002)(8660) = 17.32$ in².

By Equation (1) $N_r \cong 18.0$ which is well in the laminar range.

III DISCUSSION AND CONCLUSIONS

There would be approximately 0.1% of the total flow bypassing the core if the vertical seal was a continuous piece. This is determined by adding the amount of leakage in the first part of A to B and C ($4350 + 818 = 5168$ ft³/hr). The total flow for normal operation is about 4,850,000 ft³/hr ($5168/4,850,000 \cong 0.1\%$). If the vertical seal was made of 36 pieces the bypass would be about 0.2% (to determine this add both parts of A to B and C and proceed as above). These total nominal leakages are not considered excessive.

The gap between the vertical seals and the top seal can be kept to a minimum by hanging the top vertical seal piece from the top of the reflectors as shown in Figure 3. This allows some differential growth between the vertical seal and the reflector blocks without great leakage.

The purpose of the L shaped top seal is to prevent large amounts of leakage if two neighboring reflector blocks expand or contract due to radiation at different rates. If the two neighboring reflector blocks become different lengths only the small L piece of the seal tilts. The larger top seal pieces remain flush with their respective reflector block. An additional loss would occur if there were excessive gaps between the reflectors and the dummy reflector elements and between the reflectors themselves. The gaps between the reflectors and dummy reflector elements could be reduced by using a linkage on the bottom of the reflector block teeter-totter mechanism which would pivot the reflector against the dummy reflector (this is currently in the design). If this is done there is a negligible gap. The gaps between blocks can be plugged by horizontal pieces as shown in Figure 1. The stresses on all sealing components due to loading is small and no breakage due to any loading condition is anticipated. The system as shown will allow the removal of all components (inner and outer reflectors, top seals and vertical seals).

IV RECOMMENDATIONS FOR FUTURE WORK

When the final configuration is agreed on the thermal stresses on all components of the sealing system should be determined. Approximate calculations have been done, but a final check should be made. It would be desirable to insulate the top seals, but what this insulation looks like will depend in part on the insulation in the plenum (this plenum insulation has not as yet been decided).

Studies are being made at this time to try and determine the easiest method of removing all core components. It would be a good idea to make a model of the final system (perhaps using the flow model) to be sure the complete removal and replaceability of all components can be accomplished without any unexpected problems.

APPENDIX A
ANALYSIS TO DETERMINE THE AVERAGE EFFECTIVE
GAP BETWEEN SEALING SURFACES, Z

I INTRODUCTION

The object of this appendix is to show the method used to determine the average effective gap between sealing surfaces, Z. It is necessary to determine this gap in order to make a reasonable prediction as to the total amount of helium leakage thru the seals.

Since the top seal blocks in the reactor would probably be the most difficult to machine and keep flat (due to their length and larger size), AGOT graphite blocks were built which would simulate these top seal blocks and tests were made for the primary purpose of determining the gap, Z. The plastic block was made only in order to correlate test data of the flow model and will not be discussed in this report.

The analysis, conclusions, and recommendations for future work are discussed below.

II ANALYSIS

A schematic of the test apparatus is shown in Figure A-1. It consisted of a helium bottle and a straight copper pipe connected to a flat plate (both graphite and steel plates were used). The block shown (either graphite or plastic) was placed on top and the helium was forced into the opening. A detailed drawing of the plates and blocks is shown in Figure A-2. The pressure in the opening was recorded by means of a mercury manometer.

FIGURE A-1 - SCHEMATIC OF TEST APPARATUS

BLOCK - FOUR GRAPHITE AND ONE PLASTIC

PLATE - TWO GRAPHITE AND ONE STEEL

Block No.	Dimensions	
	A	B
1	1-1/2	1
2	1/2	1/4
3	1/2	1/4
4	1-1/2	1
Plastic	1/2	1/4

A-3

FIGURE A-2 - DETAIL OF PLATE AND BLOCK

The amount of flow through the pipe for various pressure drops across the pipe was plotted (see Figure A-3.)

Two graphite base plates were made to see if reasonably consistent results from two different plates could be obtained. The steel plate was made to see if there would be any difference between using a steel or graphite base plate. The finish on the graphite pieces was estimated to be better than a 32 rms finish. The steel piece was about 20 rms. The sealing surface wall thicknesses, as shown in Figure A-2, were $1/4$, $1/2$, 1 and $1-1/2$ inches. There were two of each of these to again see if reasonably consistent results could be obtained.

Various base plate and block combinations were tested (Plate No. 2 with all the blocks is shown as typical data in Figure A-4 since both graphite plates and the steel plate showed no significant difference.) The internal pressure was the main variable and was recorded from 1 to 3 psig. In Figure A-4 it can be seen that there are differences between two blocks with the same wall thicknesses which indicates that the surfaces are not flat but are irregular along their length. The blocks had to be held down with weights due to the internal pressure trying to lift them. Varying the weights on top of the blocks from 200 lbs to 250 lbs made no appreciable change in the leak rate.

Columns 1 through 7 show the values used for the parameters of the equations and column 8 shows the values calculated for Z for each of the block plate combinations.

The procedure for calculating the Z's is shown in the following paragraphs.

FIGURE A-3 FLOW VS. PRESSURE DROP

1	2	3	4	5	6	7	8
CASE NO.	BLOCK NO.	L, In	PRESSURE DROP GAGE INCHES OF WATER	Q, ft ³ /hr FIGURE 2	Δp , PSI	k, In	Z, AVERAGE GAP WIDTH, In
1	4	1-1/2	.010	3.5	1.0	35	.001354
2			.019	6.0	2.0		.001285
3			.029	9.0	3.0		.001285
4	1	1-1/2	.026	8.0	1.0	35	.001780
5			.052	16.0	2.0		.001780
6			.075	23.0	3.0		.001757
7	4	1	.018	5.5	1.0	39	.001327
8			.036	11.0	2.0		.001327
9			.059	18.0	3.0		.001346
10	1	1	.055	17.0	1.0	39	.001932
11			.100	30.5	2.0		.001866
12			.155	42.0	3.0		.001812
13	3	1/2	.034	10.7	1.0	43	.001272
14			.070	21.3	2.0		.001270
15			.105	32.0	3.0		.001270
16	2	1/2	.034	10.7	1.0	43	.001272
17			.068	21.0	2.0		.001264
18			.105	32.0	3.0		.001270
19	3	1/4	.112	34.0	1.0	45	.001470
20			.215	65.0	2.0		.001448
21			off scale	-	-		-
22	2	1/4	.165	50	1.0	45	.001673
23			.250	75.7	1.5		.001526
24			off scale	-	-		-
25	plastic	1/2	.115	35	1.0	43	.001888
26			.230	69.5	1.5		.002070
27		1/4	-	-	-	-	-
28			-	-	-		-

FIGURE A-4 - RESULTS OF TESTS BLOCK FLAT (Z, EFFECTIVE GAPS)

The first thing that must be done is to predict the type of flow by determining the Reynolds number. This can be done as follows:

The relation for Reynolds number is

$$N_r = \frac{wVD}{\mu} \quad (\text{ref 1, page 81}) \quad (\text{A-1})$$

An expression for hydraulic diameter is

$$D = 4R \quad (\text{ref 1, page 246}) \quad (\text{A-2})$$

The hydraulic radius is defined as

$$R = \frac{\text{cross sectional area}}{\text{wetted perimeter}} = \frac{Zk}{2k} = \frac{Z}{2} \quad (\text{ref 1, page 246}) \quad (\text{A-3})$$

The total quantity of flow Q in ft^3/hr is

$$Q = AV = ZkV \quad (\text{ref 1, page 42}) \quad (\text{A-4})$$

Combining Equations (A-1), (A-2), (A-3), and (A-4) and eliminating R , D , Z , and V , the following equation is obtained

$$N_r = \frac{2wQ}{\mu k} \quad (\text{A-5})$$

The Reynolds number can be found by substituting the following values in equation (A-5); $w = .01108 \text{ lb}/\text{ft}^3$ (ref 2, page 55 at 80°F and 16 psia), $Q = 42 \text{ ft}^3/\text{hr}$ (using case No. 12; a typical case from the data of Figure A-4), $\mu = .0480 \text{ lb}/\text{hr-ft}$ (ref 2, page 52 at 80°F) and $k = 39 \text{ in}$ (case 12 Figure A-4). It is calculated that $N_r \approx 6.0$. Since this means the flow is well in the laminar range the effective gap between the surfaces Z

is calculated by the relationship:

$$Q = \frac{\Delta p Z^3 k g}{12 L \mu} \quad (A-6)$$

(ref 3 and ref 8 page 149)

or rearranging

$$Z = \left(\frac{12 L \mu Q}{\Delta p k g} \right)^{1/3} \quad (A-7)$$

Using equation (A-7), the gap Z for each case was computed. Fig. A-4 shows the computed values of Z.

III CONCLUSIONS

The average effective gap between sealing surfaces is determined to be 0.002 in. for the purpose of computing leakage across the sealing surfaces. This may appear slightly conservative but it does not account for wearing of the surfaces and any additional bowing of blocks on the sealing surfaces due to a temperature gradient across the seals (discussed in Appendix B). No attempt to refine the test was made since the intent of the test was mainly to determine what approximate gap might occur. The surface finish does not effect the leak rate to any great degree which might at first appear to be the case, the main problem is to eliminate any unevenness between the seals and the reflector blocks.

IV RECOMMENDATIONS FOR FUTURE WORK

It would probably be worth the time to check to be sure the top seals do not flutter due to the helium going across them. This does not seem likely to occur, but it could be checked by making a simple test setup to reproduce the loading on a 3 inch by 3 inch seal.

APPENDIX B

ANALYSIS TO DETERMINE THE AMOUNT OF BOWING OF THE
TOP SEALS DUE TO THE TEMPERATURE GRADIENT ACROSS THEM

I INTRODUCTION

The purpose of this appendix is to show simply that a large temperature gradient across the top seals (700°F) does not cause an excessive bowing of the top seal blocks. It is desirable to determine the exact bow in the blocks during normal operation due to the temperature gradient. This should be determined when the final design in the area of the top seal is completed. If the additional bow can be predetermined the blocks can be made so that at normal operating temperature the sealing surfaces are flat against each other. The calculations show the worst possible case (a temperature difference of 700°F is used. This should be a conservative average gradient across the seal blocks). It is interesting to note that if the seals were made of steel the amount of bowing would increase in proportion to the ratios of the α 's, the coefficient of thermal expansion. If the seals were steel instead of graphite the gaps would be about 8 times as large.

II ANALYSIS

The amount of bow was determined in the following way:

For a straight rectangular piece the radius of curvature resulting from a temperature gradient across the piece can be calculated by the following relation. This assumes a linear gradient across the block.

$$r = \frac{h}{\alpha t} \quad (\text{ref 7 page 134}) \quad (\text{B-1})$$

If $h = 3$ in, $\alpha = 1.3 \times 10^{-6}$ in/in $^{\circ}\text{F}$, and $t = 700^{\circ}\text{F}$ then $r = 3300$ in.

The length of the block, b is about 12.5 in. To determine the gap at the center, d (shown in Figure A-1) the following relation can be written

$$r^2 = \left(\frac{b}{2} \right)^2 + (r-d)^2$$

or

$$d = - \left[r^2 - \left(\frac{b}{2} \right)^2 \right]^{1/2} + r \quad (\text{B-2})$$

By substituting $r = 3300$ in and $b = 12.5$ inches in Equation (B-2), $d = 0.006$ inches.

FIGURE B-1 SKETCH FOR EQUATION (B-2)

III DISCUSSION

It should be noted that the seal block is not a straight rectangular piece, but for the small d involved the method used is correct. It should again be mentioned that the top seal blocks could be machined with a bow in them (for instance, if the temperature gradient were 700°F a bow of 0.006 in) then the temperature would tend to remove the additional bow and the seal blocks would be flat against the sealing surface. It should also be noted that the pressure would have a tendency to make the blocks deform flat against the sealing surface.