GENERAL ATOMIC

Division of General Dynamics Corporation

John Jay Hopkins Laboratory
for Pure and Applied Science

GAMD - 2638
Category A

HELIUM INLEAKAGE THROUGH POROUS-WALLED FUEL ELEMENTS

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Project No. 32.220
U.S. Atomic Energy Commission
AT(04-3)-314

November 21, 1961

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SUMMARY

Recent theoretical and experimental studies have indicated that the effective permeability coefficient for graphite is lowered by a helium stream in-sweeping through the graphite pores. This phenomenon has been considered in the design of HTGR fuel elements. A portion of the helium gas which is drawn into each fuel element as a purge stream may enter through porous wall sections, supplementing the purge gas entering at the top of each fuel element. The purge stream leaves each fuel element through a header system which carries the purge gas to an external fission product trap. The flow rate through the trapping system determines the upper limit of the average in-leakage through the fuel element walls. In the case of the HTGR, a graphite having a helium permeability of 1.1 cm^2/sec at 350 psia and 700°F (approximately 0.1 cm^2/sec at 14.7 psia, 70°F) would result in 100% of the purge flow entering through the wall sections of the fuel element. A lower permeability graphite, with most of the purge flow entering at the top of the fuel element appears more desirable for maintaining optimum purge flow conditions.

INTRODUCTION

In an HTGR type fuel element, a purge gas stream passes through the fuel region of the element and transports fission products to charcoal traps outside the reactor core.[1] Possible advantages exist in an HTGR fuel element design wherein relatively porous graphite sleeves are used in wall sections and in which a portion of the purge stream sweeps inward through the porous walls. It appears that the in-leaking gas stream aids in preventing the release of fission products and allows a relaxation in graphite permeability requirements. The effective back diffusion coefficient against an in-leaking argon or helium sweep stream has been investigated under the Dragon project[2] and is currently under investigation at ORNL [3,4] and at General Atomic.

At present the data is insufficient to define the effective back diffusion coefficient for particular graphite types as a function of temperature, pressure, and gas concentration. However, the data obtained at ORNL and at General Atomic do indicate a decrease in the effective back-diffusion coefficient as the in-sweeping gas flow rate is increased.

A first question which arises in considering a more porous graphite wall material is whether the upper limit on permeability is below that of a base stock graphite. This report indicates an upper limit on the permeability of graphite sleeves as determined by the admittance of helium purge gas. The effective back diffusion coefficient, a parameter beyond the scope of this report, may require a graphite pore spectrum which results in an even lower helium permeability value than the upper limit described here.

A second question to be analyzed in this report is whether an advantage results from drawing 100% of the purge flow stream inward through the wall sections of the fuel elements.

CONCLUSIONS

A graphite of the approximate pore spectrum of base stock HLM-85 and Speer No. 1 or of impregnated HLM-85 grade would require a helium permeability of less than 0.1 cm^2/sec at $70^{\circ}F$ and 14.7 psia in order that the helium in-leakage not exceed the full purge flow rate of 1.1 lb/hr per element for a given HTGR reference design. If all of the purge flow were to enter through the walls of the fuel elements, the helium permeability value would have to be specified within a very narrow range, i.e., less than a factor of $\pm$ 5. If the graphite were too porous, the helium pressure differential across the wall at the upper end of the fuel element would not be maintained, and fission products would diffuse out within that zone. If the graphite were too tight, the purge flow rate through the fuel element would decrease. Any changes in graphite permeability during reactor operation would cause significant changes in the fission product trapping system flow characteristics.

The reference design of the HTGR Peach Bottom fuel element, wherein the major fraction of purge gas enters each fuel element through the upper reflector, appears more favorable for the porous-walled concept than a design in which all of the purge gas enters through the wall sections. The main reason for this conclusion is that the Peach Bottom reference design is insensitive to relatively large variations in leakage through the walls as affected by tolerances in production material and changes in permeability from reactions between the graphite and coolant impurities.

ANALYSIS

The HTGR fuel element is shown schematically in Figure 1. For purposes of this analysis, the fuel element is divided into four zones. Within each zone the sleeve temperature and the main coolant pressure are assumed to be constant. The helium pressure inside of the fuel element is assumed to be constant.

The flow of helium through the fuel element wall is calculated by the equation[5],

$$Q = K \frac{A}{L} \frac{\Delta p}{\bar{p}}$$

where

Q = volumetric flow, cm^3/sec

K = permeability coefficient, cm^2/sec

A = wall area, cm^2

L = wall thickness, cm

Δp = pressure difference across the wall atm

$\bar{p}$ = pressure, atm

The permeability coefficient, K, is dependent upon the material, the pressure, and the temperature. The permeability coefficient may be represented as[6]

$$K = K_1 \sqrt{\frac{T}{M}} + K_2 \frac{\bar{p}}{\eta}$$

where

K_1 = Coefficient for Knudsen flow

T = temperature, °K

M = molecular weight of gas

K_2 = coefficient for viscous flow, cm^2-poise/atm sec

η = viscosity of gas, poise

The permeability coefficient for representative graphite samples has been measured by Truitt[4] and by Riedinger and Graves at General Atomic. Using their curves, the permeability coefficients in each zone from Figure 1 can be calculated. The following Table I summarizes the operating conditions and the permeability coefficients in each zone for four graphite specimens. The helium permeability values at reactor temperature and pressure are calculated by separating room temperature permeabilities at pressures from 1 to 6 atmospheres into Knudsen and viscous components, and applying temperature and pressure corrections to each component.

TABLE I

Zone	Sleeve Temp., °F	Helium Δp Across Sleeve, psi	K, cm^2/sec			
			Speer* No. 1	HLM-85**	ΔZ**	GLI-S10**
1	700	6.5	9.4	24.5	8.3×10^{-2}	1.9×10^{-2}
2	1200	5.8	7.0	18.3	6.4×10^{-2}	1.5×10^{-2}
3	1600	5.2	6.3	16.3	5.9×10^{-2}	1.3×10^{-2}
4	1600	4.6	6.3	16.3	5.9×10^{-2}	1.3×10^{-2}

In all zones the pressure inside the fuel element is 343 psia.

* The Speer No.1 graphite is a moderator material made by Speer Carbon Co. The permeability of this specimen was measured by Truitt at ORNL.

** The HLM-85 is a Great Lakes Carbon Co. base stock. The ΔZ is a specimen of HLM-85 impregnated at General Atomic. The GLI-S10 is a specimen impregnated at Great Lakes Carbon Co. The permeability of these specimens was measured by Riedinger and Graves at General Atomic.

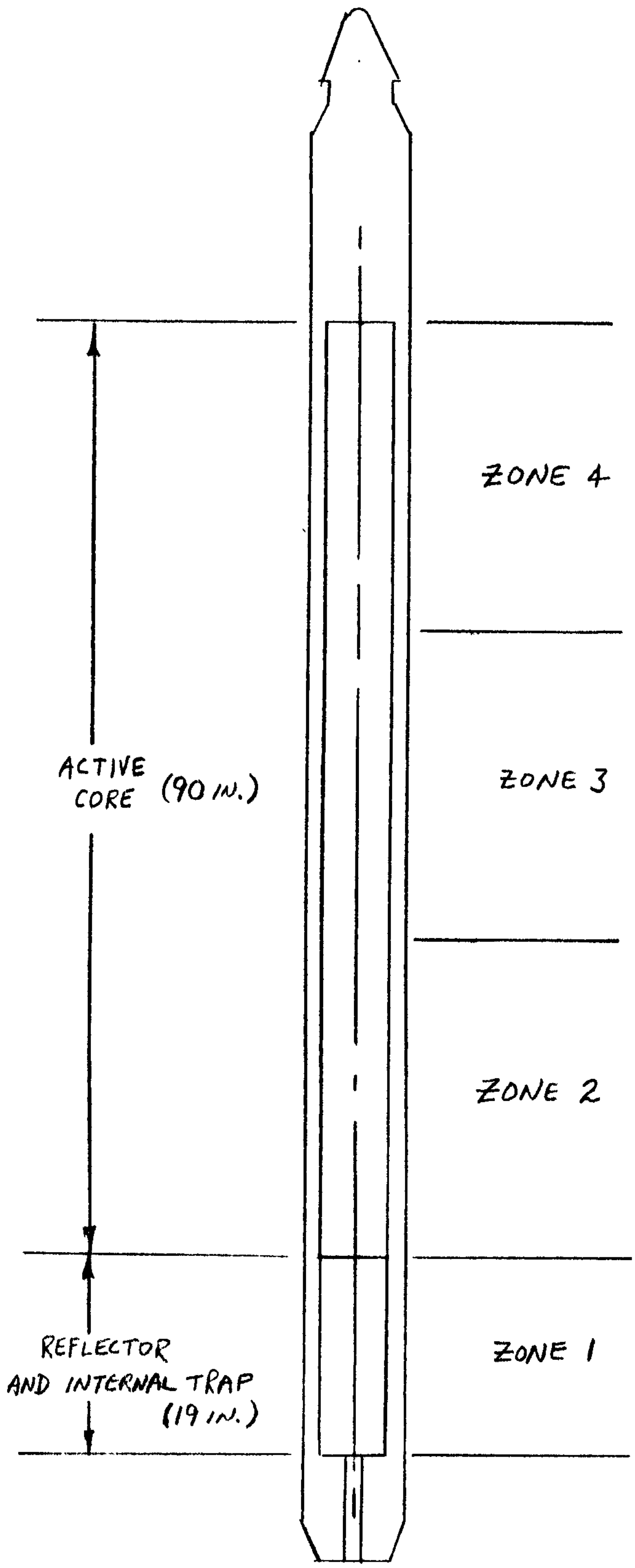
Using the permeability equation and the data is Table I, we may calculate the total flow in-leaking through the fuel element. This data is presented in Table II.

TABLE II

Zone	In-leakage of helium through fuel element wall, lb/hr			
	Speer No. 1	HLM-85	Δ Z	GLI-S-10
1	3.4	8.8	.032	.0085
2	2.3	6.3	.027	.0053
3	1.6	4.1	.018	.0036
4	1.4	3.6	.016	.0032
TOTAL	8.7	22.8	.093	.0206

The total helium in-leakage is plotted against the helium permeability coefficient in Figure 2. The mass flow in-leakages for the four graphites tested fall on a straight line on a log-log plot for the permeability values at 350 psia and 700°F and also at 14.7 psia and 70°F.

The design value of purge flow rate in the HTGR is 1.1 lb/hr per fuel element. This value is shown in Figure 2, and indicates that a graphite similar to the types measured would admit 100% of the purge gas through the wall sections for a room temperature permeability coefficient of 0.1 cm^2/sec or larger. A larger permeability coefficient would result in a lower total pressure differential across the fuel element walls; and hence, a reduced back-sweeping effect in the pores.



FUEL ELEMENT

FIG. 1

HELIUM INLEAKAGE THROUGH FUEL ELEMENT WALLS-HTGR DESIGN

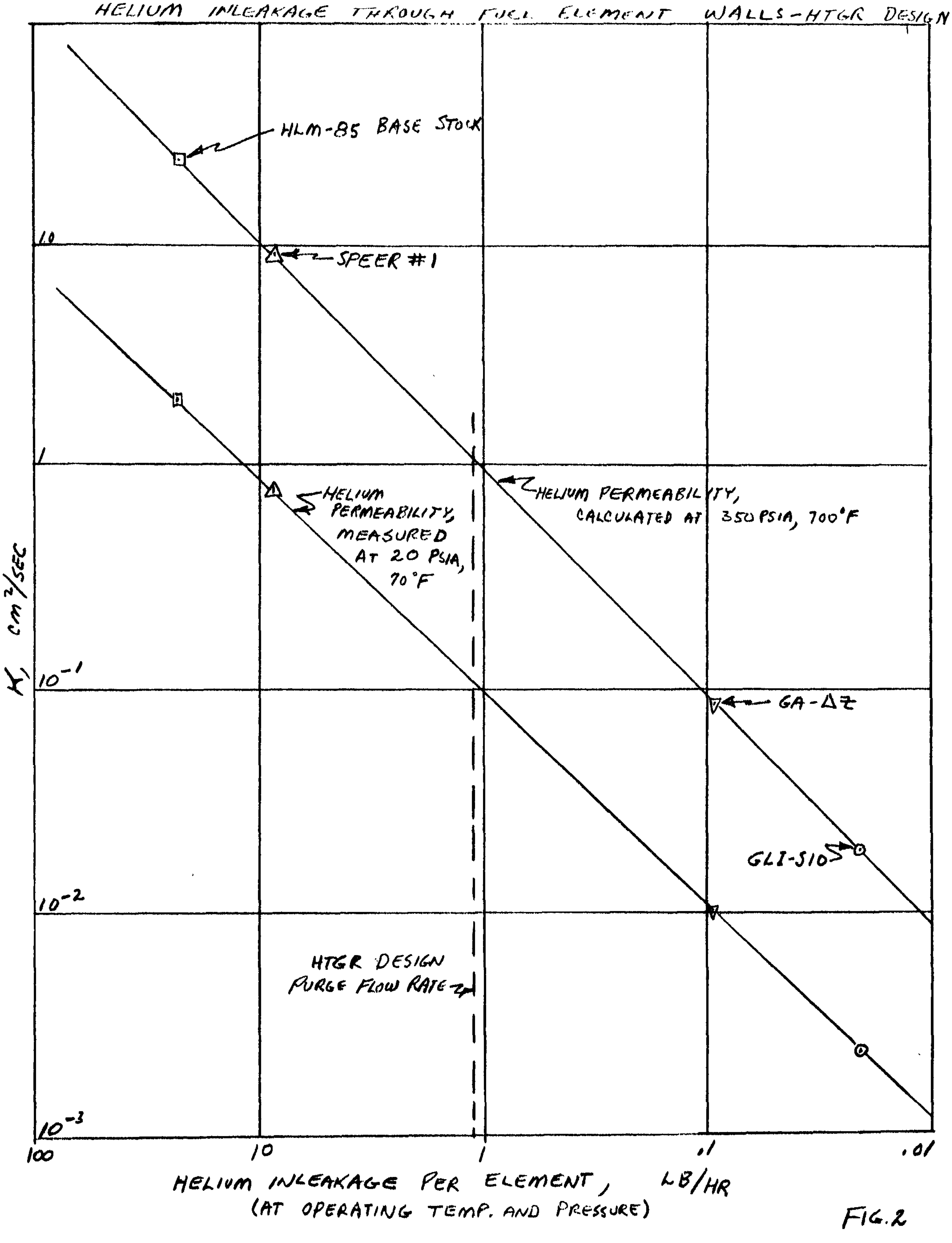


FIG. 2

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