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THE APPLICATION OF A SELF-ACTUATING SHUTDOWN SYSTEM (SASS) TO A GAS-COOLED FAST REACTOR (GCFR)

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I. SUMMARY

The application of a SASS (Self-Actuated Shutdown System) to a GCFR (Gas-Cooled Fast Reactor) is compared with similar systems designed for an LMFBR (Liquid Metal Fast Breeder Reactor). A comparison of three basic SASS concepts is given. All three require a built-in energy absorbing dashpot, and this is considerably more difficult in a GCFR than the LMFBR because of the much lower fluid density.

SASS With Hydrostatic Holdup

This can be used in either an LMFBR or a GCFR. The lower core pressure drop of the GCFR imposes a more severe limitation on the operational capability at partial flow.

SASS With Fluidic Control

This device can, in principle, operate in either reactor system. Since it utilizes only a fraction of the core pressure drop to support the rod, it is particularly sensitive to the lower core pressure drop of the GCFR. Its application is, therefore, considered to be marginal. (See further discussion in Appendix A.)

SASS With Magnetic Holdup

This type of device can be used in either system. The GCFR offers the possible advantage of allowing electrical connections to be made after the unit is installed in the core. In an LMFBR the magnetic coils must be part of the mechanism installed in the shield plug.

II. INTRODUCTION

Several types of SASS have been studied for a sodium-cooled LMFBR. The purpose of this study is to determine the applicability of such systems for a gas-cooled fast reactor. A SASS is defined as a control rod system that can scram the reactor automatically without either a signal from an external control circuit or an operator action. Initiation of the scram must be entirely from direct sensing of inadequate flow, overtemperature, or other direct indication from the reactor.

Particular requirements of the SASS are as follows:

- It must operate automatically.
- It must be fail-safe, such that no malfunction of the SASS can cause a hazardous condition.
- It must not impose excessive restrictions on normal operation of the reactor.
- It must have as little as possible adverse effect upon plant availability.
- It must contribute substantially to the overall safety of the reactor.

As a basis for comparison between gas-cooled and sodium-cooled systems, data for typical GCFR and LMFBR large commercial sized plants was used.[(1)(2)] A summary of the most significant parameters is given in Table I

TABLE I - COMPARISON OF LARGE GCFR AND LMFBR PLANT PARAMETERS AND DESIGN CONDITIONS

	GCFR	LMFBR
Reactor Power (MW)	3600	2540
Plant Output (MW)	1240	910
Number of Loops	6	4
Core Length (In.)	56.7	40.0
Assembly Length (In.)	186	201
No. of Fuel Control Assemblies	366/31	300/30
Coolant	Helium	Sodium
Core Flow Area (Ft^2)	55.1	17.8
Core Pressure Drop (psi)	26	85
Core Inlet Temperature (^oF)	575	670
Core Outlet Temperature (^oF)	1030	950
Coolant Flow Rate (lb/sec)	6000	28200
Coolant Volume Flow (Ft^3/sec)		
Inlet	11490	522
Outlet	16850	547
Coolant Inlet Pressure (psia)	1450	∿100
Coolant Density (lb/ft^3) Inlet	0.522	54.2
Outlet	0.356	51.5

Ratios of some of the basic and derived parameters for the two reactor types are given in Table II. Particularly significant are those parameters related to the coolant densities. The effects of these differences as they relate to various aspects of the design are discussed in Section IV.

TABLE II - MOST SIGNIFICANT CHARACTERISTICS OF GCFR RELATIVE TO LMFBR

		GCFR/LMFBR
Coolant Density	Inlet	0.010
	Outlet	0.007
Leakage Velocity at Same ΔP		10.
Core Pressure Drop		0.3
Core Inlet Volume Flow at Same Power Rating		16.
Power Handling Capability With Natural Convection (Based on Rated ΔP)		0.5
Core Height		1.4
Core Temperature Rise		1.6
Thermal Conductivity of Coolant		0.025
Electrical Conductivity of Coolant		0
Mean Velocity at Core Outlet		10.

III. DESCRIPTION OF THE THREE BASIC TYPES OF SASS

A. FLUIDIC CONTROLLED SASS (SASS-FC) (See also Appendix A)

This system consists of a fluidic diverter valve, absorber assembly, guide tube, dashpot, and sensors (Figure 1). Reactor coolant flows upward through the diverter valve which is located below the reactor core. The absorber assembly is elevated above the core as coolant flows from the valve through the guide tube. The sensors, located near the core, respond to high temperature and loss of flow. When the set trigger point is reached, the sensor signals the valve to "switch" the direction of flow. The coolant then flows down and out of the valve rather than up through the guide tube. With the loss of coolant flow, the absorber rod assembly drops into the core, scramming the reactor. The dashpot absorbs the impact of the absorber assembly.

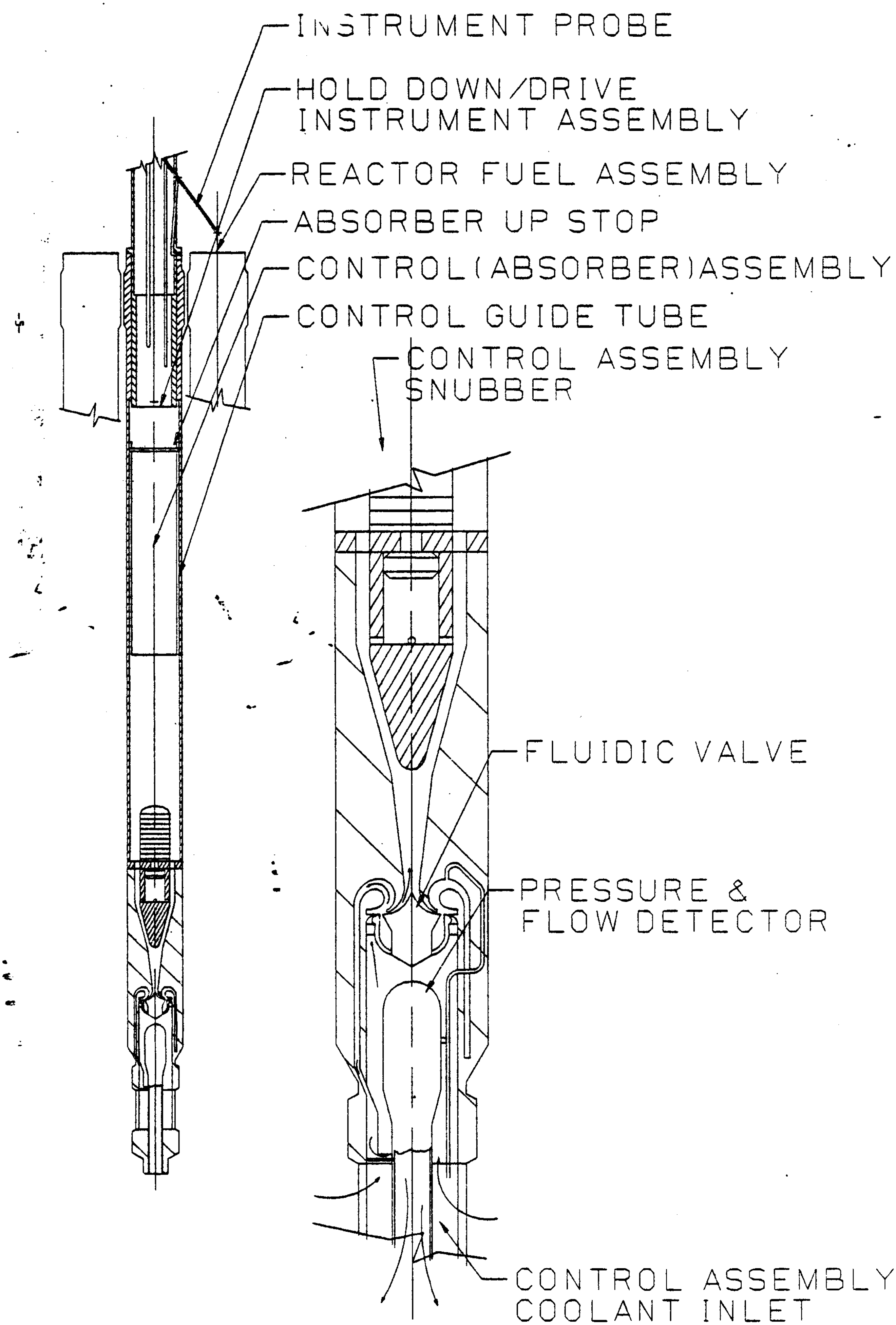


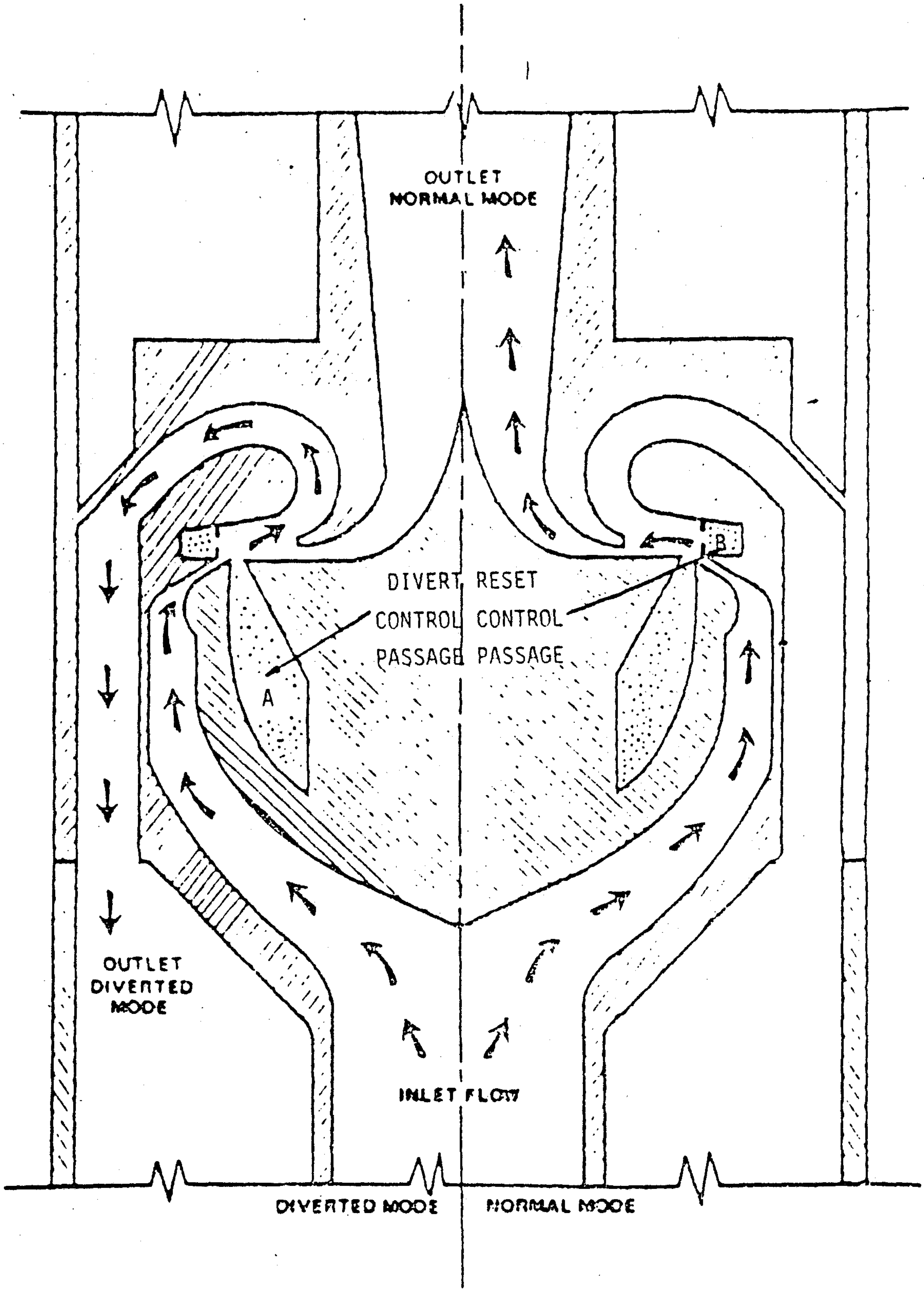
Figure 1 - SASS WITH FLUIDIC CONTROL

The concept is based on the fluidic diverter valve which operates under the bistable fluidic principle. In fluidics, there are no moving parts. The fluid flow field is controlled by the geometry of the valve and two control signals. Bistable means the ability of the flow to remain stable in either of two modes after removal of the control signal. In the normal or "on" mode, fluid flows through the axisymmetric valve, forming a jet (Figure 2). A low pressure is induced in the divert control passage "A" as the jet flows over it. The divert control signal, a pressure pulse, disrupts the low pressure causing the jet to switch its direction of flow downward. The flow remains stable in the diverted or "dump" mode after the control signal is removed. In the diverted mode, a low pressure is formed in the reset control passage "B" by the jet. The reset control signal, also a pressure pulse, disrupts the low pressure causing the jet to return to the normal mode. The flow remains stable after the control signal is removed. In the normal mode, flow elevates an absorber assembly above the core region. In the diverted mode, the absorber scrams as the fluid dumps. Successful scram times have been achieved in the water test loop at the SASS test facility.

An air operated model has been fabricated to demonstrate the ability of the fluidic diverter valve to function effectively with a gas. The one-third size model also verifies the scaleability of the fluidic diverter valve. A blower delivers air at a pressure of 30 inches of water through the clear acrylic model. Atmospheric pressure is used for the control signals. A rodded acrylic model absorber visualizes the switching by elevating to the top of a guide tube in the normal mode and dropping onto a dashpot in the diverted mode. In addition, sensors can control the SASS air model. They are representative of those used to detect increase in coolant temperature and loss of flow. The sensors divert the flow while reset to the normal mode is always manual.

B. SASS WITH MAGNETIC HOLDUP

This type of device supports the control rod in its uppermost position by magnetic means, with release initiated by either overtemperature or low-flow sensors. Several versions have been proposed, utilizing either electromagnets or permanent magnets. Either type can be made to release the control rod when an excessive temperature exceeds the curie point of part of the magnetic circuit. Other temperature and flow sensors can be



FLUIDIC DIVERTER FLOW PATHS
FIGURE 2

used to interrupt the electrical circuit that energizes an electromagnet.

One promising temperature sensor consists of a thermionic switch which becomes electrically conductive when a given temperature is reached, shorting out the electrical circuit to the electromagnet. In the concept shown in Figure 3, the temperature sensor is modified to be sensitive also to neutron flux.

C. SASS WITH HYDROSTATIC HOLDUP

This type of device is illustrated in principle in Figure 4. During reactor operation the control rod is held against a face seal at its upper end by a pressure differential. Any decrease in pressure differential below the minimum required to support the control rod weight will cause the control rod to fall. As soon as the face seal is separated, essentially all the pressure differential is lost, and the control rod will fall freely under the influence of gravity. It will be retarded only by flow resistance of the displaced fluid, and near the bottom of its stroke by a dashpot for absorbing the kinetic energy.

The pressure differential holding the control rod in its upper position will be a function of the total core pressure drop and the relative flow resistances of any active cooling passages in the control rod and of the inlet orifice. Since pressure drop across the core varies with the square of the flow, the available pressure will decrease rapidly as flow decreases. A valve bypassing the face seal can be added to provide a control rod scram as a result of excessive core outlet temperature. The valve is normally closed and is designed to open on an overtemperature signal. It can be actuated, for example, by melting a fusible material or by an electromagnetic device.

A mechanical grapple is used for raising the control rod and holding it in its upper position until adequate flow is established. The grapple must be released before reactor operation. Release can be assured after disconnecting by raising the grapple to a higher position.

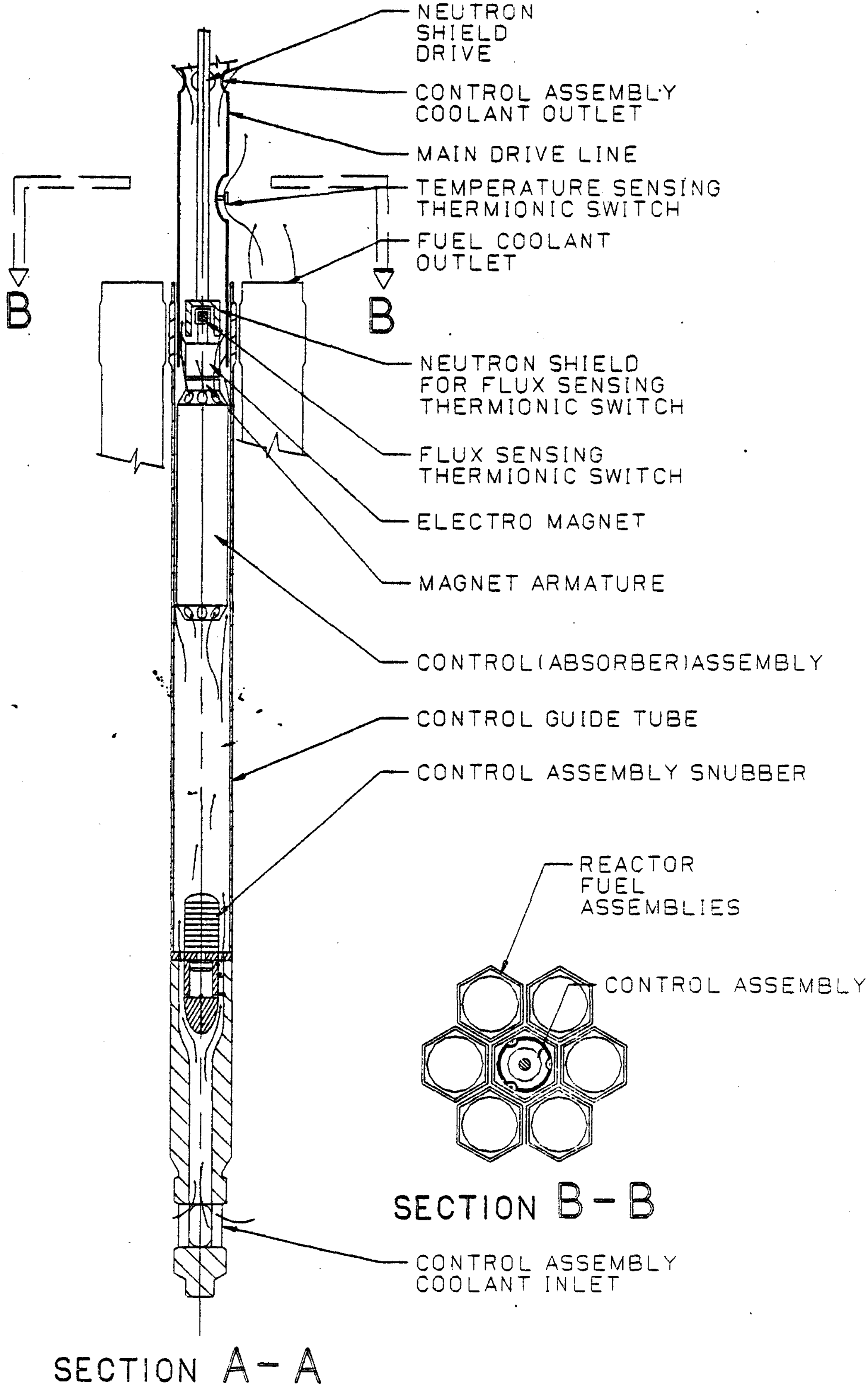


FIGURE 3 - THERMIONIC SWITCHED ELECTROMAGNETIC LATCH SASS CONCEPT

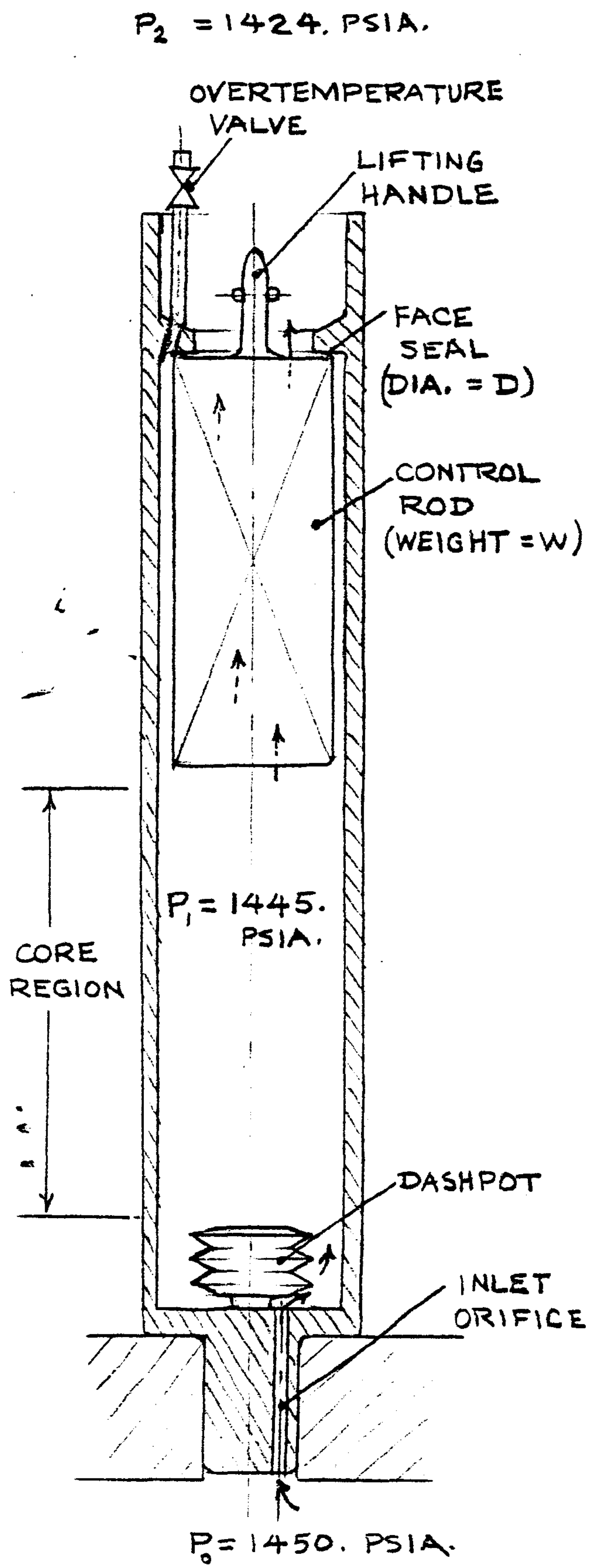


FIG. 4

SASS WITH HYDROSTATIC HOLDUP (SIMPLE FORM)

TO SUPPORT ROD:

$$(P_1 - P_2)\frac{\pi D^2}{4} > W$$

If a rapid response to pump failure is desired, this type of SASS must be designed to release at a core pressure drop only slightly below its full operating value. This would prevent the core from being operated under partial flow conditions. A variation of this basic concept is shown in Figure 5. A pressure regulator automatically maintains a fixed pressure differential across the face seal only slightly more than that required to support the control rod weight. The pressure regulator will maintain the differential over a range of core flows as long as the flow changes slowly. A dashpot within the pressure controller prevents response to rapid core flow changes. A sudden drop of the flow below its normal value will, therefore, result in a sudden drop of pressure and release of the control rod. In a gas-cooled reactor the dashpot in the pressure controller will probably require a bellows as shown in Figure 5 because of the difficulty in achieving a small enough leakage path with a piston. A piston can probably be substituted in a sodium-cooled reactor. The bellows stiffness will result in a slight variation in controlled pressure differential as the core flow changes.

The pressure controller can be located as shown, or can be made as part of the housing either above or below the control rod. The face seal as shown is attached with a flexible joint to assure an accurate fit if the control rod is warped or out of line. It prevents premature control rod release that could occur if the face seal were subjected to a tilting moment.

IV. COMPARISON OF GCFR AND LMBFR ENVIRONMENTS AS RELATED TO SASS APPLICATIONS

This section discusses the various aspects of the SASS design as they relate to the inherent differences between the two types of reactor.

A. HEAT GENERATION AND COOLING OF THE CONTROL ROD

Heat generation in the SASS assembly is made up of three main factors:

- the control rod itself
- the fixed structural material
- the coolant

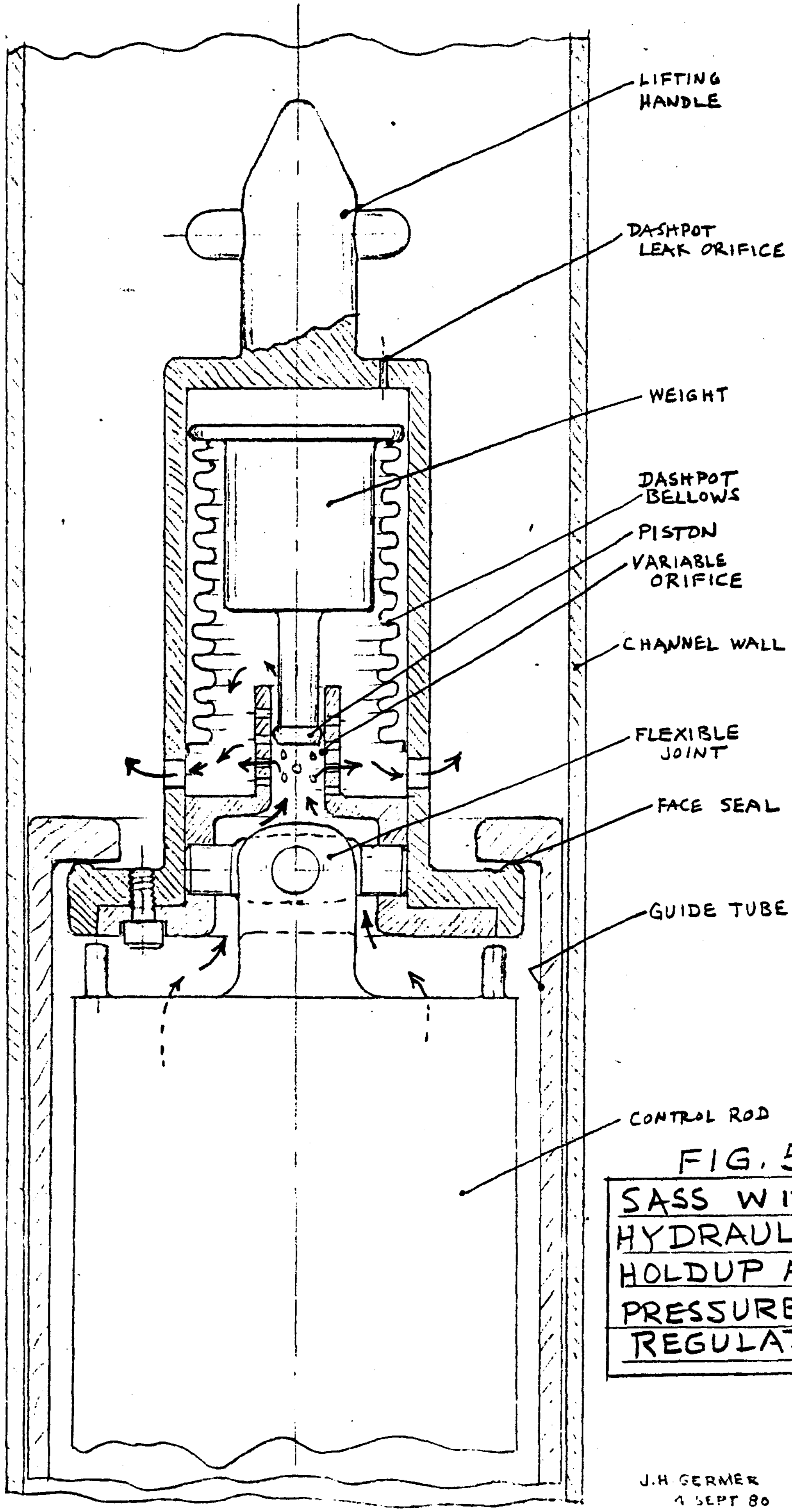


FIG. 5

SASS WITH HYDRAULIC HOLDUP AND PRESSURE REGULATOR

Heat generation in the control rod tends to be small if the rod is in its cocked position above the core, with the heat generation mainly in the lower end. The amount of heat depends upon how far the lower end of the rod is above the top of the core. Although continued operation of the reactor should not occur with the SASS control rod inserted into the core, it may be necessary to provide adequate cooling to prevent gross damage to the control rod under this condition.

Heat is generated in the guide tube and other fixed parts of the control rod assembly, caused by interaction with neutrons and gamma rays. Cooling should be adequate to avoid excessive temperatures, and to minimize temperature gradients from one side to the other that could cause warping. In a gas reactor it may be desirable to cool the guide tube by external flow rather than depending upon flow within the tube, where velocities tend to be low.

Heat generation in the coolant is significant mainly in a sodium-cooled reactor. In a helium-cooled GCFR, the very low fluid density results in an insignificant heat generation in the coolant compared to that of the control rod and fixed structure.

B. GRAVITY ACCELERATION

A SASS control rod in a gas reactor can achieve essentially the full downward acceleration of gravity without an additional force, since it is not affected by the buoyant forces of sodium. In comparison, a control rod in sodium will drop at approximately 0.8g maximum acceleration since its net weight is 0.8 times its weight in air.

C. CORE PRESSURE DROP

A SASS that is held in its uppermost or cocked position by hydraulic forces will require an adequate source of pressure under all reactor operating conditions. This source of pressure is normally the differential between the core inlet and outlet pressures. Since this core differential pressure varies approximately with the square of the core flow, a large differential pressure at full flow conditions is necessary if adequate partial flow operation is desired. For example, if reactor operation at 50% of rated flow is to be possible, the available pressure will be only 25 percent of the full reactor operating differential pressure. The following table gives an approximate comparison of the LMFBR and the GCFR in their abilities to support a SASS control rod assembly by hydraulic forces. It is assumed that the control rods have the same weights. The comparison does not include an allowance for the greater core length in the GCFR (which would tend to make the control rod assembly heavier).

	LMFBR	GCFR
Core Pressure Drop (psi)		
100% Flow	85	26
50% Flow	21.2	6.5
Control Rod Weight (lb)		
In Air	120	120
In Reactor	95	120
Minimum Area to Support		
Control Rod at 50% Flow (in.^{2})	4.47	18.46
Equivalent Diameter (in.)	2.39	4.85
Minimum Flow Required to Support		
Control Rod at 4.5" Diameter (Percent of rated flow)	26.5	53.9

D. DASHPOT DESIGN

Since a SASS control rod operates without direct connection to a drive actuator, a separate means must be provided for absorbing the kinetic energy of the control rod at the bottom ot its stroke. The usual device consists of a hydraulic dashpot, where fluid is displaced through a restricted opening by either a piston or a bellows. Three basic arrangements are considered for the dashpot:

(1) As the control rod approaches the end of its stroke, a piston attached to its bottom enters a closed end cylindrical hole at the bottom of the guide tube. Flow resistance of the fluid displaced by the piston causes a pressure drop across the piston and a resulting deceleration force. The variation in force vs displacement can be regulated by a variable radial clearance between the piston and the cylinder. An adequate taper must be provided at the entrance to the cylinder in order to assure entry of piston.

(2) The dashpot is located below the control rod, and its piston remains stationary until it is contacted by the control rod. Some impact will result from the sudden contact with the piston, and a reliable means must be provided (usually by a spring) to assure that the dashpot piston returns to its cocked position when the control rod is raised. A variation of this concept would have the dashpot built as part of the control rod rather than as part of the guide assembly.

(3) Similar to (2) above, but with the piston replaced by a bellows. Leakage could be controlled by a fixed orifice or by spring-loaded check valves. Leakage as a function of displacement is more difficult to achieve than in a piston device.

In comparing helium with sodium, the most significant difference is the density of the fluid. Since sodium has about 100 times the density of helium at reactor conditions, leakage velocity through an orifice at a given pressure drop will be only about one-tenth as great as with helium. Since a dashpot is primarily a volume displacement device, the leakage areas must be about one-tenth as large with helium as with sodium for equivalent performance.

A piston dashpot in sodium is typically about four inches in diameter and with about 0.050" minimum radial clearance. For equivalent dashpot action in helium the radial clearance would have to be one-tenth as large, or 0.005". This small clearance is considered to be impractical in an environment of high temperature and radiation swelling of metals. For this reason, a helium dashpot would probably have to be of the bellows type where the small leakage area can be achieved without unreasonably small clearances.

Compressibility of helium is much greater than that of liquid sodium, but appears to be only of secondary importance since the normal pressure differential required for the dashpot is only about 10 to 50 psi, a very small fraction of the 1450 psi ambient pressure. Therefore, most calculations can be made with the helium treated as an incompressible fluid.

Of the three basic dashpot arrangements described above, the second and third are subject to a possible failure mode where the dashpot sticks and fails to reset after use, or if the bellows develops a leak. For this reason, they should be supplemented by an auxiliary "one shot" energy absorber such as a crush device to prevent impact damage to the core support structure. There must then be a means to prevent repeated use of the control rod without replacement of the auxiliary energy absorber. This auxiliary energy absorber may be also necessary in case the control rod drops when the reactor is depressurized and the dashpot becomes ineffective. Repeated use can be prevented if collapse of the crush device results in a position of the control rod below the reach of the raising grapple.

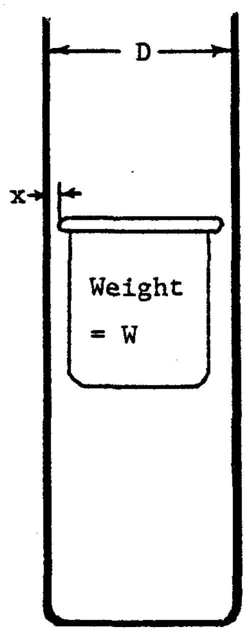
A hydraulic dashpot of the types described here are not capable of stopping the control rod completely. The final deceleration can best be accomplished by a metal spring bumper. The control rod velocity (and kinetic energy) must be reduced to the point that rebound is within tolerable limits.

Other dashpot concepts have been considered for the gas reactor system, but they have presented potentially serious deficiencies. For example, a device utilizing a spring along with an anti-return device to stop the control rod would require a very massive spring. It would require resetting before subsequent use, and failure could result in an upward ejection of the control rod. Other devices dependent upon sliding friction tend to have erratic performance that could be made worse by the severe temperature conditions. Hydraulic dashpots utilizing a separate liquid could present serious problems in the event of a leak.

E. RESISTANCE DURING DROP

The dropping time of a SASS control rod is affected by the acceleration of gravity (corrected for the fluid buoyancy) and the resistance of the displaced fluid. In this discussion it is assumed that any fluid that enters the chamber below the control rod is negligible relative to the fluid displaced by the control rod during the drop. It is also assumed that the displaced flow passes through a radial clearance gap. This gap is treated as a simple orifice with a unity flow coefficient.

The dropping resistance, k, of the control rod is expressed as the force generated per unit velocity squared of the control rod:



$$F = kV^2$$

$$k = \frac{\pi D^4 \rho}{128 . x^2 g} \quad = \text{resistance (lb sec}^2/\text{ft}^2)$$

V = Control Rod Velocity (ft/sec)

x = Radial Clearance (ft)

D = Guide Tube Diameter (ft)

g = Gravity Acceleration (32.2 ft/sec^2)

F = Net Fluid Force on Control Rod (lb)

ρ = Weight Density of Fluid (lb/ft^3)

W = Weight of Control Rod (lb)

y = Displacement (ft)

α = Weight in Fluid/Weight in Air

t = Time (sec)

The control rod dropping motion is plotted in dimensionless form in Figure 6. Distance is plotted as:

$$Y = \left[\frac{kg}{2W}\right]y$$

Time is plotted as:

$$T = \left[\frac{g}{2}\sqrt{\frac{\alpha k}{W}}\right]t$$

It will be noted that there are three parts of the curve; an initial region where resistance is negligible (T < 0.4), a transition region, and a final region where the control rod has reached terminal velocity (T > 1.0).

The following table shows the effect of equivalent radial clearance gap in typical LMFBR and in a GCFR geometries, calculated by use of Figure 6. It is seen that a 0.50 inch gap in an LMFBR has little effect upon drop time, whereas fifteen percent of this gap (0.075 in.) in a helium environment has a very similar small drag effect. One must conclude that a gas-cooled reactor can have relatively close tolerances with little penalty in drop time.

	L M F B R		G C F R		
Gap (in.)	0.25	0.50	0.25	0.075	0.025
Diameter (in.)	5.4	5.4	6.58	6.58	6.58
Weight in Air (lb)	120	120	120	120	120
Weight in Fluid (lb)	95	95	120	120	120
Fluid Density (lb/ft^3)	53	53	0.43	0.43	0.43
Stroke (ft)	3	3	4	4	4
Drop Time (sec)	0.73	0.55	0.50	0.57	1.04

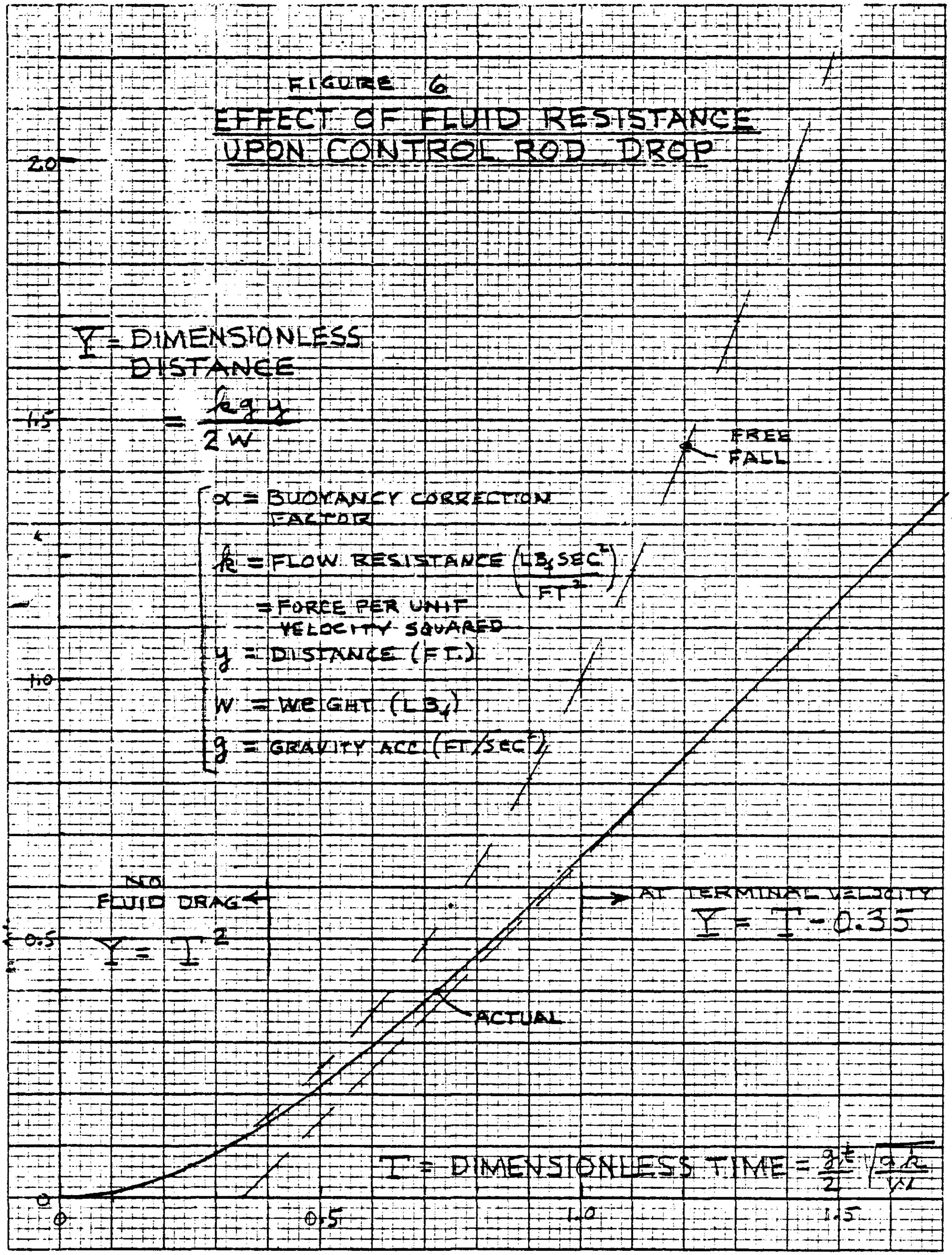


FIGURE 6
EFFECT OF FLUID RESISTANCE
UPON CONTROL ROD DROP
2.0
1.5
1.0
0.5
0
Y = DIMENSIONLESS DISTANCE = kgy / 2W
FREE FALL
α = BUOYANCY CORRECTION FACTOR
k = FLOW RESISTANCE (LB SEC² / FT²)
= FORCE PER UNIT VELOCITY SQUARED
y = DISTANCE (FT.)
W = WEIGHT (LB)
g = GRAVITY ACC (FT/SEC²)
NO FLUID DRAG
Y = T²
AT TERMINAL VELOCITY
Y = T - 0.35
ACTUAL
T = DIMENSIONLESS TIME
0
0.5
1.0
1.5

F. ELECTRICAL CONDUCTIVITY OF THE FLUID

In a SASS with magnetic holdup, it is assumed that the control rod is held in its cocked position by means of an electromagnet. Additional sensors are used to break the electrical circuit to the electromagnet as a result of excessive temperature or a sudden drop in core flow.

One important difference between sodium-cooled and gas-cooled reactors is in the possibility of attaching electrical wires. In a sodium system, it is considered impractical to have the coils of an electromagnet as part of the control rod assembly since refueling would require an electrical disconnect. A possible exception would be if an A.C. electrical system were used and coupling is by electromagnetic induction. In a helium system it is possible to make electrical connections with the control rod assembly in place. Such a circuit would tend to be fail-safe, since electrical contact failure would scram the reactor.

G. CORE SUPPORT STRUCTURE DESIGN

A low pressure plenum is required below the core for the "hydraulic holddown" of LMFBR fuel assemblies, in order to achieve a pressure balance that prevents the fuel rods from being hydraulically lifted by the high core pressure differential. This low pressure plenum is not required in a helium-cooled reactor, since the core pressure differential and required flow area result in an upward force that is too low to raise the fuel assemblies.

A sodium reactor SASS device with a fluidic flow diverter valve utilizes this low pressure plenum below the core for flow diversion. If one is to utilize a SASS with a flow diverter in a helium cooled reactor, another flow diversion path would be necessary. One could consider the space between the round control rod guid tube and the hexagonal channel wall as such a flow path to the upper core outlet plenum.

H. CONTROL ROD GAS GENERATION

A control rod containing boron as an absorber will generate significant quantities of helium as a result of neutron absorption. In the reference LMFBR design, accommodation is made for storing this gas under pressure within the control rod. The resulting control rod must, therefore, have sufficient added length to accommodate the required gas plenum. The reference GCFR control rod provides for venting the helium into the reactor cooling system, and therefore, does not require this additional length. This shorter length would be an advantage for a GCFR.

CONCLUSIONS

It appears that a SASS can be designed to operate in a Gas-Cooled Fast Reactor with either hydrostatic or magnetic holdup. Fluidic control may not be feasible because of the considerably lower available pressure head. The design of the energy-absorbing dashpot is, however, considerably more difficult in a gas-cooled reactor because of the close clearances that are necessary in order to achieve the required flow resistance.

Slightly greater insertion acceleration (essentially 1g) is practical in a GCFR, due to the negligible buoyancy forces. This is balanced by a longer required insertion distance (longer core) in the GCFR.

It is only in the SASS with magnetic support that the GCFR offers a significant advantage. The possibility of utilizing electrical connections to the SASS core assembly may permit other designs that could not be considered in an LMFBR.

RECOMMENDED DEVELOPMENT

A choice of type of SASS to be used in a gas-cooled fast reactor should be preceded by more detailed designs of the concepts operating on the principles of hydrostatic or magnetic holdup. Sensors for temperature must be developed for both concepts, as well as a pressure sensor for the magnetic holdup device. A detailed study of circulating pump coastdown characteristics under normal and accident conditions must be made in order to determine the optimum response characteristic of the pressure sensor.

Operating tests of any SASS device in a GCFR are best made in a high pressure (1450 psia) helium environment. Preliminary studies, however, can be made in an air environment with the same density (about 170 psia). With air, the dashpot for stopping the control rod will be more affected by compressibility but will otherwise have similar characteristics.

APPENDIX A

SASS WITH FLUIDIC CONTROL (SASS-FC)

INTRODUCTION

A SASS is a control rod system which shuts down a reactor independently of the operator. If both the primary and secondary shutdown systems fail, the SASS can scram the reactor for "anticipated", "unlikely" and "extremely unlikely" events (Ref. 1). GE has developed a concept called the SASS-Fluid Controlled (SASS-FC). The system consists of a fluidic diverter valve, absorber assembly, guide tube, dashpot and sensors (Figure 1). Reactor coolant (helium) flows upward through the diverter valve which is located below the reactor core. The absorber assembly is elevated above the core as coolant flows from the valve through the guide tube. The sensors, located near the core, respond to high temperature and loss of flow. When the set trigger point is reached, the sensor signals the valve to alter the direction of flow. The coolant then flows down and out of the valve rather than up through the guide tube. With the loss of coolant flow, the absorber assembly drops into the core scramming the reactor.

The recommended GCFR commercial plant parameters and design conditions are shown in Table 1. Making reference to these data and the SASS design for the CDS Phase II (Ref. 2), a feasibility study was conducted to investigate:

1. Whether the allowable pressure drop for a typical GCFR core could generate sufficient forces for a bundle (absorber assembly) levitation.
2. What flow rates would be sufficient to levitate an absorber assembly for a specific design.
3. The relationship between the pressure drop, levitation forces and bundle/bypass flow split.

METHOD OF ANALYSIS

A hydraulic model simulating a generic SASS flow pattern was prepared. A computer program was, then, written to perform the steady state flow, pressure and force calculations with the application of the Energy and Continuity equations. Flow nodes were placed at those locations where geometry changes to account for head losses. The nodal map showing the flow pattern is presented in Figure 2.

The boundary conditions used in the program were the total upward flow rate and the helium inlet pressure. The node-by-node calculations were based on the following major assumptions:

1. Incompressible fluid: This was because the fluid velocities were significantly smaller than the velocity of sound.
2. Temperature variation was not considered.
3. One-dimensional analysis

In order to levitate the absorber assembly, an adequate pressure differential has to be maintained across the assembly. The recommended core pressure drop for a GCFR commercial plant design is 26 psid*. Since the pressure recovery for a diverter valve is approximately 50%, the net pressure drop available for levitation is only about 13 psid.

RESULTS AND CONCLUSION

Figures 3 and 4 were plotted to illustrate the net upward force (total levitating minus pin bundle weight) as function of guide tube I.D. and bundle tube O.D. respectively. As expected, when the bundle tube is enlarged and/or the guide tube is contracted, both pressure drop and force will increase. The flow split between the pin bundle and the bypass annulus was found to have a more uniform distribution at higher pressure drops.

By comparing the CDS and GCRF core design data, it was estimated that the guide tube I.D. for the GCFR control assembly ranges from 5.2" to 5.6" and bundle tube O.D. shall not be less than 4.754". Since the overall pressure drop across the absorber assembly is limited to 13 psid, this increase in guide tube size has significantly lowered the total pressure drop (Figure 3) while absorber pin size is maintained at the design value or greater. This has greatly enhanced the feasibility of the GE SASS concept. Maintaining absorber pin size at the specified design value or greater is to assure that the control pins contain at least the minimum shutdown worth.

*"GCFR Program - Technical Review Proceedings," Helium Breeder Associates, DOE, San Diego, CA May 30, 31, and June 1, 1979.

APPENDIX A

The pressure drops were plotted as a function of flow rates in Figures 5 and 6. For a bundle tube O.D. of 4.754", the guide tube I.D. must stay above 5.45" in order to limit the pressure drop to 13 psid at 100% flow (Figure 5). On the other hand, if the guide tube I.D. is fixed at 5.5", the proper O.D. for the bundle tube should be 4.8" or less (Figure 6). The applicable flow rates are enveloped by both the allowable core pressure drop at 100% flow and the minimum pressure drop (5.4 psid) required to levitate the absorber bundle. Since the latter is normally a constant for a specific design, the workable range is completely determined by the allowable core pressure drop.

In conclusion, the optimum design of the absorber assembly calls for 4.80" bundle tube O.D. and 5.45" guide tube I.D. With this design the flow rates, which would levitate the absorber bundle and yield pressure drop within the allowable pressure drop, range from 60% to 100% of full flow. In other words, the bundle will not levitate for flow smaller than 60% of full flow. This design constraint is due to the low pressure drop through the core region in gas-cooled reactor and the high pressure loss through the fluidic diverter valve.

APPENDIX A

TABLE 1
RECOMMENDED INTERIM GCFR COMMERCIAL PLANT PARAMETERS
AND DESIGN CONDITIONS

Fixed Parameters	
Plant rating	3600 MW(t)
Number of loops	6
Nuclear goals	Comparable to LMFBR with oxide fuel
Major Recommended Variables	
Maximum clad temperature	750°C (1382°F)
Core outlet temperature	554°C (1030°F)
Steam generator inlet temperature[(a)]	549°C (1020°F)
Turbine-generator throttle pressure	12.41 MPa (1800 psia)
Turbine-generator throttle temperature	510°C (950°F)
Feedwater temperature	188°C (370°F)
Core inlet temperature	302°C (575°F)
Helium pressure	10 MPa (1450 psia)
Resultant Performance Parameters[(b,c)]	
Breeding ratio	1.44
Core compound doubling time	14.5 yr
Circulator motor shaft output (margin included)	22.23 MW (29,800 hp)
Plant electrical rating	1240 MW(e)
Plant efficiency	34.5%
Reactor pressure drop	0.179 MPa (26 psi)
Total helium pressure drop	0.241 MPa (35 psi)
Core helium flow rate	2722 kg/s (6000 lb/sec)
Expansion line end point moisture	13%

(a) 10°F drop between core and steam generator is an allowance for bypass, leakage, and shield cooling flows, which have not yet been accurately estimated.

(b) Non-reheat cycle with internal moisture separation.

(c) Nuclear performance assumes 1 yr out-of-pile, 2% losses, and 75% load factor. U-235 not included.

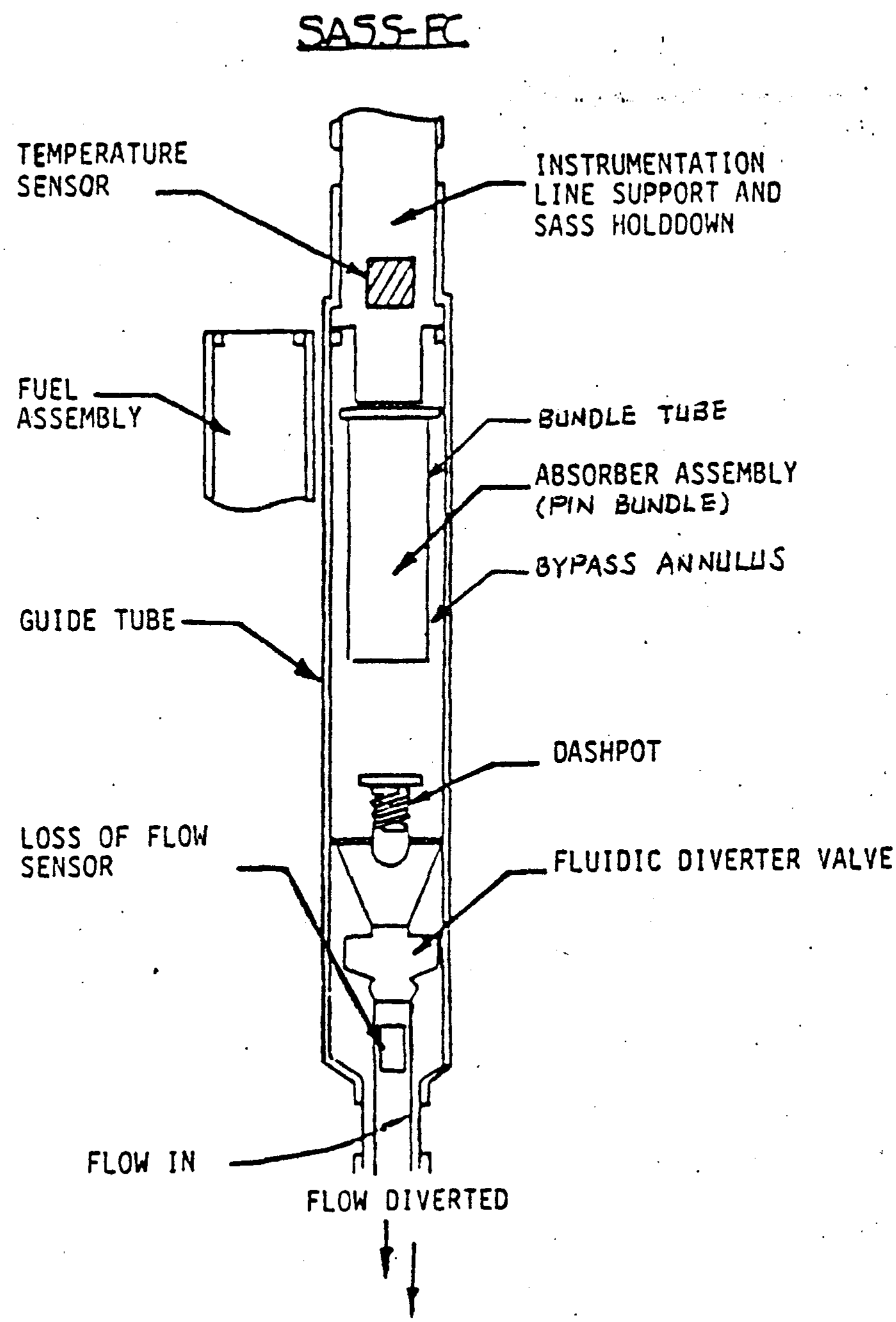


FIGURE 1. SASS SCHEMATIC

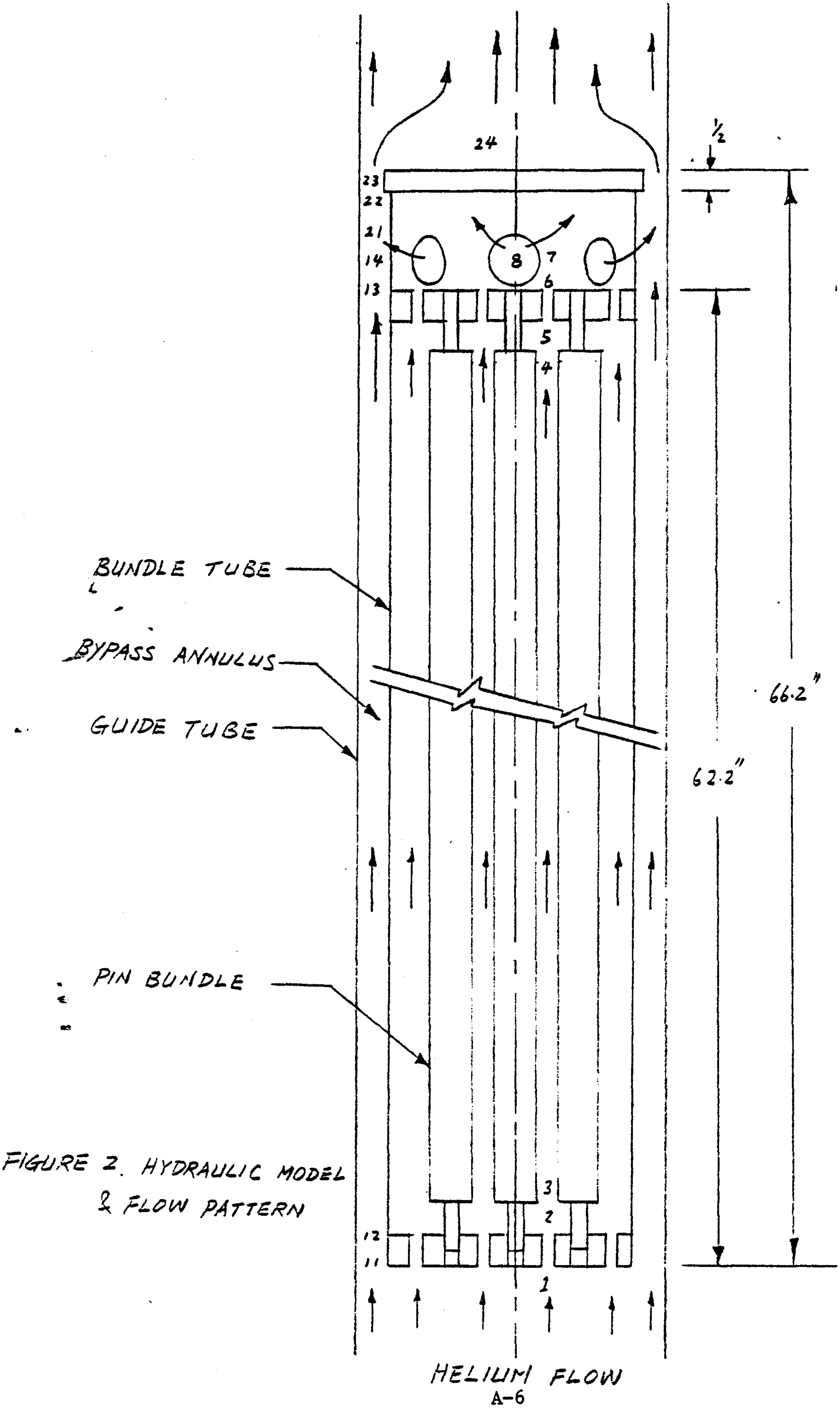
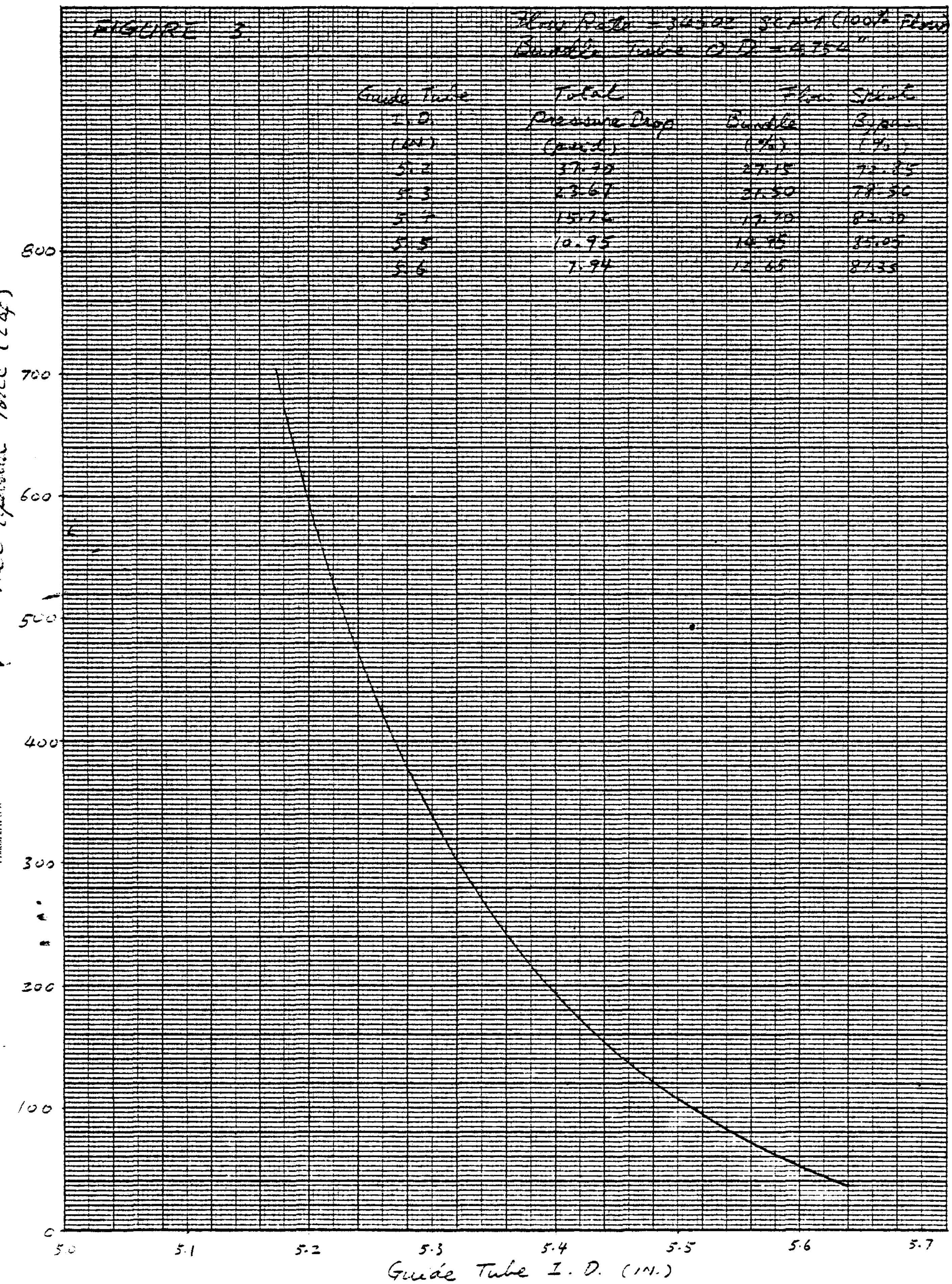
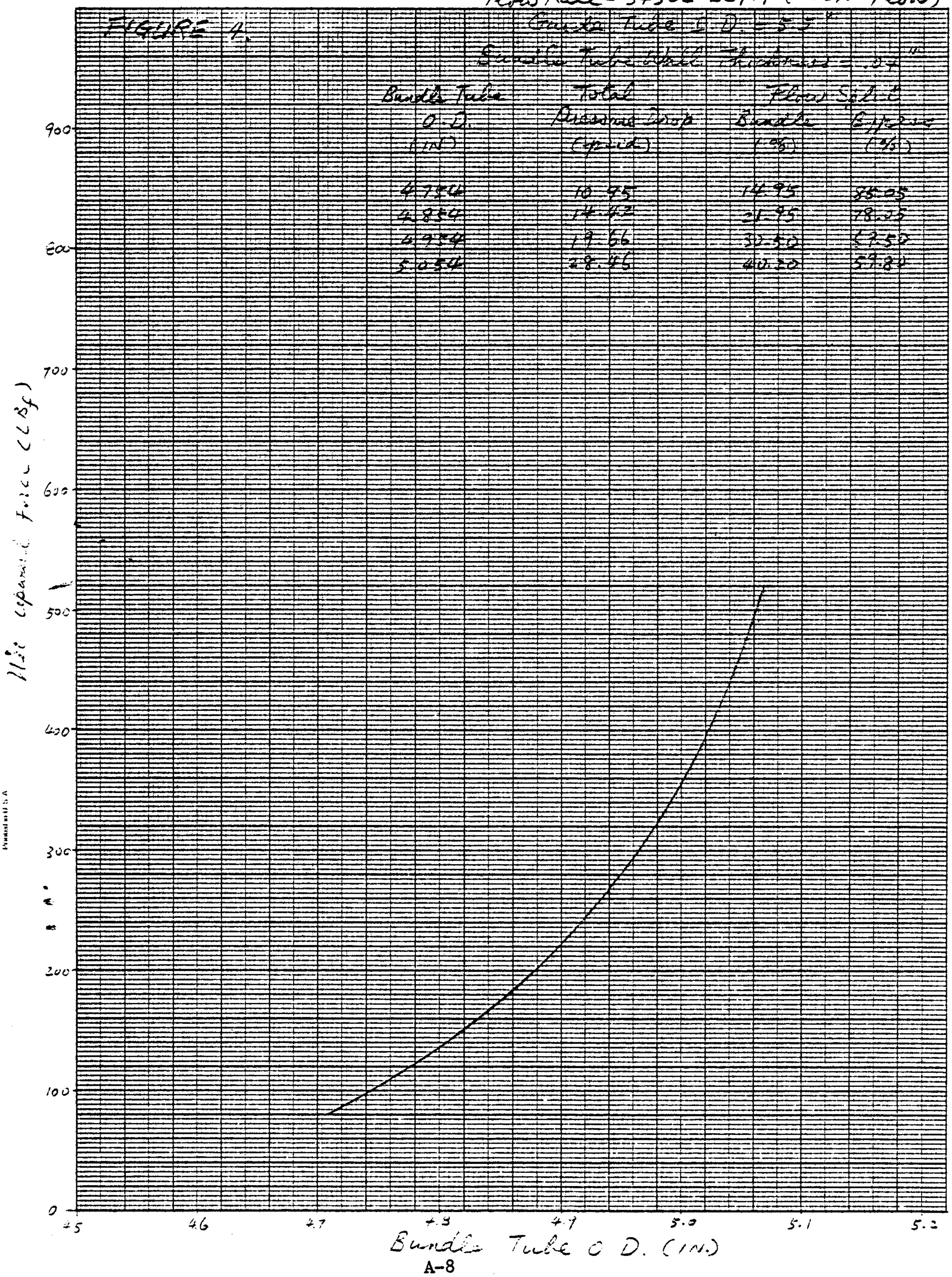


FIGURE 2. HYDRAULIC MODEL & FLOW PATTERN



Guide Tube I.D. (IN)	Total Pressure Drop (psid)	Flow Split Bundle (%)	Flow Split Bypass (%)
5.2	37.78	27.15	72.85
5.3	23.67	21.50	78.50
5.4	15.72	17.70	82.30
5.5	10.95	14.95	85.05
5.6	7.94	12.65	87.35

Flow Rate = 34502 SCFM (100% Flow)



Bundle Tube O.D. (IN)	Total Pressure Drop (psid)	Flow Split Bundle (%)	Flow Split Bypass (%)
4.754	10.95	14.95	85.05
4.854	14.42	21.95	78.05
4.954	19.66	30.50	69.50
5.054	28.46	40.20	59.80

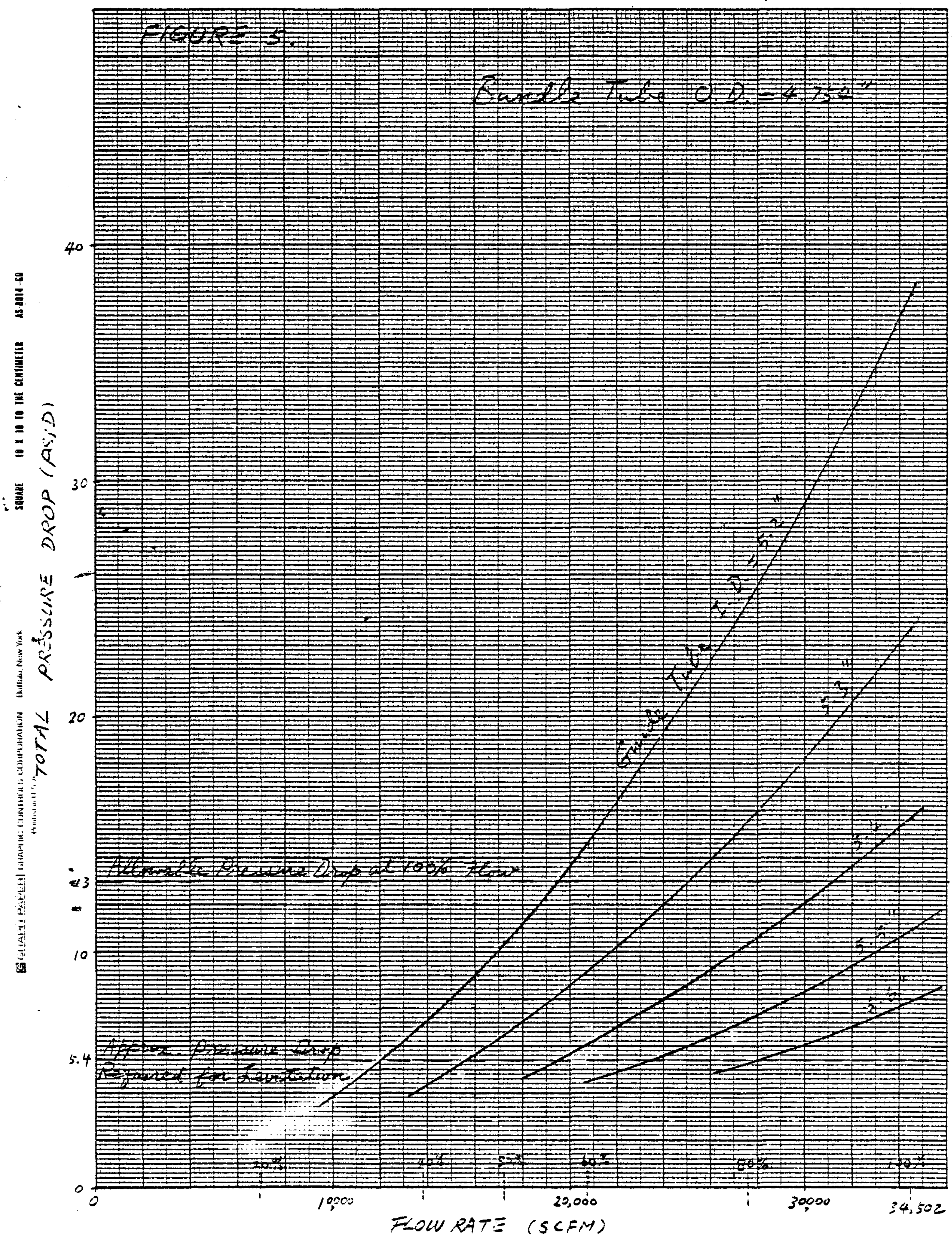


FIGURE 5.
Bundle Tube O.D. = 4.752"
Bundle Tube I.D. = 5.2"
5.3"
5.4"
5.5"
5.6"
Allowable Pressure Drop at 100% Flow
Approx. Pressure Drop Required for Levitation
TOTAL PRESSURE DROP (PSID)
FLOW RATE (SCFM)
40
30
20
13
10
5.4
0
10,000
20,000
30,000
34,502
40%
52%
60%
80%
100%
GRAPHIC CONTROLS CORPORATION Buffalo, New York
SQUARE 10 X 10 TO THE CENTIMETER AS-0014-60

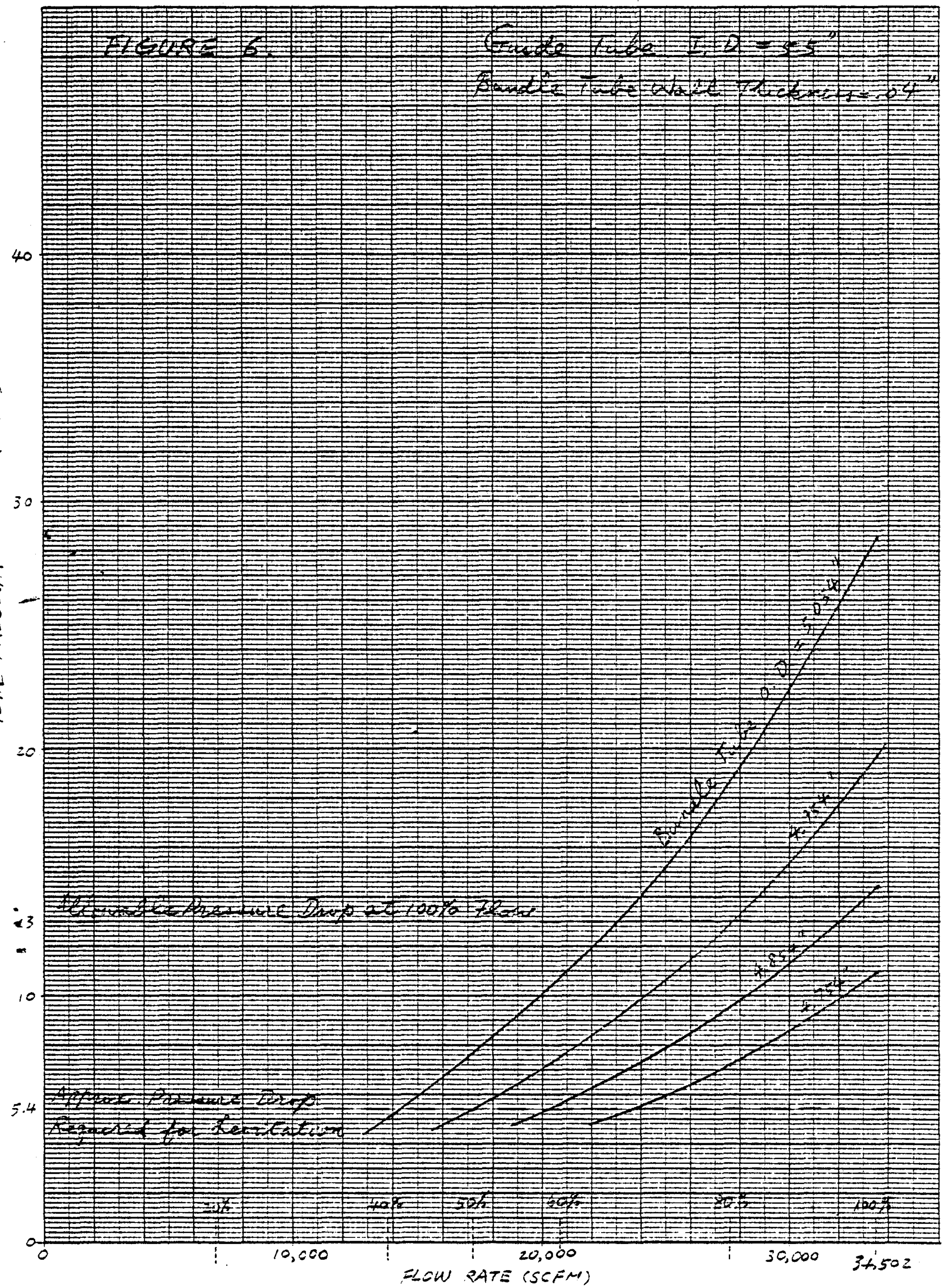


FIGURE 6.
Guide Tube I.D = 5.5"
Bundle Tube Wall Thickness = .04"
TOTAL PRESSURE DROP (PSID)
40
30
20
13
10
5.4
0
Allowable Pressure Drop at 100% Flow
Approx. Pressure Drop
Required for Levitation
Bundle Tube O.D = 5.054"
4.754"
4.854"
4.754"
40%
50%
60%
80%
100%
0
10,000
20,000
30,000
34,502
FLOW RATE (SCFM)