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February 1, 1954

INTERIM REPORT - IV, SUPPLEMENTARY CONTROL DEVELOPMENT PROGRAM

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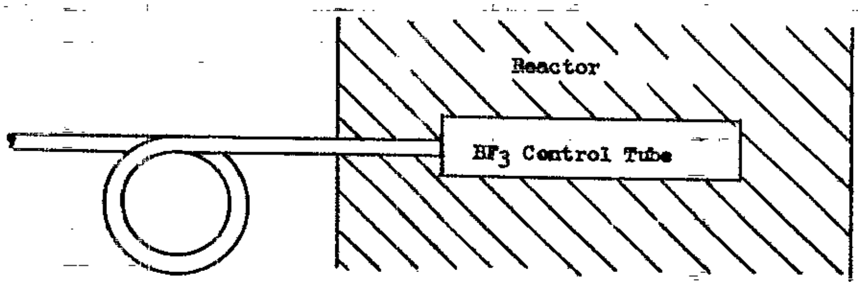
INTRODUCTION

Boron trifluoride gas has been proposed as a control medium for use in the Hanford reactors. In June 1952, a development program was initiated by the Pile Technology Mechanical Development Sub-Unit directed towards developing a practical BF_3 supplementary control system.

The principle of this type of system is simple. A tube may be located within the neutron flux of a reactor, as shown in the sketch below. Now, if BF_3 gas is introduced into this tube, some of the neutrons will be absorbed by the boron (B10 isotope) in the gas. The number of neutrons absorbed will vary in proportion to the number of B^{10} atoms present in the flux which is in turn proportional to the pressure exerted upon the gas.



It is anticipated that if the problems connected with the development of a supplementary control system can be overcome, it might be possible that BF_3 control tubes will be used for supplementary control in old piles and will replace control rods as a primary control element in future reactors.

The purpose of this document is to indicate the present status of the development program, point out the problems that have been overcome, and make recommendations concerning the areas where further development work is necessary.

SUMMARY

A simple BF_3 supplementary control system was mocked-up and tested. (up to 50 psig) Much experience has been gained in the handling of BF_3 at both high and low pressures by use of this equipment. An efficient system for disposing of the gas after irradiation has also been developed. Experience with operation of the mock-up indicates that the gas is relatively easy to handle. Various methods for controlling the pressure were investigated.

Preliminary corrosion experiments indicate that BF_3 at low pressure does not attack 2S aluminum appreciably in the presence of various amounts of moisture.

Physics calculations indicate that the level of induced radioactivity of the gas should be very low.

Aluminum capsules containing BF_3 were irradiated for one month. The gas was analyzed on the Mass Spectrometer and the solid products were analyzed by the Spectrochemical

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and wet chemical techniques. ~~The results of these analyses are included in this report.~~ There was no observable corrosion damage to the 2S aluminum capsules.

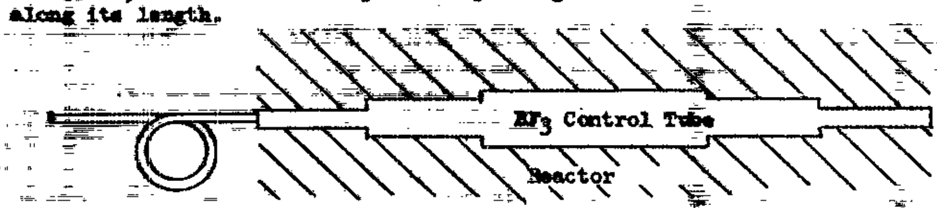
CONCLUSIONS AND RECOMMENDATIONS

All of the tests and experiments performed to date indicate that BF_3 may be used in a properly designed system for pile control. Further development is required in the areas mentioned below:

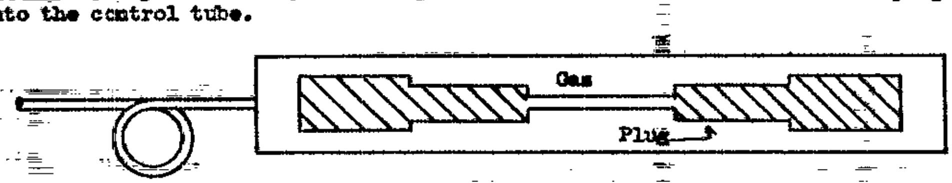
1. The economics of this type of system must be studied. This study should include the de[illegible]ation of the optimum number and location of BF_3 supplementary control tubes in present reactors. A comparison between the costs and desirability of this type of supplementary control and the poison column push system should also be made.

   BF_3 may be considered for use in the primary control system of new reactors. This type of system may also be applied to the operating piles by designing the system such that the BF_3 cannot escape into the graphite during normal operation of the reactor. In the case of loss of coolant and melting of the reactor components, the system should be designed such that gas would not be allowed to escape into the atmosphere but would be dispersed into the gas passages in the graphite stack. The cost of the BF_3 control system for this service would doubtless by much less than a rod system. The relative safety of the two systems would seem to be the governing factor in the choice between the two systems.

2. The advantages and disadvantages of uniform front-to-rear absorption should be investigated. If it appears that a non-uniform front-to-rear absorption is desirable, this can be accomplished by using a tube whose cross section is varied along its length.



Another more practical way to accomplish this is to insert a non-uniform plug into the control tube.



3. Further study of the out-of-pile corrosion rate of BF_3 gas in contact with aluminum would seem very desirable.

4. Irradiation of larger volumes of BF_3 in aluminum containers should be made to determine more accurately the induced radioactivity levels, the burnout rate of B^{10}, and the pressure increase due to the (n, α) reaction. The in-pile corrosion rate should be investigated further. It must also be determined if boron will continually plate-out on the inner surface of the control tube. If boron does plate-out on the tube an appreciable amount, this would materially reduce

the value of this type of control system since it would then be impossible to get essentially 'zero' control when desired. Preliminary data indicate that very little boron is deposited on the tube wall, but further investigation is desirable.

5. A continuing search should be made to find the optimum remote-operated pressure control and indication system for use of the operator in the control room.

6. Since pressure of the gas will increase with the length of exposure of the gas in the neutron flux as a result of B^{10} burn-out, a device to monitor the B^{10} concentration in the tube would be the only accurate indication of the "blackness" of the tube to neutrons. Instrumentation which will perform this measurement was set up and tested. It is described in the discussion of this report. It is desirable to refine this instrument if further development work indicates that BF_3 is suitable for pile control service.

DISCUSSION

1. ADVANTAGES AND DISADVANTAGES OF USING BF_3 AS A CONTROL MEDIUM

On the assumption that the future development work indicates that a satisfactory BF_3 gas control system may be designed, some of the expected advantages and disadvantages of such a system will be discussed.

A. Increased Control

At the present time there is not enough control strength in the horizontal control rods in the older piles to accommodate the reactivity transients during start-up for the power levels permitted by current corrosion and graphite temperature limits. To overcome this problem, poison columns are used, i.e., lead-cadmium slugs are placed in a number of process channels to absorb the excess neutrons, thus making it possible to control the power level with the control rods.

At B Pile a system has been set up to allow the poison columns to be washed out of the pile as the need for additional control is reduced, without shutting the unit down. All of the other old piles must be shut down usually once but occasionally twice during startup of the unit to allow discharge of the poison slugs.

If these poison columns were replaced with BF_3 tubes the operation of reducing the poison in the pile would be greatly simplified. By merely reducing the pressure in the control tube to a vacuum, the same effect is produced as in removing the slugs from the process channel. Thus, no slugs need to be handled, decontaminated, etc. Also when poison slugs are removed they must be replaced with solid aluminum dummies to keep the panellit pressures in the proper range. This aluminum absorbs some reactivity. In the case of the BF_3 control tube when zero control is desired, the pressure will be reduced to a few microns thus reducing to a minimum the amount of reactivity absorbed.

B. Control of Hot Spots during Operation

When during an operating period, a hot-spot develops, the pressure in a nearby BF_3 control tube may be increased the proper amount to reduce the temperature in that area.

C. More Rapid Scram Possible

It is expected that the pressure of the BF_3 tubes may be increased very rapidly, making possible a more rapid scram than is presently obtainable with mechanical equipment.

D. System Offers Many Possibilities for Future Utilization

From the above mentioned points it may be seen that BF_3 gas presents a very flexible and rapid means of controlling a reactor. As the power levels of the reactors are increased, the need for more and more control also increases, thus, it may be very desirable in the future to replace some horizontal and/or vertical control rods with BF_3 tubes. The advantages here, of course, are due to the larger areas of boron that may be exposed to neutron bombardment. Also the mechanical problems are reduced since no rod drive, seals, etc., would be required.

E. Possibility of Losing Pressure

There is one obvious disadvantage inherent in a gaseous control system. This is, of course, that if the system develops a leak when the tube pressure is high, there will be a loss of control. This possibility may be minimized by periodic pressure tests of the system while the unit is not operating. Also, it is desirable that the system be set up such that each tube of BF_3 is a pressure vessel separated from the other tubes.

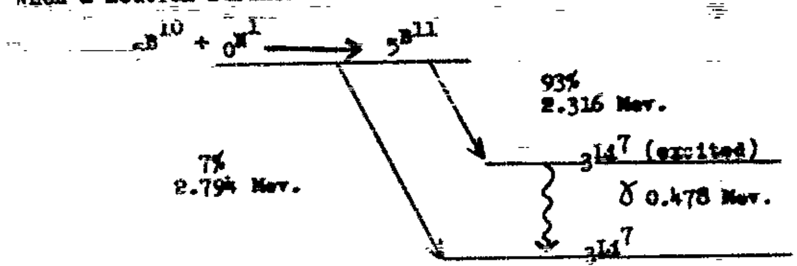
F. Danger Due to Earthquakes, Blasts, Greater With BF_3 than with Conventional Control Equipment

The effects of earthquakes, blasts, etc., probably would be more serious in a gas system in that some of the components may be ruptured and sudden reactivity increases noted.

2. THEORY

A. General

When a neutron strikes a boron atom the following reaction (1) takes place:



BORON DECAY

When the boron is in the form of $B^{10}F_3$, it is expected that the following will occur:

$$B^{10}F_3 + {}_0n^1 \longrightarrow 3F + B^{11*} \longrightarrow (3F) + He^4 + Li^7$$

assuming $Li^7 + F \longrightarrow LiF$ and $2F \longrightarrow F_2$

there will then be three mols (LiF, He, F_2) where there was one BF_3 mol originally. Spectrochemical analysis indicates that the lithium formed is deposited upon the wall of the container. The Mass Spectrometer analysis indicates that the amount of fluorine in the gas is reduced by irradiation. This may be due to the fluorine combining with the lithium. Some of the fluorine may also combine with aluminum to form aluminum fluoride. Since the corrosion rate of aluminum in contact with fluorine is less than 0.005 inches per year (2), the corrosion effect from this source should not present a problem unless radiation accelerates the reaction appreciably.

B. B^{10} Burn-out

The rate at which an element is transmuted by pile irradiation is described by the differential equation:

$$\frac{dN}{dt} = -N \phi \sigma_a$$

Where:

N is the number of atoms of the element remaining.
ϕ is flux density-neutrons/sq.cm./sec.
σ_a is the cross section for absorption - in barns

Integrating we get

$$\int_0^t \frac{dN}{N} = -\int_0^t \phi \sigma_a \, dt$$

$$\ln N \Big|_0^t = -\phi \sigma_a \int dt = -\phi \sigma_a (t - t_0)$$

at $t = 0$, $N = N_0$

$$\ln N - \ln No = \ln N/No = -\phi \sigma_a t$$

therefore: $e^{\ln N/No} = e^{-\phi \sigma_a t}$

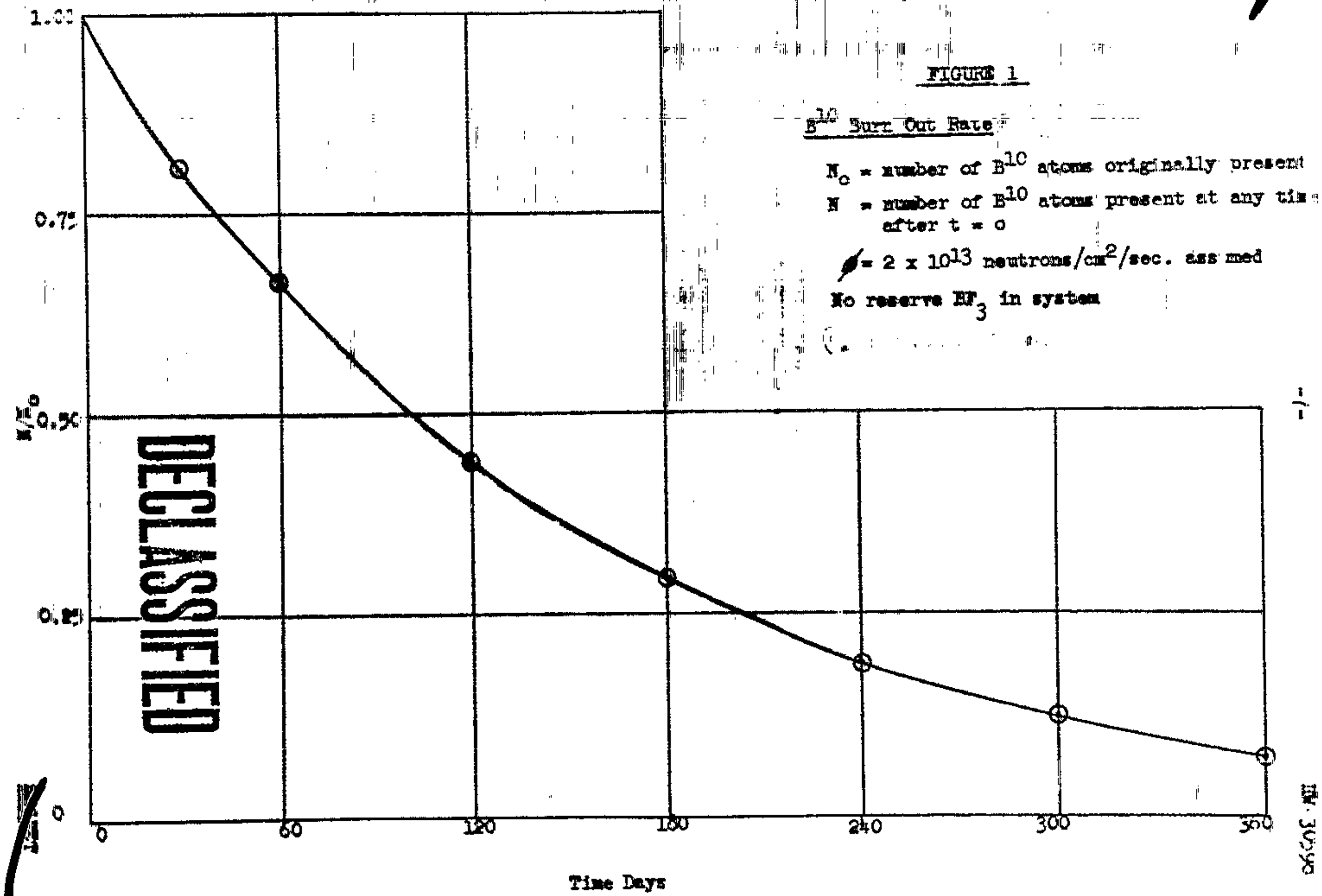
where:

No = number of atoms/cc at $t = 0$
t = time in seconds

Now, knowing that σ_a for B^{10} is approximately 3900×10^{-24} cm^2 and assuming a flux $\phi = 2 \times 10^{13}$ neutrons/sq.cm./sec. the burn-out rate of B^{10} may be calculated. Figure 1 indicates the burn-out rate as a function of time for the

FIGURE 1

B^{10} Burn Out Rate



conditions stated. The calculations assumed that there was no reserve of BF_3 in the system. The BF_3 mock-up has approximately 1/4 cubic foot of volume in the control tube and approximately 1/3 cubic foot in the reciever. The burn-out rate would therefore be lower than indicated by the curve by roughly a factor of two for this system. Since the B^{11} isotope has a capture cross section of <.05 barns, the effect of this isotope will be negligible.

C. Pressure Increase due to (n, α) Reaction

For each BF_3 molecule struck, there will be three molecules formed. The LiF is expected to be a solid. It will therefore increase the pressure a very small amount. The helium and F_2 will doubtless be gaseous. Thus, effectively there are two mols of gas formed for each mol destroyed. Figure 2 shows this increase as a function of time. From these two sample curves it will be noted that if a given pressure is to be maintained in the system by bleeding off the gas, as the pressure increases, the control value of the tube decreases not only as a result of B^{10} atoms being burned out but also some B^{10} will be removed by bleeding. This factor must be considered in the design of a control system. It indicates that it is probably more desirable to use on-off valves rather than pressure regulators to control the pressure. However, both means of pressure control were investigated.

D. Blackness of a Slug-Size Tube Charged with Commercial Boron Trifluoride in the Center of an Unflattened Pile

The in-hour value of a BF_3 control tube at various pressures was determined. A plot of control strength in in-hours versus pressure is shown in Figure 3.

2. CORROSION

A. Properties of BF_3 in Contact with Water

Dry boron trifluoride does not attack (3) aluminum, steel, brass, or any other of the usual materials used for construction of pressure vessels and valves.

When boron trifluoride is passed into water it is hydrolyzed and several acidic compounds may be formed. The formation of specific compounds is a function of the kinetics involved, for the first reaction products may, in time, be solvated. Known reactions with available equilibrium constants appear in Table I.

The solubility of boron trifluoride in water is of the same magnitude as that of ammonia in water. At 0°C under an external pressure of 762 mm., one ml. of water absorbs 1057 ml. of boron trifluoride. At room temperature the ratio of absorption is 1:700 (4). This very high solubility suggests solvation of the gaseous solute.

When boron trifluoride is passed into water it is hydrolyzed and several acidic compounds may be formed. The formation of specific compounds is a function of the kinetics involved, for the first reaction products may, in turn, be solvated. Known reactions with available equilibrium constants appear in Table I.

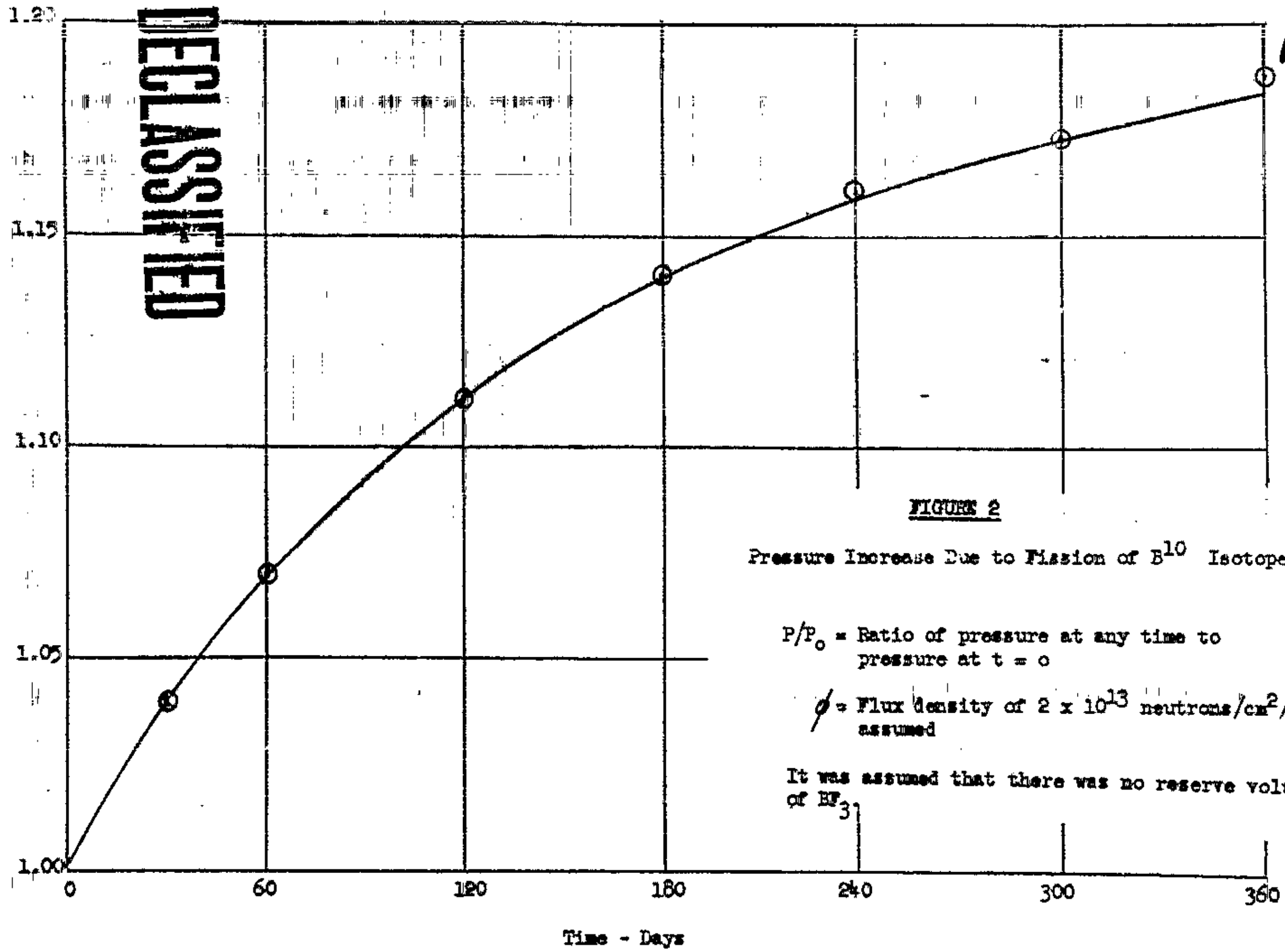


FIGURE 2

Pressure Increase Due to Fission of B^{10} Isotope

P/P_o = Ratio of pressure at any time to pressure at t = o

ϕ = Flux density of 2×10^{13} neutrons/cm^2/sec assumed

It was assumed that there was no reserve volume of BF_3.

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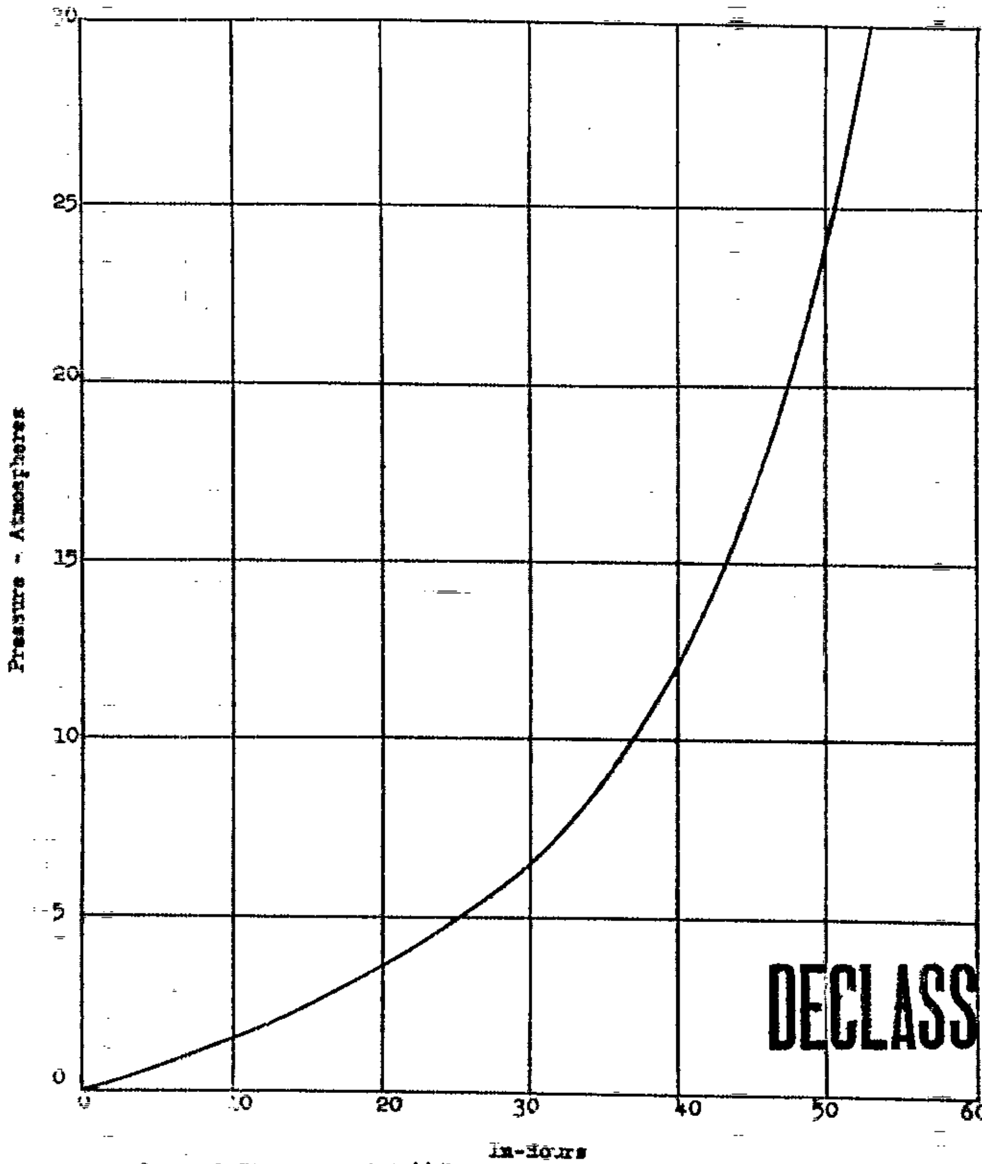


Control Strength of 1.44" O.D. Tube of Commercial BF_3 in Process Tube

FIGURE 3

TABLE I (A)

REACTIONS IN THE SYSTEM, BORON TRIFLUORIDE-WATER

Reaction		References
1. $BF_3 + H_2O \rightleftharpoons BF_3 \cdot H_2O + HBF_3OH$		(5)
2. $HBF_3OH + H_2O \rightleftharpoons HF + HBF_2(OH)_2$	$K_{equil} = 1.1 \times 10^{-2}$ at 25 C	(5)
3. $HBF_3OH + HF \xrightleftharpoons{slow} HBF_4 + H_2O$		(5,6)
4. $HBF_4 + 3H_2O \rightleftharpoons H_3BO_3 + 4HF$		(7)
5. $HBF_4 + H_2O \rightleftharpoons HF + HBF_3OH$	$K_{equil} = 2.3 \times 10^{-3}$ at 25 C	(6,8)
6. $BF_3 + 2H_2O \rightleftharpoons BF_3 \cdot 2H_2O \rightleftharpoons [H_3O^+][BF_3OH^-] \rightleftharpoons HF + HBF_2(OH)_2$		(5,9)
7. $3(BF_3 \cdot 2H_2O) \rightleftharpoons HBF_2(OH)_2 + HF \cdot 2BF_3 \cdot 4H_2O$		(10)
8. $6HBF_2(OH)_2 \rightleftharpoons 4BF_3 + B_2O_3 + 9H_2O$		(9)
9. $HBF_2(OH)_2 + 2H_2O \rightleftharpoons 2HF + H_3BO_3$		(5)
10. $4BF_3 + 3H_2O \rightleftharpoons 3HBF_4 + H_3BO_3$		(11)
11. $H_3BO_3 + HF \xrightleftharpoons{fast} HBF(OH)_3$		(12)
12. $HBF(OH)_3 + 3HF \xrightleftharpoons{slow} HBF_4 + 3H_2O$		(12)
13. $H_3BO_3 + 3HF \rightleftharpoons HBF_3OH + 2H_2O$		(6)
14. $2BF_3 + 3H_2O + H_3BO_3 \rightleftharpoons 3HBF_2(OH)_2$		(10)

For the over-all reaction of boron trifluoride and water, the equilibrium constant k(liters/mole-min.) = $6.4 \times 10^{-2} + 7.35 [H^+]$, at 25 C. (5)

B. Experiments Performed to Determine Corrosion Damage

To determine how severe the corrosion problem would be when BF_3 and 2S aluminum were in contact with various concentrations of H_2O, some 2S aluminum capsules were filled with BF_3 at atmospheric pressure. To this BF_3 was added water vapor so that some of the samples contained 5%, 10%, and 20% H_2O by weight. The capsules were then sealed and placed in an oven. The temperature in the samples was maintained at 110 C for 1400 hours. Figure 4 shows some of the capsules which indicates the extent of corrosion.

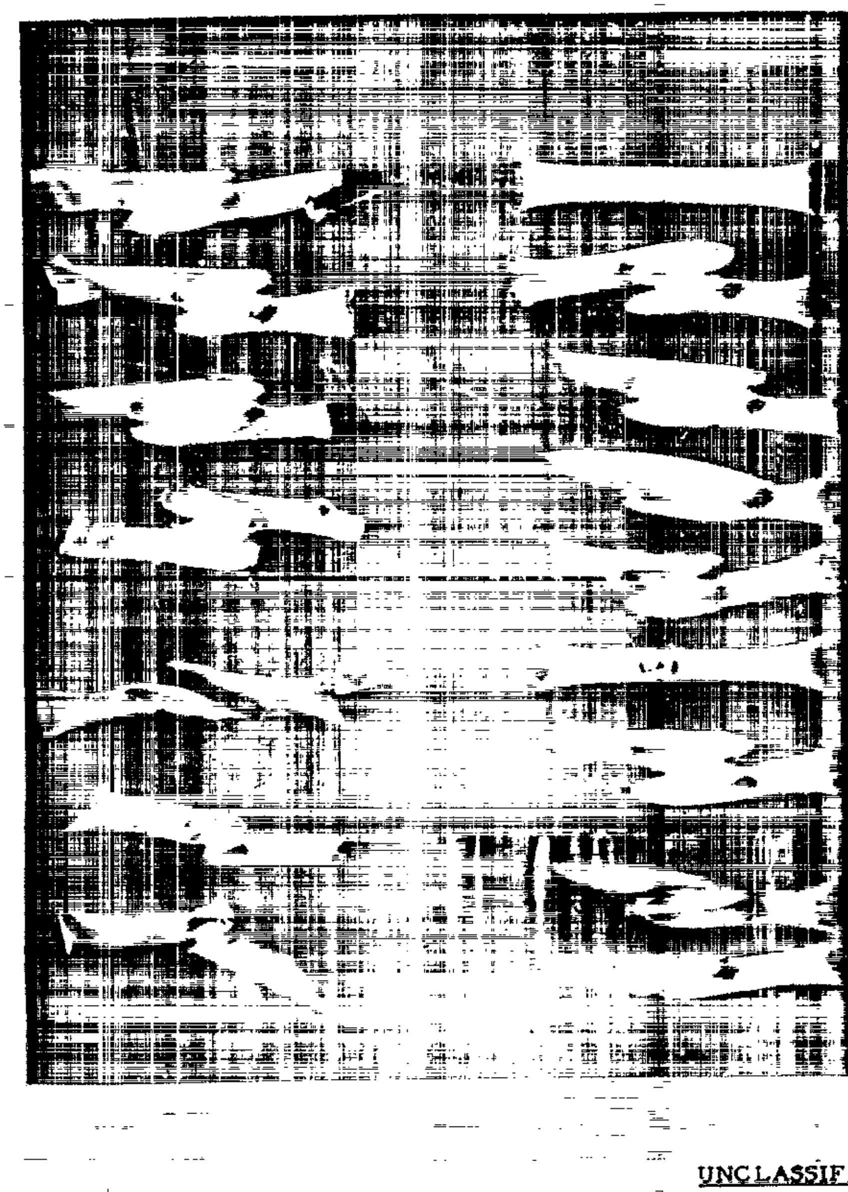


FIGURE 4

It was generally believed that, if water in an aluminum container was saturated with BF_3 the corrosion damage to the container would be severe. To determine if this theory was correct two slug cans were partially filled with water. BF_3 was then added until the water was saturated with BF_3. The experiment was performed at room temperature and pressure. Figure 5 shows the two slug cans which contained the solution. The can on the left was emptied after three months so that the corrosion damage could be observed. The can on the right contained the solution for six months. A white powder was deposited upon the w[illegible] of the container. This was analyzed and found to contain some boron and a fairly large amount of aluminum. The corrosion appeared to be slight.

Capsules similar to those shown in Figure 4 were used for the irradiation of the gas. After the gas was analyzed, these capsules were cut open. There was no observable corrosion. This is quite significant since the BF_3 which was irradiated contained H_2O to the extent of 1 mol-percent.

C. Damage to Reactor in the Event of Control Tube Leakage

If the gas escaped through a leak in the control tube into the process tube, it is expected that there will be no effect on the process tube (13) because of the small amount of BF_3 relative to the water.

4. EFFECT OF IRRADIATION ON BF_3

Two hundred cubic centimeters of BF_3 at 762 mm. pressure were irradiated in aluminum tubes for 30 days. These samples were exposed (14) in tube 2467-C. Total exposure(15) was 6.17×10^{19} nvt. (Where nvt is the total integrated flux to which the adjacent uranium columns were exposed, while the samples were in the pile, in neutrons per square centimeter.)

According to theory, the B^{11} concentration should remain practically constant due to its small cross section (0.05 barns). The concentration of the B^{10} isotope, due to its large (4000 barns) absorption cross-section, should be reduced. The helium concentration should increase in direct proportion to the B^{10} depletion.

The irradiated gas was analyzed on the 105-B Mass Spectrometer and the results are shown in Table II.

It should be noted that the sensitivity of the Mass Spectrometer to helium is shown quite precisely. The sensitivity to BF_3 has not yet been established. It is estimated that the isotopic ratios shown in Table II are accurate to ±10%.

These data show that helium is formed as theory predicts it will. The ratio of $B^{10}F_3$ to $B^{11}F_3$ should have reduced due to irradiation. These data do not confirm this assumption. Further analyses of irradiated BF_3 will be required to determine how the isotopic ratio changes due to neutron bombardment.

The irradiated sample cans were cut open and the solids adhering to the walls were analyzed spectrochemically. The results of this analysis are presented in Table III with similar data for unirradiated sample cans for comparison.

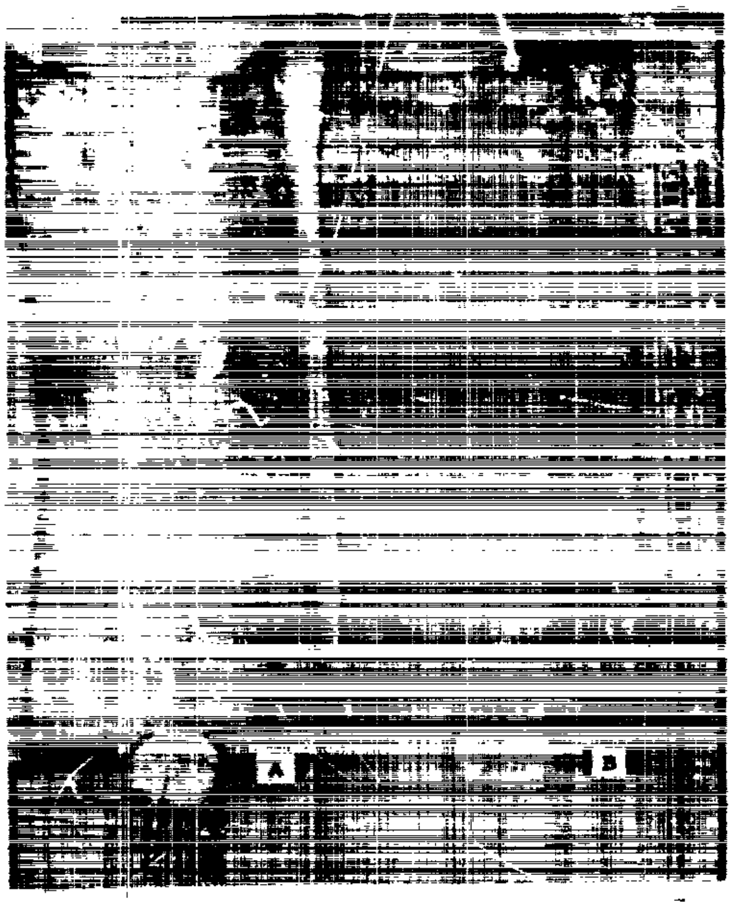


FIGURE 5

A - 2S ALUMINUM SLUG CAN CUT OPEN AFTER CONTAINING SATURATED SOLUTION OF BF_3 IN WATER FOR THREE MONTHS.
B - 2S ALUMINUM SLUG CAN AFTER CONTAINING SATURATED SOLUTION OF BF_3 IN WATER FOR SIX MONTHS.

TABLE II

	Unirradiated Non-enriched BF_3	Irradiated Non-enriched BF_3	Unirradiated Enriched BF_3	Irradiated Enriched BF_3
*He	0	10	0	48
*BF_3	98	86	98	31
**$B^{10}F_3$	19	28	87	86
**$B^{11}F_3$	80	71	13	13

*reported in mol-percent by volume
**B^{10} and B^{11} isotopic concentration in percent

TABLE III

Element	Unirradiated Non-enriched BF_3	Irradiated Non-Enriched BF_3	Unirradiated Enriched BF_3	Irradiated Enriched BF_3
Ag	T-M	T	T	T
Al	S	S	S	S
B	M	S	M	M-S
Ca	T	T-M	M	T-M
Cr	T	T	T	T
Cu	M	M	T-M	T-M
Fe	M-S	M-S	M-S	M
Ga	M	T-M	M	T
Li	-	M	-	M
Mg	T-M	M	M	T-M
Mn	T-M	T-M	T	M
Na	-	T	-	T
Ni	T	T	T	T
Pb	T-M	M	T-M	S
Si	T-M	M	T-M	M
Sn	T	-	T	-

Symbol	Meaning	Approximate Concentration
S	Strong	Greater than 1%
M	Moderate	1% to 0.01%
T	Trace	Less than 0.01%

Spectrochemical analyses of commercial 2S aluminum show that most of the elements listed are impurities in the metal. The two elements of interest are boron and litium.

No lithium was present in the tubes which contained the unirradiated gas. A moderate amount was found in the irradiated samples due, no doubt, to the nuclear reaction $B^{10} + n^1 \longrightarrow Li^7 + He^4$. The presence of boron may be explained by the chemical reaction

$2BF_3 + Al_2O_3 \longrightarrow 2AlF_3 + B_2O_3$. This reaction has been observed (16) at 450 C. Since the rate is proportional to the temperature, there should be slightly more boron present in the irradiated samples since the temperatures of these samples, while in the reactor, was somewhat higher than ambient.

5. INDUCED RADIOACTIVITY OF BF_3

A typical sample of commercial BF_3 contains the following constituents:

BF_3	- 96.2%
SiF_4	- 2.39%
SO_2	- .4%
Air	- .42%

Calculations to determine the induced radioactivity to be expected in commercial BF_3 after one, two, and three months exposure in a reactor were made. (17) The calculations assumed that the sample was contained in a pressure vessel with one cubic foot of volume at 360 psig pressure. The maximum calculated activity at a distance of one foot (18) from the container was 1.4×10^{-3} MR/hr. due to gamma.

There are, no doubt, small traces of other impurities in the gas which will increase the activity. After irradiation a sample of the gas should be analyzed on the gamma ray spectrometer to determine accurately the identify of impurities.

6. THEORY OF THE B^{10} ISOTOPE MONITOR

As was previously discussed, the total pressure exerted by the BF_3 gas will increase as the number of B^{10} atoms are struck. Thus as the "blackness" of control strength is reduced, the pressure increases. To determine the actual control strength, some measurement besides pressure must be made.

Since control strength is directly proportional to B^{10} concentration it would be most desirable to measure this value directly. Figure 7 is a sketch of the apparatus set up at 185-D to determine the feasibility of monitoring the B^{10} concentration present in BF_3 at any time.

A small capsule of radium-beryllium was used to supply neutrons. Some of the neutrons pass through the paraffin which thermalizes them. They then pass into a chamber connected directly to the BF_3 control tube. A neutron counter, located above the BF_3 container, measures the number of neutrons which pass through the gas. As the B^{10} concentration decreases, the number of neutrons which are allowed to pass through the chamber increases. The sensitivity may be controlled by varying the strength of the source, changing the volume of the pressure vessel, by varying the thickness of the moderator and by changes in the geometry and shielding. Further development work to find the optimum system will be required.

7. METHOD OF UTILIZING THE BF_3

For full scale in-pile testing a 1.44" O.D. 2S aluminum tube 35 feet long may be placed in a process tube and pressure fittings attached as shown by drawing H-1-5183. A stainless steel tube will connect the control tube to the pressure control equipment.

3. [illegible] DISTORTED PROCESS TUBE

In order to determine the feasibility of inserting a 1.440" O.D. control tube into a distorted process tube a K. D. F. DR. and H type tube was bent to reproduce the condition existing at F Pile when the growth was maximum. (19) A bullet nose was inserted in the end of the 1.440" tube. The tube was lubricated with water soluble oil. With the aid of the lubricant, insertion was not difficult.

The tube was heated internally to 100 C. A 600 psi hydrostatic pressure was exerted on the O.D. with no damage to the tube. Steam was then passed over the surface of the tube until [illegible] C was reached. This temperature was held for several hours. The internal pressure was then raised to 600 psi and held at that level for some time. The pressures was then increased slowly to 1385 psig at which pressure the tube ruptured.

4. [illegible] OF [illegible]LLING BF_3 PRESSURE

Extreme care must be taken in the selection of pressure control equipment. BF_3 hardens both synthetic and natural rubber and attacks all plastics except those with a fluorine base such as teflon. Several metals such as brass should be avoided if there is a possibility of the gas ever containing moisture. (20) If two or three-way solenoid valves are to be used they must give a dead-tight shutoff otherwise the boron concentration will vary with time. Pressure regulating valves designed for dead-end service, which are constructed of suitable materials, offer another possibility. Figure 6 shows a modification of a commercial regulator system which makes possible the close regulation of BF_3 pressure remotely by use of low pressure air. The regulator was originally designed for air service. Air was to be allowed to bleed off continuously. This bleed was eliminated. The gaskets and seats were replaced with teflon. To be completely satisfactory, the body should be silver plated to make the valve more corrosion resistant in case moisture is present in the BF_3 for a prolonged period.

A Barksdale model 9772A15 three-position, four-way valve is at present being tested at 105-D to determine its suitability for service with BF_3 gas. The valve is all stainless steel; the gaskets and O-rings are teflon. It is expected that this valve or a modification of it will be satisfactory for use with this gas.

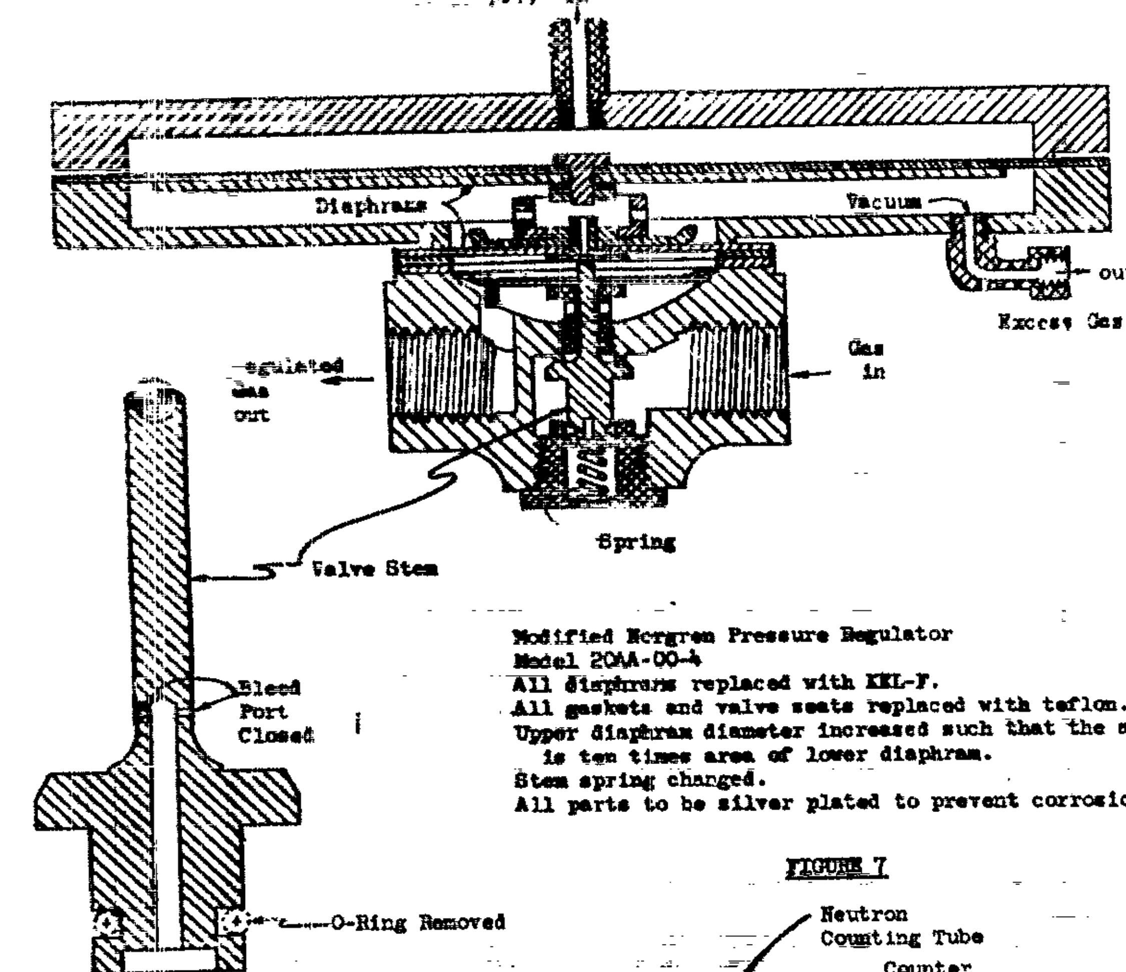
Figure 8 shows the methods by which these valves may be utilized in a BF_3 system. It may be seen that a series of separate control tubes may be attached to one supply and exhaust manifold if it is desirable to have a number of tubes in the installation.

Example A of Figure 8 shows the application of a three-position four-way valve for the purpose of controlling the pressure of the BF_3 in the control tube. The gas, after use in this case, is absorbed in water at the throat of an aspirator.

The system shown in example B is the same as A except that a remote-operated pressure regulator (for instance, the modified Norgren Regulator previously mentioned) is used to vary the pressure in the control tube.

Example C shows an entirely closed system. Either a pressure regulator or a three-position four-way valve may be employed to control the pressure. The system may be charged originally with the proper amount of gas through the valve at the left. The valve between the two tanks is to be closed. Now, to increase the pressure in the

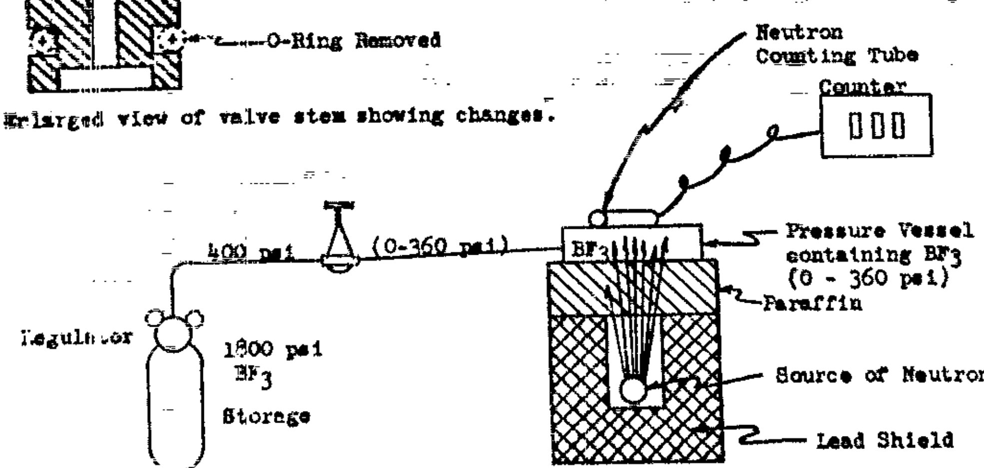
FIGURE 6



Modified Norgren Pressure Regulator
Model 20AA-00-4
All diaphrams replaced with KEL-F.
All gaskets and valve seats replaced with teflon.
Upper diaphram diameter increased such that the area is ten times area of lower diaphram.
Stem spring changed.
All parts to be silver plated to prevent corrosion.

Enlarged view of valve stem showing changes.

FIGURE 7



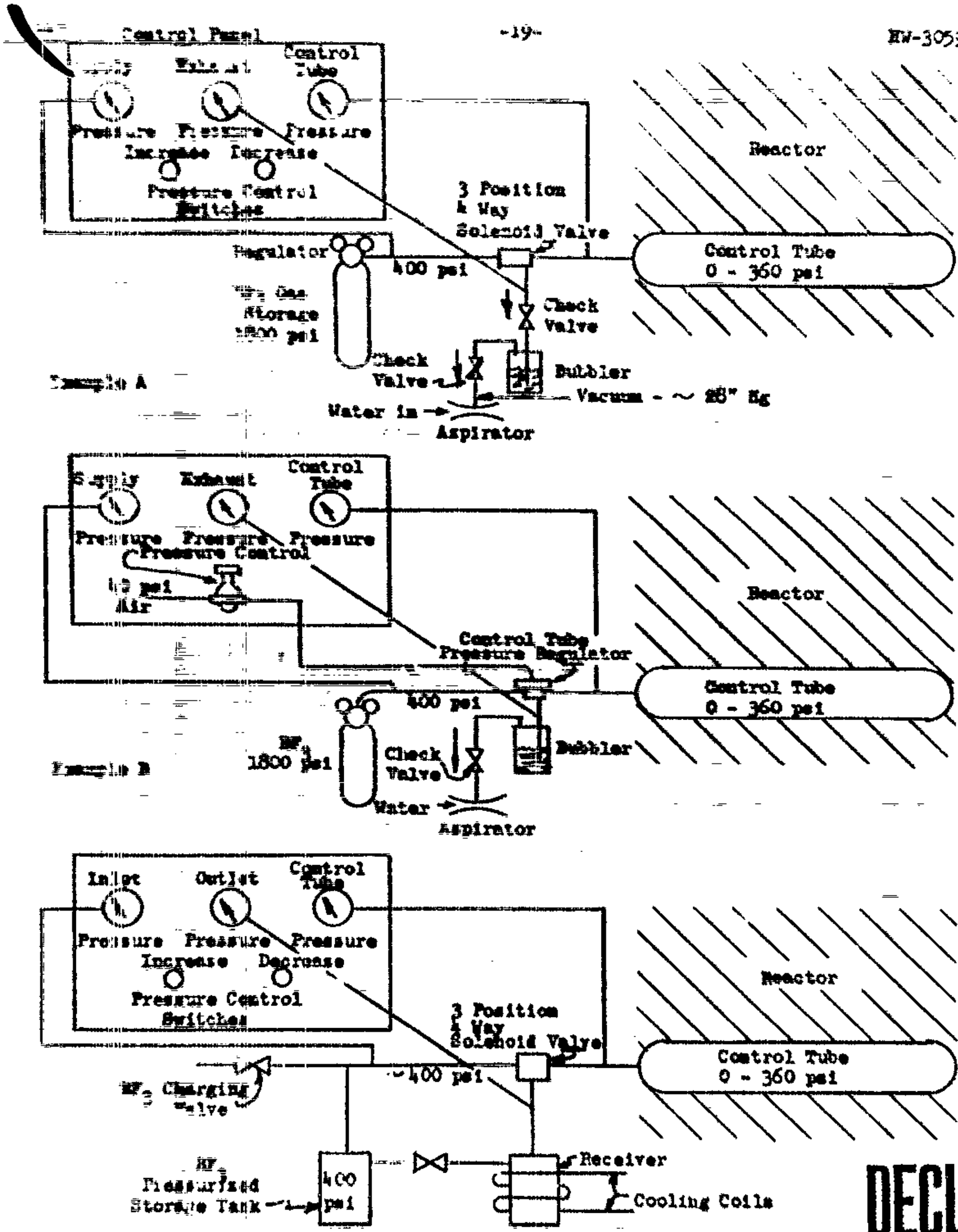

Control Panel
Control Tube
Pressure
Pressure Control Switches
Reactor
3 Position 4 Way Solenoid Valve
Regulator
400 psi
Control Tube 0 - 360 psi
Storage
Check Valve
Bubbler
Vacuum - ~ 28" Hg
Water in
Aspirator
Example A
Supply
Exhaust
Pressure Control
Air
Control Tube Pressure Regulator
1800 psi
Water
Example B
Inlet
Outlet
Increase
Decrease
Charging Valve
~400 psi
Pressurized Storage Tank
400 psi
Receiver
Cooling Coils
Example C

FIGURE 8

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control tube, the four-way valve may be opened to the pressure. To decrease pressure, the valve is opened to the vacuum tank. This tank is kept normally at -125°C by means of a refrigeration system. The BF_3 will be liquified at this temperature. This will bring the pressure above the liquified BF_3 to approximately 29.5" Hg of vacuum. During a period when the pressure on the control tube is to be maintained, the liquified BF_3 will be heated, thus increasing the pressure in the tank to a high pressure. The valve between the tanks may then be opened and the gas expanded to 400 psi in the pressure storage tank. The valve may then be closed and the residual gas again liquified thus producing a vacuum in the tank. This example indicates the basic features of a refrigerated system. An operating system would doubtless require at least one more vacuum tank, etc.

10. BF_3 MOCK-UP

Figure 9 is a schematic showing the BF_3 mock-up which was set up at 185-D.

BF_3 was stored at 700 psi in the pressure bottle shown. This storage bottle was located within the insulated container as shown so that the gas could be either cooled or heated. The air-operated needle valve could be operated remotely from the control panel. If this valve was opened, the pressure in the control tube increased from a vacuum to 360 psi as the pressure in the storage tank varied from 700 psi to 360 psi.

If the valve were then closed the control tube pressure remained constant. Now, if liquid nitrogen were to be poured into the insulated container around the storage bottle the gas was liquified, thus reducing the pressure to a few millimeters of mercury. To reduce the pressure in the control tube the control valve was opened, thus allowing the gas to expand into the storage container.

To discharge the gas after most of the B^{10} has been burned-out the gas may be valved into the bubbler. It may then be valved directly to the aspirator where it is rapidly absorbed in the water. Since the He^4 which is formed by fission of the B^{10} isotopes is not soluble in water, a vent was installed on the water recycle tank. The aspirator is capable of reducing the pressure in the system to approximately 28.5 inches Hg of vacuum. To scavenge the rest of the gas a vacuum pump may be valved into the exhaust line.

As the gas is absorbed in the water, the pH of the solution goes down rapidly. A mild steel corrosion sample was corroded rather badly after a period of two weeks in the solution. A 2S aluminum coupon appeared to be unharmed in the same solution. Stainless steel parts were not harmed.

Commercial refrigeration units are available which operate in the range - 125°C, the temperature at which BF_3 liquifies, which could be utilized if an adaptation of this type of system were to be used.

Figures 10 through 14 show the physical layout of the mock-up. Figure 15 shows details of the nozzle attachments, flaring tool, etc.

11. A SUGGESTED IN-PILE TEST

The poison effect of a BF_3 tube has been determined quite accurately by calculation. A satisfactory method for controlling the pressure and disposing of the gas has been

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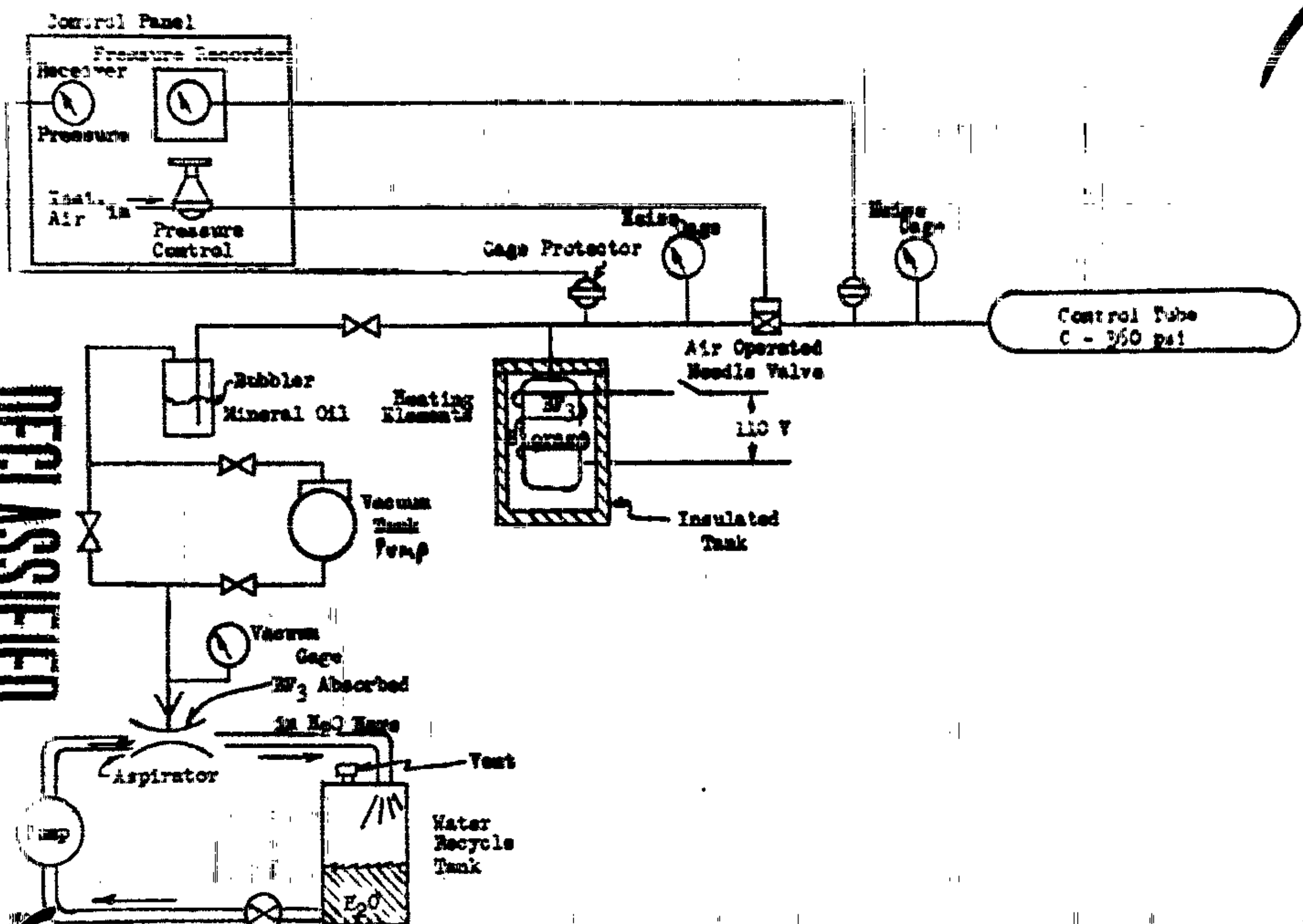


BF_3 SUPPLEMENTARY CONTROL SYSTEM MOCK-UP

FIGURE 9

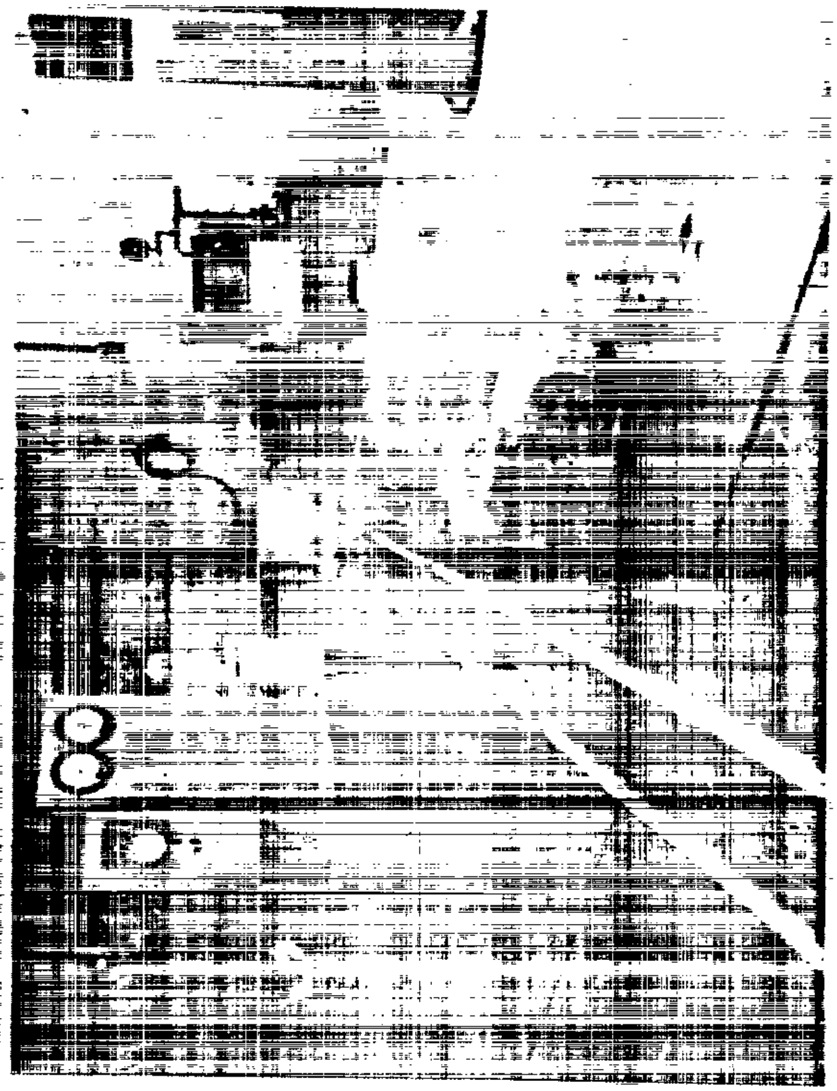


FIGURE 10
GENERAL VIEW OF BF_3 CONTROL EXPERIMENT APPARATUS WHICH WAS SET UP AT 185-D.

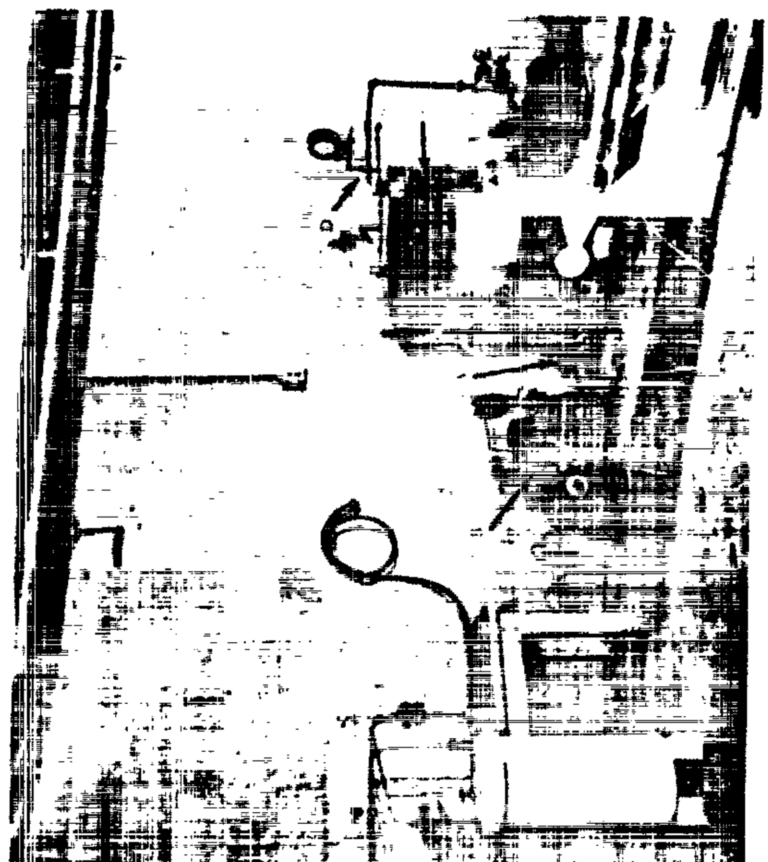


FIGURE 11

GENERAL VIEW OF MOCK-UP OF BF_3 CONTROL EXPERIMENT EQUIPMENT
SHOWING: A - NOZZLE ATTACHMENTS
B - VACUUM PUMP
C - BUBBLER
D - ASPIRATOR
E - CENTRIFUGAL PUMP

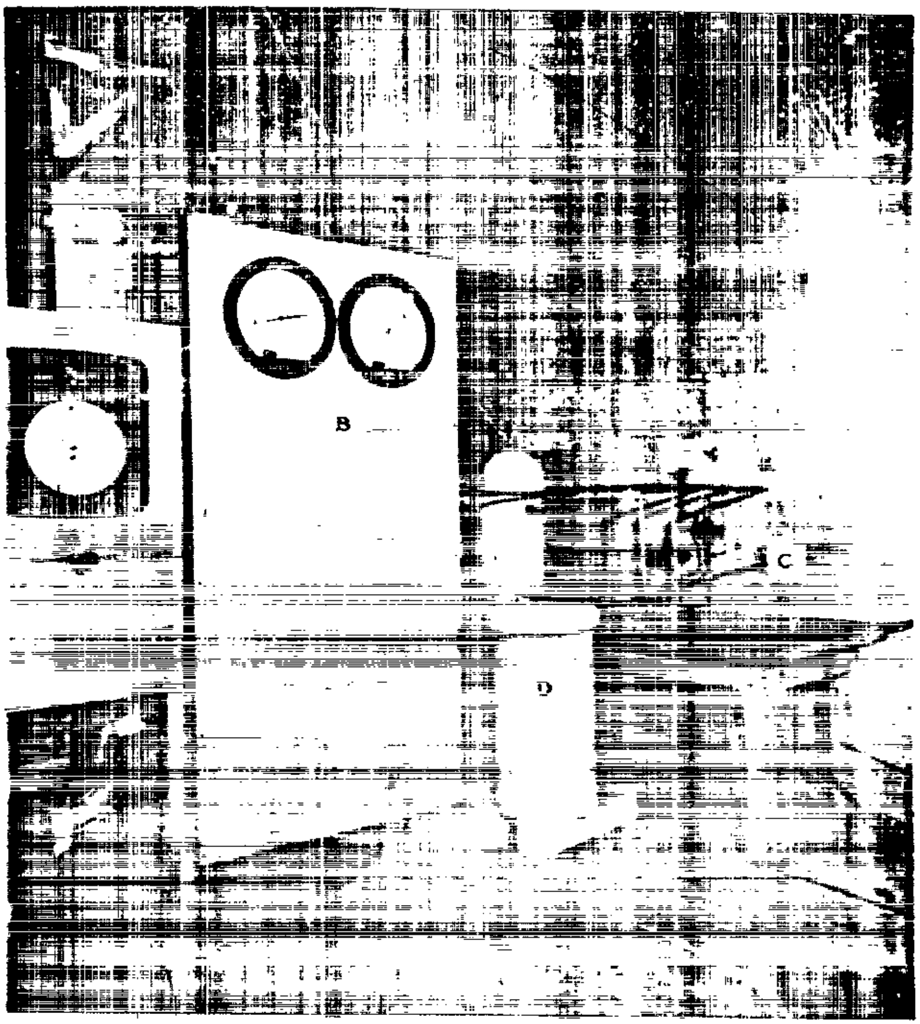


FIGURE 12

A - FOXBORO PRESSURE RECORDER AND VALVE TO REMOTELY OPERATE VALVE C. TO BE SET UP IN CONTROL ROOM.

B - INSTRUMENT PANEL WITH TWO HEISE PRESSURE GAGES. TO BE LOCATED ON X-LEVEL.

D - BF_3 RECEIVER IN AN INSULATED CONTAINER.

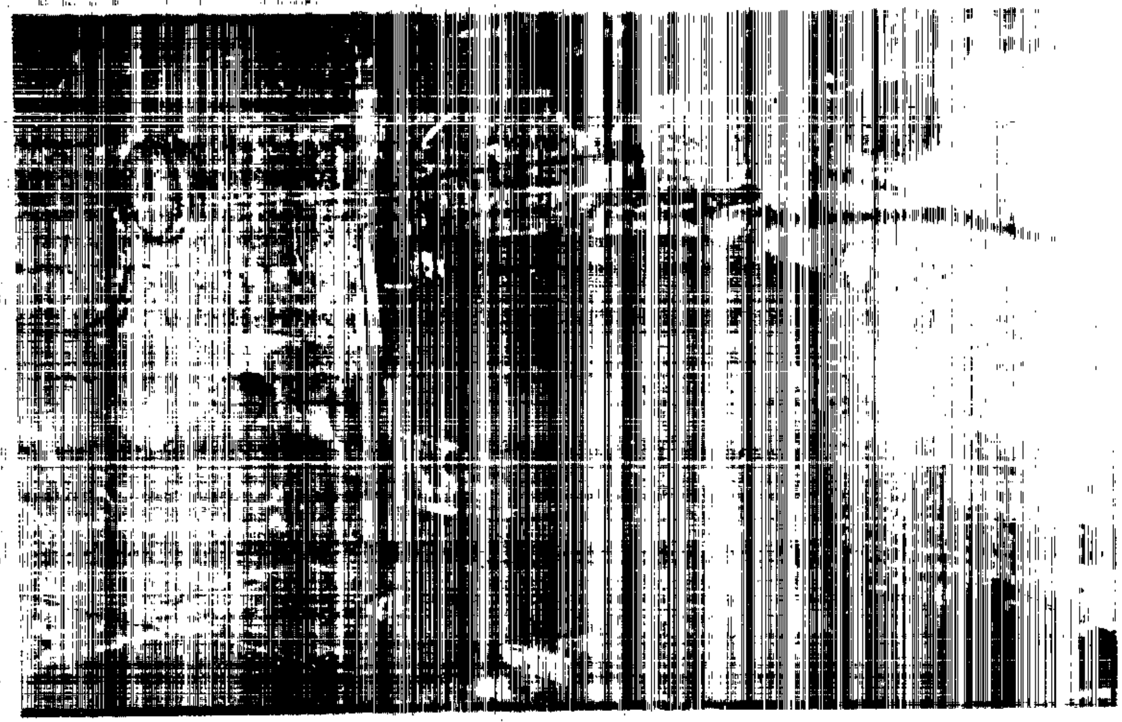


FIGURE 13
CLOSE-UP OF BF_3 DISPOSAL APPARATUS

BF_3 MAY BE VALVED OUT OF THE RECEIVER. IT FOLLOWS THE PATH INDICATED BY THE ARROWS PASSING INTO THE BUBBLER, UP THROUGH THE MINERAL OIL, OVER INTO THE THROAT OF THE ASPIRATOR WHERE IT IS ABSORBED BY WATER. TWELVE GALLONS OF WATER WERE RECYCLED THROUGH THE CLOSED WATER LOOP TO CONTINUALLY SCAVENGE THE BF_3 FROM ABOVE THE MINERAL OIL.
THE VACUUM PUMP IS TO BE USED TO REMOVE THE SMALL AMOUNT OF BF_3 LEFT IN THE SYSTEM.

FIGURE 14
VIEW SHOWING SPACE RELATIONSHIPS OF REAR NOZZLE ATTACHMENTS, PIGTAILS, CROSSHEADER.

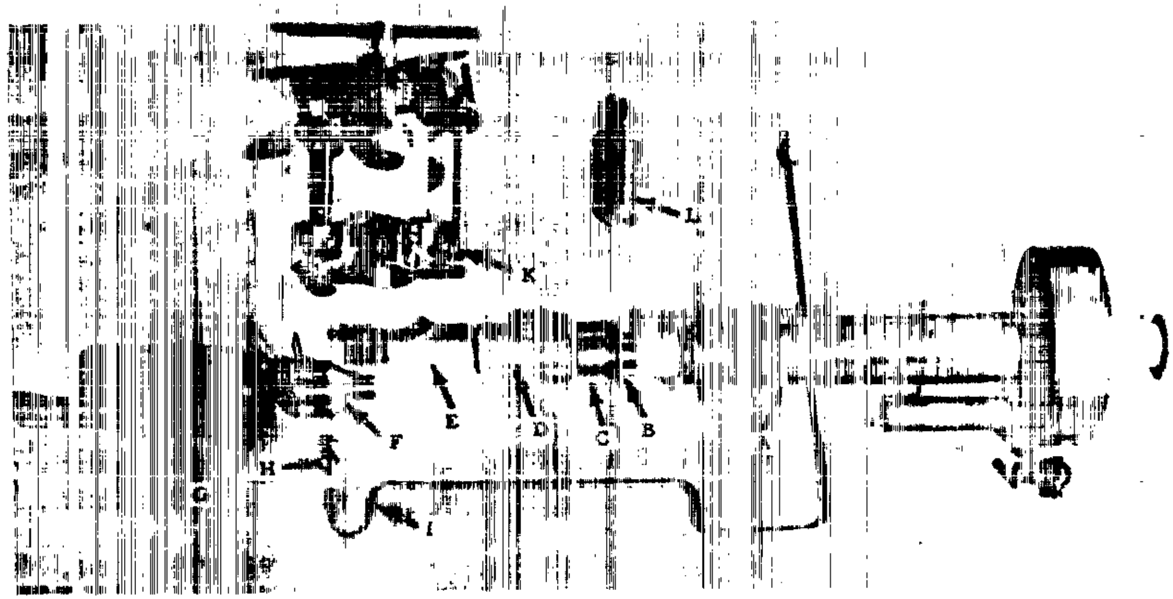


FIGURE 15

BF_3 CONTROL SYSTEM NOZZLE ATTACHMENTS:

A - STANDARD REAR NOZZLE
B - BF_3 CONTROL TUBE - 1.44" O.D. 2S ALUMINUM TUBE 35' LONG.
C - FEMALE COMPRESSION FITTING
D - FLEXITALIC GASKET - STANDARD
E - 8-FOOT LONG ALUMINUM SHIELD PLUG
F - MALE COMPRESSION FITTING
G - MODIFIED FRONT NOZZLE CAP
H - STAINLESS STEEL CONNECTOR
I - 1/4 STAINLESS STEEL TUBING
K - FLARING TOOL TO APPLY 30° FLARE ON CONTROL SIDE
L - BULLET-NOSE TO GUIDE CONTROL TUBE THROUGH PROCESS TUBE

developed in the laboratory. Out-of-pile corrosion studies indicate that aluminum and stainless steel are satisfactory materials of construction for use with boron trifluoride gas. Limited in-pile data indicate that the corrosion rate is not appreciably affected by the neutron flux. Further in-pile testing is therefore recommended. A simple experiment is outlined below.

The Y-test hole at either 105-H or 105-C could be used to irradiate a small scale version of the control system. The Y-hole is a water-cooled facility which extends about twelve feet into the graphite packing. It is arranged such that it is possible to insert a [illegible]" O.D. tube into the flux at any time during operation or under shut-down conditions. A sketch showing the layout of the Y-hole and proposed test apparatus is shown in Figure 16. From the sketch it may be seen that the test set-up is very simple, consisting of a 1.44" O.D. 2S aluminum tube, 18" long, attached to an 11/16" O.D. 2S aluminum tube which is approximately 19 feet long. To the opposite end of the 11/16" tube a pressure gage and gas storage bottle are attached.

The object of the test is to:

1. Determine quantatively the in-pile corrosion rate of BF_3 on aluminum.
2. Determine quantatively the residual poison effect, if any, due to the boron coating-out on the tube.
3. Determine quantatively the burn-out rate and resulting pressure increase.
4. Determine quantatively the induced radioactivity of the irradiated gas.

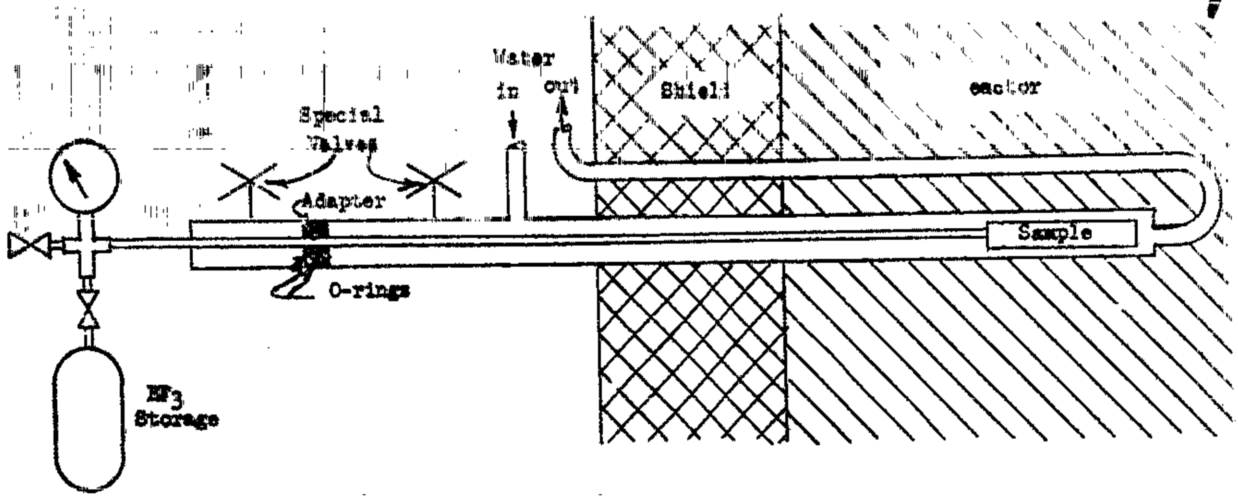
To obtain this data the following procedure may be used:

1. Fabricate the test equipment. During construction, two flat 2S coupons with known surface conditions should also be made. One coupon to be placed in the 1.44" O.D. section to be located in the flux. The other to be placed in the storage bottle to be located outside of the reactor. After the test is complete, the tube and pressure bottle will be cut open to study the surfaces. The condition of the coupons may be compared at that time to learn the relative amount of attack at the two locations.

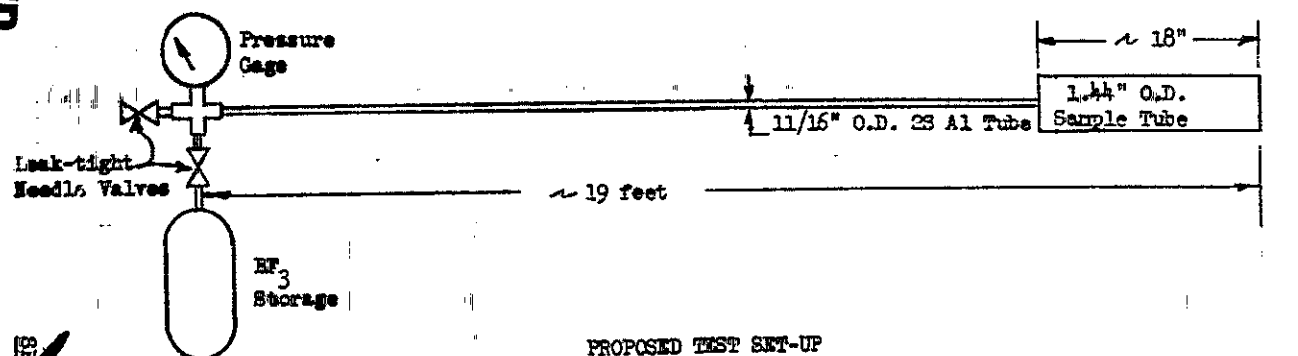
2. After the equipment is pressure tested and charged with BF_3 it should be set up in the 305 test pile and the neutron absorption of the 1.44" O.D. tube section determined at various pressures from a high vacuum to 360 psi. The pressure in the system may be reduced by freezing the gas in the storage tank.

   This step is to be repeated when the radiation level is reduced sufficiently after irradiation. The difference in the neutron absorption with the sample tube evacuated before and after irradiation will be a measure of the amount of boron which has been deposited on the tube wall.

3. A sample of the gas is to be taken before irradiation. Another sample will be taken after the irradiation to determine the change in concentration of the B^{10} isotope relative to B^{11}. The pressure increase as a function of time and flux density may be measured directly on a carefully calibrated Heise pressure gage.



Schematic of Y-Hole with Test Equipment in Place



PROPOSED TEST SET-UP

FIGURE 16

4. After irradiation, the BF_3 may be concentrated in the storage tank by freezing it out with liquid nitrogen. RMU measurements of the induced activity may be taken at this time. A sample of the irradiated gas may be analyzed on the gamma ray spectrometer to determine accurately which elements present are responsible for the activity. If a high reading is caused by impurities it may be desirable to remove the impurities prior to irradiating the gas in future installations.

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Technical Section
ENGINEERING DEPARTMENT

Recommendations Approved by:

Supervisor, Mechanical Development
Technical Section
ENGINEERING DEPARTMENT

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