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NPR PILE GAS PURIFICATION**DECLASSIFIED**ABSTRACT

Research and development effort has shown the need for a small amount of water vapor in the pile gas atmosphere to prevent hydriding of zircaloy. To retard graphite burnout by the water, small amounts of carbon monoxide or hydrogen are also required in the pile helium. Results of machine computations were recently published⁽¹⁾ which give some quantitative data on gas concentrations. Using those data, an analysis has been made with the objective of definitely establishing or eliminating the need for built-in helium purification equipment. That is desirable so that any necessary changes in the gas system can be designed on time.

The use of a gas atmosphere which permits small amounts of impurities opens the possibility of purging out excess CO and H₂ by adding fresh helium to the loop. The increase in CO and H₂ content is caused by the small amount of water vapor which does decompose. Using no more helium than KE reactor and less than KW (about 60%) would lead to a circulating load of about 0.1 vol. % CO, 0.1 vol. % H₂. When used with about 0.25 mm Hg water vapor in the pile inlet, this mixture will satisfy the oxidation requirements of the zircaloy and keep graphite burnout within acceptable levels, 0.2 to 0.5 wt % per full power year. The computations have not been verified experimentally. Unless they are shown to be quite far in error, maintaining an acceptable gas mixture by a feed-bleed method appears feasible. (This approach would also be eliminated if the need developed for the complete exclusion of any single constituent in the gas mixture while permitting others.) The advantage of feed-bleed is, of course, the deferment of the capital cost of purification facilities until clear-cut economic justification can be shown to exist.

CONCLUSIONS

The conclusions given here are based on a particular value of water vapor in the pile inlet, 0.25 mm Hg partial pressure. This level of water vapor is believed suitable to protect the zircaloy from gas side hydriding. The burnout of graphite has been calculated⁽¹⁾ to be within a suitable level, 0.2 to 0.5 weight per cent per year, when hydrogen is introduced in the pile inlet in the quantities used in this report.

The results given here are based on the machine computations and to that extent are conditional. In any case, the conclusions show the effects of best current estimates on the design of the pile gas system.

The conclusions are:

1. At the design leak rate of the biological shield, 40 scfh, pile gas purity levels out at about 2.4 mm Hg of hydrogen and an equal amount of carbon monoxide. These gas concentrations and those given below refer to normal operating conditions after the graphite has been degassed. An impurity level of about 1.0 mm H₂, 1.0 mm CO can be maintained by using about the same amount of helium as KE reactor, about 1.6 million cubic feet annually. The minimum level of impurities believed feasible is about 0.7 mm each of

(1) GE Zima, "Some Aspects of Graphite - Pile Gas Reactivity in the NPR", HW-69370, June 25, 1961.

CO and H₂. This could be achieved by an annual helium consumption about equivalent to recent KW reactor experience, 3.1 million cubic feet.

2. During the first year of reactor operation, while the graphite is degassing, helium requirements will differ. But it appears a satisfactory level of purity could be maintained by using about 2.2 million cubic feet.
3. The addition of purification equipment to the pile gas loop is considered desirable because of the greater degree of control it can provide. It also provides a hedge against effects which cannot be quantitatively assessed like radiolytic influence on reaction rates with pile graphite. However, in view of the desirability to defer capital costs for such equipment, N reactor could startup without built-in purification equipment providing:
 - a. The need does not develop for the complete exclusion of one or more gas contaminants while permitting others, or a gas atmosphere containing no less than about 0.7 mm each of CO and H₂ is required.
 - b. Experimental data obtained between now and startup are essentially in agreement with the calculations upon which this analysis is based.

RECOMMENDATIONS

1. The pile gas analytical instrumentation should be placed in operation well in advance of reactor startup. The careful control required on the composition of the pile gas makes it necessary to have reliable analytical data from the start.
2. The pile gas system as now designed should be reviewed for its ability to control the introduction of trace amounts of water vapor into the pile. Modifications to the duct work and flow controls may be needed if a bleed-feed system is used.
3. Graphite test coupons should be introduced in the stack so that checks can be made on graphite burnout.

INTRODUCTION

Work done by the corrosion and coatings unit, HLO, shows that the NPR pile gas atmosphere must contain an oxidant to protect the zircaloy process tubes from gas side hydriding.⁽²⁾⁽³⁾ The proposed oxidant is water vapor in trace quantities. A concentration in the inlet gas stream such that the outlet will contain 130 to 1300 parts per million by volume (.1 to 1.0 mm Hg) water vapor is currently considered adequate.⁽⁴⁾

- (2) D. W. Shannon, R. W. Dillon, HW-66692 RD, "Status of the Zircaloy-2 Hydriding Problem", September 16, 1960.
- (3) D. W. Shannon, HW-67811, "The Role of the Oxidation Rate on the Hydriding of Zircaloy-2 by Gaseous Hydrogen", December 15, 1960.
- (4) Verbal Communications - D. W. Shannon.

The addition of water vapor, however, causes undesirable side effects. Water will attack the graphite causing mass transport of carbon. Also, the reaction products themselves CO and H₂ can further attack graphite. The former product is able to form polymers, carbon sub-oxides, which can later decompose leaving soot-like deposits. These deposits are undesirable because they may clog pores in the graphite blocks. Retention of the porous character of the tube blocks is essential because we are depending on these passages to carry water vapor into the rather constricted region surrounding the process tubes. There is also some concern that CO will react with the water vapor itself, thus preventing the protective reaction with zircaloy. Hydrogen is able to remove graphite by forming methane. So that even though its threat to the zircaloy may be neutralized by water vapor, the hydrogen must be controlled to keep it from weakening structural graphite.

The reaction of water vapor with graphite can be inhibited by controlled additions of CO or H₂. This has been demonstrated by work done by the Non-Metallic Materials Development Operation. High concentrations of CO or H₂, 5 or 10% by volume of the pile gas atmosphere would essentially completely prevent the decomposition of water vapor over graphite.⁽⁵⁾ However, a high level of hydrogen has the obvious disadvantage of causing hydriding if the water vapor supply should suddenly fail and go undetected for a short period of time. The high levels of CO and H₂ would be detrimental in themselves as previously outlined.

The answer seems to be the use of trace quantities of water vapor along with trace quantities of hydrogen or carbon monoxide as inhibitor for graphite burnup. Extensive calculations by G. E. Zima suggest that 0.25 mm of water vapor in the pile gas inlet along with about 1 mm H₂ will limit carbon mass transport to 0.2 weight per cent per full power year. This is a satisfactory level. Presumably CO would act in a similar manner but data available now is restricted to hydrogen. None of these results have been experimentally verified. However, they are the best predictions of a satisfactory environment available at this time. Therefore, we have used 0.25 mm Hg inlet water along with a range of hydrogen level including one to two mm Hg partial pressure as a basis for this analysis. Even though water decomposition is small per pass through the reactor with this gas mixture, a finite amount of CO + H₂ is formed. It amounts to a few CFH depending upon the level of hydrogen in the inlet gas. It is this quantity of gas which must be continuously removed in order to maintain the hydrogen level in the one to two mm range. This report is concerned with methods of accomplishing this degree of control over the gas composition.

Owing to the lack of kinetics data on the affects of CO in retarding water decomposition, reference (1) treats carbon monoxide as a chemical inert with only hydrogen active in that respect. To be consistent, it was necessary to do the same in this analysis. This treatment introduces some conservatism in the results with regard to both the amount of water which decomposes and the quantity of bleed helium required to maintain a given level of hydrogen (and CO) in the pile inlet. If a helium bleed method is used for controlling pile gas purity, it is realized that both CO and H₂ will be present in the inlet in equal amounts. That is, even if the gas starts out with CO only or H₂ only as the retardant, it will eventually contain an equi-molar mixture of H₂ and CO. However, for the reasons given, reference

(5) R. G. Giberson, B. A. Ryan, HW-69950, "Water Vapor-Graphite Compatibility in the NPR - Preliminary Report", July 10, 1961.

will be made primarily to the control of hydrogen in the inlet. The degree of conservatism which results is probably appropriate. The experimental and analytical work which suggests the use of a gas atmosphere containing small but controlled amounts of water vapor and CO and H₂ pertain to normal steady state operating conditions. During reactor startup, the problem is a little different. Owing to evolution of adsorbed gases from the moderator graphite, a higher rate of introduction of contaminants into the pile gas is expected. However, at least during the initial low power phase of pile operation, a higher impurity load can probably be tolerated since the lower moderator temperatures will lessen reaction rates. After the reactor reaches full power, some degassing is still expected. The impurities become a more serious threat at that time and higher purge rates will be required. Estimates of purge requirements and purity levels during the out-gassing period are also included in this report.

PROCEDURES AND RESULTS

I. Steady-State Full-Power Helium Requirement

The quantity of gas (CO + H₂) generated per pass through the reactor has been determined by machine computations (reference 1). Figure 1 is a plot of gas generated as a function of hydrogen in the inlet gas for a water vapor concentration of 0.25 mm in the inlet. This inlet water concentration guarantees an outlet water concentration ≥ 0.1 mm.

The plot, Figure 1, has been corrected to CFH at 100 F and 1 atm, the temperature at the exhaust side of the pile gas system main blower. (To avoid errors from the large thermal expansion and contraction which the gas undergoes in making the loop, the full volume of the loop has also been standardized to 100 F.)

A material balance is needed to calculate effects of different purge rates on the impurity level in the inlet gas. The balance is:

$$\frac{dQ}{d\theta} = G - \frac{QR}{V}$$

where $Q = \text{ft}^3$ (100 F and 1 atm) of CO + H₂ present in the pile at any time, θ
 $R = \text{Purge rate of fresh helium, ft}^3/\text{hr}$ at 100 F
 $V = \text{Volume of helium in the pile} = 3000 \text{ ft}^3$ at 100 F, 1 atm.
 $G = \text{Rate of generation of H}_2$, CFH at 100 F

In order to maintain the inlet H₂ level at any specified value, the quantity of gas generated per hour must be removed each hour. Therefore, the rate of accumulation, $\frac{dQ}{d\theta}$ must be zero, giving $G = \frac{QR}{V}$. (1)

G is only known as a function of x , inlet partial pressure of hydrogen (Figure 1). It can be related to Q by the following expression:

$$Q = \frac{xV}{P} + \frac{GV}{v} \quad (2)$$

where $P = \text{Total pressure in pile} = 760 \text{ mm}$
 $v = \text{Volumetric helium circulation rate through the pile} = 24,000 \text{ CFH}$.

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FIG. 1
RATE OF GAS GENERATION
VS.
INLET CONCENTRATION

FOR 0.25 m.m. HG WATER VAPOR AT INLET
400 CFM CIRCULATION RATE THROUGH PILE

FT³ (100°F & 1 ATM) H₂ AND CO GENERATED PER HOUR

PARTIAL PRESSURE HYDROGEN AT INLET, m.m. Hg.

The computations on which Figure 1 is based included 1 mm H₂ maximum. To facilitate extrapolation, an equation was written to fit the data:

$$y = 4.48 - \frac{x}{.0318 + .224 x} \quad (3)$$

where y = generation rate of CO + H₂ = 2G, since H₂ and CO are formed in very nearly equal amounts.

These three equations can be combined to find x as a function of R or they can be solved step-wise as written. The results are plotted on Figure 2. CO partial pressure will be the same as hydrogen. Inspection shows that the purity level is somewhat insensitive to purge rate, with a 100 fold increase in bleed causing only about a ten fold decrease in impurity level.

The purge rate to use will depend, of course, on the degree of purity required. Since this is not known precisely at this time, at least the level of purity which can be achieved at reasonable purge rates can be investigated. Table 1 shows concentration of hydrogen which can be maintained in the pile gas inlet for three purge rates, 40, 220 and 430 CFH.

TABLE 1

Bleed Rate SCFH	H ₂ Partial Pressure mm Hg	H ₂ Vol. %
40	2.4	0.32
220	0.96	0.13
430	0.66	0.09

These particular values have the following bases. The first rate is the design leak rate from the biological shield with all tubes and seals installed. It is taken from the acceptance test procedure⁽⁶⁾ and corrected for the differences in the test conditions and normal operating conditions. The corrections allow for the difference in permeability of helium and air, temperature, and an operating pressure of 5" H₂O instead of 10" test. Forty SCFH is essentially a minimum purge rate since the system will bleed at least this amount whether or not its needed. The other two purge rates are based on recent helium usage in the K reactors. During the past four months, KE has been using helium at an annual rate of 1,604,000 SCF (70F, 1 atm). We have allowed for two outages per year where air must be purged out of the reactor. This would require about 55,000 SCF to get the pile gas to 99.5% He, remainder air, for N reactor. Deducting this amount and using a TOE of 80%, allowable helium consumption could be 220 SCFH and still approximate the helium performance of a relatively tight reactor under present experience. KW used 3,076,000 SCF on the same basis. This is still somewhat below the average reactor usage during recent months, but it would of course be undesirable to design a system to leak that large amount. We have taken that value as an upper limit. It is equivalent to 430 SCFH.

(6) H. S. Davis, ATP-2407, "Gas Leakage Test of Process Unit", March 10, 1961.

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FIG 2

HELIUM FEED RATE VS. CONCENTRATION
OF HYDROGEN IN FILE INLET FOR
0.25 mm. Hg. WATER VAPOR AT INLET

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A. Cost of Helium

The annual cost of helium versus CO + H₂ concentration is shown on Figure 3. The cost is based on a new helium price of \$43.00/1000 ft³ delivered at Hanford. Although the price rise is not definite, it is the best estimate available of the new cost. The same plot, Figure 3, is also used to show annual capital recovery of a purification facility at zero interest rate. The difference between the two curves is \$22,800 per year, the value of helium loss at the design leak rate. This amount is an uncontrollable loss and would appear in either case.

The cost of built-in helium purification equipment is estimated at about \$100,000. This is not an accurate estimate. A system considered for NPR would include the ability to remove air so that helium leakage could be minimized by low pile pressure in a manner similar to that planned for some existing reactors. It should be possible to buy such a system in the \$100,000 range. Using that cost, one can see that the equipment could pay for itself in a short time if a very low level of contaminants is needed. However, it can also be seen that in a strict economic sense, the investment is not attractive in the 2 to 3 mm range. If however, no more than about 0.6 mm each of CO and H₂ is tolerable, than built-in purification equipment becomes highly attractive with capital recovery in about one year.

B. Other Factors Affecting Feasibility of Bleed-Feed

Other factors affecting the feasibility of maintaining pile gas purity by continuous bleed-feed are:

- (1) Storage facilities at the reactor site and normal inventory at Hanford.
- (2) Facilities for introducing the purge into the loop.
- (3) Purity of fresh helium.

All of the above points are adequate. The storage facilities at N Reactor site will hold 278,000 SCF. This is over one month's supply. Normal plant inventory is 5 or 6 tank cars with about 260,000 SCF per car.⁽⁷⁾ The pile gas loop is equipped with controls for adding 0 to 50 CFM makeup. Thus, up to 3000 SCFH makeup could be used. The helium used at Hanford is Bureau of Mines Grade A. It is as pure or purer than could be obtained with a built-in purification system. The Bureau of Mines states that the gas contains less than 50 ppm total of impurities. Neon is 1-20 ppm. The other constituents, CO₂, Ar, N₂, O₂, CO, H₂ are all below 10 ppm by volume. Mass spectrometer analyses made here on grab samples from tank cars have sometimes shown more impurities. However, some of those results may have been caused by sampling error.

II. Purge Requirements During Graphite Degassing

The calculations and estimates made up till now, refer to normal operating conditions. During part of the first year of operation of the reactor the

(7) These data and other information on helium usage and purity were obtained from Elliott Bailey.

PARTIAL PRESSURE HYDROGEN, MM HG AT INLET TO PILE

ANNUAL CAPITAL RECOVERY FROM PURIFICATION FACILITY
TOTAL ANNUAL HELIUM COST USING BLEED-FEED

ANNUAL HELIUM COSTS VS. CONCENTRATION OF HYDROGEN IN PILE GAS LOOP (FOR 0.25 MM HG WATER VAPOR AT INLET.)

FIG. 3

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problem will be somewhat different owing to release of adsorbed impurities from the graphite. Some reactor projects, EGCR at Oak Ridge and the Turret Reactor at Los Alamos justify helium purification primarily for removal of impurities released in the degassing of new graphite. Therefore it is of interest to examine bleed-feed requirements during the first year of NPR operation.

In an attempt to get a realistic estimate of the graphite degassing, the literature was again reviewed. Since the last estimates were made⁽⁸⁾ some degassing tests have been done at Oak Ridge on NPR graphite. However, the problem of knowing evolution rates still remains. The tests are made by raising the temperature in steps and holding the specimens at each temperature for 20 to 40 hours. The tests include temperatures at which NPR graphite will operate, but the large discrepancy in time at temperature requires guessing at rates of gas release from the NPR pile. The rate and duration of evolution may also be affected by the radiation field in the pile.

A. NPR Degassing Temperatures

During about the first six months of NPR operation, the reactor will be controlled at about one-half design power. Graphite temperatures were estimated by taking one-half of the ΔT between primary cooling water and the full power graphite temperature. This results in a temperature of 557 C compared with 822 C full power,⁽⁹⁾ for the midplane of uncooled filler bars and about 415 C for cooled filler bars. A weighted average graphite temperature at half power is about 380 C compared with 520 C at full power. The maximum temperatures are controlling when considering graphite burnout, but they represent only small volumes of graphite. In considering degassing of the graphite, effects should be more nearly related to the temperature of the bulk of the graphite. Therefore, the degassing temperature has been taken as the average, 380 C at half power and 520 C at full power.

B. Total Amount of Adsorbed Gas

The samples of NPR graphite tested by ORNL were found to liberate 113 CC gas/100 CC graphite and 136 CC/100 CC graphite when heated to 1800 C.⁽¹⁰⁾ Another publication⁽¹¹⁾ states that graphite will liberate as little as 0.7 CC gas/100 CC of graphite (0.4 ft³/ton) under favorable conditions, and up to 2800 cc/100 CC (1600 ft³/ton) under unfavorable conditions. For our purposes, we have assumed that 100 CC of gas/100 CC of graphite will eventually come off.

C. Rate of Gas Evolution

At 600 C the rate was about 0.084 CC/100 CC/hr; at 300 C the rate found by Oak Ridge was about 20% of the 600 C rate. It was about 0.5 CC/hr at 1000 C for the first 19 hours and then dropped to about .05 CC/hr/100 CC graphite.

(8) D. D. Stepnewski, HW-63954, "Gas Side Hydridding of NPR Zircaloy", February 29, 1960.

(9) F. J. Mollerus, HW-64930, "A Discussion of NPR Graphite Overbore and Process Tube Temperatures", May 23, 1960.

(10) ORNL 3102, EGCR Quarterly Report, March 31, 1961, P. 218, Table 6.5.

(11) R. C. Asher, "The Degassing of Graphite", GCM-UK-17, January, 1960.

Thus, the rate is initially quite fast and then drops off to lower values. There is no data for long periods of time at the temperature range we expect nor for any other temperature for periods longer than a day or two. For our purposes, we have assumed the rate of evolution at half power to average about 0.02 CC/100 C /hr. The six month low power period has about 3500 operating hours assuming 80% TOE. At the assumed rate of gas evolution, 70% of the adsorbed gas will be liberated leaving 30 CC/100 CC to come off at full power.

Although the gas release rate at 600 C is .084 CC/hr/100 CC, the data were only taken over a 43 hour period. In obtaining these data, the technique involves heating to a specified temperature, holding the sample at that temperature until evolution slows down or essentially stops. The sample tube is then evacuated and heated to the next temperature point. Initially the gas comes off at a faster rate and then decreases to a low but presumably still finite value. Since we are concerned with long periods of time, we will again assume a degassing rate of 0.02 CC/hr/100 CC. It is understood that the rate could initially be higher than this and finally much lower near the end of degassing.

Although we have assumed the same average rate of gas evolution at 380 C and 520 C average graphite temperature, the composition of off-gas at the two temperatures would be expected to differ. Gas composition was estimated by straight line interpolation of 300 and 600 C experimental data, ⁽¹⁰⁾ plotted as $\frac{1}{T^{\circ}K}$ vs log volume %. Results are given in Table II.

TABLE II

COMPOSITION OF OFF-GAS, VOLUME PER CENT

	H ₂	Hydro Carbons	H ₂ O	CO ₂	N ₂	CO
300 C	0.7	1.	92	2	2	0.6
380 C	1.7	3.3	78.1	10.8	3.5	2.6
520 C	3.1	8.0	29.9	47.9	3.8	7.3
600 C	4.	10.	13.	60.	2.	10.

D. Purge Gas Requirements

There are 15, 100 ft³ or 4.27×10^8 CC of graphite in the active zone. ⁽¹²⁾
At 0.02 CC/hr/100 CC, release would be

$$\frac{.02}{100} \frac{(4.27 \times 10^8)}{(2.83 \times 10^8)} = 3 \frac{\text{ft}^3}{\text{hr.}}$$

out of this quantity, at half power, 78.1% is water which will be removed in driers leaving .66 ft³/hr of gas which is not wanted. If a purge rate of 200 CFH is used, impurity load will level out at 0.33 volume per cent or about 2.5 mm Hg. The relatively low graphite temperature at this time, 380 C average, 557 C maximum, should make the CO₂ present quite unreactive. Apparently the hydrogen could react. However, the quantity appears small so that even if it completely reacted, only about 3 lbs. of carbon could be removed during the entire six month period. On this basis, a 200 CFH fresh helium purge is considered reasonable during the half-power period.

(12) Data from D. Marinos.

At full power, about 30% of the effluent gas from the graphite is water, leaving about 2.1 ft³ hr of gas to be eliminated. At a purge rate of 430 CFH, the pile gas would circulate 0.5 volume per cent impurities or about 3.8 mm Hg.

During this period graphite temperatures are expected to be at maximum values and the presence of impurities is more serious than during half-power. But these conditions are not expected to last very long, perhaps 1500 hours so that the degree of purity possible with a 430 CFH purge seems reasonable. Furthermore there is considerable uncertainty in the estimates of off-gassing rates and composition. When the reactor is started, gas analyses may show that more or less purge gas is required, but hopefully, requirements should be in the range used here.

E. Helium Consumption During First Year

In addition to the purge requirements during operation, some helium will be required for purging air out of the system. Assuming two outages during the year where gas seals are opened plus initial startup, three air purges would be required. Starting with air in the loop and assuming perfect mixing of incoming helium with the air in the loop, 27,000 ft³ of He are required to get pile gas to 99.5% helium 0.5% air, purging air out of the helium storage facilities will require at least 32,000 ft³. The initial filling of storage tanks will amount to about 280,000 ft³. Following outages where air fills the pile, certain impurities will be re-adsorbed and will degas much the same as new graphite except the total adsorbed gas is only 5 to 10% of the original degassing. About 100,000 ft³ of helium would be required for bleed-feed each time this occurs. However, since most of the first year may involve degassing anyway, no helium for this type of usage will be included in first year estimates. A summary of the requirement follows:

Original filling of system	280,000 ft ³
Storage tank air purge	32,000
Loop air purges (three times)	81,000
3500 hrs at 200 CFH	700,000
1500 hrs at 430 CFH	650,000
2000 hrs (remainder of year at 220 CFH)	440,000
	2,183,000 ft ³

Thus, the requirements are about 2.2 million cubic feet. Other leaks or losses which may occur during the usual startup mishaps may increase the requirements. So long as the apparent purity levels obtained with the purge rates assumed are satisfactory, it appears that the graphite degassing load could be handled by the bleed-feed approach.

DISCUSSION

The analysis made here has been based entirely upon control of hydrogen. The rate of carbon monoxide generation and removal is assumed numerically identical to hydrogen although this assumption does not enter into the calculations. The remaining impurities in the gas stream, A, Ne, Co₂, O₂, N₂, and hydrocarbons will be purged out in the same ratio as CO and H₂. An examination of the effects

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of these other gases has not been made. They are not continuously generated like CO and H₂. However, they must be considered before any decisive provisions are made for pile gas purity control.

The change of impurity level with fresh helium purge rate partly explains why gas analyses from existing reactors shows so little hydrogen. Because of comparatively low graphite temperatures, perhaps not much is generated, but more hydrogen may be produced in the radiation field in the reactor than analytical results now show. The high bleed rate from helium leaks acts to effectively remove it from the circulating loop.

The assumption of only 40 CFH loss from pile gas system leakage may be quite optimistic. However, attempts will be made to achieve that level at startup. Although the K Reactors were leak tested to rates of that magnitude, it is believed that the test was made with tube holes sealed off.⁽¹³⁾ N Reactor will be leak checked with all tubes and seals in place so that leaking seals can be corrected before startup. Therefore, initially at least, there is a chance that leakage will be limited to that level.

Slow water leaks would, of course, upset the water control level and lead to different purge requirements. However, water leaks may not be a problem from the pile gas standpoint during early years of reactor life. This is not to say that slow leaks aren't expected. The process tubes contain rolled zircaloy to steel joints which are in effect on the gas side of the biological shield gas seals. It would be optimistic to expect none of these to ever develop slow leaks. But if a slow leak is detected by the gas analysis, a controlled shutdown will probably be started immediately because of the fear that the leak might propagate into a big steam release into the stack. Therefore, it seems that until enough experience with zircaloy has been obtained, operations will consider it prudent to locate and repair the leak as soon as possible.

On the moderator cooling tubes, the zircaloy to steel joints have been designed to drain water leakage outside the gas seal. Therefore, except for a break in the tube, these tubes should not be a source of water.

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Reactor Design Analysis
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